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Estimation of Chinook Salmon Abundance and Spawning Distribution in the Unalakleet River, 2010

by

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and

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, 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. 14-38

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

Salmon escapement in the Unalakleet River drainage is monitored by a counting tower on the North River. Prior research documented that 37% (1997) and 40% (1998) of Chinook salmon escapement migrated up the North River. In 2009 and 2010, this experiment was repeated to evaluate whether North River escapement provided a consistent index of total Unalakleet River escapement. The 2009 experiment produced an estimate of 34%.

In 2010, 142 Chinook salmon were captured with gillnets in the lower Unalakleet River and fitted with radio tags. Spawning destinations of radiotagged salmon were determined using 3 stationary receiving stations and boat and aerial surveys. Chinook salmon were also sampled for age, sex, and length.

Radiotagged Chinook salmon migrated into all tributaries except the South River. Salmon that migrated upriver were concentrated in 2 areas, one in the North River and one in the mainstem Unalakleet River near the Old Woman River. A late run of Chinook salmon resulted in uncertainty regarding the results because 20% of the North River tower count occurred after August 1, the last day a radiotagged salmon migrated past the tower. An estimated 1,256 (SE = 95) Chinook salmon passed the North River tower, with 1,003 (SE = 85) migrating before August 2. A drainagewide abundance estimate of 2,391 (SE = 283) was derived using the entire tower count, and an abundance estimate of 2,163 (SE = 240) was derived using tower counts prior to August 2. The proportion of fish that migrated up the North River was estimated to be 53% (SE = 5%) and 58% (SE = 5%) using these 2 estimates, respectively. Both proportions were significantly higher than 1997, 1998, and 2009. Chinook salmon ages ranged from age-1.1 to age-1.5, but age, sex, and length distributions were considered biased due to the late migration and insufficient sampling.

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 covers 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 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 belong to the 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 in addition to 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).

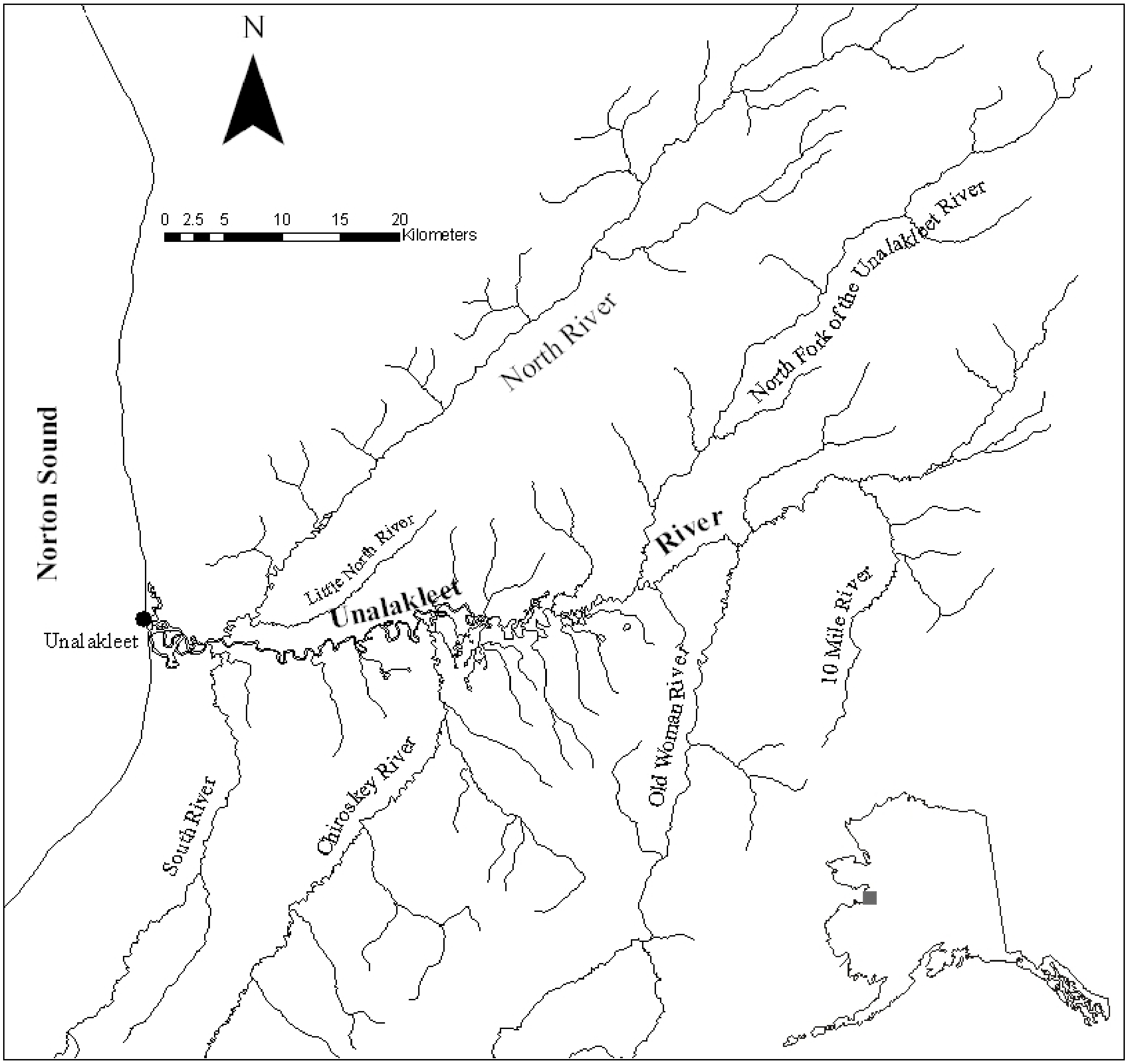

Figure 1.–Map of the Unalakleet River and its tributaries.

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 [ADF&G], Division of Commercial Fisheries) located 5 km from the mouth, aerial surveys of index areas in the Unalakleet and Old Woman rivers, and a weir on the mainstem of the Unalakleet River that was installed in 2010 (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 2010, the counting tower was operated by the 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 in the Old Woman River. Chinook salmon sustainable escapement goals (SEGs) have been established for the aerial survey index areas (550–1,100) and the North River counting tower (1,200–2,600) (Brannian et al. 2006).

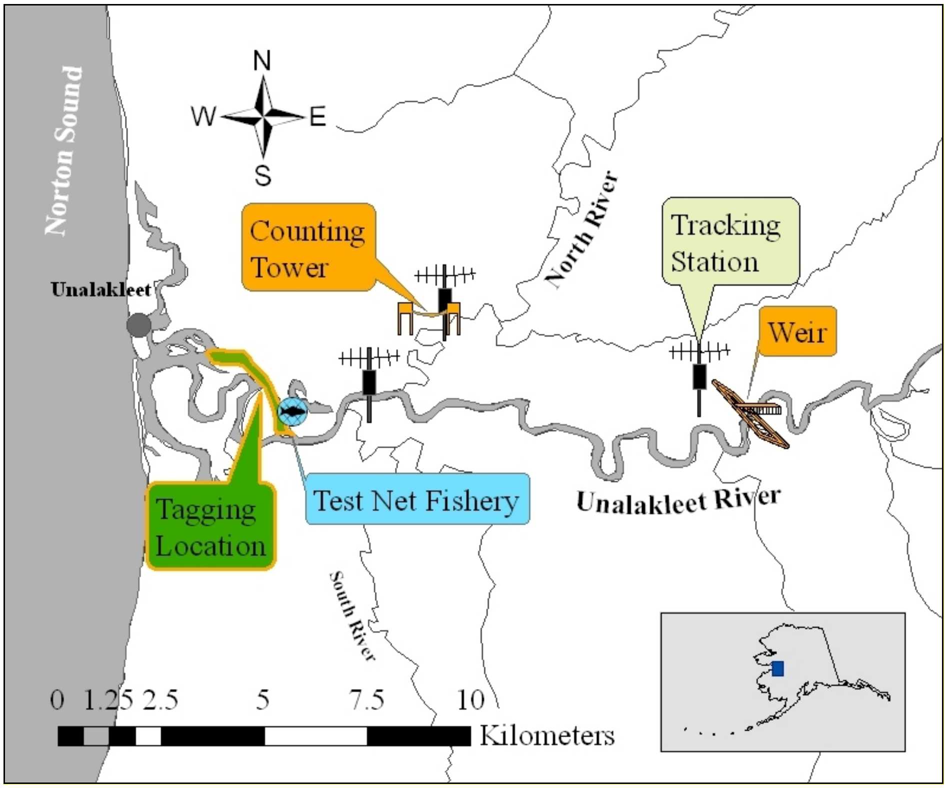

Figure 2.–Chinook salmon tagging location, tracking station locations, ADF&G-CF test net, North River counting tower, and weir location in the Unalakleet River drainage, 2010.

