Fishery Data Series No. 13-07

Chinook Salmon Escapement and Run Timing in the Gulkana River, 2011–2012

by

Scott H. Maclean

March 2013

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

FISHERY DATA SERIES NO. 13-07

CHINOOK SALMON ESCAPEMENT AND RUN TIMING IN THE GULKANA RIVER, 2011–2012

By
Scott H. Maclean
Alaska Department of Fish and Game, Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

March 2013

Development and publication of this manuscript were partially financed under Grant Numbers F10AF00553 and F11AF01015, and by the Federal Aid in Sport fish Restoration Act (16 U.S.C.777-777K) under Project F-10-26 and 27, Job No. S-3-1(a).

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/ This publication has undergone editorial and peer review.

Scott H. Maclean,
Alaska Department of Fish and Game, Division of Sport Fish,
Mile 186 Glenn Hwy, Glennallen, AK 99588, USA

This document should be cited as:
Maclean, S. H. 2013. Chinook salmon escapement and run timing in the Gulkana River, 2011-2012. Alaska Department of Fish and Game, Fishery Data Series No. 13-07, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES....i

LIST OF FIGURES.... ii

ABSTRACT....1

INTRODUCTION....1

OBJECTIVES....3

METHODS....3

Chinook Salmon Escapement....3

  Data Analysis....4

Sockeye Salmon Escapement....6

RESULTS....6

Chinook Salmon Escapement....6

Sockeye Salmon Escapement....7

DISCUSSION....7

CONCLUSION....27

ACKNOWLEDGMENTS....27

REFERENCES CITED....28

LIST OF TABLES

Table **Page**

1. Water clarity classification scheme. 7
2. Daily counts, expanded counts, and the cumulative estimated escapement of Chinook salmon at the Gulkana River tower, 2011. 8
3. Daily counts, expanded counts, interpolations, and the cumulative estimated escapement of Chinook salmon at the Gulkana River tower, 2012. 10
4. Daily expanded counts, including interpolations, of Chinook salmon at the Gulkana River tower, 2002–2012. 13
5. Daily average water level at the Gulkana River tower, 2002–2012. 15
6. Daily maximum water temperature at the Gulkana River tower, 2002–2012. 17
7. Percent of Gulkana River Chinook salmon run past the counting tower by 1 July and average maximum water temperature between 10 June and 30 June, 2002–2012, including the percent of return interpolated each year. 19
8. Escapement, standard error, aerial count, and proportion of escapement by survey date of Chinook salmon upstream of the tower in the Gulkana River, 2002–2012, excluding 2003 and 2008. 20
9. Daily counts, expanded counts, and the cumulative estimated escapement of sockeye salmon at the Gulkana River tower, 2011. 22
10. Daily counts, expanded counts, interpolations, and the cumulative estimated escapement of sockeye salmon at the Gulkana River tower, 2012. 24

LIST OF FIGURES

Figure **Page**

1. The Gulkana River drainage and location of the counting tower. 2
2. Estimated diel migratory pattern for 2011 and 2012, the cumulative proportion of average daily counts by hour of day for Chinook salmon migrating past the Gulkana River counting tower. 12
3. Estimated run timing pattern for Gulkana River Chinook salmon past the counting tower in 2011 and 2012, compared to the 2002–2010 average. 12
4. June 10–30 average maximum water temperature and the arcsine transformed percentage of the Chinook salmon run on June 30 at the Gulkana River fish counting tower, 2003–2012. 19
5. Percent of Gulkana River Chinook salmon run past the counting tower by 1 July, 2002–2012. 20
6. Counting tower escapement estimates with 95% confidence intervals compared with aerial index counts for Gulkana River Chinook, 2002–2012 excluding 2003 and 2008. 21

ABSTRACT

Counting tower techniques were used for the 10th and 11th consecutive years on the Gulkana River to estimate the escapement of Chinook salmon *Oncorhynchus tshawytscha* upstream of the West Fork Gulkana River. During 2011 and 2012, the Gulkana River counting tower was in operation from 2 June through 10 August and 5 June through 10 August, respectively. This time period accounted for the entire Chinook salmon run and a portion of the sockeye salmon *O. nerka* run. The estimated escapement of Chinook salmon was 3,804 (SE=257) in 2011 and 1,730 (SE=157) in 2012. The estimated minimum escapement of sockeye salmon was 38,048 (SE=1,683) in 2011 and 41,953 (SE=1,951) in 2012. Analysis of 10 years of Gulkana River Chinook salmon counting tower data revealed a significant positive correlation between water temperature and run timing. Results indicate 88% of the variation in run timing prior to 1 July can be explained by average maximum water temperature. The majority of the run migrates upstream of the counting tower before 1 July in years when average maximum water temperatures are considered warm (16^{o}–18^{o}C) versus a smaller proportion when the water temperatures are considered cool (9^{o}–14^{o}C). The temperature and run timing relationship may aid managers when making inseason decisions about the Gulkana River Chinook salmon sport fishery.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, sockeye salmon, *O. nerka*, Copper River, Gulkana River, counting tower, escapement, run timing, water temperature

INTRODUCTION

The Gulkana River supports spawning populations of Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, rainbow/steelhead trout *O. mykiss*, and Arctic grayling *Thymallus arcticus*. The mainstem of the river is fed by the East Fork, Middle Fork, and West Fork Gulkana rivers (Figure 1). The river is one of six major spawning tributaries for Chinook salmon in the Copper River drainage and it supports the largest Chinook salmon sport fishery in the Copper River drainage and Upper Copper-Upper Susitna Management Area (Jennings et al. 2009a, 2009b, 2010). Annual sport harvest and effort has increased substantially from 606 Chinook salmon in 1978 (Mills 1979) to an average of 2,687 Chinook salmon during 2000–2009 (Somerville 2011). In addition to the inriver sport fishery, the Gulkana River Chinook salmon stock is subject to harvest in commercial fisheries located near the mouth of the Copper River and subsistence and personal use (PU) fisheries located in the mainstem of the Copper River. There are no stock specific estimates of harvest available for these fisheries, but similar to the Gulkana River sport harvest, these mixed stock fisheries have also shown an overall increase in harvest until recently (Botz and Somerville 2011).

In 2003, the Alaska Board of Fisheries amended the *Copper River King Salmon Management Plan* to include a sustainable escapement goal of 24,000 or more Chinook salmon for the Copper River drainage. Inriver abundance is estimated annually and inriver harvest is subtracted post-season to obtain an estimate of drainagewide escapement. In contrast, there is no information available regarding stock-specific escapements or exploitation rates, and there are no established escapement goals for any of the Copper River tributaries.

The section of the Gulkana River upstream of Sourdough Landing (Figure 1) has been designated by the U.S. Congress as a "wild river," which makes it part of the *National Wild and Scenic Rivers System*. The Bureau of Land Management (BLM) manages the adjacent lands along both banks within this area and has the authority to limit the number of trips per year or number of people per trip. To date, no permit system isin place; however, increased fishing effort coupled with diminishing Chinook salmon escapements during the beginning of this century led stakeholders to submit proposals to the Alaska Board of Fisheries to limit motor boat use.

