Fishery Data Series No. 07-48

Estimation of Coho Salmon Abundance and Spawning Distribution in the Unalakleet River 2004 - 2006

Final Report for Study 05-101
USFWS Office of Subsistence Management
Fishery Information Service Division

by

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and

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August 2007

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Escapement in the Unalakleet River drainage is indexed annually with a counting tower that has been in operation for several years on the North River, a large tributary. A 3-year investigation was initiated in 2004 to describe the extent to which the North River tower counts index escapement of coho salmon into the entire Unalakleet River drainage. This report describes results from 2006, the third year of the study, and compares results from all three years.

In 2006, 307 coho salmon were captured with beach seines in the lower portion of the Unalakleet River and fitted with esophageal radio tags and their final spawning destinations were determined using stationary receiving stations and aerial tracking techniques. Coho salmon were sampled for age, sex, and length data above the North River counting tower and in the Unalakleet River above the North River confluence. Two sample mark-recapture techniques were used to estimate total drainage abundance.

A population abundance estimate of 116,965 coho salmon (SE = 27,502; 95% credibility interval of 80,440 to 206,200) was generated for the entire Unalakleet River drainage, and 9,679 (8% of total drainage estimate) were counted past the North River tower. Nearly all sampled coho salmon were age-2.1 or -1.1and similar proportions of both ages were observed in the North and Unalakleet rivers throughout the run. Coho salmon sampled in the North River were smaller, on average, than those sampled in the Unalakleet River, and the run timing pattern of North River coho salmon was similar to the pattern for those returning to other parts of the drainage.

Coho salmon migrated into all tributaries of the drainage. The largest concentration of fish migrated to the stretch of the Unalakleet River between the Chiroskey River and the North Fork Unalakleet River and those fish tended to have later run timing. Estimated proportions of coho salmon migrating to various portions of the drainage were 0.083 (SE = 0.019) to the North River, 0.684 (SE = 0.032) to the mainstem of the Unalakleet River below the North Fork, and 0.233 (SE=0.032) to the upper Unalakleet and it's tributaries including 0.044 (SE = 0.012) to the Chiroskey River, 0.028 (SE = 0.012) to the Old Woman River, 0.016 (SE = 0.008) to the North Fork, and 0.726 (SE = 0.031) through the Federal Wild and Scenic portion of the river. An approximate estimate of abundance for coho salmon entering the Wild and Scenic portion of the river was 84,928 (SE = 25,270).

Although the proportion of coho salmon migrating past the North River tower in 2006 was significantly less than in 2004 (15%, Joy et al. 2005) and 2005 (14%, Joy and Reed 2006) the proportions were reasonably consistent over the three years of the study. This along with similar age composition and run timing between fish bound for the Unalakleet and the North River suggested the North River tower provides a reasonable and cost-effective index for coho escapement into the Unalakleet River drainage.

Key Words: coho salmon, *Oncorhynchus kisutch*, Unalakleet River, Norton Sound, counting tower, North River, escapement, radio-tagging, distribution, mark-recapture.

INTRODUCTION

The Unalakleet River is a clear, run-off river that drains an area approximately 5,400 square km as it flows southwesterly through the Nulato Hills into Norton Sound (Sloan et al. 1986; Figure 1). The river supports a large run of coho salmon *Oncorhynchus kisutch* as well as runs of Chinook salmon *O. tshawytscha*, chum salmon *O. keta*, pink salmon *O. gorbuscha* and a small run of sockeye salmon *O. nerka*. The Unalakleet River also supports resident populations of Dolly Varden *Salvelinus malma,* Arctic grayling *Thymallus arcticus* and burbot *Lota lota*.

Unalakleet River coho salmon stocks support substantial subsistence and sport fisheries as well as the largest commercial coho salmon fishery in Norton Sound. The Norton Sound District 6 commercial fishery occurs near the mouth of the Unalakleet River and the majority of fish caught in that fishery are believed to be Unalakleet River stocks. The 2006 District 6 commercial harvest estimate was 97,811 coho salmon with a recent 5-year average (2001–2005) of 35,667 fish. Subsistence harvests have ranged from 4,988 to 16,081 from 1994–2003, and the most

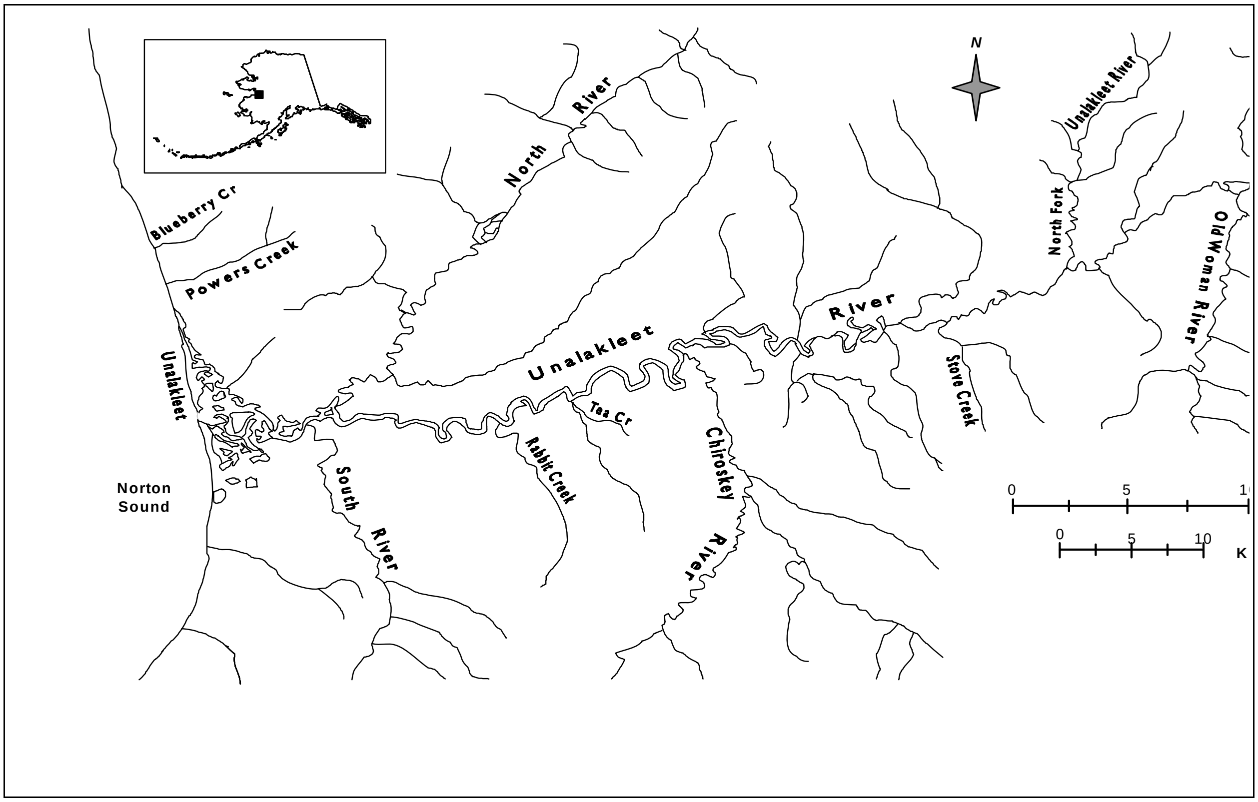

Figure 1.–Map of the Unalakleet River and its tributaries.

recent 5-year (1999–2003) average harvest was 6,294. The recent 5-year average (2000–2004) annual sport coho salmon harvest was 2,987 fish (Table 1).

In the past 10 years there has been a noticeable increase in the number of sport fishermen participating in the Unalakleet River coho salmon fishery. This increase has been of concern to the Unalakleet area residents, who use coho salmon for subsistence. In 2003, Unalakleet residents approached the Alaska Department of Fish and Game (ADF&G) and the U.S. Bureau of Land Management (BLM) over their concern about the rising amount of sport angling and their uncertainty in escapement estimates for coho salmon.

Escapement of Unalakleet River coho salmon is monitored by a counting tower located on the North River, a large tributary system draining into the lower river. The tower has been operated by two different regional organizations. From 1996–2001 it was operated by Kawerak Inc., and in 2002 the Native Village of Unalakleet (NVU) took over operation of the tower with assistance from the ADF&G – Division of Commercial Fisheries (CF). The counting tower is typically in operation from June 15 through September 10. In past years tower counts have ceased prior to

Table 1.–Unalakleet River coho salmon commercial, subsistence and sport harvest, sport catch, and counts from the North River tower, 1980–2005.

Brood Year	North River Tower Counts	Last Day of Operation	District 6 Commercial Harvest	District 6 Subsistence Harvest	Unalakleet River Sport Catch	Unalakleet River Sport Harvest
1980			21,512	4,758		
1981			29,845	5,808		
1982			61,343	7,037		
1983			36,098	6,888		
1984			47,904	6,675		
1985			15,421	2,244		
1986			20,580			
1987			15,097			
1988			24,232			
1989			36,025	4,681		
1990			52,015		3,396	1,826
1991			52,033		2,882	2,180
1992			84,449		2,802	1,555
1993			26,290		1,572	643
1994			71,019	16,081	2,488	2,425
1995			31,280	13,110	3,086	2,033
1996	1,229	25-Jul	52,200	15,963	5,863	3,411
1997	5,768	26-Aug	26,079	9,120	4,020	2,784
1998	3,361	12-Aug	24,534	7,303	3,213	2,742
1999	4,792	31-Aug	10,264	8,140	9,593	2,691
2000	6,959	12-Aug	29,803	5,878	9,184	4,103
2001	12,383	15-Sep	15,102	6,270	5,399	2,766
2002	2,966	28-Aug	1,079	4,988	3,691	2,937
2003	5,837	13-Sep	13,027	6,192	2,832	1,604
2004	11,187	14-Sep	29,282	5,978	12,655	3,524
2005	19,189	14-Sep	63,437	11,148	14,936	3,959
5 yr average						
2001–2005			17,659	7,896	6,752	2,987

Note: Shaded cells indicate an incomplete count of the run.

the end of the coho salmon run due to high water events that created poor viewing conditions (Table 1; Jones 2006). Run strength of coho salmon in the Unalakleet River drainage has varied annually as indicated by past tower counts and by commercial and subsistence catches. Total escapement counts past the North River counting tower have varied from 2,966 fish in 2002 to 19,189 fish in 2005.

This project was initiated in 2004 as a three year study and the primary objective was to evaluate the North River tower project as an index of drainage-wide escapement. This report summarizes results from the last year of the project, 2006, and compares results between 2004, 2005 and 2006.

OBJECTIVES

The objectives of this study in 2006 were to:

1. Estimate the proportions of the coho salmon escapement migrating up the mainstem Unalakleet, North, Chiroskey, and Old Woman rivers, and the North Fork of the Unalakleet River, and into all waters designated Federal Wild and Scenic rivers such that the estimates were within 7.5 percentage points of the actual values 90% of the time;
2. Estimate the abundance of coho 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 age, sex and length composition of the coho salmon escapement into the Unalakleet and the North rivers such that all estimated proportions were within 10 percentage points of the true values 95% of the time; and,
4. Document the locations of coho salmon spawning areas throughout the Unalakleet River drainage, including the Federal Wild and Scenic River portion of the river.

A project task was to estimate the abundance of coho salmon migrating through the Federal Wild and Scenic portion of the Unalakleet River, which is defined as the portion of the mainstem Unalakleet River above the confluence with the Chiroskey River.

METHODS

This study used radiotelemetry and mark-recapture techniques to estimate drainage-wide abundance and spawning distribution of coho salmon. Abundance was estimated using a Petersen-type two-sample mark-recapture experiment for a closed population (Seber 1982). The first sample consisted of coho salmon being captured and marked using radio tags in the mainstem Unalakleet River below the confluence with the North River. The second sample consisted of the total number of coho salmon that were counted past the North River counting tower. Radio-tagged coho salmon that passed the North River tower served as marked fish in the second event. All radio-tagged coho salmon were sampled for age, sex, and length (ASL) data, and ASL sampling was also conducted above the North River tower and in the Unalakleet River upstream from the capture site (referred to below as "upriver sampling") to evaluate mark-recapture assumptions of equal probability of capture for all fish. The spawning distribution of coho salmon was estimated by apportioning the total abundance estimate based on the proportion of radio-tagged fish in that area.

CAPTURE

Coho salmon were captured by beach seining. Capture for radio-tagging occurred at a single site approximately 5 km upstream from the mouth of the Unalakleet River and 3 km downstream of the mouth of the North River (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. The beach seine was 150 ft long and 8 ft deep with 2 3/4 in mesh.

The seine was operated by a crew of four persons utilizing an 18 ft jet-powered skiff. Two people stood and anchored one end of the seine off the bank of the river while the other two crew members in the skiff deployed the seine perpendicular to the bank, looped it downstream and returned back to the bank. The two ends of the seine were then pursed together and brought onshore by pulling in both ends of the seine by hand. Four to five seine hauls were performed per shift with one out of every four seine hauls being performed on the south side of the island and three out of four being performed on the north side of the island.

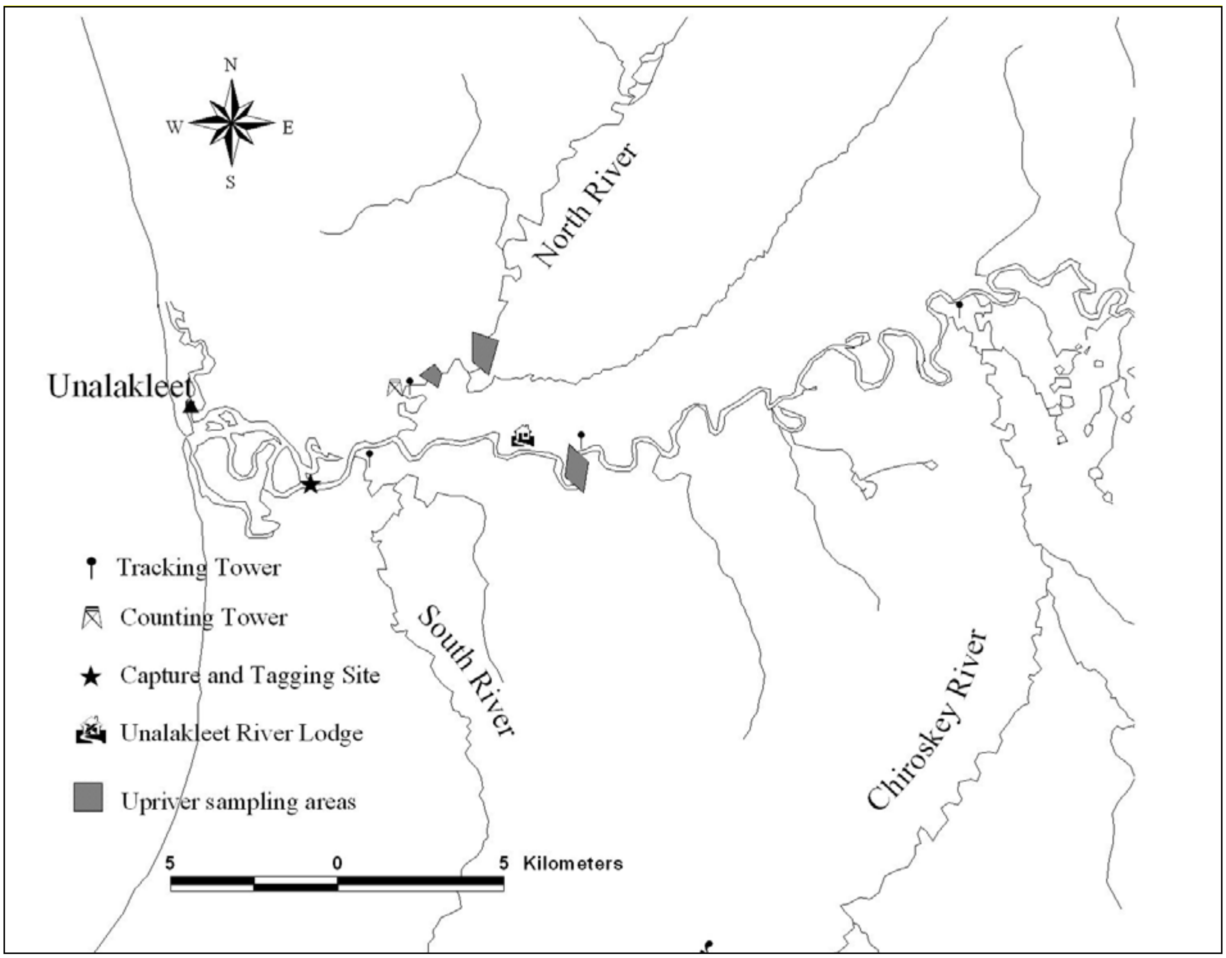

Figure 2.–Coho salmon capture and tracking station locations and North River counting tower site in the Unalakleet River drainage, 2006.