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 (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). From 2004 to 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 to 2007 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.

Table 1.–Unalakleet River Chinook salmon North River tower counts, CF test fishery catch, District 6 commercial harvest, estimated District 6 subsistence harvest, estimated sport catch, and estimated sport harvest 1985–2009.

Year	North River Tower Counts	CF Test Fishery Catch	District 6 Commercial Harvest	District 6 Subsistence Harvest	Unalakleet River Sport Catch	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
2009	2,352	135	80	2,310	515	248
2010	1,230	41	124	1,615	61	99

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 indicated 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 study 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 Joy and Reed (2014) and to estimate drainagewide abundance of Chinook salmon in the Unalakleet River drainage using two-event mark–recapture techniques.

OBJECTIVES

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

1. estimate the proportions 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, 1998, and 2009;
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 two-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 counting tower.

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 6, 7, and 8 in stretch measure.

The crew began standardized fishing for Chinook salmon on June 15 with 2 shifts per day. One shift began 3–4 hours before high tide and continued until 300 minutes of soak time had been achieved, and the second shift began at 1800 hours and continued until 250 minutes of soak time had been achieved. Fishing continued until catches diminished to less than 1 fish per day for several days. Crews rotated through the different mesh size gillnets over the course of each shift. Eventually the time spent fishing the 6” gillnet was reduced and eliminated because a strong chum salmon run resulted in considerable bycatch and large amounts of time spent removing chum salmon from the net. The final day of fishing was July 25.

After capture, Chinook salmon were placed in a large holding tub and received a Model Five pulse encoded radio tag made by ATS[1] (Advanced Telemetry Systems, Isanti, MN) 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. The 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 posterior to the base of the pectoral fin. Salmon were also measured to the nearest 5 mm length 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 radiotag Chinook salmon in relation to their true run timing. The tagging schedule required 1 or 2 tags to be deployed per day until more than 2 Chinook salmon were gillnetted per hour or the CF test fishery captured at least 3 Chinook salmon in a single day. Once this trigger was reached, approximately 90% of the tags were deployed over the next 3 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 at the test fishery. Historically, run timing at the counting tower has consistently lagged behind the test fishery such that Chinook salmon do not begin passing the counting tower in significant numbers until approximately 50% of the annual Chinook salmon test fishery catch has been recorded (Tables 2 and 4). The date that 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

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[1] Product names are included for completeness but do not constitute endorsement.

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.

UPRIVER SAMPLING

Seining was conducted in the North River upstream from the counting tower (Figure 2) once fish were counted passing the North River tower. Fish were sampled in river sections that appeared clear of debris and snags and had Chinook salmon present. Chinook salmon escaping into the Unalakleet River were to be sampled at the Unalakleet River weir; however, a representative sample was not obtained due to difficulties with capturing Chinook salmon at the weir.

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 collected.

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 ASL. To determine age, 3 scales were removed from the left side of each fish (approximately 2 rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin) and placed on gum cards. 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).

RADIO-TRACKING 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 1 gel-cell deep-cycle 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 (aimed upstream and 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.

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.

Cumulative Percentage	CF Test Fishery			North River counting tower		
	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 percentages of their run in the Unalakleet River as recorded in the CF test fishery from 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 from 1997 through 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

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 towers 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 its 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 tracking 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/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 towers* **–** 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 towers, that had not been recorded above a tracking station for at least 7 days.
>
> ***Fate 5)*** *Harvested above tracking towers* **–** a fish that was determined to have been harvested by a subsistence or sport fisherman upstream from the North, Unalakleet, or South River tracking towers and that had been above the tracking tower for at least 7 days.
>
> ***Fate 6)*** *Backed out/unknown* **–** a fish that was tagged and never recorded at any tracking towers or on any aerial or boat tracking surveys. This includes fish that were recorded at or below the tracking towers but not upriver of the towers 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 below), 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, it was 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 the North River tracking tower or the mainstem Unalakleet River tracking tower 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 towers and aerial and boat tracking surveys were 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 captured 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 and 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 proportions of 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). ASL data were collected from the samples of fish past the North River counting tower. 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 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.

In 2010, abundance of Chinook salmon in the Unalakleet River drainage was estimated using a form of Chapman's (1951) modification to the Petersen estimator:

$$\hat{N} = \frac{(M+1)(\hat{C}+1)}{R+1} - 1 \quad (1)$$

where M is the number of radiotagged Chinook salmon with fates 1, 2, or 5; $\hat{C}$ is the estimated number of Chinook salmon past the North River counting tower; and R is those fish from M that spawned above the North River counting tower.

The proportion of the Chinook salmon escapement that passed the North River counting tower was then estimated using:

$$\hat{p}_{NR} = \hat{C}/\hat{N} \quad (2)$$

Variance and 95% credible interval for the estimators (equations 1 and 2) were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, a posterior distribution for $\hat{N}$ was generated by collecting 1,000,000 simulated values of $\hat{N}$, which were calculated using equation (1) from simulated values of equation parameters. Simulated values were modeled from observed data. The number of marks deployed was modeled as a fixed value (M). The proportion of marked fish passing the North River tower was modeled as a binomial distribution with a rate parameter R/M with M observations. The total number of Chinook salmon passing the North River counting tower was modeled as a normal distribution with expected value $\hat{C}$ and variance $v\hat{a}r(\hat{C})$, which were derived using the methods of Perry-Plake and Antonovich (2009).

After collecting the simulated values, the following statistics were calculated:

$$\overline{N} = \frac{\sum_{b=1}^{1,000,000} \hat{N}_{(b)}}{1,000,000} \text{; and,} \tag{3}$$

$$v\hat{a}r(\hat{N}') = \frac{\sum_{b=1}^{1,000,000} (\hat{N}_{(b)} - \overline{N})^2}{1,000,000 - 1} \tag{4}$$

where $\hat{N}_{(b)}$ is the *b*th simulated observation. The sampling variance for $\hat{p}_{NR}$ was calculated using equations (4) and (5) with appropriate substitutions.

SPAWNING DISTRIBUTION

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

$$\hat{p}_i = n_i / n \tag{5}$$

$$v\hat{a}r(\hat{p}_i) = \frac{\hat{p}_i(1 - \hat{p}_i)}{n - 1} \tag{6}$$

where:

n_i = number of radiotagged Chinook salmon that traveled to spawning area *i*; and

n = total number of radiotagged Chinook salmon tracked to a spawning area.

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 site, up to and including that particular day. Run timing was compared using paired K-S tests.

AGE, SEX, AND LENGTH COMPOSITION

The numbers and proportions of Chinook salmon by sex and age were estimated first by sex, and then by age within sex. Composition proportions were estimated by sex *g* (*g* = males or females) using:

$$\hat{p}_g = \frac{n_g}{n_\bullet} \tag{7}$$

where:

$\hat{p}_g$ = estimated proportion of Chinook salmon of sex *g*;

n_g = number of sampled Chinook salmon of sex *g*; and,

$n_{\bullet}$ = total number of Chinook salmon sampled for sex.