In 2002, a multi-year cooperative project was initiated between ADF&G and BLM to monitor Chinook salmon escapement on the Gulkana River using counting tower techniques. The Gulkana River was selected because (1) the stock on average makes up a significant percentage (~ 20%) of the total Copper River escapement (Savereide 2005), (2) it supports the largest sport

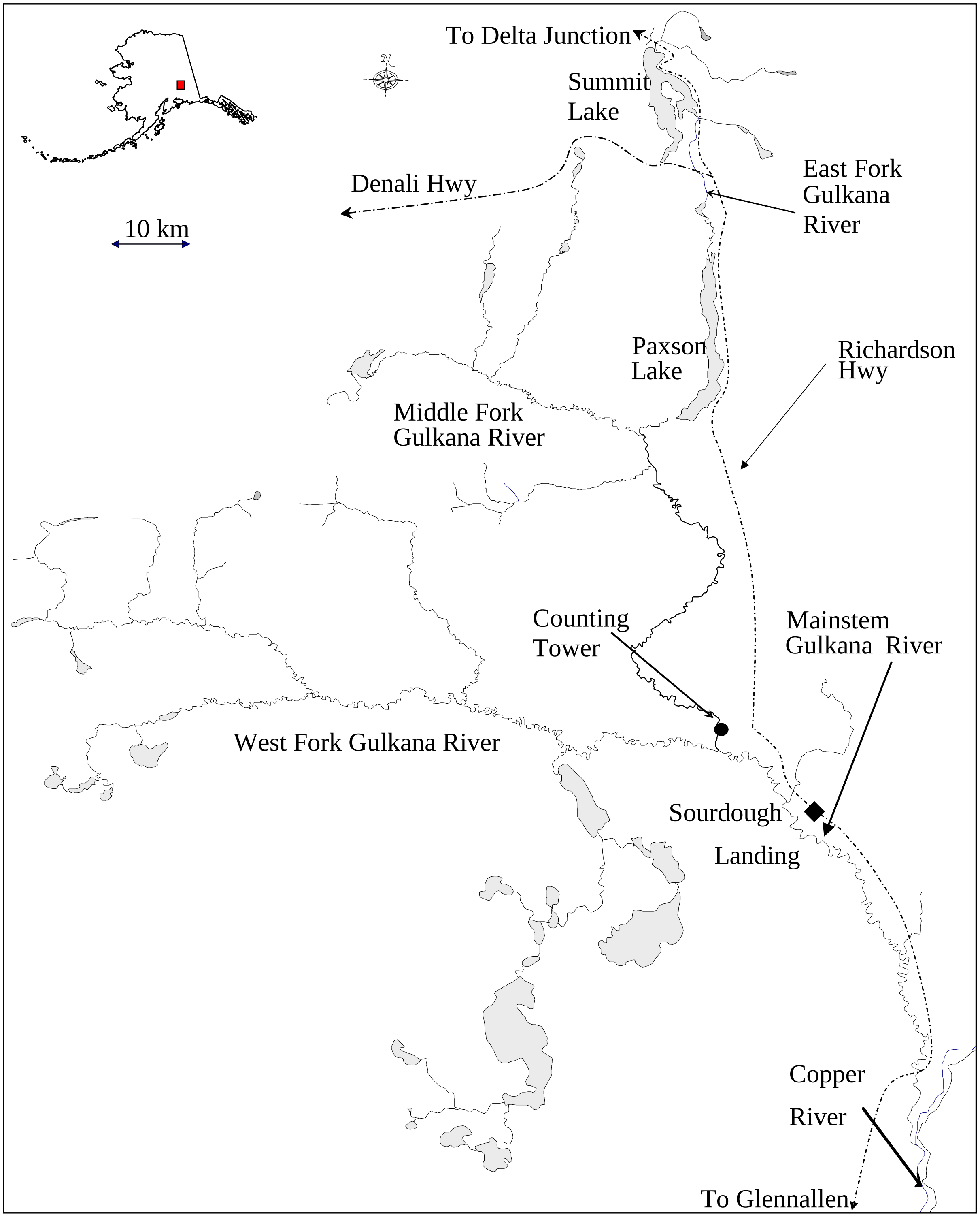

Figure 1.–The Gulkana River drainage and location of the counting tower.

fishery in the Copper River drainage, (3) fishing pressure had increased, (4) the accuracy of annual aerial escapement surveys was unknown, and (5) it is the only tributary in the Copper River drainage supporting a substantial Chinook salmon sport fishery that is not glacially occluded. Managers need inseason information on run size, run timing, and an escapement goal to better manage the sport fishery and ensure escapements are adequate enough to sustain production. The long-term goal of this project is to collect Chinook salmon escapement data to establish an escapement goal and aid in developing inseason management guidelines for (i.e., whether to close, restrict, or liberalize) the Gulkana River sport fishery.

OBJECTIVES

The 2011–2012 project objectives were to:

1. Estimate escapement of Chinook salmon, within 15 percent of the actual value 95 percent of the time, upstream of an established counting tower site on the mainstem Gulkana River;
2. Describe inriver run timing for Chinook salmon past the counting tower; and
3. Enumerate sockeye salmon passage at the counting tower during the period of tower operation.

METHODS

CHINOOK SALMON ESCAPEMENT

The number of Chinook salmon migrating upstream of the counting tower in the mainstem Gulkana River was estimated using counting tower techniques. Anecdotal information from sport fishers and guides and the results from previous aerial surveys (Taube 2002) and radiotelemetry studies (Savereide 2005) indicated that the majority (>80%) of spawning in the Gulkana River drainage occurred upstream of the selected tower site (Figure 1). Counting begins on or about 1 June and continues into August until there are three continuous days with no net upstream migration of Chinook salmon.

The number of Chinook salmon that migrate past the counting tower is equal to escapement above the tower if there is no harvest upstream of the tower site. Even though this is not true, the harvest upstream of the tower has been relatively small (<5%) compared to the estimate of escapement and its associated uncertainty. Since 2007, the Statewide Harvest Survey has delineated the harvest between Paxson and Sourdough Landing to estimate the harvest above the counting tower, which averaged 102 Chinook salmon from 2007–2010.

The counting tower was located approximately 2.5 km upstream from the confluence of the West Fork and the mainstem Gulkana River and 72.4 km from the mouth of the Gulkana at the Copper River and 296 km from the mouth of the Copper River (Figure 1). This location was chosen because the majority of spawning occurs upstream of this site and to avoid the often turbid discharge of the West Fork. A small island splits the mainstem into two channels at the tower site. Steel scaffolding platforms approximately 4 m above the water were located on each side of the island to provide a comprehensive view of the entire river (approximately 30 m wide per channel). The towers supported dome-shaped pole frames that were covered on the top and three sides with camouflage-print tarps to prevent shadows on the water and to provide the observer with protection from wind and rain. Maximum depth in both channels ranged from 1 to 1.5 m.

To ensure migrating fish were clearly visible a continuous band of white vinyl panels, approximately 2.5 m wide, was anchored to the river bottom across each river channel. There was also a 2–3 m section of picket weir placed near the base of each tower to ensure no fish were able to pass undetected directly beneath the towers. To ensure optimal viewing conditions, the panels were cleaned of debris, silt, gravel, and fish carcasses between scheduled counts as necessary. During periods of low ambient light, exterior-grade floodlights were used to illuminate the panels across each channel. Once the lights were turned on, they remained on between counts to maintain consistent conditions until no longer needed. This was done to reduce any associated effect that lighting changes may have had on salmon migration.

Six technicians (two three-person crews) were assigned to enumerate the salmon escapement in the Gulkana River in 2011 and 2012. Two 10-min counting periods (one per channel, 20 min total) were scheduled every hour, for 24 h each day. Each day was divided into three 8-h shifts. Shift I began at 0600 and ended at 1359; Shift II began at 1400 and ended at 2159 hour; Shift III began at 2200 hour and ended at 0559 hour. The 10-min count for the west channel began between the top of the hour and 10 min past, and the 10-min count for the east channel immediately followed.

Numbers of Chinook and sockeye salmon were tallied and recorded on data forms at the end of each 10-min counting period. Separate data forms were maintained for each day and channel. Migration (upstream and downstream) was recorded to provide a net upstream migration during each 10-min count. Migration was defined as passage across the full width of the vinyl panels. In addition, at the beginning of each hour, water level (relative level on a staff gauge) and water clarity (Table 1) were recorded. Conditions that might affect the counts (e.g., heavy rain or strong winds) and general observations were recorded in the comments column. Water and air temperature were recorded at the beginning of each shift.

Data Analysis

Estimates of Chinook salmon escapement were stratified by day. Daily estimates of escapement were a single-stage direct expansion from the 10-min counting periods. The 10-min counting periods were considered a systematic sample because the counting periods were not chosen randomly. Hourly count data were combined across channels before calculating estimates in order to account for the covariance between channel-specific hourly counts.