Standardized fishing for coho salmon began on July 17. Fishing continued until catches had fallen off to less than two fish per day for several days. The final day of fishing was September 20. Fish capture for radio-tagging occurred four days each week (Monday, Tuesday, Thursday and Friday). Sampling was conducted during a morning shift, approximately 0900-1300 hours, and an evening shift, approximately 1800–2200 hours. Initially, 4 seine hauls were made during each shift (total of 8 per day). When fishing was slow, an extra seine haul was added on each shift. A 15 minute break was taken between seine hauls in the same stretch of water. If the second haul could be performed 50 to 100 meters below where the first seine haul was performed, then seine hauls were performed without a break.

TAGGING

After capture, coho salmon were placed in a large holding tub or were left in the beach seine while it was pursed up and acted as a net pen. All captured coho salmon were marked with an operculum punch unique to the periods corresponding to the expected quintiles of the run (Table 2). The sex of each coho salmon was determined by external characteristics and the fish were measured to the nearest 5 mm MEF length.

Table 2.–Unalakleet River coho salmon radio-tagging goals, 2006.

Date	Number of Radio Tags Deployed	Cumulative No. of Tags Deployed	Operculum Punch Pattern
7/14-8/4	60	60	Left diamond
8/5-8/11	60	120	Left tear drop
8/12-8/18	60	180	Left heart
8/19-8/28	60	240	Left rectangle
8/29-9/30[a]	60	300	Left circle

[a] Anticipated end date; last day of tagging was 9/16.

A proportion of the coho salmon caught received a Model Five pulse encoded transmitter made by ATS[1]. Each radio-tag was distinguishable by its frequency and encoded pulse pattern. Fifteen frequencies spaced approximately 10 kHz apart in the 148-149 MHz range with 20 encoded pulse patterns per frequency were used for a total of 300 uniquely identifiable tags. Transmitters were 5.5 cm long, 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 transmitters 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.

Each radio-tagged coho salmon was also tagged with a uniquely numbered spaghetti tag constructed of a 5-cm section of blue tubing shrunk onto a 38-cm piece of 80-lb monofilament. The monofilament was sewn through the musculature of the fish 1-2 cm ventral to the insertion of the dorsal fin between the third and forth fin rays from the posterior of the dorsal fin. This tag

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

was used to help identify spawning fates of those fish that had lost their radio tag or were later harvested or recovered during upriver seining. After handling, the radio-tagged coho 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 spaghetti tags were labeled with return information to facilitate identification of the final fates of all fish (i.e., if harvested in sport, commercial or subsistence fishery). 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.

ADF&G-CF has operated a set gillnet test fishery in the Unalakleet River since 1981. The historic average run timing of coho salmon through this test fishery was used to develop the tagging schedule for distributing radio tags in proportion to run strength throughout the duration of the run (Figure 3). Tagging goals coincided with twentieth percentile increments of the average run timing pattern to ensure that run size was examined on a fine enough scale to adjust tagging rates if necessary (Table 2). A systematic sampling approach (*x* number of fish tagged per sampling day) was used to meet the tagging goals.

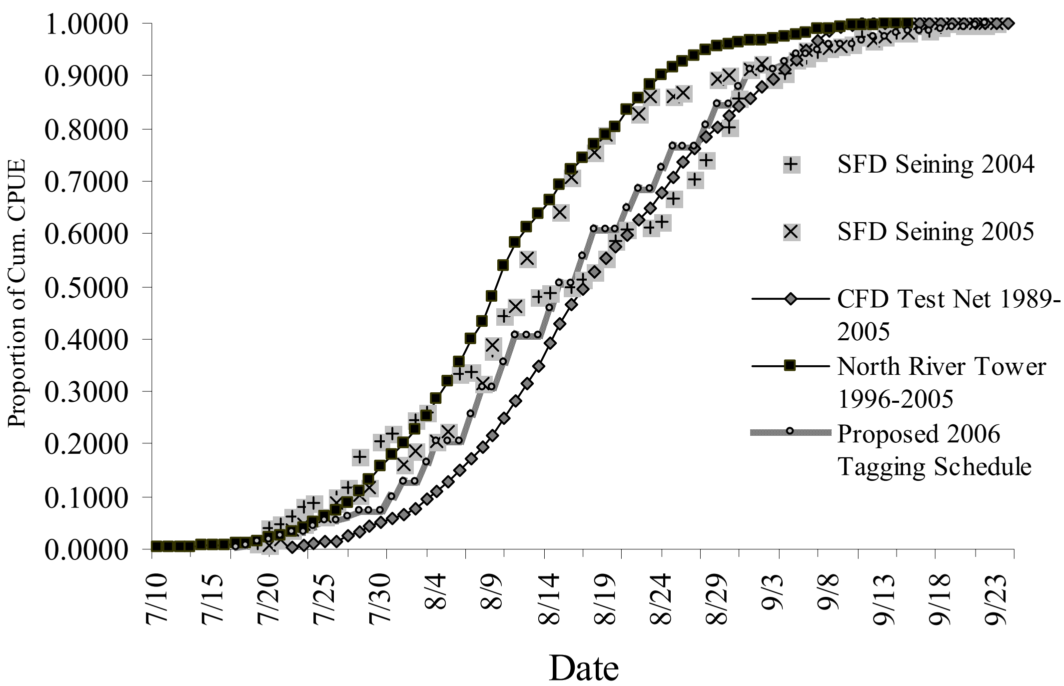

Figure 3.–Average cumulative CPUE of Unalakleet River coho salmon at the ADF&G-CF test fishery from 1986 through 2005, the North River counting tower from 1996 through 2005, the 2004 and 2005 seining catch of the ADF&G - Sport Fish Division (SFD), and the 2006 proposed tagging schedule.

UPRIVER SAMPLING

Every Wednesday and Saturday from July 20 through September 20, 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). Both rivers were sampled on each day, one river in the morning and the other in the afternoon and then reversing the order on the following sampling day. Up to four seine hauls were made in each area on each day. In both areas, the initial objective was to find one or more sites that were suitable for seining. After locating a site, the primary objective was to collect a systematic sample of coho salmon throughout the run to estimate ASL composition. Criteria for a "suitable" site included: 1) moderate to slow current velocity; 2) free of snags and large rocks; 3) an adequate beach to "land" the seine; and, 4) coho salmon were successfully captured at the site. In the Unalakleet River, the section of river that was sampled was approximately 1 km above the Unalakleet River Lodge (Figure 2). In the North River, two sections of river were used at approximately 1 and 4 km above the counting tower respectively. These sections were chosen for investigation because they met the criteria for a suitable seining area and were located a moderate distance upstream from the marking site which allowed marked fish to recover from any handling effects and allowed marked and unmarked fish to mix between capture events.

Upriver seining procedures were similar to those previously described. All coho salmon captured during upriver seining were given an adipose fin clip to identify them as being captured upriver. All captured fish were inspected for tags and operculum punches and sampled for length, sex, and age. To determine age, three 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 post-season 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

Radio-tagged coho salmon were tracked and spawning destinations were discerned through the use of four stationary radio-tracking towers and four aerial radio-tracking surveys. One tower was located 200 m up the South River, one was located at the North River counting tower, one was located on the Unalakleet River several kilometers above the confluence with the North River and one was located 100 m up the Chiroskey River (Figure 2).

Each tracking station included one gel-cell, deep-cycle battery, an 80-watt solar array, an ATS model R4500c receiver, an antenna switching box, a weather-proof metal housing box, and two, four-element Yagi antennas (one aimed upstream and the other downstream). The receiver was programmed to scan through the frequencies at three-second intervals receiving with 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 radio-tagged salmon throughout the Unalakleet River drainage was further determined by aerial tracking from fixed-wing aircraft and from weekly boat surveys to: 1) locate tags in areas other than those monitored with tracking stations; 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 surveys were restricted to the mainstem of the Unalakleet River upstream to the Chiroskey River and up the North River to the upriver sampling site. Aerial surveys performed on August 19, August 30, September 21 and October 18 included all tributaries and tertiary streams.

DATA ANALYSIS

Fates of Radio-Tagged Fish

For data analysis, each radio-tagged fish was assigned 1 of 8 possible fates based on information collected from aerial tracking surveys and from stationary data logging stations. Each fish was assigned a "final location" based on data from these two sources.

> ***Fate 1)*** In the North River – a fish that was determined to have entered the North River, passed the North River tracking station and remained above the tracking tower for at least 7 days.
>
> ***Fate 2)*** In the Upper Unalakleet River/ Tributaries – a fish that was determined to have migrated into one of the tributaries of the Unalakleet River other than the North River and including the South River, the Chiroskey River, the North Fork, the 10 mile River, and the Old Woman River. Additionally, the section of the Unalakleet River that is above the Old Woman River confluence was included in this group based on the GIS analysis and the similarity of these fish to the rest of the tributary destined fish.
>
> ***Fate 3)*** In the Mainstem Unalakleet River - a fish that was determined to have migrated into the Unalakleet River upstream of the North River, was never detected in any tributary or above the confluence with the Old Woman River, and remained above the tracking tower for at least 7 days.
>
> ***Fate 4)*** 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 5)*** Dead/Regurgitated–a fish that did not migrate past the confluence of the North and Unalakleet rivers and was assumed to have died and/or regurgitated its radio tag.
>
> ***Fate 6)*** 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.
>
> ***Fate 7)*** Backed-out –a fish that was recorded at or below the tracking stations but was never recorded by the stations or during boat and aerial surveys as having passed upstream of the stations; and, fish that migrated upstream of a tracking tower but remained above the tower for less than 7 days before migrating back down and out of the drainage.
>
> ***Fate 8)*** Unknown- a fish that was never recorded at any of the tracking stations or located during any aerial or boat surveys.

Based on the criteria established for fates 1-3, it was assumed that coho salmon spawned in those locations. Radio-tagged coho salmon given fates 1-4 were used to estimate abundance, those with fates 1-3 were used to describe spawning distributions, and those with fates 5-8 were culled from all analyses.

Mark-Recapture Experiment

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).

Conditions for a Consistent Petersen Estimator

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

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 coho 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 coho 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 radio-tagged. Radio-tagged 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 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 coho salmon had the same probability of being caught in the first sampling event;
2. All coho 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 also vary. If discrete coho 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 length and temporally. Coho salmon were captured and tagged over the entire span of the run. Radio tags were implanted into coho salmon of various lengths. Length, date, and time of release were recorded for all tagged fish. The North River tower counts occurred over the span of the run. Age, sex, and length data were collected from the samples of fish above 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 length 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 coho salmon at the tagging site, sex ratios of tagged fish and fish spawning in the North River were not compared.

To further evaluate the three 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 to calculate an unbiased estimate of abundance are described in Appendix A2.

Abundance of coho salmon ≥450 mm MEF in 2006 was estimated after stratification by length to minimize bias. For each stratum, abundance was estimated using the Chapman modification to the Petersen estimator (Chapman 1951) and stratum estimates were summed to estimate total abundance:

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

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

where:

$\hat{N}_s$ = estimated abundance of coho salmon ≥450 mm MEF in the Unalakleet River upstream from tagging site in stratum *s*, *s* = 1 to *S*;

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

R_s = the number of radio-tagged coho salmon in stratum *s* moving past the North River counting tower; and,

$\hat{C}_s$ = the estimated number of coho salmon in stratum *s* counted past the North River tower.

The number of coho salmon in stratum *s* that passed the North River tower was estimated:

$$\hat{C}_s = \hat{p}_s C \tag{3}$$

where the proportion of salmon in stratum s was estimated from length composition data collected inriver above the North River tower:

$$\hat{p}_s = n_{Cs} / n_C \tag{4}$$

where:

- n_{Cs} = number of coho salmon in length stratum s observed of those sampled for composition above the tower;
- n_C = the total number of coho salmon sampled for composition above the tower; and,
- C = the number of coho salmon counted past North River tower.

Variance and 95% credibility interval for the estimator (equation 1) were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, posterior distributions for the $\hat{N}_s$ and $\hat{N}$ were generated by collecting 100,000 simulated values of $\hat{N}_s$ and $\hat{N}$ which were calculated using equations (1-4) from simulated values of equation parameters. Simulated values were modeled from observed data using the following distributions:

observed $n_{C1},\ldots,n_{CS}$ ~multinomial (($p_1,\ldots,p_S$), n_C); and ,

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

where q_s is the probability that a radio-tagged salmon from stratum s passed the North River tower and was treated as a recapture.

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

$$\overline{N} = \frac{\sum_{b=1}^{100,000} \hat{N}_{(b)}}{100,000} \text{ and,} \tag{5}$$

$$V\hat{a}r(\hat{N}) = \frac{\sum_{b=1}^{100,000} (\hat{N}_{(b)} - \overline{N})^2}{100,000 - 1} \tag{6}$$

where $\hat{N}_{(b)}$ is the bth simulated value of $\hat{N}$.

AGE, SEX, AND LENGTH COMPOSITION AND SPAWNING PROPORTIONS

The numbers of coho salmon by length, age, or sex group k were estimated within a major spawning destination d where d indicates either North River or mainstem Unalakleet River stocks and then combined arithmetically. Composition proportions were first estimated using:

$$\hat{p}_{kd} = \frac{n_{kd}}{n_d} \tag{7}$$

where:

- $\hat{p}_{kd}$ = estimated proportion of coho salmon in group k at destination d;

n_{kd} = number of sampled coho salmon in group *k* at destination *d*; and,

n_d = total number of coho salmon sampled at destination *d*.

Estimates of total numbers of salmon in group *k* within each system of *d* were calculated:

$$\hat{N}_{kd} = \hat{N}_d \, \hat{p}_{kd} \tag{8}$$

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

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

$$\hat{N}_k = \sum_{d=1}^{2} \hat{N}_{kd} \,, \tag{9}$$

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \,. \tag{10}$$

Variance and 95% credibility interval for $\hat{N}_k$ and $\hat{p}_k$ were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, posterior distributions for $\hat{N}_k$ and $\hat{p}_k$, which were calculated using equations (7-10) were generated by collecting 1,000 simulated values of $\hat{N}_k$ and $\hat{p}_k$ from simulated values of equation parameters. The simulated values were modeled from observed data using multinomial models within destination for composition proportions.