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

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

where:

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

$n_{a,g}$ = number of sampled Chinook salmon of age *a* and sex *g*; and,

$n_{\bullet,g}$ = total number of Chinook salmon successfully aged for sex *g*.

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

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

and variance was estimated (Goodman 1960):

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

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

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

with variance (Goodman 1960):

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

where $\hat{N}$ = the estimated Chinook salmon escapement into the Unalakleet River.

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 archival (Appendix B).

RESULTS

CAPTURE, TAGGING, AND FATES OF RADIOTAGGED CHINOOK SALMON

Between June 15 and July 27, a total of 149 Chinook salmon were captured at the lower river tagging site, and 142 were large enough to radiotag (> 500 mm MEF). Daily CPUE of Chinook salmon large enough to radiotag averaged 0.55 (SE = 0.53) Chinook salmon per hour and ranged from 0 to 2.1 Chinook salmon/hour (Figure 3). Captured Chinook salmon ranged in METF lengths from 350 to 970 mm. The average daily CPUE for the different sized gillnets was 0.52 (SE = 0.41) Chinook salmon per hour for the 6-inch mesh, 0.82 (SE = 1.08) for the 7-inch mesh, and 0.53 (SE = 0.64) for the 8-inch mesh.

Of the 142 salmon that were radiotagged, 117 continued upstream migration past the tracking towers on the Unalakleet and North rivers. Eight radiotagged Chinook salmon were harvested (5 in the subsistence fishery, 1 in the sport fishery, and 2 others in unknown fisheries), 7 radiotagged Chinook salmon died or regurgitated their radio tag shortly after release, 9 backed out of the drainage or had failed radio tags, and 1 was assigned an unknown fate (Table 6).

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 between the length distributions of radiotagged Chinook salmon that passed the North River counting tower (Recaptures) and those sampled above the North River counting tower that were over 500 mm METF (Captures) (Recaptures vs. Captures $D = 0.33$, $P < 0.01$; Figure 4). There was, however, no significant difference between the length distributions of all radiotagged Chinook salmon (Marks) and the Recaptures (Marks vs. Recaptures $D = 0.07$, $P = 0.93$; Figure 4), 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).

Chinook salmon captured at the tagging site (including those that were too small to receive a radio tag or failed to migrate upriver) were significantly older than those sampled during upriver sampling (Tables 5 and 7; $\chi^2 = 42.30$, $P < 0.01$). Age-1.1 and -1.2 fish were underrepresented at the tagging location compared to North River seining samples whereas age-1.3 and -1.4 fish were overrepresented (Table 7). Salmon age-1.1 were too small to radiotag and also likely to have not been counted at the North River counting tower as Chinook salmon "jacks" because they are hard to differentiate from pink salmon without careful examination. Given their likely exclusion from tower counts, it is unlikely that their presence confounded results so long as Chinook salmon abundance estimates are limited to Chinook salmon age-1.2 and older. Nevertheless, even when age-1.1 salmon were excluded from the analysis, radiotagged Chinook salmon were still significantly older than those sampled during North River seining ($\chi^2 = 25.13$, $P < 0.01$).

Temporal violations of equal probability of capture during the second event were explored using contingency table analyses (Appendix A2). Significant differences in the probability that a marked fish was recaptured during the second event were detected between the quartiles of the run when examining all radiotagged salmon ($\chi^2 = 7.50$, $P = 0.06$; Table 8). Comparing the run quartiles to each other indicated that quartiles 1, 3, and 4 were similar ($\chi^2 = 1.16$, $P = 0.56$), whereas the second quartile was significantly different ($\chi^2 = 6.38$, $P = 0.01$; Table 8).

A similar pattern emerged when examining capture probabilities in the first event. During the last quartile of the run, no radio tags were observed passing the North River counting tower (Table 9). When this last quartile was removed from the analysis, significant differences in capture probabilities were still evident between the first 3 quartiles ($\chi^2 = 9.28$, P = 0.01), with the first and third quartiles having similar capture probabilities and the second quartile differing significantly.

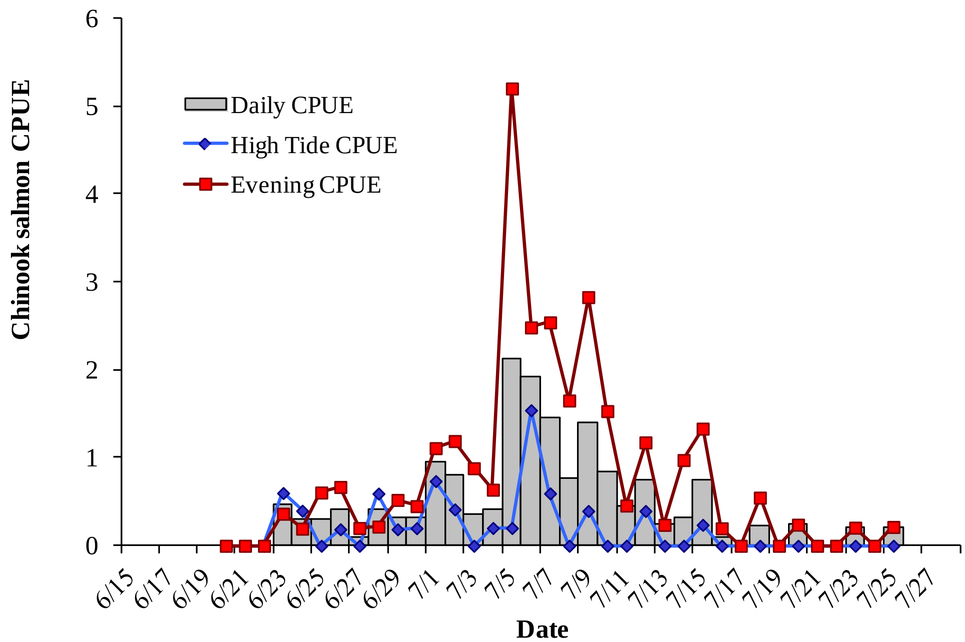

Figure 3.–Catch-per-unit-effort (CPUE) of Chinook salmon at the Unalakleet River tagging site by date for high tide sampling, evening sampling, and total daily sampling.

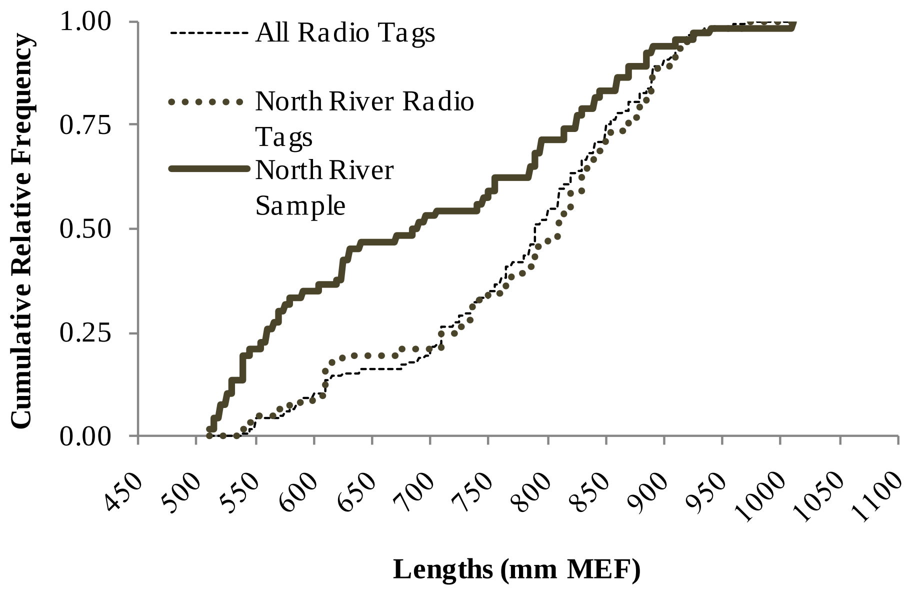

Figure 4.–Cumulative length frequency distributions of all radiotagged fish, all fish sampled above the North River counting tower, and all radiotagged fish migrating above the North River counting tower, 2010.