An analysis of data collected during 2002 revealed that Chinook salmon had a distinct diel migratory pattern where the majority of salmon migration takes place in the evening and early morning hours (Taras and Sarafin 2005). To account for this pattern of migration, a "count day" was defined as 1600 to 1559. Taras and Sarafin (2005) also demonstrated that interpolating for undercounts (a rank of 4.5 or 5) using this diel migratory pattern yielded more accurate estimates of escapement than using a direct expansion of the successful counts within eight-hour shifts for that day.

The diel pattern is derived from all days with complete counts (no missing hours). A diel pattern consists of 24 proportion estimates, which indicate the hourly proportion of fish passing through the tower over the entire day. In order to estimate the diel pattern, all fish counts in a particular hour over all complete count days are summed to determine a total fish count for this hour throughout the entire counting season. The proportion of this hour's counts out of the total counts of all the passing fish is one element of the diel pattern.

To be reliable, interpolations based on the diel pattern must have at least some counts that were successfully completed during the period of peak migration. Peak migration is defined and estimated as the shortest, continuous period of time during a count day that accounted for 80% of the upstream migration of Chinook salmon. Therefore, daily escapement and its variance were estimated using one of three scenarios depending on water clarity conditions (Table 1):

1. When water clarity was *excellent* to *poor* (rank 1–4) for all scheduled counts during a day, actual counts were expanded to estimate daily escapement (equations 1–3);

2. When a *small portion* (defined below) of a day's counts were conducted under *very poor* or *unobservable* water clarity (rank 4.5 or 5), daily escapement was estimated using a combination of expanded actual (equations 1–3) and interpolated (equations 1–4) counts; and

3. When *most or all* of a day's counts were conducted under *very poor* or *unobservable* water clarity (rank 4.5 or 5), escapement for the entire day was interpolated (equations 5–6) using a moving average estimate of daily passage estimates before and after the missing day(s).

Scenario 1: For days when all counts were conducted under excellent to poor conditions, daily escapement, $\hat{N}_d$, was calculated by expanding counts within a shift for day *d* (Cochran 1977):

$$\hat{N}_d = \frac{M_d}{m_d} \sum_{j=1}^{m_d} y_{dj} \ . \qquad (1)$$

The period sampling is systematic, because the sample (or primary unit) has secondary units taken within every hour in a day (i.e., systematically throughout the day). As provided in Wolter (1985), the variance associated with periods was calculated as:

$$s_d^2 = \frac{1}{2(m_d - 1)} \sum_{j=2}^{m_d} \left(y_{dj} - y_{d(j-1)}\right)^2 \ . \qquad (2)$$

The variance for the expanded daily escapement was estimated as:

$$\hat{V}\left(\hat{N}_d\right) = \left(1 - \frac{m_d}{M_d}\right) M_d^2 \frac{s_d^2}{m_d} \ . \qquad (3)$$

where:

- d = day;
- j = paired 10-min counting period (a paired 10-min counting period consists of the two 10-min counts, one per channel, during a given hour);
- y = observed period count (both channels combined);
- m = number of paired 10-min counting periods sampled;
- M = total number of possible paired 10-min counting periods.

Scenario 2: If counts were conducted successfully for a portion of the day that represents 25% or more of the expected migration for that day (as defined by the diel relationship), and if at least 25% of the periods during peak migration were successfully counted, then the channel-specific interpolated count was calculated as the product of the sum of successful counts for the day and the ratio of the expected daily escapement not represented to the daily escapement that was represented, or:

$$y_{dc,\text{interp}} = y_{dc,\text{actual}} \times \frac{1 - p_{edp}}{p_{edp}} \ , \qquad (4)$$

where:

- $y_{dc,\text{interp}}$ = interpolated sum of counts for missing (i.e. very poor or unobservable) 10-min periods by channel;
- $y_{dc,\text{actual}}$ = daily sum of successful 10-min counts by channel; and,
- p_{edp} = proportion of expected daily escapement successfully counted.

The interpolated count was then allocated among missed 10-min counting periods based on the diel pattern for the current year. For example, if four 10-min counting periods were missed and the interpolated count for that period was 10 Chinook salmon, those 10 fish would be allocated to each of the missed periods in proportion to the diel pattern.

Daily escapement and variances were calculated using a combination of actual and interpolated counts. Treating interpolated counts as “known” would result in underestimating the daily variances. Therefore, daily variance estimates were inflated by decreasing the number of 10-min counting periods, m_d, sampled each day by the proportion of the expected daily migration successfully counted on that day. For example, if 85% of the expected run was successfully counted on a given day, then the adjusted m_d = 0.85 x m_d = 0.85 x 24. For the channel-combined counts the proportion successfully counted was the channel-specific proportions weighted by the proportion of the overall run passing each channel. Although inflating the variance calculations guards against a negative bias in estimation of the total variance, this approach could still lead to unacceptably large biases if days with diel interpolations contribute substantially to the overall variance. Therefore, daily variances are estimated using this approach as long as interpolations using the diel pattern account for a small proportion of the total variance.

Scenario 3: If counts were conducted for a portion of the day that represented less than 25% of the expected escapement for that day, or if less than 25% of the periods during peak migration were counted successfully, then the moving average estimate for the missing day *i* was calculated as:

$$\hat{N}_i = \frac{\sum_{j=i-k}^{i+k} I(day\, j \;\; was\, sampled)\hat{N}_j}{\sum_{j=i-k}^{i+k} I(day\, j \;\; was\, sampled)} \qquad (5)$$

where:

k = number of days missed due to adverse viewing conditions; and

$$\mathrm{I}(\cdot) = \begin{cases} 1 & \text{when the condition is true} \\ 0 & \text{otherwise} \end{cases} \qquad (6)$$

is an indicator function.

The interpolated values were used as the point estimates for the daily counts and the daily variation for undercounted days was the maximum variance of the k days before and the k days after the undercounted day i.

Escapement upstream of the counting tower and its associated variance incorporated all three daily migration estimation scenarios, and was estimated as (Cochran 1977):

$$\hat{N}_{PT} = \sum_{d=1}^{D} \hat{N}_d \text{ ; and} \qquad (7)$$

$$\hat{V}\left(\hat{N}_{PT}\right) = \sum_{d=1}^{D} \hat{V}(\hat{N}_d), \qquad (8)$$

where:

D = total number of possible days.

Prior to the initiation of the counting tower project in 2002, escapement of Chinook salmon in the Gulkana River was monitored by aerial survey counts. Aerial surveys were continued and provided data to investigate the relationship between the index counts and escapement measured at the towers. Analysis of all years of Gulkana River Chinook salmon counting tower data was completed to test for significant correlations between water temperature and run timing. Regression analysis was used to define the relationship of 2002–2012 escapements to: aerial survey counts, water level, and water temperature.

SOCKEYE SALMON ESCAPEMENT

The number of sockeye salmon migrating past the counting tower was estimated using the methods described for estimating Chinook salmon escapement. Because the sockeye salmon run was known to continue after counting ceased each year, the escapement estimate reflects an unknown portion of the total run and should be considered a minimum estimate of escapement.

RESULTS

CHINOOK SALMON ESCAPEMENT

In 2011, the Gulkana River counting tower was in operation from 2 June through 10 August. In 2012, the tower was in operation from 5 June through 10 August. Inclement weather resulted in less than favorable viewing conditions for zero days in 2011 and 7+ days in 2012 (Tables 2 and 3). The estimated Chinook salmon escapement upstream of the counting tower was 3,804 (SE = 257) in 2011 and 1,730 (SE = 157) in 2012. Interpolated estimates of daily passage, for days when visibility precluded counting, represented 0.0% of the total escapement estimate in 2011 and 6.0% of the total estimate in 2012.

During 2011 and 2012, the estimated diel migratory pattern encompassed 82% and 81% of the daily migration from 0000 through 0700, respectively (Figure 2). The first Chinook salmon was observed on 12 and 11 June during each year respectively. The run was considered complete each year on 10 August. The 2011 and 2012 run timing pattern observed past the counting tower was later than the average over all years (2002–2010; Figure 3).