Variances estimates were calculated from simulated values in the posterior distribution for each parameter estimate using equations similar to (5) and (6) above.

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 from capture, tagging, and radiotelemetry used to estimate parameters of the coho salmon abundance and length, age, and sex compositions in this study were entered into Excel spreadsheets for analysis and archival (Appendix B).

RESULTS

TAGGING AND FATES OF RADIO-TAGGED COHO SALMON IN 2006

Between July 17 and September 20 789 coho salmon were captured at the lower river tagging site and 307 were fitted with radio transmitters. Captured fish ranged in length from 310 to 660 mm MEF, and radio-tagged fish ranged in length from 450 to 660 mm MEF (Figure 4; Table 3). Of the 307 salmon that were radio-tagged, 253 continued upstream migration past the tracking towers on the Unalakleet and North rivers. Eighteen radio-tagged coho salmon were harvested below the tracking stations and two were harvested after passing tracking stations. Nine radio-tagged coho salmon either died or regurgitated their radio tag shortly after handling. Twenty-five radio-tagged coho salmon were determined to have backed-out of the drainage and two radio-tagged coho salmon could not have an accurate fate assigned (Table 4).

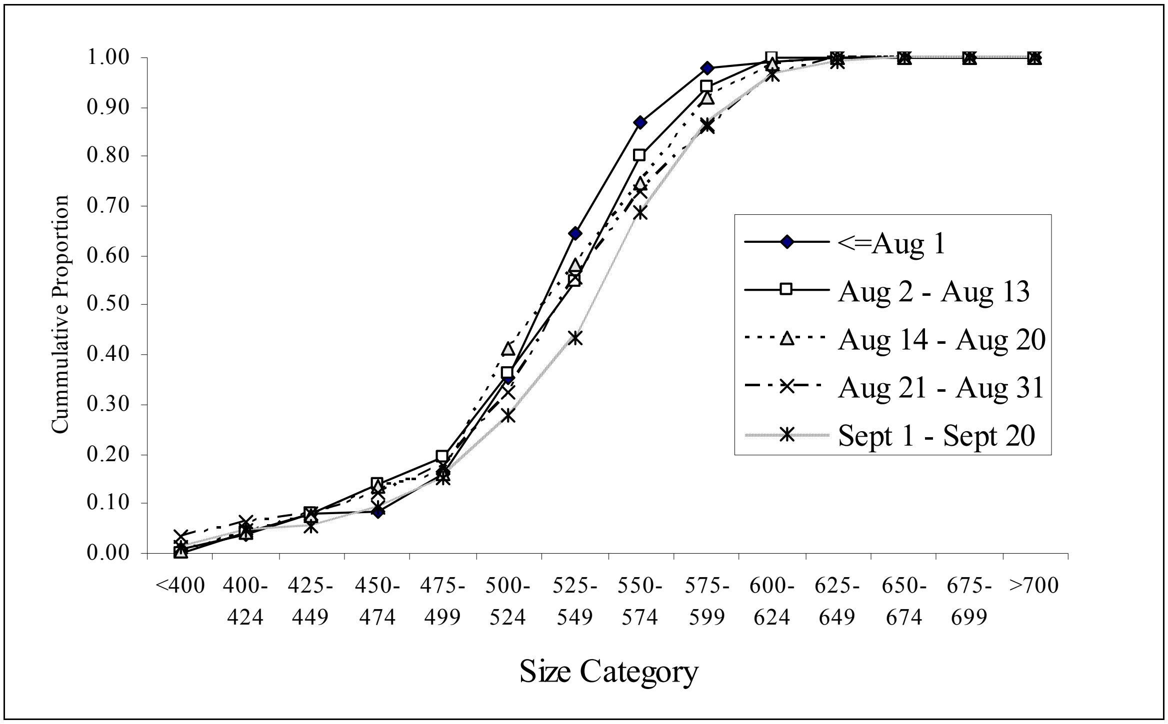

Figure 4.–Length distribution of Unalakleet River coho salmon captured at the tagging site for each of the five run quintiles, 2006.

Table 3.–Catch and length statistics for male and female coho salmon sampled at the downriver tagging location and in upriver sampling areas in the North and mainstem Unalakleet rivers, 2006.

Statistic	Downriver Tagging Location		Upriver Sampling	
	All Fish	Tagged Fish	Unalakleet River	North River
Number caught				
All	789	308	887	673
Male	418	169	527	358
Female	358	139	357	315
Mean Length (mm)				
All (SD)	535.9 (51.4)	552.8 (38.5)	547.5 (50.6)	533.2 (50.9)
Male (SD)	537.8 (54.9)	556.8 (40.9)	547.4 (55.4)	532.7 (57.2)
Age 1.1		550.7 (37.1)	545.7 (53.6)	532.9 (50.4)
Age 2.1		555.2 (43.5)	553.7 (54.4)	541.4 (60.8)
Female (SD)	538.6 (39.8)	548.0 (35.0)	548.3 (41.7)	533.7 (42.8)
Age 1.1		545.0 (34.8)	533.7 (45.1)	533.3 (42.3)
Age 2.1		551.5 (33.6)	558.1 (40.6)	534.6 (40.6)
Length Range				
All	310-660	450-660	375-640	345-645
Male	310-660	450-660	375-640	345-645
Female	400-635	465-635	430-620	420-615

Table 4.–Fates of radio-tagged coho salmon in the Unalakleet River drainage, 2006.

General fate[a]	Number of Radio tags	Specific Fate	Number of Radio Tags
		North River	20
1) North River	22	Little North River	2
		Harvested in North River	0
2) Upper Unalakleet/ Tributaries	53	Upper Mainstem	16
		South River	9
		Chiroskey River	10
		North Fork Unalakleet	6
		Old Woman River	6
		10 Mile River	3
		Other	3
3) Mainstem Unalakleet	176		
4) Harvested above tracking tower on Unalakleet	2		
Total past tracking towers	**253**		
5) Dead or Regurgitated Tags	9		
6) Harvested below tracking towers	18	Caught in Sport fishery	9
		Caught in Inriver Test Net (ADF&G-CF)	2
		Known to be harvested but fishery unknown	7
7) Backed-out	25	Caught in Commercial fishery	5
		Migrated to Shaktoolik River	1
		Migrated to Egavik River	1
		Not located after backing-out	18
8) Unknown	2		
Total that never passed tracking towers	**54**		

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

Five coho salmon that backed-out of the drainage in 2006 were harvested in the district 6 commercial fishery, a set gillnet fishery that operates along the Norton Sound coast north and south of the mouth to the Unalakleet River. One salmon was detected in the Shaktoolik River and another was detected in the mouth of the Egavik River, both of which are north of the Unalakleet River. The remaining 18 coho salmon that backed-out of the drainage spent less than one week above a tracking tower and were never detected again after leaving the drainage. The proportion of radio-tagged coho salmon that backed-out after tagging was significantly greater in 2006 than during the 2004 and 2005 experiments (Table 5).

Table 5.–Number of radio-tagged coho salmon that were judged to have roamed in-river prior to spawning or backed-out of the Unalakleet River drainage prior to spawning.

	2004	2005	2006
Total number radio-tagged	208	290	307
Roamed In-River	3	8	20
Backed-out	2	7	25

Note: For explanation of terms see Fates of Radio-Tagged Fish, in text above.

DISTRIBUTION OF RADIO-TAGGED COHO SALMON IN 2006

Radio-tagged coho salmon were detected extensively throughout the Unalakleet River drainage including in the South, North, Chiroskey, 10 Mile, North Fork Unalakleet, and Old Woman rivers (Figure 5; Tables 4 and 6). The area with the highest concentration of coho salmon as determined by aerial radio-tracking surveys was the section of the Unalakleet River that lies above the Chiroskey River and below the North Fork.

Coho salmon that migrated a significant distance (several kilometers) into a given tributary or section of the Unalakleet River and then subsequently turned around, migrated back downstream, and then migrated into a different tributary or section of river were termed as having "roamed" prior to spawning. This was particularly prevalent among coho salmon ultimately bound for North and South rivers, several of which migrated above the Unalakleet River tower as far as the Chiroskey River tower for up to two weeks before turning around and ultimately migrating up the North or South rivers. This roaming behavior was more prevalent in 2006 than in 2004 or 2005 (Table 5).

Of the 253 radio-tagged coho salmon that passed the tracking stations and were located upriver, 22 migrated past the North River counting tower (hereafter referred to as *North River coho salmon*), 53 coho salmon migrated into other tributaries or migrated up the mainstem of the Unalakleet River above the Old Woman River (hereafter referred to as *upper Unalakleet/tributary coho salmon*), 176 coho salmon migrated up the mainstem of the Unalakleet River and remained in the section between the North River and the Old Woman River (hereafter referred to as *mainstem coho salmon*) and two migrated up the Unalakleet River but were harvested before reaching their spawning destination. When referring to *upper Unalakleet/tributary coho* and *mainstem coho* collectively, the term *Unalakleet coho salmon* is used hereafter. Estimated proportions of coho salmon migrating to these various portions of the drainage were 0.083 (SE=0.019) to the *North River*, 0.684 (SE=0.032) to the *mainstem*, and 0.233 (SE=0.032) to the *upper Unalakleet/tributaries,* including 0.044 (SE=0.015) to the Chiroskey River, 0.028 (SE=0.012) to the Old Woman River, and 0.016 (SE=0.008) to the North Fork (Table 6; Figure 6). Of the tributary streams, the North River accounted for the largest proportion of radio-tagged fish that migrated upstream after capture (Figure 6, Table 6). Additionally, 0.726 (SE=0.031) coho salmon migrated into or through the Federal Wild and Scenic portion of the river.

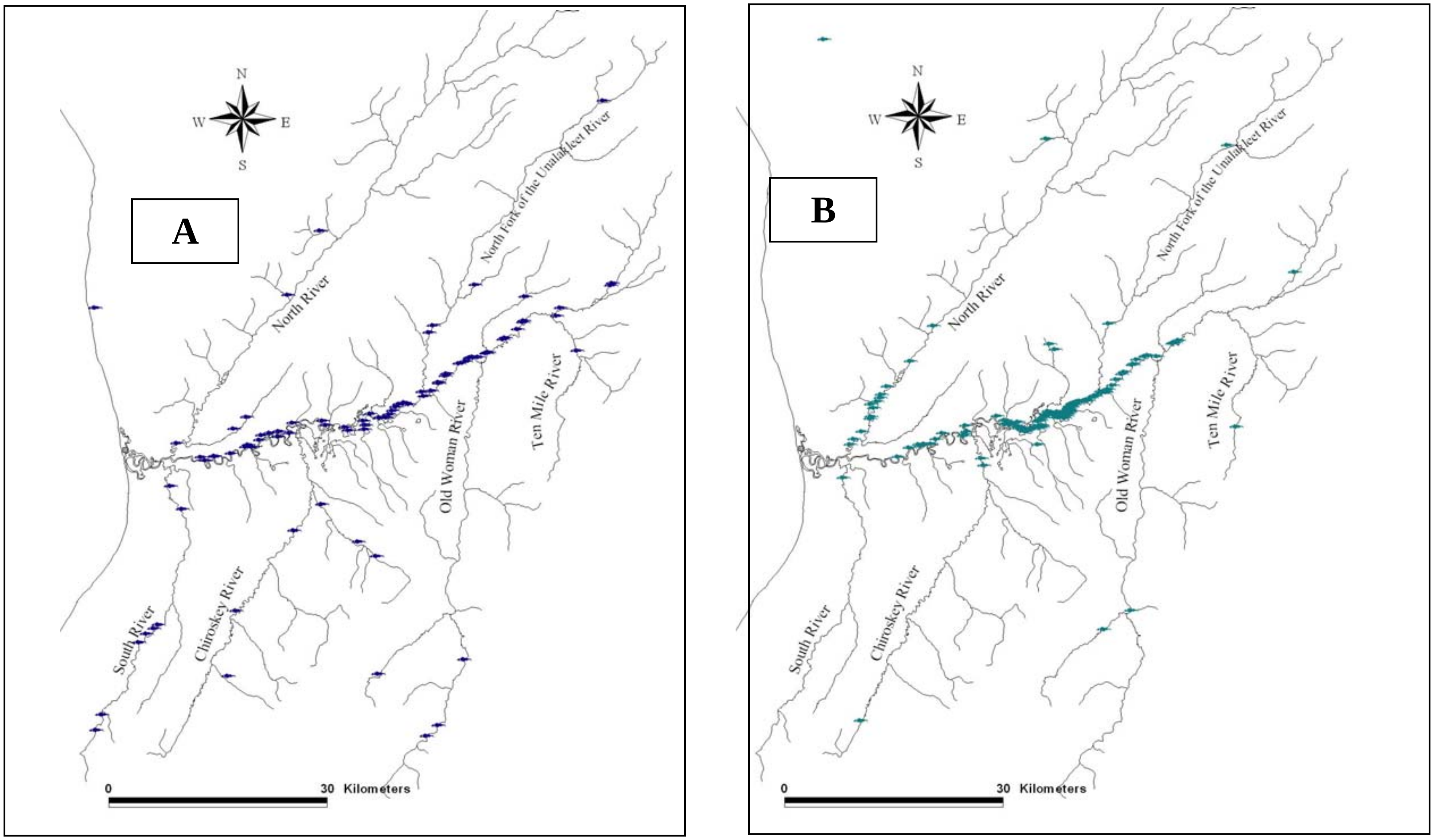

Figure 5.–Maps showing the farthest upstream locations of all radio-tagged coho salmon in the Unalakleet drainage, 2006. A shows the distribution of coho salmon that were radio-tagged on or before August 13, and B shows the distribution of coho salmon that were radio-tagged after August 13.

Table 6.–Estimated proportions of coho salmon entering the North River, the mainstem Unalakleet River, the Upper Unalakleet/ tributaries, the Chiroskey River, the Old Woman River, the North Fork Unalakleet River, the entire Unalakleet drainage (excluding the North River), and in the Federal Wild and Scenic portion of the drainage, 2006.