Table 5.–Catch and length statistics for male and female Chinook salmon sampled at the downriver tagging location and in the North and Unalakleet rivers, 2010. Standard errors for estimates are in parentheses.

	Downriver Tagging Location			Upriver Sampling
Statistic	All Fish	Unalakleet Tags	North Tags	North River
Number caught				
All	149	61	56	91
Male	No sex data	No sex data	No sex data	72
Female	No sex data	No sex data	No sex data	19
Mean Length (mm)				
All (SD)	770 (131)	772 (99)	779 (113)	633 (196)
Male and Female				
Age 1.1	370 (19)			
Age 1.2	578 (27)	573 (19)	581 (32)	
Age 1.3	773 (60)	759 (61)	771 (59)	
Age 1.4	857 (62)	859 (57)	851 (72)	
Age 1.5	955 (21)		970 (na)	
Male (SD)				545 (175)
Age 1.1				351 (39)
Age 1.2				559 (41)
Age 1.3				695 (41)
Age 1.4				852 (88)
Female (SD)				827 (49)
Age 1.3				812 (44)
Age 1.4				848 (46)
Length Range				
All	350-970	550-960	540-970	275-1030
Male				275-1030
Female				745-925

Table 6.–Fates of 142 radiotagged Chinook salmon in the Unalakleet River drainage, 2010.

General Fate[a]	Number of radio tags	Specific Fate	Number of radio Tags
		North River	61
North River	61	Little North River	0
		Harvested in North River	0
		Upper Mainstem	34
		South River	0
Unalakleet River	56	Chiroskey River	1
		North Fork Unalakleet	5
		Old Woman River	16
		10 Mile River	0
Harvested above tracking tower on Unalakleet	0		
Total past tracking towers	117		
Dead or regurgitated tags	7		
		Sport fishery	1
Harvested below tracking towers	8	Subsistence fishery	5
		Unidentified fishery	2
Backed out	9		
Indeterminate fate	1		
Total that never passed tracking towers	25		

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

Table 7.–Proportion of male and female Chinook salmon that migrated up the North River that were age-1.1, -1.2, -1.3, and -1.4 in 2010. Standard errors for estimates are in parentheses.

Sex	Age 1.1	Age 1.2	Age 1.3	Age 1.4
Male	0.31 (0.06)	0.45 (0.07)	0.09 (0.04)	0.16 (0.05)
Female	0	0	0.44 (0.13)	0.56 (0.13)
Male + Female	0.25 (0.05)	0.35 (0.06)	0.16 (0.04)	0.24 (0.05)

Although significant heterogeneity in capture probabilities in both the first and second event indicated the need to stratify temporally, no viable abundance estimates could be generated with the required stratification methods of Darroch (1961). As such, a Chapman (1951) estimate was calculated that was acknowledged as being biased low, although the degree of bias was unknown. Nevertheless, an estimate of drainagewide escapement generated from the North River tower count and the Unalakleet River weir was available for comparison to estimates based on the Chapman model.

Abundance Estimate

A total of 1,256 (SE = 95) Chinook salmon were estimated to have passed the North River counting tower by August 15, and 1,021 were counted past the Unalakleet River weir by August 1. Total escapement estimated from these 2 projects was 2,277 (SE = 95). However, 253 (SE = 44) Chinook salmon were estimated past the North River counting tower after August 1, the date at which the Unalakleet River weir was closed for the season.

A total of 117 radiotagged Chinook salmon continued their upstream migration past the tracking towers on the Unalakleet and North rivers and served as the first (marked) event. A total estimate of 1,256 (SE = 95) Chinook salmon migrated past the North River counting tower (Kent *In prep*); however, only 1,003 (SE = 85) had migrated past the tower through August 1, which was the last day a radiotagged Chinook salmon migrated past the counting tower. The Chapman estimate of drainagewide abundance generated from using the entire tower count as the second event was 2,391 (SE = 283). The drainagewide abundance estimate using data through August 1 was 1,910 (SE = 236). Adding the 253 fish estimated past the North River counting tower after August 1 produced an estimate of 2,163 (SE = 240). Neither of these 2 estimates based on the Chapman model is significantly different from the total generated by the counting tower and weir estimates (2,277), nor are they significantly different from each other.

SPAWNING DISTRIBUTION

Radiotagged Chinook salmon were detected in all tributaries of the Unalakleet River drainage except the South River (Figure 5; Table 6). Chinook salmon were concentrated in 2 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 5 and 6). Of the 117 radiotagged Chinook salmon that passed the tracking towers and were located upriver, 61 migrated past the North River counting tower and 56 migrated up the mainstem of the Unalakleet River. Estimated proportions of Chinook salmon migrating to these various portions of the drainage were 0.52 (SE = 0.05) to the North River, 0.29 (SE = 0.04) to the mainstem of the Unalakleet River, 0.01 (SE = 0.01) to the Chiroskey River, 0.14 (SE = 0.03) to the Old Woman River, and 0.04 (SE = 0.02) to the North Fork of the Unalakleet River (Figure 5).

Table 8.–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–July 2	14	11
July 3–July 6	12	23
July 7–July 9	16	13
July 10–July 27	19	9

Four-part χ^2 test: $\chi^2 = 7.50$

1 vs. 3 vs. 4 quartile χ^2 test: $\chi^2 = 1.16$

2 vs. 1, 3 and 4 pooled χ^2 test: $\chi^2 = 6.38$

Table 9.–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[a]
June 15–July 17	12	336
July 18–July 22	28	288
July 23–July 31	21	372
Aug 1–Aug 15	0	234

Four-part χ^2 test: $\chi^2 = 25.21$.

Three-part (1 – 3 quartile) χ^2 test: $\chi^2 = 9.28$.