Analysis of 10 years of Gulkana River Chinook salmon counting tower data revealed a significant positive correlation between water temperature and run timing. However, Chinook salmon run timing was not significantly related to water level ($p > 0.05$; Tables 4 and 5). The lowest water level recorded was during 2004 when 82% of the escapement returned by 1 July compared to an average of 33% for the other 10 years. Since

Table 1.–Water clarity classification scheme.

Rank	Description	Salmon Viewing	Water Condition
1	Excellent	All passing salmon are observable	Virtually no turbidity or glare, "drinking water" clarity; all routes of migration observable
2	Good	All passing salmon are observable	Minimal to very low levels of turbidity or glare; all routes of migration observable
3	Fair	All passing salmon are observable	Low to moderate levels of turbidity or glare; all routes of migration observable
4	Poor	Possible, but not likely, that some passing salmon may be missed	Moderate to high levels of turbidity or glare; a few likely routes of migration are partially obscured
4.5[a]	Very poor	Likely that some passing salmon may be missed	Moderate to high levels of turbidity or glare; some, to many, likely routes of migration are obscured
5	Unobservable	Passing fish are not observable	High level of turbidity or glare; ALL routes of migration obscured

[a] The ranking of 4.5 was inserted in 2007 to emphasize that further delineation was necessary for defining "poor" visibility. This allows continuity with the scale used in previous years rather than change the scale to 1–6.

2002, over 81% of the Chinook salmon escapement passed the tower between 17 June and 31 July. The earliest count occurred on 3 June 2005. On average, the date 10 June is equivalent to the 1st percentile and 30 June the 41st percentile of the cumulative daily observations.

A higher percentage of Chinook salmon returned early (by 1 July) in 2004 (82%) and 2005 (60%), which coincided with warmer water temperatures. In contrast, a lower percentage of Chinook salmon returned by 1 July in 2009 (11%), which coincided with cooler water temperatures. A significant exponential relationship was revealed between the transformed percent of the run by 1 July and the average maximum water temperature between 10 June and 30 June ($r^2 = 0.88$, $p < 0.05$, Tables 4, 6 and 7, Figure 4). Water temperature data was incomplete during 2002. Overall, the Chinook run timing has been trending later in recent years and experiencing cooler temperatures (Table 7; Figure 5).

A statistically significant relationship was also found between aerial index counts and escapement of Chinook salmon upstream of the tower ($r^2 = 0.84$, $p < 0.05$; Table 8; Figure 6). Aerial survey data was incomplete during 2003 and inclement weather prohibited conducting a survey in 2008.

SOCKEYE SALMON ESCAPEMENT

In 2011 and 2012, the minimum escapement estimate for sockeye salmon was 38,048 (SE = 1,683) and 41,953 (SE = 1,951). These were among the highest three escapements recorded since 2002 and more than 1.7 times higher than the 2002–2010 average of 22,955. The first sockeye salmon was observed on 3 and 6 June of each year respectively and counting ceased on 10 August (Tables 9 and 10).

DISCUSSION

The main objective of an escapement monitoring project is to estimate total escapement for a particular stock, or provide an index of escapement that is relatively consistent over time with respect to the proportion of the escapement that is enumerated. In 2011 and 2012, the entire Chinook salmon run was assessed and enumerated successfully providing precise estimates of Chinook salmon escapement of 3,804 (SE = 257) and 1,730 (SE = 157) above the counting tower.

The run timing patterns of Chinook salmon past the tower, since 2003, are positively correlated with increasing water temperature. In other words, the majority of the run migrates upstream of the counting tower before 1 July in years

Table 2.–Daily counts, expanded counts, and the cumulative estimated escapement of Chinook salmon at the Gulkana River tower, 2011.

	West Channel		East Channel		Combined		Total
Date	Daily	Expanded	Daily	Expanded	Daily	Expanded	Escapement
2-Jun	0	0	0	0	0	0	0
3-Jun	0	0	0	0	0	0	0
4-Jun	0	0	0	0	0	0	0
5-Jun	0	0	0	0	0	0	0
6-Jun	0	0	0	0	0	0	0
7-Jun	0	0	0	0	0	0	0
8-Jun	0	0	0	0	0	0	0
9-Jun	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0
11-Jun	0	0	0	0	0	0	0
12-Jun	0	0	1	6	1	6	6
13-Jun	1	6	1	6	2	12	18
14-Jun	1	6	0	0	1	6	24
15-Jun	0	0	0	0	0	0	24
16-Jun	4	24	0	0	4	24	48
17-Jun	3	18	1	6	4	24	72
18-Jun	2	12	0	0	2	12	84
19-Jun	7	42	1	6	8	48	132
20-Jun	4	24	5	30	9	54	186
21-Jun	5	30	2	12	7	42	228
22-Jun	1	6	1	6	2	12	240
23-Jun	3	18	1	6	4	24	264
24-Jun	0	0	2	12	2	12	276
25-Jun	9	54	7	42	16	96	372
26-Jun	27	162	23	138	50	300	672
27-Jun	11	66	7	42	18	108	780
28-Jun	6	36	0	0	6	36	816
29-Jun	0	0	0	0	0	0	816
30-Jun	3	18	1	6	4	24	840
1-Jul	4	24	-1	-6	3	18	858
2-Jul	2	12	1	6	3	18	876
3-Jul	31	186	32	192	63	378	1,254
4-Jul	8	48	1	6	9	54	1,308
5-Jul	5	30	1	6	6	36	1,344
6-Jul	-1	-6	0	0	-1	-6	1,338
7-Jul	15	90	1	6	16	96	1,434
8-Jul	22	132	4	24	26	156	1,590

-continued-

Table 2.–Page 2 of 2.

	West Channel		East Channel		Combined		Total
Date	Daily	Expanded	Daily	Expanded	Daily	Expanded	Escapement
9-Jul	36	216	25	150	61	366	1,956
10-Jul	2	12	7	42	9	54	2,010
11-Jul	8	48	2	12	10	60	2,070
12-Jul	22	132	1	6	23	138	2,208
13-Jul	0	0	2	12	2	12	2,220
14-Jul	15	90	10	60	25	150	2,370
15-Jul	0	0	0	0	0	0	2,370
16-Jul	0	0	0	0	0	0	2,370
17-Jul	2	12	0	0	2	12	2,382
18-Jul	2	12	2	12	4	24	2,406
19-Jul	0	0	2	12	2	12	2,418
20-Jul	1	6	2	12	3	18	2,436
21-Jul	7	42	9	54	16	96	2,532
22-Jul	8	48	4	24	12	72	2,604
23-Jul	10	60	0	0	10	60	2,664
24-Jul	14	84	19	114	33	198	2,862
25-Jul	1	6	7	42	8	48	2,910
26-Jul	3	18	-1	-6	2	12	2,922
27-Jul	3	18	7	42	10	60	2,982
28-Jul	5	30	4	24	9	54	3,036
29-Jul	12	72	7	42	19	114	3,150
30-Jul	13	78	7	42	20	120	3,270
31-Jul	18	108	9	54	27	162	3,432
1-Aug	17	102	6	36	23	138	3,570
2-Aug	4	24	6	36	10	60	3,630
3-Aug	8	48	14	84	22	132	3,762
4-Aug	4	24	1	6	5	30	3,792
5-Aug	1	6	0	0	1	6	3,798
6-Aug	1	6	0	0	1	6	3,804
7-Aug	0	0	0	0	0	0	3,804
8-Aug	0	0	0	0	0	0	3,804
9-Aug	0	0	0	0	0	0	3,804
10-Aug	0	0	0	0	0	0	3,804

Table 3.–Daily counts, expanded counts, interpolations, and the cumulative estimated escapement of Chinook salmon at the Gulkana River tower, 2012. Shading identifies days with counts that included interpolation.