Area	Proportion (SE)
North River	0.083 (0.019)
Mainstem Unalakleet	0.684 (0.032)
Upper Unalakleet/Tributaries	0.233 (0.032)
Chiroskey River	0.044 (0.015)
Old Woman River	0.028 (0.012)
North Fork	0.016 (0.008)
Entire Unalakleet	0.917 (0.019)
Federal Wild and Scenic portion of Unalakleet	0.726 (0.031)

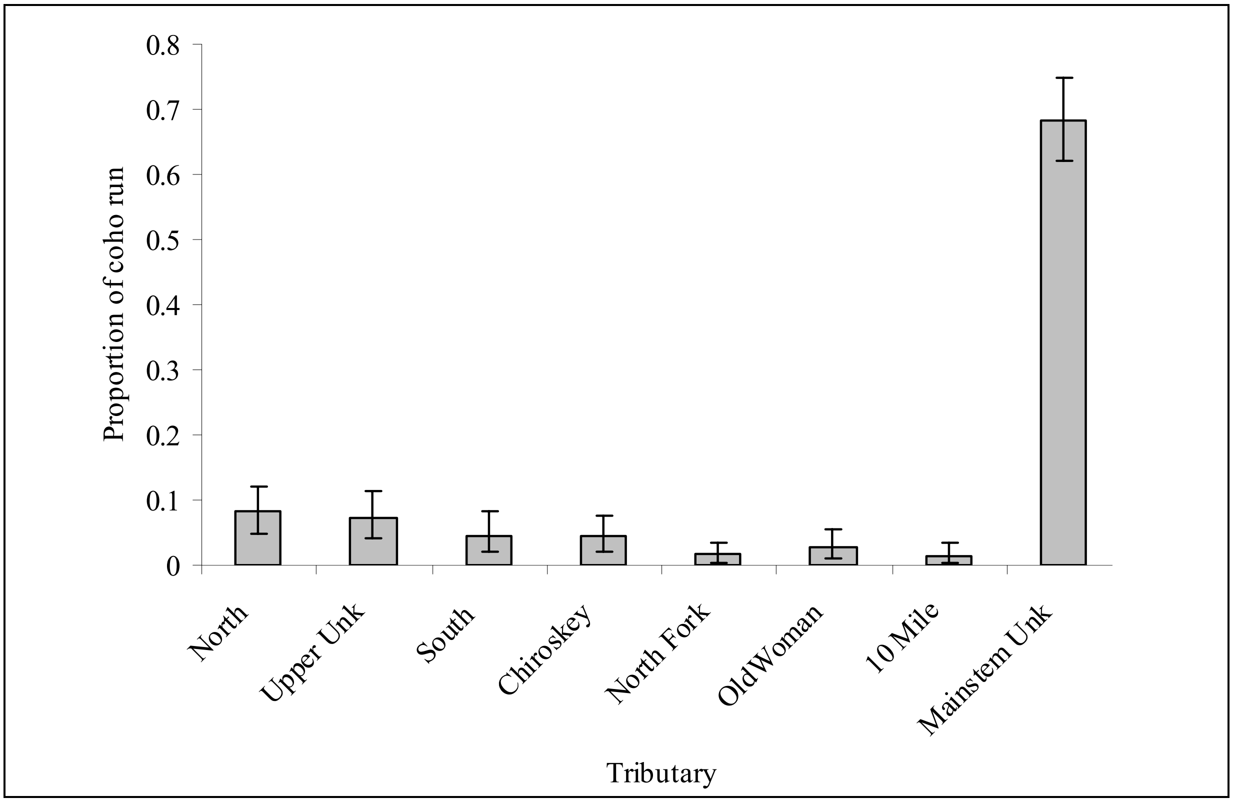

Figure 6.–Estimated proportional distribution of coho salmon in the Unalakleet River drainage in 2006.

Note: The Upper Unalakleet is defined in this report as the section of the Unalakleet River located above its confluence with the Old Woman River. The mainstem Unalakleet River is defined in this report as the section of the Unalakleet River located below its confluence with the Old Woman River. Error bars represent 95% confidence intervals.

MARK-RECAPTURE EXPERIMENT IN 2006

Tests of Sampling Bias

Tests for length biased sampling (Appendix A1) indicated that there was a significant difference in the length distribution of all radio-tagged coho salmon and the length distribution of those fish sampled above the North River counting tower (Marks vs. Captures: D = 0.159, P <0.001; Figure 7). There was also a significant difference in length distribution of radio-tagged coho salmon that migrated past the North River counting tower and those salmon sampled in the North River (R vs. C: D = 0.326, P=0.019). There was no significant difference between all radio-tagged coho salmon and radio-tagged coho salmon that migrated past the North River counting tower (M vs. R: D = 0.188, C = 0.433). The results of these tests indicated a case III experiment which precludes the need for a stratified estimator. However, there was also a significant difference in the length distribution of North River and Unalakleet River coho salmon (D = 0.149, P <0.001) with North River fish being, on average, smaller than those that migrated up the mainstem of the Unalakleet (Figure 8). This additional test result and the significant results obtained comparing captured fish with both recaptures and marks led to the conclusion that stratification by length, though conservative, would be prudent for this experiment.

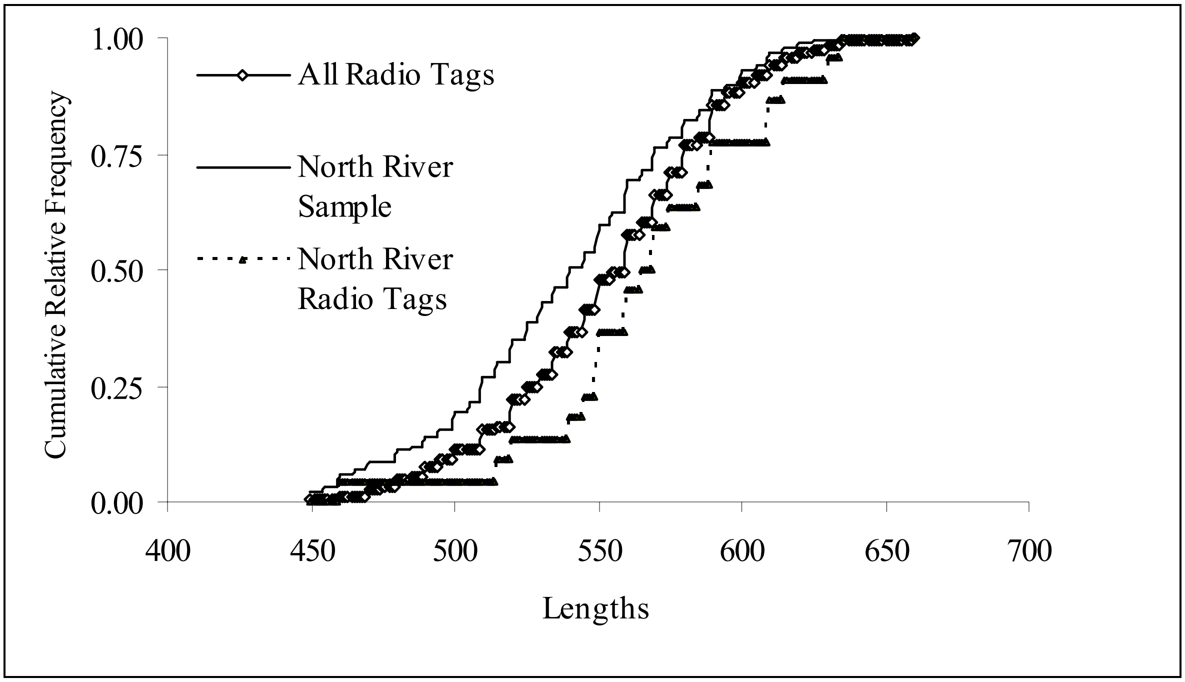

Figure 7.–Cumulative length frequency distributions of all radio-tagged fish, all fish sampled above the North River counting tower, and all radio-tagged fish migrating above the North River counting tower, 2006.

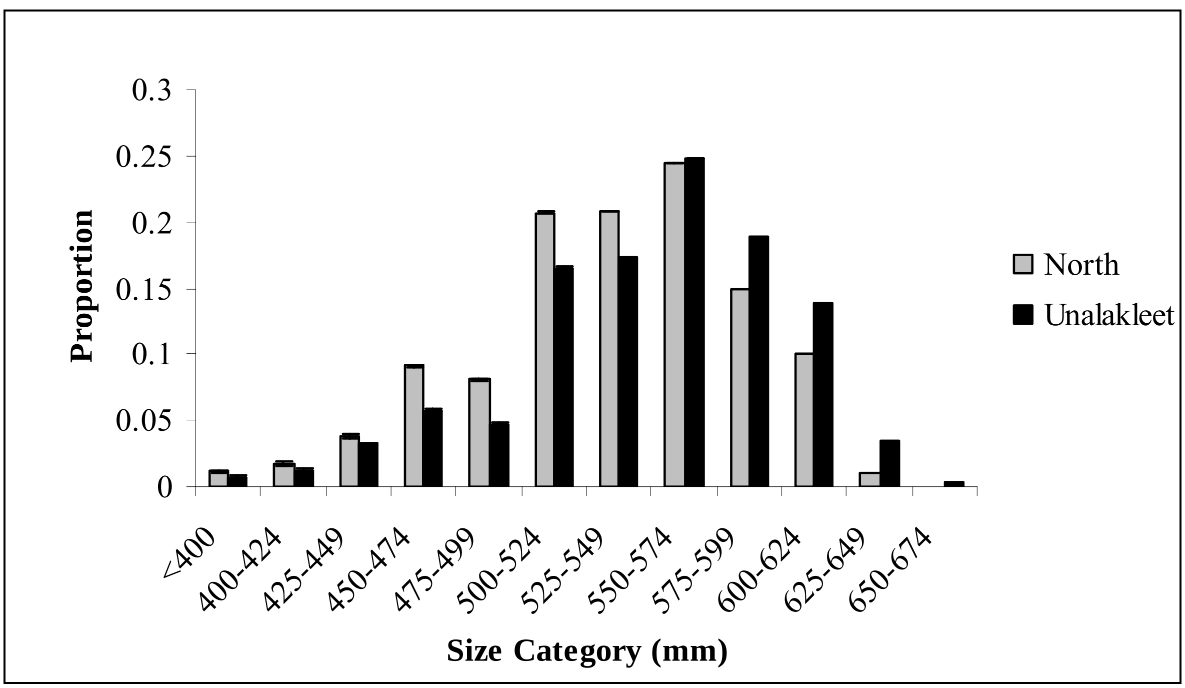

Figure 8.–Length distribution of coho salmon sampled in the Unalakleet and North rivers, 2006.

The data were split into two length categories; <560 mm MEF and ≥560 mm MEF. Within each length strata there was no significant difference in the length distribution of coho salmon sampled in the Unalakleet River and the North River above the counting tower (<560: D = 0.063, P = 0.305; ≥560: D = 0.101, P = 0.077). For fish <560 mm MEF, there was still a significant difference between marked coho salmon and coho salmon sampled above the North River counting tower (M vs. C: D = 0.158, P = 0.015). However, there was no significant difference in length distribution between radio-tagged coho salmon and radio-tagged coho salmon that migrated past the North River tower (M vs. R: D = 0.273, P = 0.609), nor was there a significant difference between radio-tagged salmon that migrated past the North River tower and those salmon sampled above the North River tower (R vs. C: D = 0.367, P = 0.236). For coho salmon ≥560 mm MEF, there were no significant differences for any of the diagnostic tests (M vs. C: D = 0.040, P = 0.997; M vs. R: D = 0.194, P = 0.681; R vs. C: D = 0.201, P = 0.649). These results indicated no evidence of length biased sampling within the two length strata, and further stratification was unnecessary.

Run timing of coho salmon migrating up the North River and the Unalakleet River at the lower river capture site was compared and there was no significant difference for all fish (D = 0.119, P = 0.926; Figure 9). The results were similarly insignificant for coho salmon <560 mm MEF (D = 0.177, P = 0.970) and for coho salmon ≥560 mm MEF (D = 0.251, P = 0.364). The run-timing of mainstem coho salmon and upper Unalakleet/tributary coho salmon were also compared (Figure 10), and there was a significant difference in run-timing of these two groups of fish (D = 0.382, P <0.001) with the upper Unalakleet/tributary coho salmon entering the system significantly earlier than mainstem coho salmon.

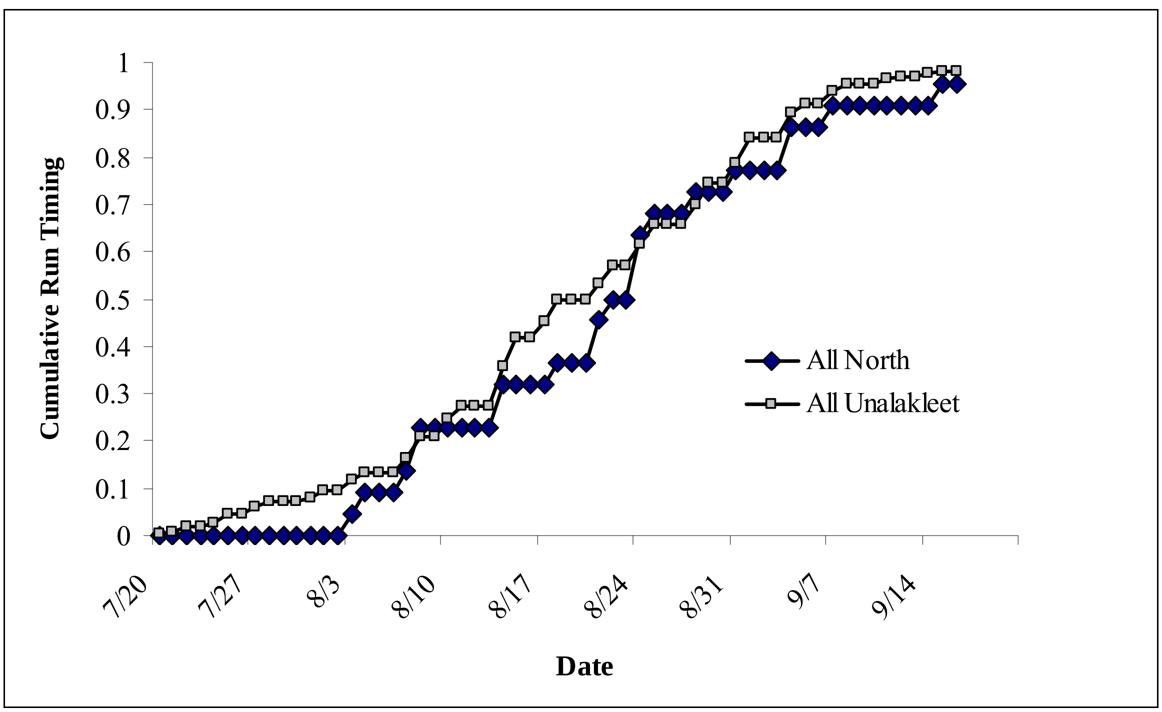

Figure 9.–Cumulative run timing past the capture site for radio-tagged coho salmon that migrated up the North River and up all other areas of the Unalakleet River, 2006.

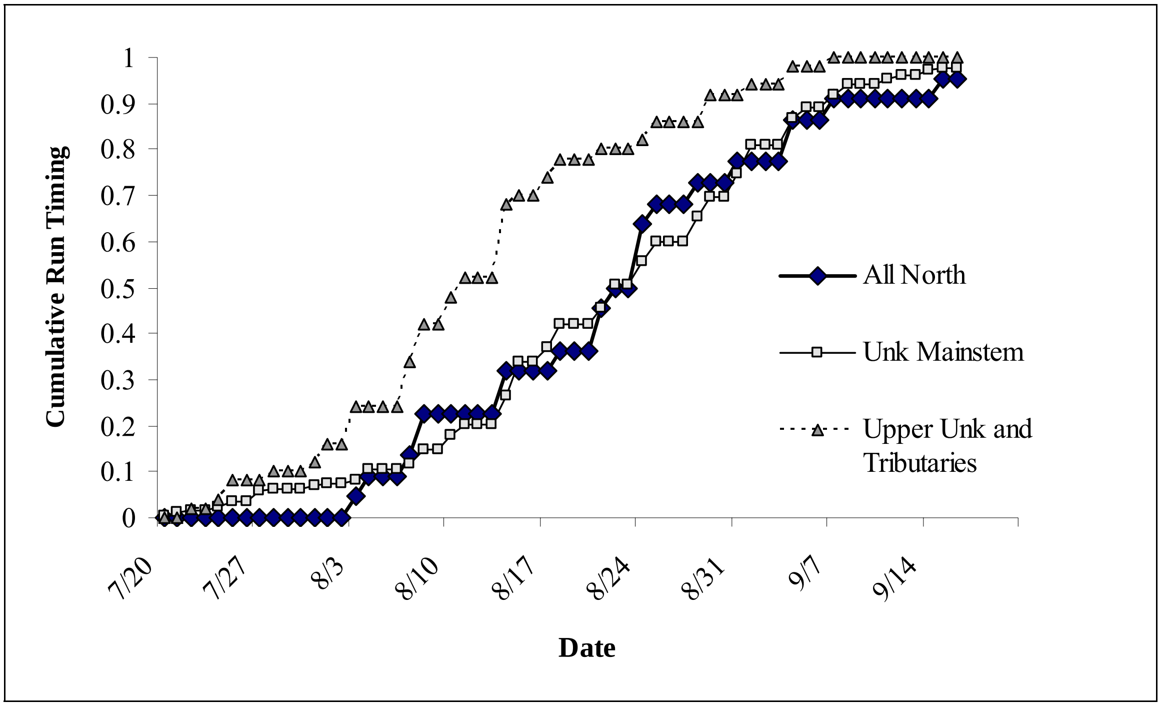

Figure 10.–Cumulative run timing past the capture site for three groups of coho salmon in the Unalakleet River drainage, 2006.