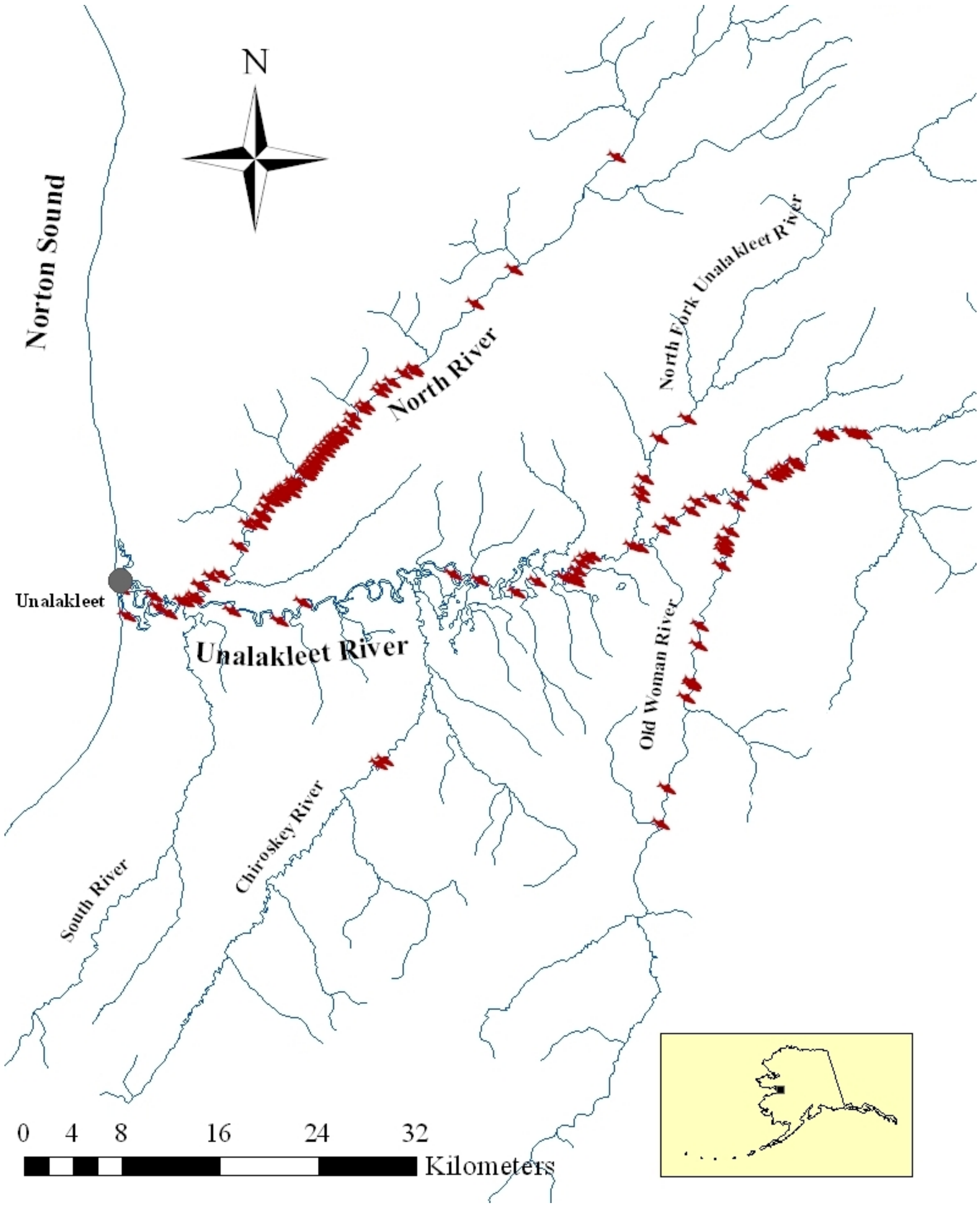

Figure 5.–Maps showing the farthest upstream locations of all radiotagged Chinook salmon in the Unalakleet drainage, 2010.

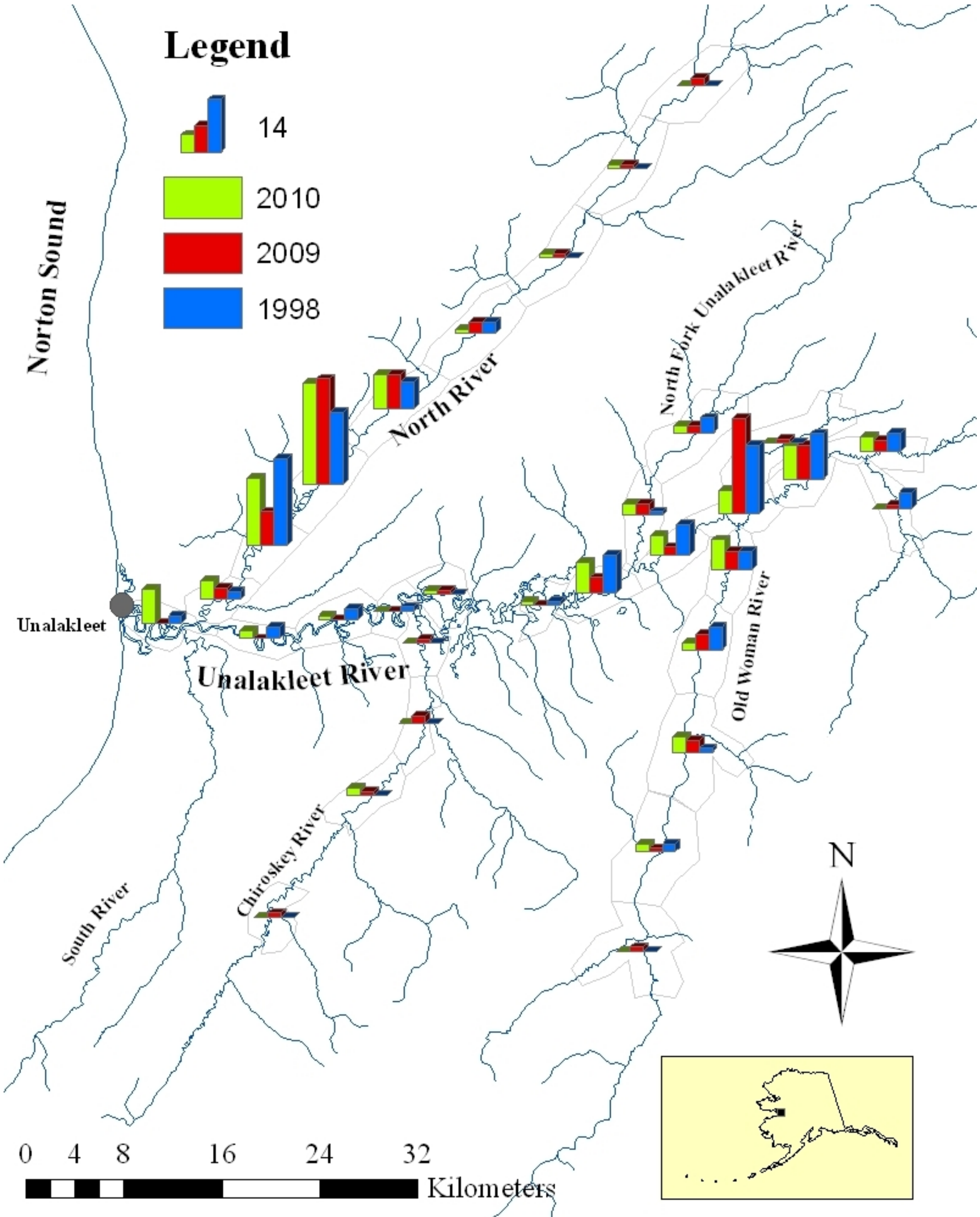

Figure 6.–The number of radiotagged Chinook salmon tracked to 10 km river sections in 2010 (n = 117), 2009 (n = 126), and 1998 (n = 149). Legend displays scale of bar heights (bar height in legend is equal to 14 radio tags).

The proportion of the Chinook salmon migration that passed the North River counting tower was also calculated using Chapman estimators based on 2 different tower counts in an attempt to account for the uncertainty in salmon migration after August 1. The first estimate used the entire tower count and produced an estimate of 53% (SE = 0.05) of total escapement past the counting tower. The second estimate used only the portion of the tower count that occurred before August 2 and produced an estimate of 58% (SE = 0.05).

The proportion migrating past the North River counting tower was also estimated using the counts from the North River counting tower and the Unalakleet River weir (Kent *In prep*). Using the entire count from both projects resulted in an estimate of 0.55 (SE = 0.02) as the proportion of the escapement that migrated past the counting tower. Restricting the inference to only those fish that were detected at either site through August 1 resulted in an estimate of 0.49 (SE = 0.05) of total escapement past the North River counting tower.

The proportion of Chinook salmon that migrated past the North River counting tower using a Chapman estimator with the total North River tower count (53%) was significantly higher than that measured in 2009 (34%; $P = 0.06$), 1998 (40%; $P = 0.04$), and 1997 (37%; $P = 0.01$) (Joy and Reed *In prep*; Wuttig 1998, 1999). The proportion estimated using the Chapman estimator and a partial tower count (through August 1) produced similar results (58% vs. 34%, $P = 0.02$; vs. 40%, $P < 0.01$; vs. 37%, $P < 0.01$), as did the proportion estimated solely from the tower and weir estimates (55% vs. 34%, $P = 0.02$; vs. 40%, $P < 0.01$; vs. 37%, $P < 0.01$).