	West Channel			East Channel			Combined			Cumulative
Date	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Escapement
6-Jun	0	0	0	0	0	0	0	0	0	0
7-Jun	0	0	0	0	0	0	0	0	0	0
8-Jun	0	0	0	0	0	0	0	0	0	0
9-Jun	0	0	0	0	0	0	0	0	0	0
10-Jun	0	0	0	0	0	0	0	0	0	0
11-Jun	0	0	0	0	0	0	0	0	0	0
12-Jun	0	0	0	0	0	0	0	0	2.3	2
13-Jun	0	0	0.9	0	0	1.3	0	0	4.7	7
14-Jun	0	0	1.7	0	0	1.3	0	0	6.2	13
15-Jun	0	0	1.7	0	0	4.0	0	0	6.9	20
16-Jun	0	0	2.6	0	0	13.3	0	0	11.4	32
17-Jun	0	0	4.3	0	0	12.7	0	0	24.2	56
18-Jun	0	0	6.9	0	0	12.7	0	0	23.4	79
19-Jun	1	6	6	0	0	12.7	1	6	18.7	98
20-Jun	1	6	6	0	0	12.7	1	6	18.7	116
21-Jun	0	0	0	2	12	12	2	12	12	128
22-Jun	1	6	6	0	0	0	1	6	6	134
23-Jun	2	12	12	4	24	24	6	36	36	170
24-Jun	3	18	18	14	84	84	17	102	102	272
25-Jun	0	0	0	-1	-6	-6	-1	-6	-6	266
26-Jun	1	6	6	0	0	0	1	6	6	272
27-Jun	0	0	0	0	0	0	0	0	0	272
28-Jun	1	6	6	0	0	0	1	6	6	278
29-Jun	1	6	6	1	6	6	2	12	12	290
30-Jun	1	6	6	2	12	12	3	18	18	308
1-Jul	2	12	12	1	6	6	3	18	18	326
2-Jul	1	6	6	3	18	18	4	24	24	350
3-Jul	4	24	24	4	24	24	8	48	48	398
4-Jul	0	0	0	1	6	6	1	6	6	404
5-Jul	5	30	30	0	0	0	5	30	30	434
6-Jul	2	12	12	1	6	6	3	18	18	452
7-Jul	1	6	6	5	30	30	6	36	36	488
8-Jul	2	12	12	3	18	18	5	30	30	518
9-Jul	0	0	0	2	12	12	2	12	12	530
10-Jul	1	6	6	0	0	0	1	6	6	536
11-Jul	2	12	12	0	0	0	2	12	12	548
12-Jul	5	30	30	4	24	24	9	54	54	602
13-Jul	2	12	12	1	6	6	3	18	18	620
14-Jul	2	12	12	1	6	6	3	18	18	638
15-Jul	2	12	12	2	12	12	4	24	24	662
16-Jul	0	0	0	1	6	6	1	6	6	668
17-Jul	2	12	12	0	0	0	2	12	12	680
18-Jul	0	0	0	0	0	0	0	0	0	680

-continued-

Table 3.–Page 2 of 2.

Date	West Channel			East Channel			Combined			Cumulative
	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Escapement
19-Jul	7	42	42	3	18	18	10	60	60	740
20-Jul	5	30	30	2	12	12	7	42	42	782
21-Jul	16	96	96	11	66	66	27	162	162	944
22-Jul	3	18	18	4	24	24	7	42	42	986
23-Jul	5	30	30	0	0	0	5	30	30	1,016
24-Jul	6	36	36	-1	-6	-6	5	30	30	1,046
25-Jul	7	42	42	6	36	36	13	78	78	1,124
26-Jul	17	102	102	8	48	48	25	150	150	1,274
27-Jul	10	60	60	7	42	42	17	102	102	1,376
28-Jul	19	114	114	6	36	36	25	150	150	1,526
29-Jul	4	24	24	4	24	24	8	48	48	1,574
30-Jul	9	54	54	0	0	0	9	54	54	1,628
31-Jul	4	24	24	-1	-6	-6	3	18	18	1,646
1-Aug	4	24	24	5	30	30	9	54	54	1,700
2-Aug	3	18	18	0	0	0	3	18	18	1,718
3-Aug	1	6	6	0	0	0	1	6	6	1,724
4-Aug	0	0	0	0	0	0	0	0	0	1,724
5-Aug	1	6	6	0	0	0	1	6	6	1,730
6-Aug	0	0	0	0	0	0	0	0	0	1,730
7-Aug	0	0	0	0	0	0	0	0	0	1,730
8-Aug	0	0	0	0	0	0	0	0	0	1,730
9-Aug	0	0	0	0	0	0	0	0	0	1,730
10-Aug	0	0	0	0	0	0	0	0	0	1,730
Totals	166	996	1,014	105	630	701	271	1,626	1,730	1,730

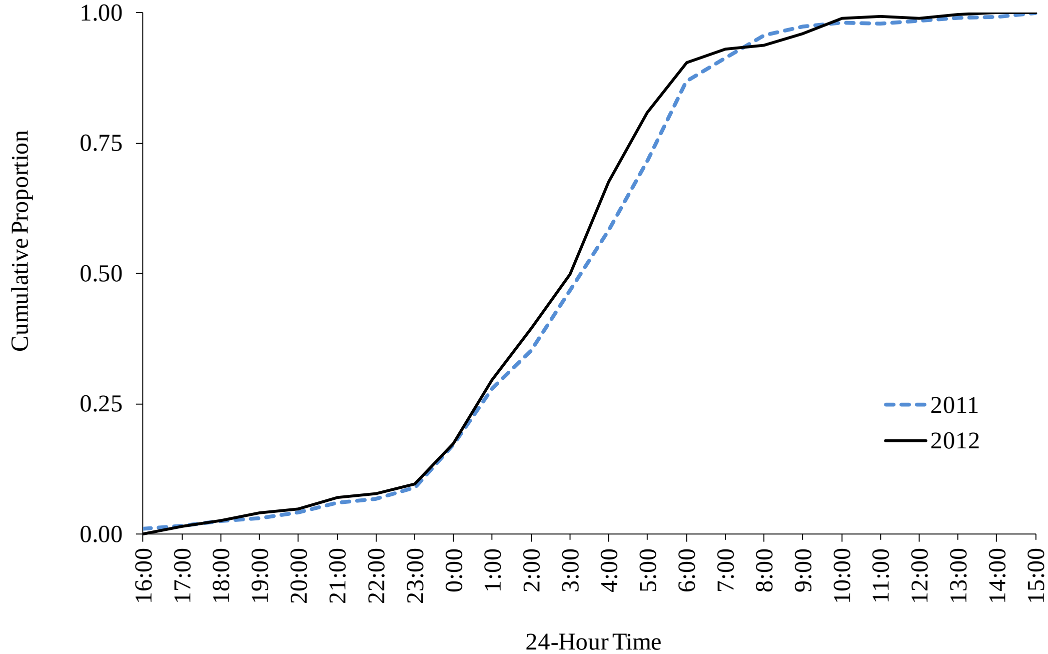

Figure 2.–Estimated diel migratory pattern for 2011 and 2012, the cumulative proportion of average daily counts by hour of day for Chinook salmon migrating past the Gulkana River counting tower.