Note: North River coho salmon are those fish that migrated up the North River; Upper Unalakleet/Tributary coho salmon are those that migrated into tributaries other than the North River or migrated up the Unalakleet River past the Old Woman River confluence. Mainstem Unalakleet refers to those coho salmon that migrated up the Unalakleet River but never entered a tributary nor passed the confluence with the Old Woman River.

Sampling occurred in two channels on either side of an island at the sampling site. There was no significant difference in the probability of recapturing a fish based on the channel in which it was captured (χ^2 = 0.102, P = 0.750; Table 7).

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

	North Channel	South Channel
North River	18	4
All other areas of Unalakleet drainage	195	36

Temporal violations of equal probability of capture during the second event were explored using contingency table analyses (Appendix A2; Table 8). No significant difference was detected in the probability that a marked fish was recaptured during the second event between the five quintiles of the run when examining all radio-tagged salmon (χ^2 = 4.162, P = 0.384) and these results held up for both length strata of fish (<560 mm MEF: χ^2 = 3.962, P = 0.411; ≥560 mm

MEF: χ^2 = 3.228, P = 0.520). A further test to detect temporal violations of the equal probability of capture assumption during the first event was significant (χ^2 = 9.971, P = 0.041), however, the results for each length strata were insignificant (<560 mm MEF: χ^2 = 4.729, P = 0.316; ≥560 mm MEF: χ^2 = 7.111, P = 0.130; Table 9). These results were sufficient to conclude that a Petersen-type model could be used to estimate abundance in each length strata.

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
7/16-8/1	0	22
8/2-8/13	5	43
8/14-8/20	3	51
8/21-8/31	9	64
9/1-9/20	5	51

Table 9.–Data used to test the assumption of equal probability of capture by time during the first event for all fish <560 mm MEF and fish ≥560 mm MEF.

Tagging Period	All Coho Salmon		<560 mm MEF		≥560 mm MEF	
	Marked	Unmarked[a]	Marked	Unmarked[b]	Marked	Unmarked[b]
7/16-8/1	0	1,862	0	1,693	0	339
8/2-8/13	5	2,370	3	1,659	2	840
8/14-8/20	3	1,431	1	1,331	2	249
8/21-8/31	9	1,788	2	1,130	7	783
9/1-9/20	5	1,587	2	665	3	991

[a] Estimated number past the North River counting tower based on estimated portion of coho salmon ≥450 mm MEF sampled above the North River tower for each sampling period and the total number counted past the tower.

[b] Estimated number past the North River counting tower based on estimated portion of coho salmon < or ≥560 mm MEF sampled above the North River tower for each sampling period and the total number counted past the tower.

ABUNDANCE ESTIMATE

Two hundred fifty-three radio-tagged coho salmon continued upstream migration past the tracking towers on the Unalakleet and North rivers and served as the first (marked) sample. A total of 9,679 coho salmon were counted past the North River counting tower through September 15 (J. Menard, ADF&G-CF Area Management Biologist, personal communication) and served as the second sample. Twenty-two radio-tagged coho salmon migrated past the North River counting tower and served as recaptures in the second sample (Table 9). The estimated abundance of coho salmon ≥450 mm MEF that entered into the Unalakleet River drainage above the capture site was 116,965 fish (SE = 27,502; 95% credibility interval = 80,440 to 206,200).

An approximate estimate of abundance of coho salmon migrating into the Federal Wild and Scenic portion of the river was 84,928 (SE = 25,270) fish. The estimate is approximate because coho salmon were harvested between the point for which abundance was estimated (capture and tagging site in the lower river) and the lower boundary of the wild and scenic portion of the river. Sport harvest of coho salmon is estimated from the ADF&G Sport Fish Statewide Harvest Survey and those estimates were not available in time to accommodate the reporting schedule for this project. Because sport harvest was not subtracted from the total drainage abundance estimate prior to multiplying by the estimated proportion of coho salmon migrating through the Federal Wild and Scenic portion of the drainage, the resulting estimate of abundance of fish migrating through that portion of the drainage is biased high, but the bias is not likely to be greater than 5%.

Estimation of Age-Sex-Length Composition in 2006

Age, sex, and length compositions of the escapement were estimated from coho salmon sampled at the upriver sites on the North River and Unalakleet River. The length distribution of coho salmon sampled at each site was considered unbiased because a beach seine was used that caught coho as small as 310 mm MEF. However, the length distribution of coho salmon sampled at the upper site in the Unalakleet River was significantly different than the length distribution of those fish sampled above the North River counting tower (D = 0.149, P <0.001; Figure 8).

Estimates of mean length of male and female coho salmon in the North River and Unalakleet River were similar within, but differed between the two drainages (Table 3). The average length of male coho salmon in the North River was 525 mm MEF (SD = 57) and the average length of female coho salmon was 523 mm MEF (SD = 38). The average length of male coho salmon sampled in the Unalakleet River was 532 mm MEF (SD = 49) and the average length of female coho salmon was 534 mm MEF (SD = 36). The proportion of male coho salmon in the North River sample was 0.53 (SE = 0.019), and the proportion of male coho salmon in the Unalakleet River was 0.60 (SE = 0.017).

There was also evidence of temporal differences in length distribution. The length distribution of coho salmon handled at the capture location during the first two quintiles of the run (July 20–August 11) was significantly smaller than the coho salmon handled during the last three quintiles of the run (August 12–September 20; D-statistic = 0.120, P = 0.008; Figure 4). This difference was significant for males (D = 0.137, P = 0.033) and females (D = 0.199, P = 0.004). Temporal differences in length distribution were also apparent in upriver samples as the proportion of coho ≥560 mm MEF increased significantly over the five run quintiles in both the Unalakleet River (χ^2 = 56.38, P <0.001) and the North River (χ^2 = 61.26, P <0.001; Figure 11).

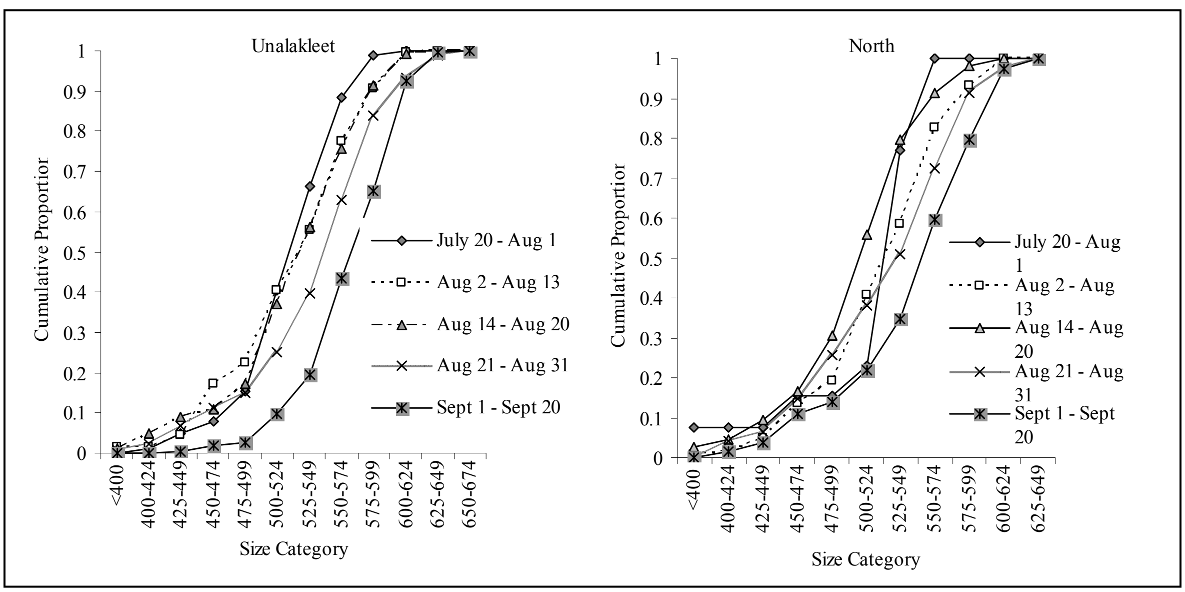

Figure 11.–Length distribution of coho salmon sampled upriver in the Unalakleet and North rivers during each run quintile in 2006.

Coho salmon ages ranged from 1.1 to 3.1 with the predominant ages being 1.1 and 2.1 (Tables 10 and 11). Proportions of age 1.1 and 2.1 coho salmon during the first two quintiles of the run were similar to the last three quintiles (Figure 12), and were similar among coho salmon bound for the North River (χ^2 = 0.96, P = 0.328) and for the Unalakleet River (χ^2 = 0.44, P = 0.51). Additionally, for male coho salmon, proportions were not significantly different in the North River (χ^2 = 0.199, P = 0.66) or the Unalakleet River (χ^2 = 0.13, P = 0.72). For female coho salmon, proportions were not significantly different in the North River (χ^2 = 1.07, P = 0.30) nor in the Unalakleet River (χ^2= 0.46, P = 0.50; Table 10).

Table 10.–Proportions of male and female coho salmon that migrated up the North and Unalakleet rivers that were age-1.1 and -2.1 in 2006. Standard errors for estimates are in parentheses.

Sex	River	Age 1.1	Age 2.1	Age 3.1
Male	North River	0.31 (0.036)	0.66 (0.036)	0.02 (0.012)
	Unalakleet River	0.21 (0.025)	0.76 (0.027)	0.03 (0.011)
	Entire Drainage	0.23 (0.029)	0.75 (0.029)	0.02 (0.010)
Female	North River	0.31 (0.040)	0.67 (0.040)	0.02 (0.012)
	Unalakleet River	0.19 (0.033)	0.80 (0.034)	0.01 (0.007)
	Entire Drainage	0.24 (0.040)	0.74 (0.040)	0.01 (0.010)

Table 11.–Estimated age, sex and length composition of the coho salmon escapement in the Unalakleet River drainage, 2006.

Sex/Age Category	$\hat{p}_k$	SE($\hat{p}_k$)	$\hat{N}_k$	SE($\hat{N}_k$)
Male	0.581	0.017	67,936	18,790
1.1	0.225	0.028	15,317	4,747
2.1	0.751	0.029	51,001	14,410
3.1	0.024	0.010	1,617	805
Female	0.419	0.017	49,029	13,870
1.1	0.243	0.040	11,907	4,298
2.1	0.744	0.040	36,467	10,260
3.1	0.012	0.010	591	610

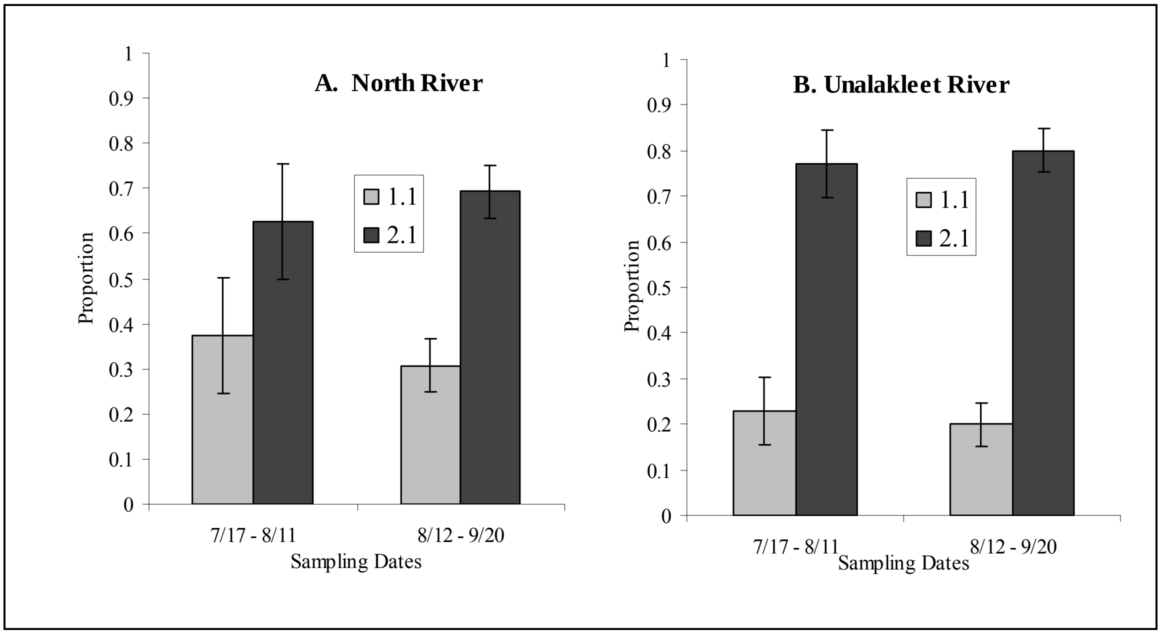

Figure 12.–Proportion of fish age-1.1 and -2.1 in the North (A) and Unalakleet rivers (B) during the first two run quintiles (July 17–August 11) and the last three run quintiles (August 12–September 20), 2006. Error bars represent 95% confidence intervals.

There were differences in the proportion of age-1.1 and -2.1 coho salmon in the North River and the mainstem of the Unalakleet. There were significantly more age-1.1 coho salmon in the North River when compared to the Unalakleet mainstem (χ^2=10.96, P = 0.001). This held for both males (χ^2=5.89, P = 0.02) and females (χ^2=5.56, P = 0.02; Table 10). The distribution of age-1.1 radio-tagged coho salmon was predominantly limited to the mainstem of the Unalakleet River whereas age-2.1 coho salmon were distributed throughout the mainstem and tributaries (Figure 13).

Age-2.1 coho salmon appeared to be, on average, slightly larger than fish age-1.1, however, results of hypotheses tests indicated than only Unalakleet females were significantly larger (P = 0.01; Figure 14).