RUN TIMING

Problems with the power supply at the Unalakleet River tracking tower resulted in gaps in radiotagged fish passage data at the tracking site. Only 18 of the 56 radio tags that migrated up the Unalakleet River have an accurate date assigned for passing the tower. Only these 18 fish were included in analysis where exact dates were necessary.

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 7). Chinook salmon radiotagged in the lower river took from 4 to 26 days (average = 13.0; SE = 4.8) to pass the tracking towers (Figure 8). 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 8). This regression was significant for both Unalakleet River Chinook salmon ($P < 0.01$; Adjusted $R^2 = 0.40$) and North River Chinook salmon ($P < 0.01$; Adjusted $R^2 = 0.40$).

The run timing of radiotagged North River Chinook salmon lagged behind that of radiotagged Unalakleet River Chinook salmon (Figure 7). The difference was not significant at the tagging site ($D = 0.21$, $P = 0.11$); however, it was significant at the upriver tracking towers ($D = 0.68$, $P < 0.01$; Figure 7). Radiotagged Chinook salmon that migrated up the North River took significantly longer to migrate from the tagging location past the tracking station (13.9 days) than did radiotagged fish that migrated up the Unalakleet River (11.0 days; $t = -3.05$, $P < 0.01$).

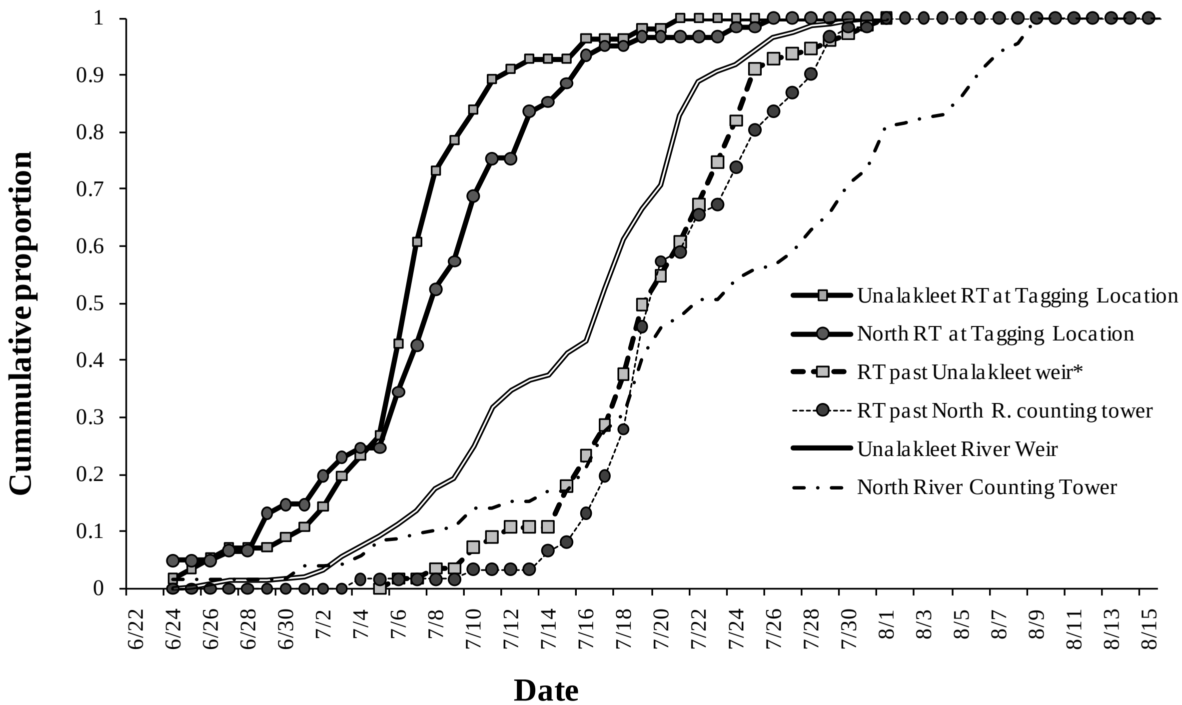

Figure 7.–Cumulative catch at the capture site (solid lines) and passage by upriver tracking stations (dashed lines) for radiotagged Chinook salmon and the cumulative count at the ADF&G-CF Unalakleet River weir and North River counting tower in 2010.

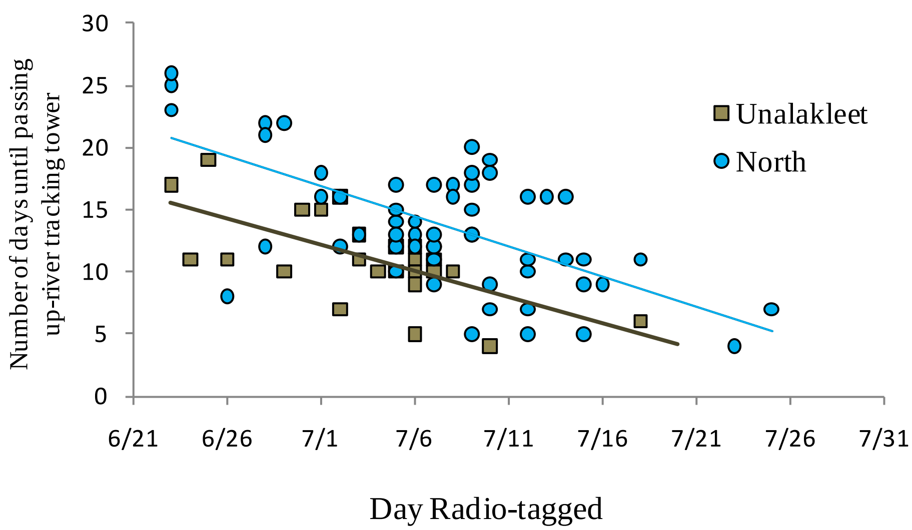

Figure 8.–The number of days between radiotagging Chinook salmon and their passage by either the North or Unalakleet upriver tracking station relative to the day they were captured and radiotagged. Lines represent linear regression for Chinook salmon migrating up either the North (blue) or Unalakleet (grey) River.

AGE, SEX, AND LENGTH COMPOSITION

Age, sex, and length composition estimates of the escapement were from Chinook salmon sampled above the tracking tower on the North River. Seining was conducted between July 14 and July 24 and Chinook salmon ranged in length from 285 to 1,030 mm METF. No age, sex, and length composition estimates were generated from the Unalakleet River weir because of technical difficulties in catching Chinook salmon as they passed through the weir chute. This precluded thorough analysis of North River and Unalakleet River escapements other than by examination of radiotagged Chinook salmon with known spawning destinations.

The length distribution of radiotagged Chinook salmon revealed no significant differences between fish that migrated up the North River and those that migrated up the Unalakleet River ($D = 0.15$; $P = 0.40$; Figure 9).

Chinook salmon ages ranged from age-1.1 to -1.5. The predominant ages in North River seine samples was age-1.2, whereas the predominant age in tagging samples was age-1.3 and -1.4 (Tables 7). The difference in age distributions of fish captured at the tagging site and fish captured by beach seine in the North River was significantly different ($\chi^2 = 42.3$; $P < 0.01$). However, the age distribution of radiotagged Chinook salmon that migrated up the North and Unalakleet River was not significantly different ($\chi^2 = 2.35$; $P = 0.50$; Figure 10, Table 10). Of the estimated escapement, 587 (SE = 138) were age-1.1 males, 848 (SE = 166) were age-1.2 males, 163 (SE = 73) were age-1.3 males, 294 (SE = 98) were age-1.4 males, 218 (SE = 81) were age-1.3 females, and 281 (SE = 91) were age-1.4 females (Table 11).