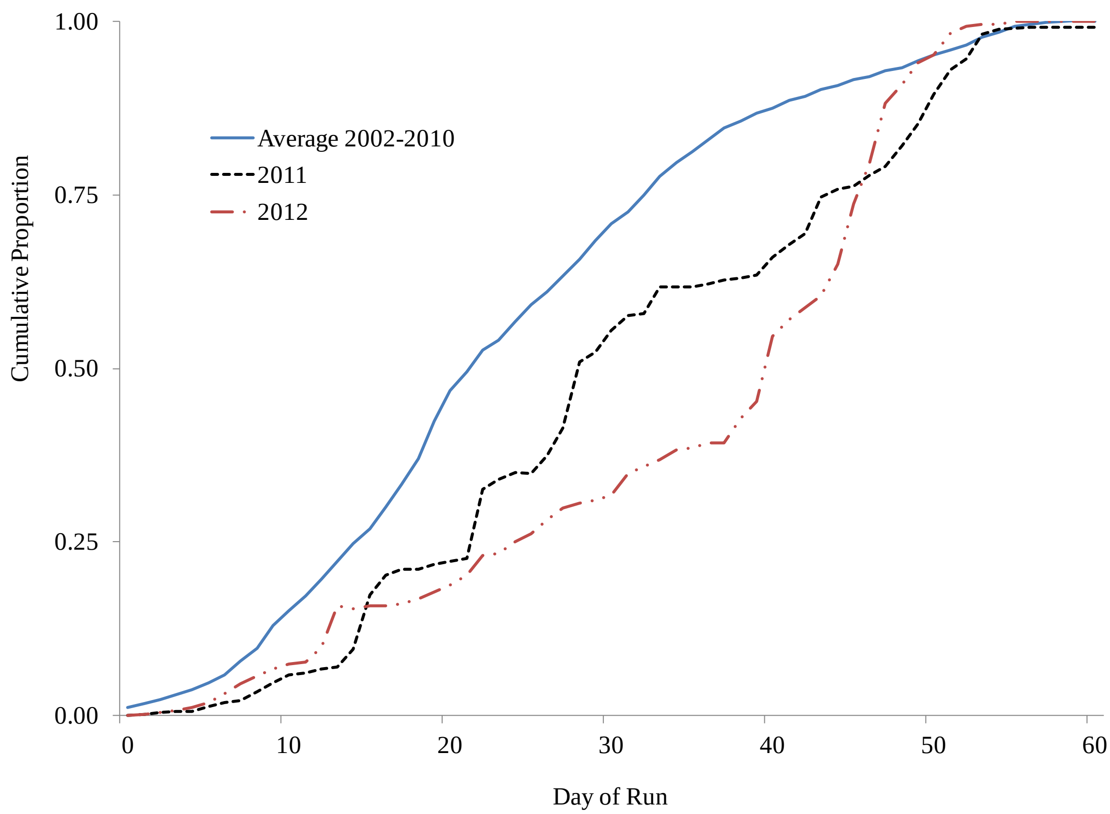

Figure 3.–Estimated run timing pattern for Gulkana River Chinook salmon past the counting tower in 2011 and 2012, compared to the 2002–2010 average.

Table 4.–Daily expanded counts, including interpolations, of Chinook salmon at the Gulkana River tower, 2002–2012. Shading identifies days with counts that included interpolation.

Day	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
27-May											
28 May											
29 May											
30 May											
31-May		0	0	0				0	0		
1-Jun		0	0	0			0	0	0		
2-Jun		0	0	0		0	0	0	0		
3-Jun		0	0	6		0	0	0	0	0	
4-Jun		0	0	12	0	0	0	0	0	0	
5-Jun		0	0	6	0	0	0	0	0	0	0
6-Jun		0	54	12	0	0	0	0	0	0	0
7-Jun	0	0	114	6	0	0	0	0	0	0	0
8-Jun	0	0	42	6	0	0	6	0	6	0	0
9-Jun	0	6	6	0	0	-6	6	12	0	0	0
10-Jun	0	6	18	6	0	12	0	-6	42	0	0
11-Jun	0	6	24	12	0	24	12	0	0	0	0
12-Jun	18	54	6	48	6	12	24	4.5	6	6	2.3
13-Jun	0	24	0	72	18	18	6	4.5	0	12	4.7
14-Jun	0	30	6	78	36	66	24	10.5	0	6	6.2
15-Jun	0	42	24	96	42	0	42	12	0	0	6.9
16-Jun	18	90	42	54	24	48	72	12	6	24	11.4
17-Jun	48	36	48	114	18	6	90	6	24	24	24.2
18-Jun	78	30	42	282	84	30	120	24	36	12	23.4
19-Jun	96	36	174	120	48	36	90	24	42	48	18.7
20-Jun	408	36	372	90	46	90	48	48	18	54	18.7
21-Jun	198	120	342	12	42	66	96	18	30	42	12
22-Jun	218	42	360	0	12	60	126	12	54	12	6
23-Jun	90	138	318	78	6	120	42	0	54	24	36
24-Jun	156	78	234	120	92	168	24	6	66	12	102
25-Jun	282	30	390	90	100	90	46	6	24	96	-6
26-Jun	132	18	324	48	103	114	54	12	48	300	6
27-Jun	126	6	534	54	107	306	72	30	30	108	0
28-Jun	348	24	360	30	111	252	66	60	42	36	6
29-Jun	210	528	54	48	141	312	6	36	18	0	12
30-Jun	678	444	54	126	318	168	48	54	39	24	18
1-Jul	342	648	0	90	120	90	60	108	54	18	18
2-Jul	84	438	-18	66	120	132	30	90	18	18	24
3-Jul	336	66	48	78	132	72	156	36	144	378	48
4-Jul	30	30	12	54	72	66	60	276	48	54	6
5-Jul	80	102	18	36	216	84	318	180	12	36	30
6-Jul	38	138	6	6	138	54	198	342	18	-6	18
7-Jul	90	108	6	48	96	36	66		24	96	36
8-Jul	120	36	18	12	210	12	142		48	156	30

-continued-

Table 4.–Page 2 of 2.

Day	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
9-Jul	276	66	6	30	60	36	137	276	42	366	12
10-Jul	156	174	24	60	96	30	123	342	66	54	6
11-Jul	228	180	0	18	150	6	85	126	84	60	12
12-Jul	54	96	-6	6	228	36	40	132	30	138	54
13-Jul	78	114	72	42	186	72	90	138	6	12	18
14-Jul	156	102	78	30	372	150	72	66	6	150	18
15-Jul	78	96	12	6	108	192	36	54	12	0	24
16-Jul	132	54	30	48	18	210	54	42	24	0	6
17-Jul	204	12	18	24	30	132	18	12	102	12	12
18-Jul	96	36	0	12	84	168	18	6	108	24	0
19-Jul	66	30	18	18	18	126	48	6	126	12	60
20-Jul	66	18	0	30	54	132	24	12	60	18	42
21-Jul	66	0	12	6	24	60	6	0	72	96	162
22-Jul	66	18	6	24	24	120	30	0	108	72	42
23-Jul	66	18	0	18	18	42	12	0	69	60	30
24-Jul	12	0	0	36	132	84	6	6	57	198	30
25-Jul	42	-6	-12	12	54	54	102	0	50	48	78
26-Jul	6	6	-6	24	36	42	132	12	36	12	150
27-Jul	12	-12	-12	12	60	24	66	6	12	60	102
28-Jul	0	42	0	72	78	36	36	0	42	54	150
29-Jul	0	-12	12	6	96	12	61	0	24	114	48
30-Jul	0	72	78	30	48	18	58	12	30	120	54
31-Jul	54	30	66	24	108	12	58	18	0	162	18
1-Aug	6	114	60	18	36	6	50	0	30	138	54
2-Aug	42	24	54	12	42	0	40	12	54	60	18
3-Aug	60	30	102	30	66	42	25	6	6	132	6
4-Aug	24	30	72	36	18	12	88	6	-12	30	0
5-Aug	12	48	-24	18	114	30	0	12	60	6	6
6-Aug	36	72	6	0	30	0	12	0	12	6	0
7-Aug	48	24	18	0	0	0	0	0	0	0	0
8-Aug	30	0	18	0	0	0	0	0	0	0	0
9-Aug	0	24	0	0	0	0	0	0	0	0	0
10-Aug	0	0	0	0	0	0	0	0	0	0	0
Total	6,396	4,890	4,734	2,718	4,846	4,422	3,677	2,720	2,267	3,804	1,730

Table 5.–Daily average water level (nearest 10ths of an inch) at the Gulkana River tower, 2002–2012.