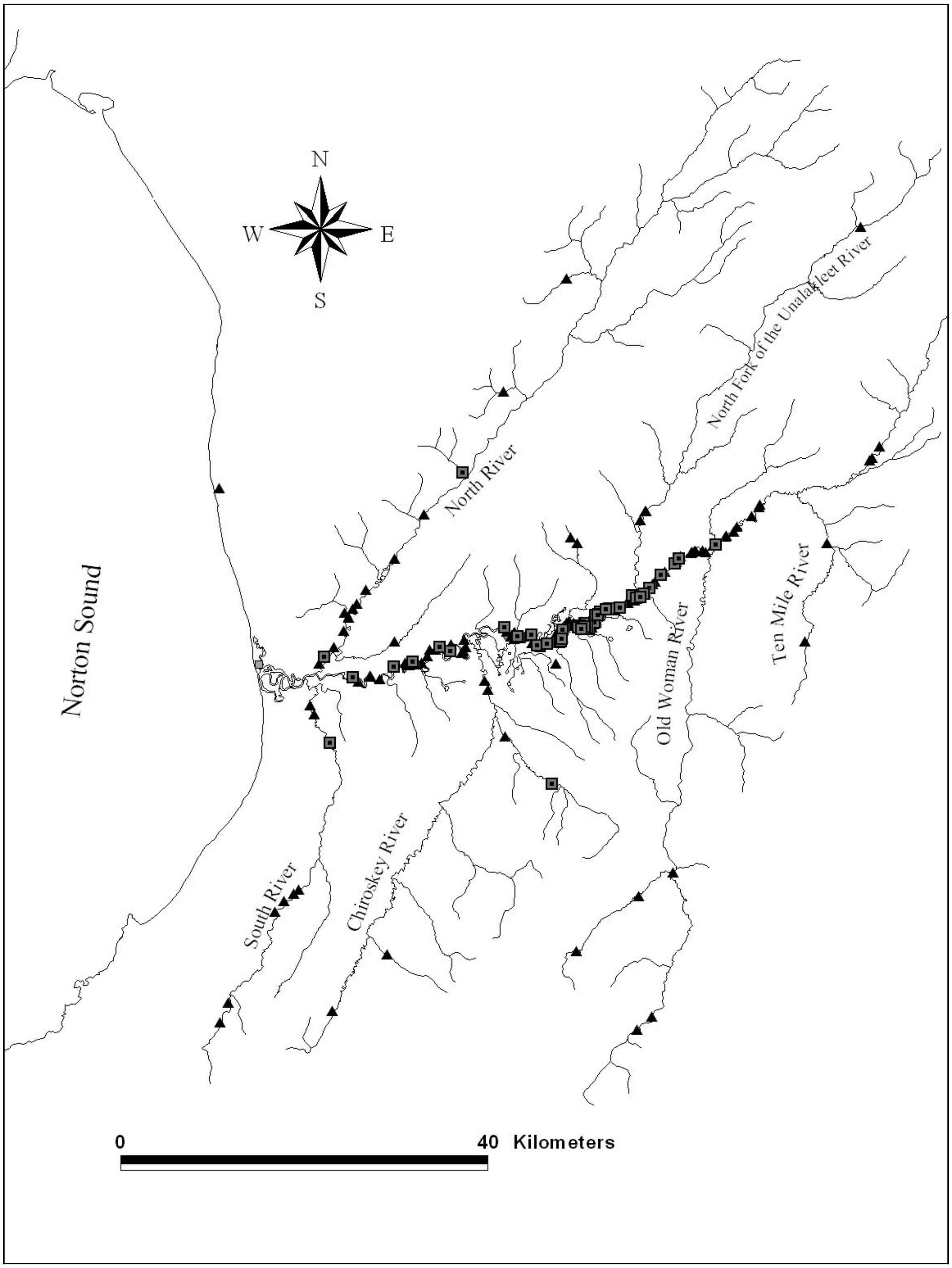

Figure 13.–Spawning locations of radio-tagged age 1.1 (squares) and 2.1 (triangles) coho salmon in the Unalakleet River drainage in 2006.

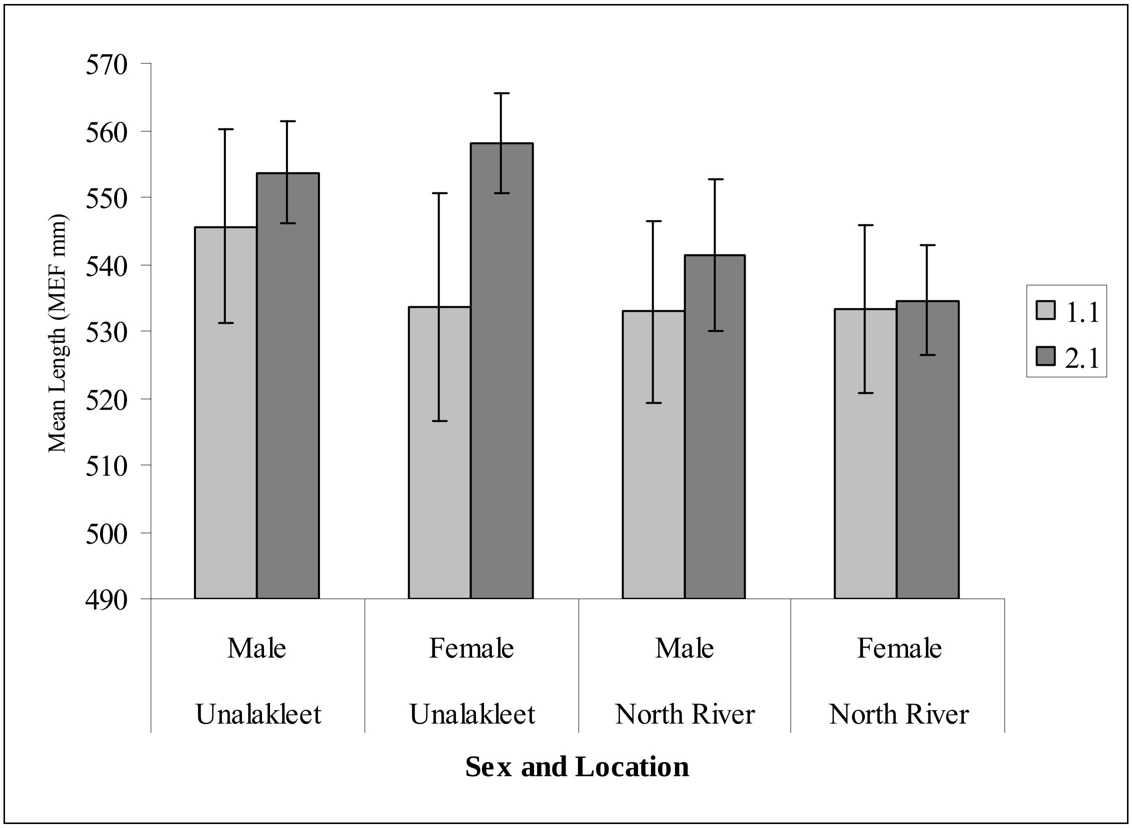

Figure 14.–Mean length of male and female coho salmon in the North and Unalakleet rivers that were age-1.1 and -2.1, 2006. Error bars represent 95% confidence intervals.

INTER-ANNUAL COMPARISONS, 2004-2006

Coho salmon sampled in the Unalakleet River were significantly smaller in 2006 when compared to 2004 ($D = 0.324$, $P < 0.001$) and 2005 ($D = 0.343$, $P < 0.001$). In 2004 and 2005 coho salmon had similar in length distribution ($D = 0.065$, $P = 0.292$; Figure 15). Coho salmon sampled in the North River exhibited the same pattern with 2006 salmon being significantly smaller than 2004 salmon ($D = 0.323$, $P < 0.001$) and 2005 salmon ($D = 0.330$, $P < 0.001$) and 2004 and 2005 salmon had similar length distributions ($D = 0.072$, $P = 0.099$; Figure 15).

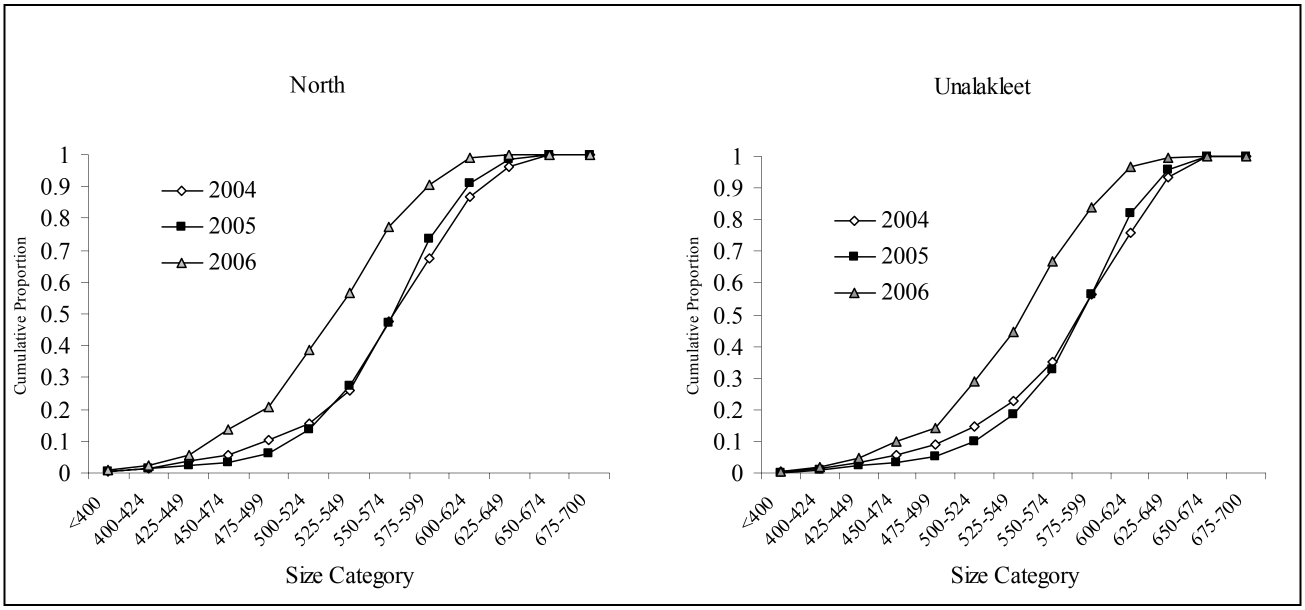

Figure 15.–Cumulative length distribution of coho salmon sampled in the Unalakleet and North Rivers in 2004-2006.

Age distribution of coho salmon varied significantly between years in both the Unalakleet River (χ^2=141.76, P <0.001) and the North River (χ^2=79.75, P = 0.001). Over the three years of the study the proportion of coho salmon aged 2.1 varied between 28% in 2004 and 68% in 2006 in the North River and between 37% in 2004 and 79% in 2006 in the Unalakleet River (Figure 16).

Run timing of all coho salmon, as calculated by cumulative proportion caught at the tagging location, varied significantly between all three years of the project (2004 vs. 2005: D = 0.294, P <0.001; 2005 vs. 2006: D = 0.190, P <0.001; 2004 vs. 2006: D = 0.145, P <0.001) (Figure 17). When the drainage was divided into lower Unalakleet (mainstem Unalakleet below the Old Woman River) and the Upper Unalakleet and Tributaries (including the North River) differences in run timing were observed in the Upper Unalakleet and tributaries.

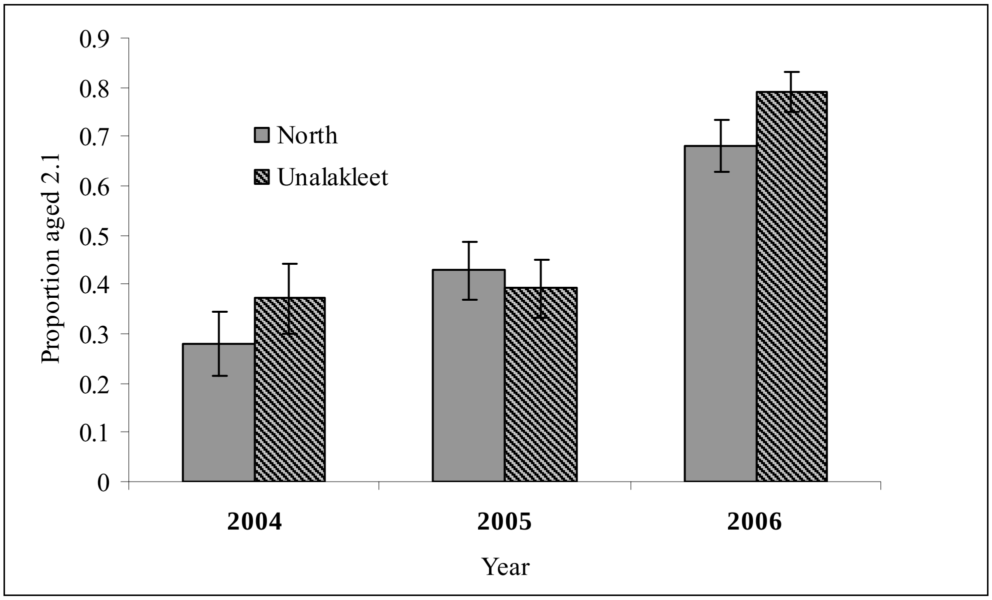

Figure 16.–The proportion of coho salmon aged 2.1 in the Unalakleet and North Rivers in 2004-2006. Error bars represent 95% confidence intervals.

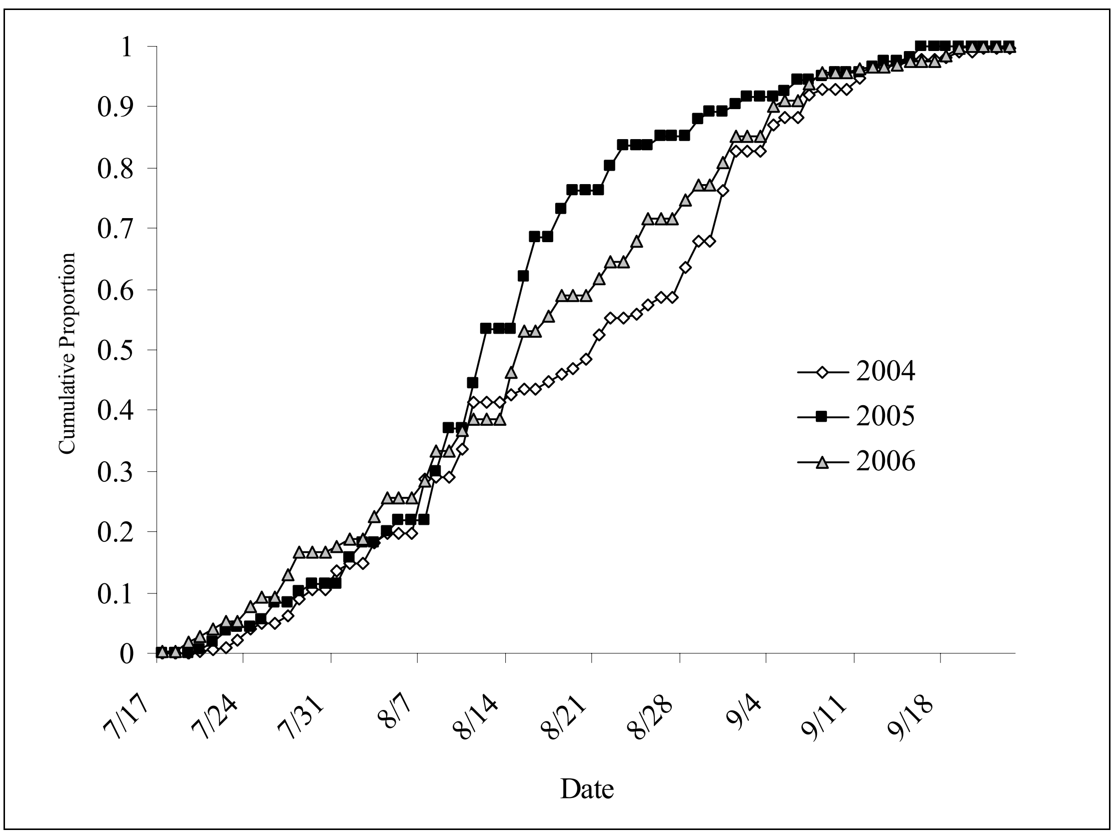

Figure 17.–Run timing of coho salmon based on cumulative catch at the tagging location in 2004-2006.