DISCUSSION

SPAWNING DISTRIBUTION AND RUN TIMING

The run timing of Chinook salmon in 2010 was the latest observed since the installation of the North River counting tower in 1996. In prior years Chinook salmon had never been observed migrating past the counting tower after August 1, whereas in 2010 an estimated 253 out of a total of 1,256 Chinook salmon (20%) migrated after that date (Kent *In prep*). A persistent east wind in June pinned sea ice into the east end of Norton Sound throughout most of June, which was reported by locals as being a one-in-fifty-year event. Consequently, river temperatures recorded at the North River counting tower, the Unalakleet River weir, and the Unalakleet River test net fishery remained well below normal through June (Kent *In prep*). The unusual ice conditions and cold temperatures were the likely cause of the delayed run.

The late run of Unalakleet River Chinook salmon introduced various degrees of uncertainty as it pertained to this experiment. The Unalakleet River weir was pulled on August 1 as planned and because Chinook salmon passage had dwindled. Additionally, no radio tags were observed passing the North River tower after August 1, and no ASL samples were obtained after this date. The absence of data after August 1 makes interpreting escapement past the North River counting tower after August 1 speculative in nature. The predominance of males in ASL seining samples before August 1 and the late push of females observed in the North River in 2009 (Joy and Reed 2014) suggests that the female sex ratio estimated in the North River in 2010 may be biased low.

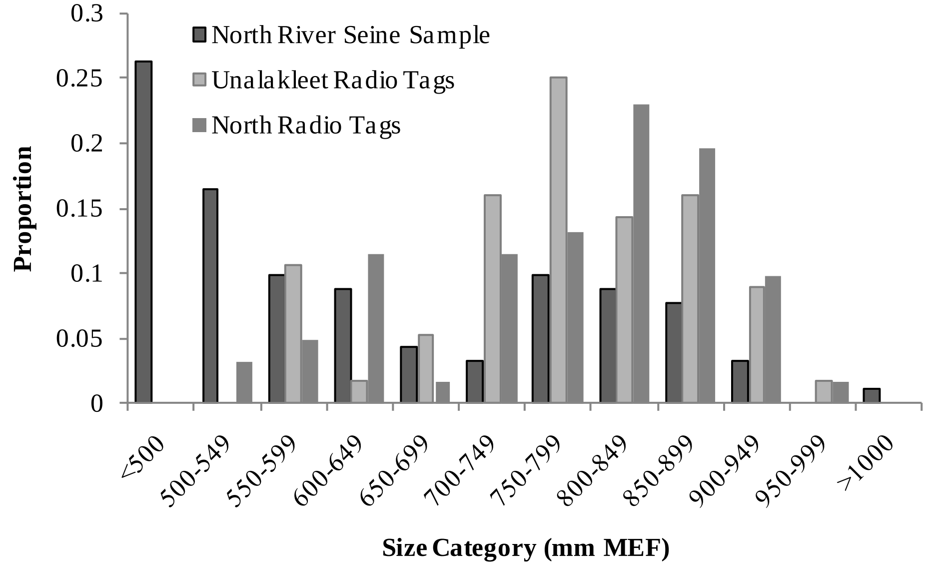

Figure 9.–Size distribution of Chinook salmon that were radiotagged and sampled in the North River by beach seine, 2010.

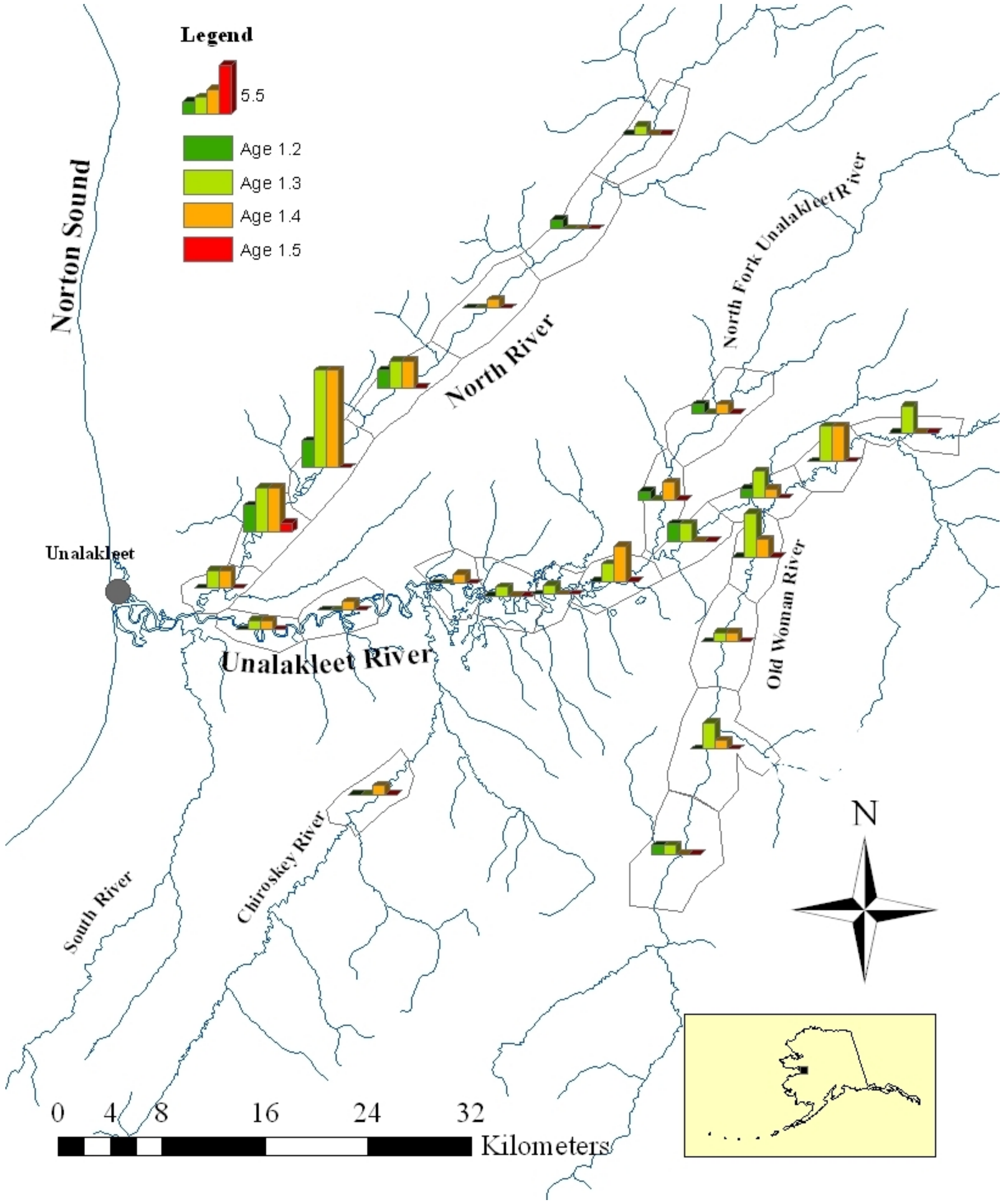

Figure 10.–Map showing the number of radiotagged Chinook salmon from 4 age classes that migrated to each 10 km section of river. Legend displays scale of bar heights (bar height in legend is equal to 5.5 radio tags).

Table 10.–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	1.5
Unalakleet	6	25	17	0
North	9	21	22	1

Table 11.–Estimated age and sex composition of the Chinook salmon escapement in the Unalakleet River drainage, 2010.