Day	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
27-May	ND	24.0	13.8	23.0	ND	ND	ND	ND	ND	ND	ND
28-May	ND	23.5	17.3	21.5	ND	ND	ND	ND	ND	ND	ND
29-May	ND	23.0	16.3	20.5	ND	ND	ND	20.0	ND	ND	ND
30-May	ND	23.0	14.8	19.3	ND	ND	ND	19.0	ND	ND	ND
31-May	ND	23.5	13.3	18.8	ND	ND	ND	18.0	ND	ND	ND
1-Jun	ND	25.0	12.5	19.0	ND	19.5	ND	16.0	ND	ND	ND
2-Jun	ND	26.0	15.3	19.5	ND	19.5	ND	15.5	ND	ND	ND
3-Jun	ND	24.0	18.0	19.0	16.5	19.0	ND	14.5	ND	22.6	ND
4-Jun	ND	22.5	15.3	18.5	15.3	18.5	ND	14.5	ND	21.6	ND
5-Jun	ND	21.5	13.8	18.0	14.5	18.0	ND	13.0	ND	20.8	26.0
6-Jun	ND	21.5	12.3	17.5	13.5	17.5	ND	12.0	14.3	19.9	26.3
7-Jun	ND	21.5	11.3	17.3	12.5	17.0	ND	11.0	14.0	19.1	26.8
8-Jun	21.5	21.0	13.3	16.3	12.0	16.5	ND	10.5	14.8	18.5	26.6
9-Jun	20.5	20.3	15.3	16.0	11.5	16.0	14.5	10.3	15.5	18.3	26.5
10-Jun	18.5	20.0	16.3	16.5	10.8	15.5	15.3	9.8	15.5	17.9	26.8
11-Jun	18.0	19.5	14.3	16.0	10.5	15.0	16.3	9.5	ND	17.6	26.5
12-Jun	18.5	19.5	12.8	15.8	10.3	14.5	16.0	11.0	ND	17.3	29.1
13-Jun	16.5	19.5	11.8	15.8	10.0	14.5	17.0	16.0	20.5	17.0	34.1
14-Jun	16.0	19.0	10.5	15.8	ND	13.8	16.5	17.0	19.4	16.6	34.5
15-Jun	16.0	19.0	9.5	16.3	9.8	ND	16.0	ND	18.6	16.4	33.1
16-Jun	15.5	19.0	8.5	15.5	10.0	ND	15.0	13.8	17.8	16.3	31.2
17-Jun	15.0	19.0	7.5	15.3	11.5	13.5	15.0	13.8	18.0	16.4	29.5
18-Jun	14.5	19.0	7.3	16.3	14.8	13.0	14.5	13.8	17.5	16.5	27.8
19-Jun	14.5	19.0	6.3	19.0	18.5	13.0	14.0	14.3	17.0	16.1	26.2
20-Jun	20.0	19.5	6.0	18.0	15.5	12.5	13.8	14.0	16.8	16.0	25.2
21-Jun	23.0	20.8	5.3	16.8	13.5	12.5	13.3	13.0	16.0	16.7	24.8
22-Jun	22.0	21.0	5.0	17.0	16.3	ND	13.3	13.0	16.0	16.9	24.4
23-Jun	20.5	20.0	4.5	16.8	ND	ND	13.3	14.0	16.5	17.1	23.7
24-Jun	19.0	19.5	4.3	16.5	24.0	11.5	15.5	14.0	16.5	17.0	22.8
25-Jun	17.5	19.0	3.8	16.0	26.0	11.0	20.3	14.3	16.5	16.0	21.9
26-Jun	17.0	18.8	3.5	15.8	26.0	11.0	18.0	13.0	16.5	15.6	22.0
27-Jun	16.5	18.0	3.3	15.8	27.8	10.5	16.5	12.5	16.5	15.3	23.9
28-Jun	15.5	17.5	3.0	15.8	25.5	10.5	15.8	11.8	18.0	15.0	24.6
29-Jun	15.0	17.0	2.8	14.8	22.0	ND	15.8	11.3	21.2	14.6	24.1
30-Jun	14.8	16.8	2.8	14.8	20.5	11.0	16.3	10.5	20.5	14.8	23.2
1-Jul	15.0	16.5	2.5	15.3	18.0	11.0	16.0	9.8	19.8	15.1	23.4
2-Jul	18.0	16.5	2.5	17.3	15.5	11.0	16.6	9.0	18.5	15.9	23.4
3-Jul	20.0	18.0	2.5	19.0	13.5	11.8	15.8	8.5	18.0	16.5	23.4
4-Jul	21.0	20.5	2.3	17.3	13.0	13.0	15.0	8.0	20.8	16.3	23.4
5-Jul	21.0	20.3	2.3	16.5	12.0	13.4	14.5	8.0	19.8	16.0	22.4
6-Jul	19.0	19.0	2.8	16.3	12.0	ND	14.3	7.0	19.0	16.0	21.5
7-Jul	18.0	18.0	2.5	15.8	ND	ND	21.3	7.0	19.0	16.2	21.1
8-Jul	17.5	17.5	2.3	15.0	ND	12.5	24.0	7.0	18.0	16.4	21.2
9-Jul	16.5	16.8	2.3	14.8	ND	12.0	23.5	7.0	17.0	16.6	20.6
10-Jul	15.5	16.3	2.3	16.0	12.3	12.0	23.0	6.5	16.0	16.0	20.1
11-Jul	15.5	16.0	1.8	15.8	11.5	11.6	21.0	6.5	15.0	15.5	22.0
12-Jul	14.5	15.8	1.5	15.0	11.0	11.5	20.3	6.5	15.0	14.9	22.4
13-Jul	14.5	15.5	1.3	14.8	11.5	ND	19.0	6.5	15.0	14.8	21.2
14-Jul	14.5	15.0	1.0	13.8	ND	ND	18.0	5.0	15.3	14.7	20.7
15-Jul	14.5	15.0	1.0	13.5	ND	10.8	17.0	5.0	16.0	14.5	20.1

-continued-

Table 5.–Page 2 of 2.

Day	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
16-Jul	13.8	15.0	1.0	13.5	15.0	10.6	16.0	5.0	20.3	14.3	19.4
17-Jul	13.5	14.8	0.5	13.5	ND	10.5	15.5	5.0	19.8	15.0	18.8
18-Jul	13.5	14.8	0.5	13.3	13.0	10.5	15.8	5.0	18.3	15.5	18.4
19-Jul	13.5	14.5	0.3	13.0	12.0	10.3	16.0	5.0	17.8	17.8	17.9
20-Jul	13.0	14.5	0.3	12.5	11.0	ND	16.5	5.0	18.3	18.9	17.2
21-Jul	13.0	14.0	0.3	12.5	ND	ND	17.0	4.8	20.0	17.9	16.9
22-Jul	12.5	14.0	0.3	12.5	ND	11.0	16.3	4.5	23.0	17.3	16.9
23-Jul	12.5	14.3	0.3	11.8	9.8	11.0	16.5	4.5	24.0	16.5	17.0
24-Jul	12.0	14.0	0.3	11.8	9.5	11.0	17.8	4.3	24.0	15.8	16.8
25-Jul	12.5	13.8	0.3	11.8	9.5	10.8	18.0	4.3	23.8	15.5	16.9
26-Jul	14.0	13.8	0.3	12.0	9.5	10.8	17.5	4.3	22.0	15.3	16.6
27-Jul	14.5	14.0	0.3	12.0	9.5	ND	17.5	4.0	21.5	15.4	16.4
28-Jul	14.5	14.5	0.5	12.3	9.0	ND	19.0	4.0	21.3	15.5	16.0
29-Jul	14.0	15.0	0.8	14.5	9.0	10.5	27.5	4.0	20.0	15.5	15.7
30-Jul	13.8	15.5	1.0	16.5	8.5	10.8	26.8	3.8	19.5	15.5	15.4
31-Jul	13.0	17.0	1.3	17.3	9.0	10.8	25.5	3.5	18.5	15.7	15.3
1-Aug	13.0	17.5	1.3	16.5	9.3	12.2	25.5	3.5	18.0	17.8	15.0
2-Aug	12.5	16.8	1.3	15.0	9.8	12.0	24.5	3.5	17.3	19.4	15.0
3-Aug	12.0	16.5	1.0	15.0	9.5	ND	23.5	ND	16.5	18.4	15.6
4-Aug	12.0	15.8	0.8	14.5	9.5	ND	23.3	ND	16.0	17.9	16.7
5-Aug	12.0	15.8	0.5	13.5	9.8	12.0	23.3	ND	16.3	17.0	16.6
6-Aug	12.0	15.8	0.3	13.0	10.0	12.9	22.5	ND	16.3	16.8	16.3
7-Aug	12.5	15.3	0.3	12.0	9.8	12.9	22.5	ND	16.0	16.9	15.9
8-Aug	14.0	15.0	0.3	12.0	9.5	12.2	23.0	ND	15.8	16.9	15.5
9-Aug	15.0	14.8	0.3	11.5	9.3	12.0	22.3	ND	15.5	16.9	15.3
10-Aug	16.5	14.5	0.0	10.8	8.8	11.8	22.0	ND	15.3	18.2	15.2

Note: Water levels among years, prior to 2011, are not directly comparable given staff gages were not installed with a common bench mark. However, the staff gage was consistently installed in the same location. To avoid negative numbers, water levels for 2004 were adjusted by adding 2.25.