In contrast, for all lower Unalakleet coho salmon, statistical tests revealed there were no significant differences between 2004 and 2005 (D = 0.134, P = 0.148) but there were significant differences between 2005 and 2006 (D = 0.150, P = 0.033) and marginally significant differences between 2004 and 2006 (D = 0.152, P = 0.069). When run timing was compared for only those fish that spawned in the Unalakleet River between the Chiroskey River and the North Fork of the Unalakleet, the pattern seen was more pronounced with no significant difference between 2004 and 2005 (D = 0.155, P = 0.250) but significant differences between 2005 and 2006 (D = 0.228, P = 0.007) and between 2004 and 2006 (D = 0.230, P = 0.002; Figure 19). GIS analysis of coho distribution also indicated that coho salmon migrating into the lower Unalakleet (below the Old Woman River) and in particular, those migrating into the section between the Chiroskey River and the North Fork of the Unalakleet River, arrived significantly earlier in 2006 than in 2004 or 2005 (Figure 18).

The proportion of coho salmon estimated to have escaped past the North River counting tower varied significantly between years (Figure 20; Table 12). The proportions measured in 2004 and 2005 were not statistically different (P = 0.80) however, the proportion measured in 2006 was statistically less than in 2004 (P = 0.060) and 2005 (P = 0.078) at the $\alpha = 0.10$ level. In 2006 there was also a significantly higher proportion of coho salmon escaping to the mainstem of the Unalakleet River (below the Old Woman) than in 2004 (P = 0.038) and 2005 (P = 0.051). There was no other significant variation in the estimated proportions of coho escapement to the various tributaries of the drainage over the 3 years of the study except for in the Old Woman River which had a significantly lower proportion in 2006 when compared to 2005 (P = 0.008) and nearly so when compared to 2004 (P = 0.103; Figure 20).

Estimated escapement into the entire Unalakleet River drainage varied over the course of the study from 73,582 (SE = 15,570) in 2004 (Joy et al. 2005) to 134,531 (SE = 28,550) in 2005 (Joy and Reed 2006). While there was no detectable difference in escapement between 2005 and 2006 (P = 0.32), 2004 had significantly lower escapement than both 2005 (P = 0.030) and 2006 (P = 0.085). Estimated escapement into the various portions of the drainage did not differ significantly between the three years of the study with the exception of the Old Woman River which was estimated to have had significantly higher escapement in 2005 when compared to 2004 (P = 0.110) and 2006 (P = 0.061; Figure 21).

Densities of spawning coho salmon were calculated for the various tributaries and sections of the Unalakleet River drainage. Spawner densities were similar for the various tributaries of the drainage including the North River (Figure 22), but were significantly higher in the mainstem sections (upper and lower) of the Unalakleet River during all 3 years of the study (Figure 22).

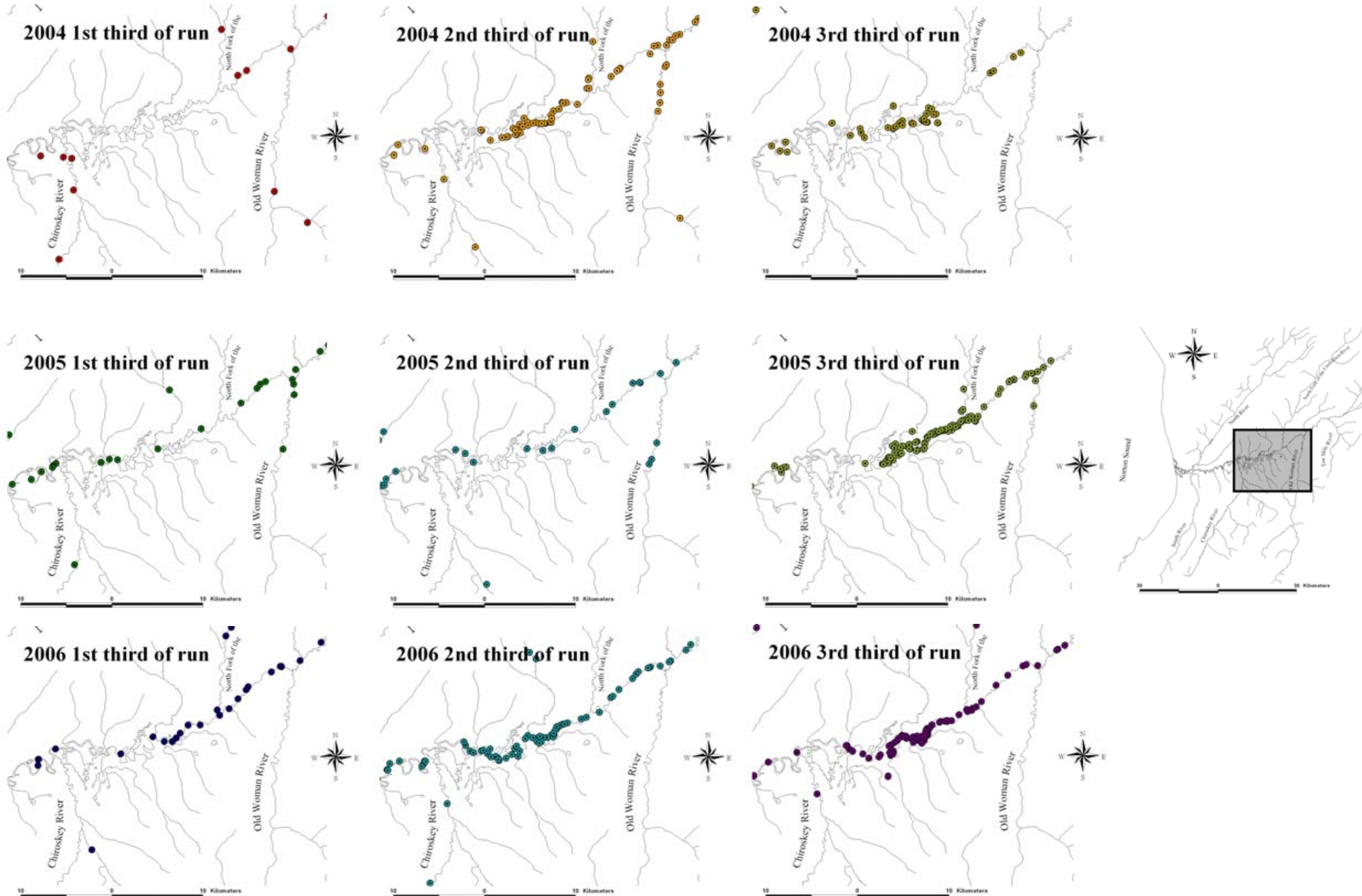

Figure 18.–The farthest detected location of radio-tagged coho salmon in the Unalakleet River between the Chiroskey and Old Woman rivers in 2004-2006 that were radio-tagged in the Unalakleet River during each third of the respective run.

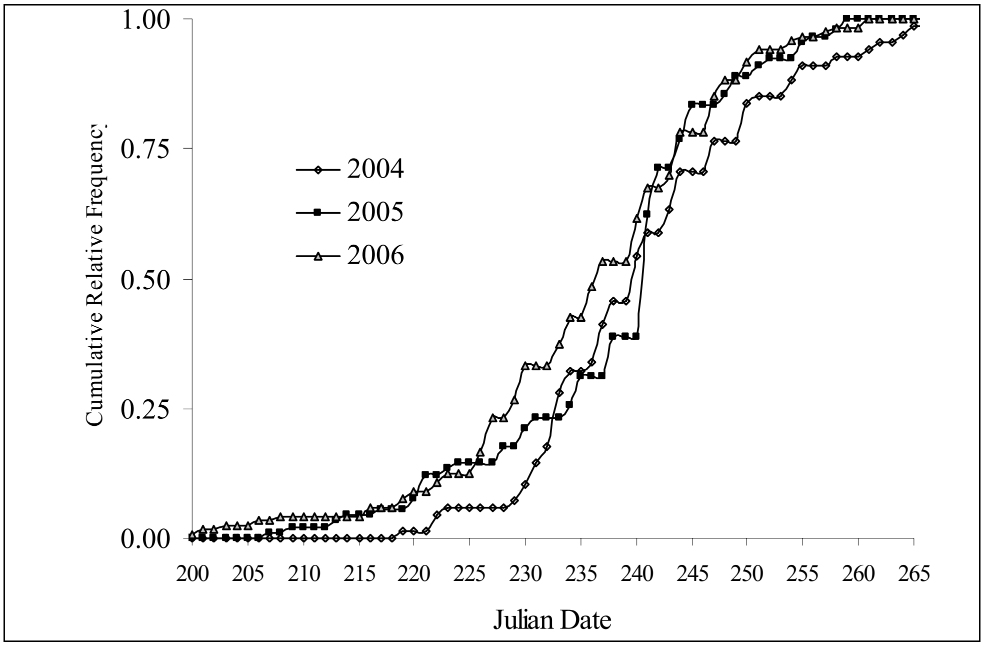

Figure 19.–Run timing of coho salmon that spawned in the Unalakleet River between the Chiroskey River and the North Fork of the Unalakleet River in 2004-2006.

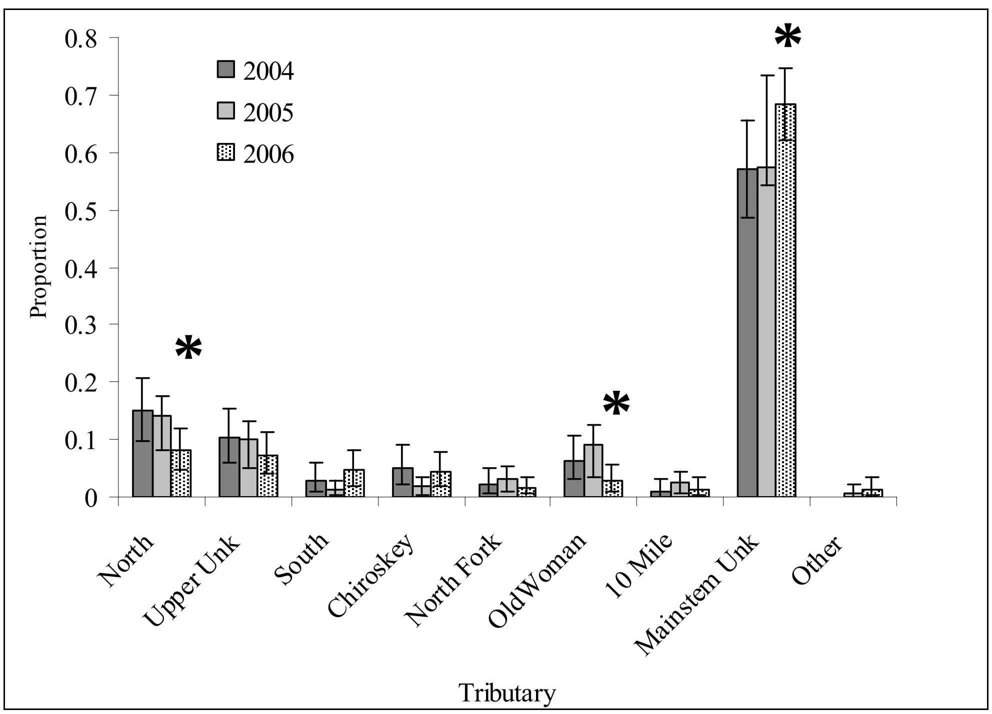

Figure 20.–The estimated proportional distribution of coho salmon in the Unalakleet River drainage in 2004-2006. The Upper Unalakleet is defined in this report as the section of the Unalakleet River located above its confluence with the Old Woman River.

Note: The mainstem Unalakleet River is defined in this report as the section of the Unalakleet River located below its confluence with the Old Woman River. Asterisks indicate where proportions differed significantly from the other 2 years in the study (see text). Error bars represent 95% confidence intervals.

Table 12.–Estimated proportions of coho salmon escaping into the Unalakleet River tributaries in 2004-2006.

	2004	2005	2006
North	0.152	0.143	0.083
Upper Unalakleet	0.100	0.101	0.072
South	0.028	0.013	0.044
Chiroskey	0.053	0.017	0.044
North Fork	0.023	0.030	0.016
Old Woman	0.065	0.092	0.028
10 Mile	0.010	0.024	0.014
Other	0.000	0.007	0.014
Unalakleet Mainstem	0.569	0.573	0.684
North	0.152	0.143	0.083
Upper Unk + Tributaries	0.279	0.284	0.233
Mainstem	0.569	0.573	0.684

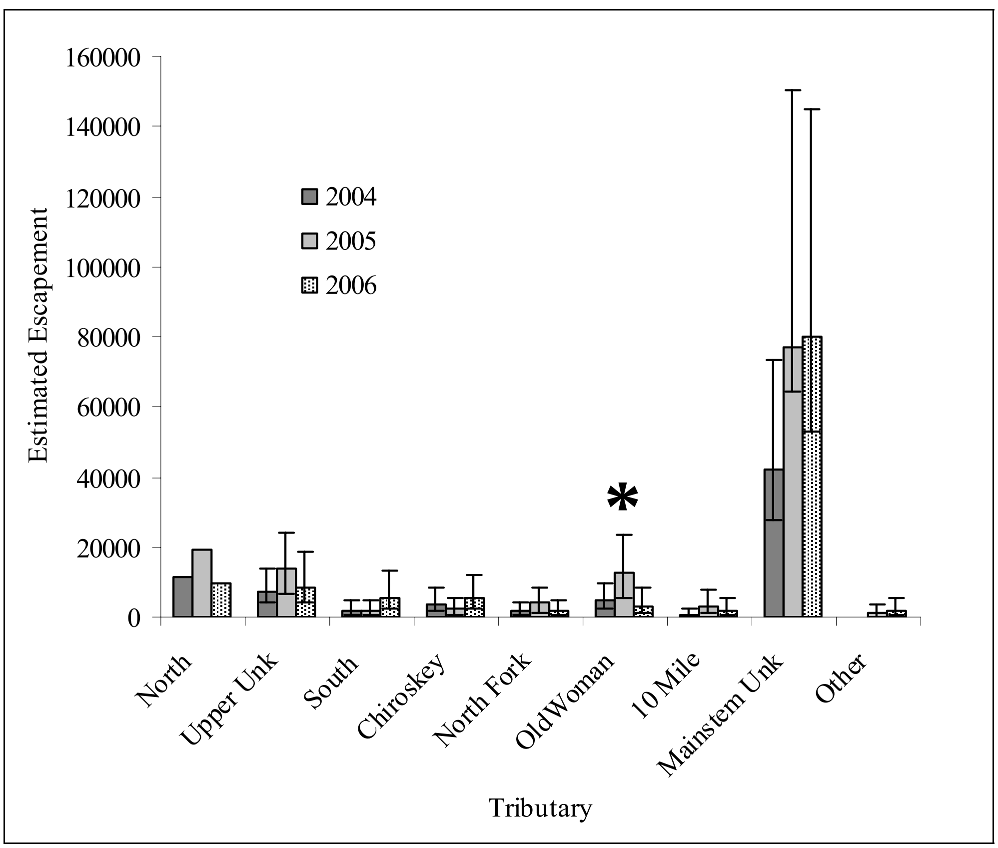

Figure 21.–Estimated escapement of coho salmon into the various tributaries and river sections of the Unalakleet River in 2004-2006. Asterisks indicate where proportions differed significantly from the other 2 years in the study (see text). Error bars represent 95% confidence intervals.