Sex/Age Category	Proportion $\hat{p}_k$	SE($\hat{p}_k$)	Abundance $\hat{N}_k$	SE($\hat{N}_k$)
Male				
1.0	0	0	0	0
1.1	0.246	0.050	587	138
1.2	0.355	0.055	848	166
1.3	0.068	0.030	163	73
2.2	0	0	0	0
1.4	0.122	0.038	294	98
Female				
1.3	0.091	0.032	218	81
1.4	0.117	0.036	281	91

The earlier run timing of Unalakleet River fish compared to North River fish detected in this experiment is notable for several reasons. In prior radiotelemetry experiments, run timing between the 2 sub-stocks has never differed significantly (Joy and Reed 2014). This is also true for past telemetry studies on chum salmon (Estensen and Balland *In prep*, Estensen and Hamazaki 2007; Estensen et al. 2005) and coho salmon (Joy and Reed 2007) in this drainage, suggesting that conditions affecting salmon migration timing may be similar between the 2 drainages in most years. The later run timing of North River Chinook salmon observed in 2010 also suggests that a lesser proportion of the total Unalakleet River Chinook salmon escapement migrated upriver after August 1 than the 20% observed in the North River. If this assumption is correct, then fewer than 205 Chinook salmon (20% of 1,021) migrated upriver after the weir was pulled; this estimate is consistent with the various proportion estimates presented (55%, 58%, and 53%). However, it is also possible the differences in run timing stem from the Unalakleet stock being underrepresented in the radio tag sample due to the delayed run.

Despite incomplete data and later run timing resulting from the unusual weather conditions seen in 2010, the estimated proportion of the overall escapement that migrated past the North River counting tower and the associated abundance estimates are plausible. The proportions estimated for the North River escapement using 2 different approaches were 53% and 58%. These estimates did not differ significantly from each other and encompassed the estimate of 55% derived from the weir and tower counts. The abundance estimates derived with different approaches also did not differ significantly from each other and were in agreement with the estimate from the tower and weir counts. Despite questions about escapements after August 1, the telemetry data combined with tower and weir counts provides a reasonable approximation of drainagewide escapement and the proportional relationship between the 2 sub-stocks in 2010.

The proportion of overall escapement migrating up the North River was significantly higher than that observed in 1997, 1998 (Wuttig 1998, 1999), and 2009 (Joy and Reed 2014) under all estimation methods (Figure 6). However, the overall distribution pattern seen in the North and Unalakleet River sub-stocks in 2010 is not different from past years, and the change in the proportion of overall escapement that migrated into the North River appears to be the result of weaker returns in the Unalakleet sub-stock compared to the North River sub-stock. As in past years, radiotagged Chinook salmon were detected in every major tributary except the South River and were distributed around the same 2 distinct spawning congregations in the mainstem Unalakleet and North rivers (Figures 4, 5, and 8).

It is beyond the scope of this report to determine the cause of increased North River or decreased Unalakleet River productivity, but some reasonable hypotheses can be posited. If one accepts the assumption that North River and Unalakleet River sub-stocks overlap in oceanic distribution and thus experience similar oceanic conditions, the shift in spawning distribution seen in 2010 may suggest possible differences in freshwater rearing conditions between the 2 stocks. Chinook salmon returning in 2010 would be from brood year 2004 (age-1.4), 2005 (age-1.3), and 2006 (age-1.2) and would have spent 2005–2007 (depending on brood year) rearing in the system. Future studies about differential productivity in the drainage should examine possible differences in rearing conditions between the 2 sub-stocks.

AGE COMPOSITION

The age, sex, and length compositions presented in this study are probably biased due to unrepresentative and incomplete sampling of the migration and gear limitations. The age composition estimates derived from beach seining in the North River were determined from a sample size below the sample size goal of 149, and all samples were taken before August 1 when the last 20% of the North River run occurred. Males accounted for 72% of sampled fish, and of the male samples, 31% were age-1.1 and 45% -1.2 (Table 7). However, the sex ratio of Chinook salmon age-1.3 and -1.4 was 53% female, which was similar to the 44% seen in 2009. In 2009, females appeared to migrate later in the North River, with 26% of seining samples before July 22 and 46% after July 22 being females. This male to female pattern in run timing is commonly seen in Chinook salmon throughout their distribution (Quinn 2005). Given the pattern seen in 2009 and what is known about differential run timing of male and female Chinook salmon, it is reasonable to infer that the sex ratio (M:F) as presented (Tables 5, 7, 10, and 11) is biased high and length and age distributions are biased low.

Unfortunately, historical ASL samples of the escapement are lacking and/or biased as well. ASL compositions derived from the ADF&G test net fishery are probably biased due to mesh size (5 ¾ in), as are samples taken from the subsistence fishery (8 in mesh). ADF&G-CF has collected samples by seine in the Unalakleet River, but small and potentially biased samples limited the use of this 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 less biased as a result of the easier access to the spawning population. There were no significant differences detected between the 2 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 males and females (Wuttig 1999).

Understanding the age structure of the Unalakleet and North River Chinook salmon stocks will require more comprehensive sampling in the future. Studies indicate large numbers of jack salmon (age-1.1 males) and smaller males (age-1.2) in the escapement, which is supported by the number of jacks caught in gillnets in 2010. However, it has been demonstrated that the timing of ASL sampling of the escapement can bias results and any effort to assess ASL distributions must include comprehensive sampling of the entire migration.

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 drainagewide 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 counting 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 37% in 1997 (Wuttig 1998), 40% in 1998 (Wuttig 1999), 34% in 2009 (Joy and Reed 2014), and between 53% and 58% (depending on method) in 2010. The proportion was significantly different in 2010, although the overall distribution of Chinook salmon spawners remained centered on the 2 sub-stocks in the North and Unalakleet rivers (Figure 5). In addition to an overall difference in the proportional relationship of the 2 sub-stocks, North River Chinook salmon exhibited significantly later run timing compared to Unalakleet River Chinook salmon, which has not been documented before.

All the ADF&G telemetry research on the Unalakleet River has documented a consistent relationship in the proportion of total chum, coho, and Chinook salmon escapement that migrates up the North River (Estensen and Hamazaki 2007; Joy and Reed 2007, 2014). As such, the North River counting tower has been regarded as a good indicator of overall run strength in the drainage, but results from this study suggest otherwise because the proportion can vary significantly from one year to the next. Although the proportion of Chinook salmon migrating up the North River was significantly different, the overall distribution of Chinook salmon indicated that fish utilized the same spawning areas. Significant variation in the relative strength of the 2 sub-stocks may be a reflection of the natural variation present in the system that would be evident were the project to be run for 20 years. Alternatively, the variation seen in this data set may reflect differing productivity between the 2 sub-stocks. Assuming that both sub-stocks experience similar ocean conditions, differential return rates may be the result of differential productivity of smolt from the 2 sub-stocks. In reevaluating how to interpret North River tower counts, managers should consider modeling the expansion of the tower counts over a range of proportions or enumerate the entire drainage, which began in 2010 with the installation of the Unalakleet River weir.

The weir will provide much of the necessary data to deal with these uncertainties. 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 observe 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 to evaluate potential differences in the 2 sub-stocks and to provide for more accurate brood-year return estimates. Although the Unalakleet River weir was installed primarily to obtain escapement data on Chinook salmon, it could be used, in conjunction with North River tower counts, to reexamine the proportional distribution of chum and coho salmon between the North and Unalakleet rivers and compare these results to the proportion measured by past ADF&G telemetry studies (Estensen and Hamazaki 2007; Joy and Reed 2007, 2014).

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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 two 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-square 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 two-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 formulas 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;

$\hat{N}_\Sigma$ = 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, 2010.

Data File	Description
AbundanceEstimates_&_Analysis_UnkChinook_2010.xlsx	Excel spreadsheet with finalized population parameters and estimates.
Chinook_Tracking_10.xlsx	Excel spreadsheet with consolidated data on all radiotagged Chinook, including calculations used in Chapman estimates.
UnkChinook_masterdata_2010.xls	Excel spreadsheet with raw data on all captured and sampled Chinook in the Unalakleet River drainage in 2010, including data from upriver sampling occasions.

Note: 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 at Division of Sport Fish, 1300 College Road, Fairbanks, AK 99701.