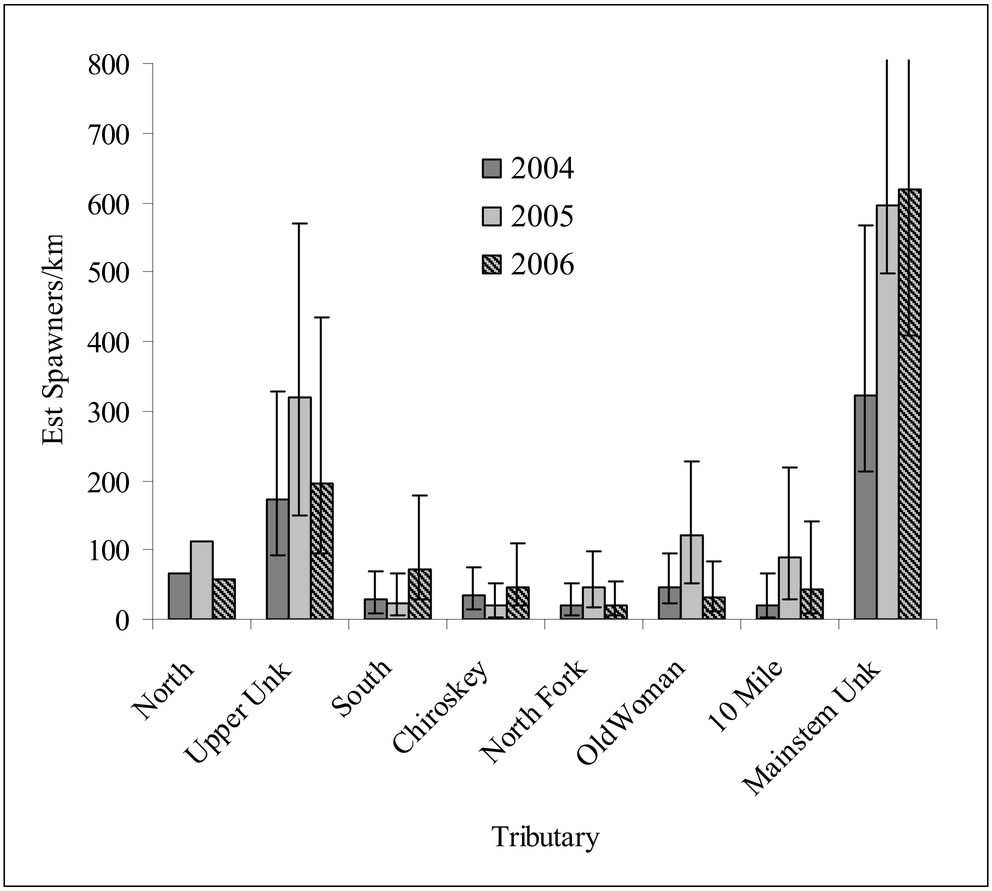

Figure 22.–Estimated densities of spawning coho salmon (coho salmon per km) in the various tributaries and river sections of the Unalakleet River in 2004-2006. Error bars represent 95% confidence intervals.

DISCUSSION

A primary goal of this study was to determine whether the population assessed at the North River counting tower provided a good index of the overall Unalakleet River drainage stock. The proportion of coho salmon entering the Unalakleet River that migrated past the North River tower was 14% in 2005 (Joy and Reed 2006), 15% in 2004 (Joy et al. 2005), and 8% in 2006. Although the proportion migrating up the North River was significantly lower in 2006 than in 2004 or 2005, the variation observed over the three years is not so great so as to preclude the utility of the North River counts as an index of abundance for the entire Unalakleet River. Coho salmon sampled in the North River had a smaller mean length than those sampled in the Unalakleet River and had a significantly smaller length distribution. This is unlikely to have resulted from biased sampling as the same beach seine was used for sampling in both rivers, and sampling occurred in both rivers on each sampling day. While North River coho salmon were smaller than their counterparts in the Unalakleet River, their run-timing and age distribution patterns were similar to coho salmon in the Unalakleet River in all 3 years (Joy and Reed 2006; Joy et al. 2005). The run timing of North River coho salmon appeared to overlap the run timing of both *upper Unalakleet/tributary* coho and *mainstem coho* (Figure 10; Joy and Reed 2006; Joy et al. 2005). Given the reasonably consistent proportions of coho salmon escapement to the various portions of the drainage (Figure 20), the consistent age patterns seen between the Unalakleet and the North River (Figure 12) and the consistent run timing between the two drainages, the results of this study suggested the North River tower provides a reasonable and cost-effective index for coho escapement into the Unalakleet River drainage.

While the results of this project appear to indicate that the North River counting tower provides a reasonable estimate of escapement into the entire Unalakleet River drainage, it is important to remember that this project only encompassed one life cycle of coho salmon and the degree to which this proportion may vary or drift over a longer time period is unknown. Extending this project for another 3 years or repeating this project every 4 to 5 years would be useful for determining the degree of variability in the North River's proportional contribution to the Unalakleet River drainage stock. Until further study ensures that these proportions do not shift significantly over time managers will need to be conscientious of other indicators of run strength to ensure that they are not over reliant on the North River tower counts.

The proportion estimates of coho salmon migrating past the North River tower measured in this study provides a foundation for constructing a brood table back to 1996 when the counting tower project was initiated and thus may allow for an escapement goal analysis. Unless this project is continued and a better understanding of the inter-annual variation in the coho escapement past the North River tower is documented and measured, any such analysis must proceed with caution. Reconstructing runs with currently available data only provides 7 years of spawner/return data and several more years of data from the North River tower may be needed to produce a meaningful analysis. Nevertheless, if brood table construction is done for a range of scenarios encompassing variation in the North River proportion, then a reasonable analysis may be performed.

Results from this study may also be discussed in the context of Bradford et al.'s (1997, 2000) habitat models that predict minimum spawning densities required to fully seed a given system. Nemeth et al. (2004) found that distribution of juvenile coho salmon in the North River was consistent with Bradford et al. (2000) and spawning densities measured in this study indicated that these values were surpassed in the Unalakleet River drainage during the 3 years of this study. Further smolt and habitat work throughout the Unalakleet drainage, including the mainstem between the Chiroskey River and the North Fork of the Unalakleet, would be useful for further development of a habitat based model to derive more refined escapement goals.

Radio-tagged coho salmon were detected in every major tributary and in many tertiary streams in all three years of the study. The section of the Unalakleet River between the Chiroskey River and the North Fork supported the largest number and density of spawning coho salmon in all three years of the study. Coho salmon migrating to this area appeared inriver later in the run in all three years (Joy and Reed 2006; Joy et al. 2005; Figures 5 and 10) compared to coho salmon that spawned in other areas of the drainage. The large escapements in 2005 and 2006 coincided with increased escapement to this area (Figure 21) and the run timing of these fish was earlier than in 2004 (Figures 18 and 19). Unalakleet residents report springs in the area that may explain the preference for these spawning destinations late in the season.

Coho salmon migration patterns varied greatly among individual fish. Some coho salmon migrated quickly to spawning destinations after tagging while others milled in the mainstem of the Unalakleet River for up to two weeks before moving towards spawning destinations. Still others roamed up the mainstem of the Unalakleet past the Chiroskey River before turning around and ultimately migrating up either the North or South rivers. Additionally, 5 coho salmon were captured in the commercial fishery up to 20 km away from the mouth of the Unalakleet River, one coho salmon apparently migrated into the Shaktoolik River (approximately 56 kilometers north of the Unalakleet River), and one migrated into the mouth of the Egavik River (approximately 25 kilometers north of the Unalakleet River) after being tagged in the Unalakleet River. The only year the Egavik and Shaktoolik rivers were surveyed for radio-tagged salmon was 2006, and these drainages were only flown once cursorily due to budgetary constraints. As this single survey cannot be considered thorough and comprehensive, it is possible that more radio-tagged coho salmon migrated out of the Unalakleet River and into either the Egavik or Shaktoolik rivers. While the nature of these data does not allow for a detailed analysis of migratory behavior, they nevertheless illustrate irregular migration patterns among coho salmon that has been observed in other coho salmon stocks (Clark et al. 2005, 2006; Jones et al. 2001; Waltemyer et al. 2005; Weller et al. 2005).

In 2006, as in 2005 and 2004, the objective criteria for precision of abundance estimates given in the project objectives were not met. This was the result of several conditions. The first was that sample sizes prescribed during experimental design were estimated based on a much smaller in-river abundance than that which occurred in 2006. The 2006 coho run was, by all indications, among the largest on record. Secondly, a stratified model was necessary used to estimate abundance which resulted in lower precision than would have been realized if an unstratified model were appropriate using the same sample sizes. Finally, smaller proportion of radio-tagged coho migrated past the North River tower than was expected from results in 2004 and 2005 (22 tags or 8.2%).

While the relative abundance of age-1.1 and -2.1 coho salmon spawning in the North and Unalakleet rivers in 2004 appeared to vary temporally and geographically (Joy et al. 2005), there was little variation in the relative abundance of age-1.1 and -2.1 coho salmon in 2005 (Joy and Reed 2006) or 2006. The proportion of age-1.1 and -2.1 coho did not differ between the early and late portions of the run (Figure 12). Unlike in 2005, however, there was an apparent difference in the spawning location of age-1.1 and -2.1 coho with age-1.1 radio-tagged coho salmon migrating predominantly into the mainstem of the Unalakleet River in 2006 (Figure 13).

The mixture of age-1.1 and -2.1 fish in the population is not unusual for coho salmon stocks and the ratios observed in this study are comparable to other studied coho runs at this latitude (Sandercock 1991). The age ratio within a stock may vary between years (Sandercock 1991) as was estimated between 2004 (Joy at al. 2005), 2005 (Joy and Reed 2006) and 2006.

Aging results from this study were compared to aging results from the Unalakleet River test fishery (CF) and the District 6 commercial harvest (J. Menard, ADF&G-CF, Area Management Biologist, personal communication). The results were not in agreement and it appeared that a much higher proportion of coho salmon were aged 2.1 in the test net fishery than in this study. Given that the test net fishery occurs less than 1 km downstream from the tagging location, it seems unlikely that different groups of fish were being sampled. The observed inconsistency was likely the result of either aging error by the different scale readers or selective fishing by different gear. Inconsistent aging of coho salmon scales has been problematic in southeast Alaska (Shaul et al. 2004) and appears to be an issue in Norton Sound. Given these results, the aging presented in this report and in Joy et al. (2005) and Joy and Reed (2006) should be viewed with caution. Resolution of these inconsistencies would best be resolved through an aging study that utilizes known aged fish (e.g., marking juveniles and aging recaptured adult fish), that compares scale age assignments by multiple readers, and that evaluates otoliths as an alternative aging structure.

Ambiguous aging results do not, however, discredit the conclusions reached in this and prior reports in this study. Although the exact age proportions may not be accurate, the fact that there were no significant differences between the North River age distribution and the Unalakleet River age distributions when read by the same reader during 2004, 2005, and 2006 indicates that the North River was reflective of the entire Unalakleet River drainage from an age distribution stand point. For each given year there was one scale reader and thus within-year comparisons are valid. The actual proportions may not be valid, however differences in proportions within a given year (and thus read by a single reader) are. Therefore, age distribution data can still be used as evidence supporting the use of the North River counting tower as a useful index of the entire Unalakleet River drainage.

Proportional escapement to the various areas of the drainage remained relatively consistent over the three years of the study (Figure 20) with the only exceptions being the Old Woman River and mainstem Unalakleet had proportionally larger escapements in 2006 and the North River had a proportionally smaller escapement in 2006. The degree to which these values vary over time and how variation in the distribution of the escapement affects productivity over time would require telemetry data over several life cycles of coho salmon.

Evidence from this 3-year study indicates that the section of the Unalakleet between the Chiroskey and Old Woman rivers may provide the most productive spawning habitat (Figure 22) in the Unalakleet River drainage and is certainly the predominant spawning destination for the Unalakleet River run (Figures 5, 18, 20, 21, and 22). The distribution of spawners in the Unalakleet drainage is consistent with research showing higher smolt and fry densities in rivers that flow through broad, flat valleys (the mainstem Unalakleet River) when compared to those that flow through mountainous regions (all of the Unalakleet River tributaries; Bradford et al. 2000). Observed spawning densities were much higher than the 11 to 33 spawners/km that Bradford et al. (2000, 1997) estimated as necessary to completely seed the system and thus may indicate escapements that exceeded freshwater carrying capacity. Nemeth et al. (2004) report that the North River, as well as the Nome River on the Seward Peninsula, had a distribution of juvenile coho salmon consistent with Bradford et al. (2000). In addition to continuing the radio-telemetry study on this system, smolt and fry production and abundance studies would be needed to determine whether observed spawning densities are correlated with fry and smolt production.

The fact that increased escapement and salmon returns are associated with one particular portion of the drainage may indicate increased productivity in this section of the river in 2001 through 2003, the respective brood years for returns observed in this study. Coincidently, these years also exhibited extremely high pink salmon returns. Given that pink salmon are most likely limited to the lower reaches of the drainage and that evidence on marine derived nutrients indicates that pink and chum salmon carcasses can have impacts on the size and health of coho salmon fry and smolts (Wipfli et al. 2003), it is reasonable to hypothesize that coho salmon may be benefiting from a fertilizer effect of pink salmon. Pink salmon runs in the Unalakleet River and across Norton Sound have increased dramatically in recent years (Eggers 2007) and will provide an opportunity to observe this relationship in coming years.

Coho salmon were significantly smaller in 2006 than in 2004 and 2005 (which were very similar; Figure 15). Although escapement in 2006 was not noticeably higher than in 2005, the commercial harvest set a record for the District 6 harvest and thus total returns were most likely the highest observed since records have been kept. Coho commercial harvests also set records across Norton Sound (Eggers 2007). While it is generally believed that coho salmon production is more a function of freshwater conditions (where coho spend one to 3 years) than oceanic conditions (where coho salmon spend 1 year; Bradford et al. 2000, 1997), smaller sizes seen in returning salmon may be indicative of oceanic conditions and available forage.

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APPENDIX A

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

Length selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that length 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 of 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 an 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 length/sex selectivity detected during either sampling event.

Case II:		
Reject H_o	Fail to reject H_o	Reject H_o

There is no length/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 length/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 length/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 likely detecting small differences which 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 likely the result of length/sex selectivity during the second event which 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 likely the result of length/sex selectivity during the first event which 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 length/sex selectivity during both events which 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 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 parameters (p_k) is estimating 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/length strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or length *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 Where Marked	Area/Time Where Recaptured				Not Recaptured
	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)				

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[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

Appendix B1.–Data files used to estimate parameters of the coho salmon abundance and length, age and sex distributions in the Unalakleet River drainage, 2004**.**

Data File	Description
04UnakPopEst.xls[a]	Excel spreadsheet with finalized population parameters and estimates.
Chapman Estimates – Unk Coho 2004.xls[a]	Excel spreadsheet with finalized Chapman calculations and estimates for coho abundance.
Tagged Coho Log – Final.xls [a]	Excel spreadsheet with consolidated data on all radio-tagged coho including calculations used in Chapman estimates.
Unk Coho Master Data – Final.xls[a]	Excel spreadsheet with raw data on all captured and sampled coho in the Unalakleet River drainage in 2004 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; and are available from the authors, Division of Sport Fish, 1300 College Road, Fairbanks, AK 99701.