Table 6.–Daily maximum water temperature (Celsius) at the Gulkana River tower, 2002–2012.

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1-Jun	9.0	10.0	ND	ND	12.0	7.0	7.0	15.0	ND	ND
2-Jun	9.0	9.0	ND	ND	ND	9.0	10.0	14.5	ND	ND
3-Jun	9.0	9.0	ND	9.0	ND	8.0	10.0	13.0	9.0	ND
4-Jun	10.0	10.0	ND	9.0	ND	8.0	8.0	11.0	9.0	ND
5-Jun	10.0	12.0	ND	9.0	ND	15.0	8.0	12.0	9.0	ND
6-Jun	11.0	14.0	ND	8.0	ND	8.0	12.0	13.0	10.0	9.0
7-Jun	10.0	12.0	ND	11.0	10.0	9.0	12.0	14.0	9.0	10.0
8-Jun	11.0	12.0	ND	12.0	10.0	10.0	15.0	13.0	10.0	10.0
9-Jun	12.0	9.0	ND	15.0	13.0	10.0	15.0	13.0	10.0	9.0
10-Jun	14.0	8.0	13.0	15.0	14.0	11.0	18.0	13.0	12.0	11.0
11-Jun	15.0	9.0	11.0	14.0	14.0	11.0	12.0	12.0	10.0	9.0
12-Jun	18.0	9.0	13.0	15.0	13.0	10.0	8.0	10.0	11.0	8.0
13-Jun	16.0	11.0	14.0	15.0	13.0	9.0	7.0	9.0	11.0	7.0
14-Jun	15.0	12.0	15.0	16.0	14.0	9.0	7.0	11.5	10.0	9.0
15-Jun	14.0	13.0	19.0	16.0	14.0	11.0	10.0	10.0	10.0	10.0
16-Jun	14.0	15.0	25.0	18.0	14.0	12.0	12.0	10.0	9.0	10.0
17-Jun	14.0	18.0	24.0	19.0	11.0	13.0	9.0	11.0	11.0	11.0
18-Jun	14.0	19.0	22.0	18.0	19.0	10.0	9.0	11.0	12.0	12.0
19-Jun	12.0	22.0	22.0	12.0	22.0	11.0	9.0	12.0	12.0	14.0
20-Jun	13.0	21.0	14.0	12.0	13.0	12.0	8.0	13.0	11.0	13.0
21-Jun	12.0	22.0	19.0	12.0	18.0	14.0	9.0	13.0	11.0	14.0
22-Jun	12.5	23.0	19.0	10.0	16.0	11.0	8.0	14.0	12.0	15.0
23-Jun	13.0	22.0	13.0	9.0	16.0	8.0	8.0	14.0	13.0	16.0
24-Jun	12.0	23.0	14.0	8.0	16.0	7.0	9.0	15.0	16.0	14.0
25-Jun	12.0	23.0	19.0	8.0	16.0	9.0	9.0	16.0	16.0	14.0
26-Jun	12.0	24.0	10.0	8.0	16.0	10.0	6.0	14.0	16.0	13.0
27-Jun	14.0	23.0	14.0	11.0	18.0	10.0	7.0	14.0	15.0	10.0
28-Jun	16.0	22.0	16.0	14.0	12.0	10.0	8.0	13.0	13.0	10.0
29-Jun	17.0	22.0	17.0	14.0	18.0	10.0	8.0	12.0	14.0	12.0
30-Jun	19.0	19.0	21.5	17.0	18.0	10.0	13.0	12.0	13.0	11.0
1-Jul	19.0	20.0	20.0	14.0	12.0	9.0	14.0	14.0	14.0	11.0
2-Jul	18.0	20.0	14.0	13.0	13.0	11.0	14.0	16.0	14.0	12.0
3-Jul	13.0	18.0	18.0	14.0	12.0	13.0	17.0	14.0	12.0	12.0
4-Jul	15.0	20.0	18.0	15.0	15.0	13.0	15.0	13.0	12.0	11.0
5-Jul	16.0	17.0	18.0	17.0	14.0	15.0	16.0	13.0	12.0	12.0
6-Jul	15.5	20.0	20.0	18.0	11.0	14.0	18.0	13.0	13.0	14.0
7-Jul	15.5	20.0	14.0	15.0	14.0	9.0	18.0	13.0	14.0	13.0
8-Jul	17.5	20.0	16.0	16.0	14.0	6.0	19.0	14.5	14.0	14.0
9-Jul	19.0	19.0	16.0	17.0	13.0	7.0	18.0	16.0	14.0	13.0
10-Jul	20.0	18.0	15.0	18.0	15.0	10.0	17.0	15.5	15.0	11.0
11-Jul	20.0	22.0	15.0	17.0	16.0	10.0	17.0	13.0	16.0	12.0
12-Jul	20.0	22.0	15.0	18.0	15.0	13.0	17.0	15.0	15.0	12.0
13-Jul	19.0	23.0	15.0	19.0	15.0	11.0	18.0	13.0	15.0	12.0
14-Jul	20.0	22.0	22.0	15.0	15.0	11.0	18.0	14.0	14.0	14.0
15-Jul	18.0	22.0	23.0	19.0	15.0	13.0	14.0	13.0	16.0	13.0

-continued-

Table 6.– Page 2 of 2.

Day	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
17-Jul	15.0	20.0	14.0	18.0	18.0	10.0	15.0	15.0	14.0	14.0
18-Jul	17.5	21.0	20.0	18.0	16.0	8.0	14.0	14.0	14.0	15.0
19-Jul	18.0	21.0	17.5	19.0	19.0	9.0	13.0	14.0	12.0	17.0
20-Jul	21.0	21.0	17.0	15.0	19.0	10.0	13.0	15.0	14.0	16.0
21-Jul	18.0	21.0	14.0	15.0	20.0	9.0	14.0	14.0	15.0	15.0
22-Jul	17.0	20.0	14.0	15.0	17.0	8.0	13.0	14.0	15.0	15.0
23-Jul	17.0	18.0	15.0	16.0	17.0	9.0	12.0	14.0	15.0	14.0
24-Jul	18.0	17.0	13.0	14.0	16.0	8.0	12.0	13.0	14.0	14.0
25-Jul	16.0	19.0	12.0	16.0	15.0	9.0	13.0	13.0	14.0	15.0
26-Jul	15.0	14.0	14.0	16.0	17.0	9.0	12.0	13.0	14.0	17.0
27-Jul	11.0	15.0	14.0	17.0	18.0	8.0	14.0	14.0	15.0	18.0
28-Jul	13.0	16.0	16.0	17.0	18.0	7.0	16.0	14.0	15.0	17.0
29-Jul	13.0	17.0	14.0	17.0	18.0	5.0	15.0	14.0	14.0	16.0
30-Jul	14.0	17.0	10.0	19.0	17.0	7.0	15.0	15.0	14.0	12.0
31-Jul	14.0	18.0	9.0	19.0	17.5	7.0	14.0	15.0	13.0	14.0
1-Aug	12.0	15.0	15.0	18.0	17.5	7.0	13.0	17.0	12.0	13.0
2-Aug	14.0	16.0	17.0	18.0	17.0	9.0	14.0	17.0	11.0	13.0
3-Aug	12.0	17.0	14.0	14.0	16.0	10.0	14.0	17.0	12.0	12.0
4-Aug	13.5	17.0	11.0	14.0	15.0	9.0	15.0	17.0	14.0	12.0
5-Aug	14.0	20.0	12.0	14.0	15.0	8.0	13.0	15.0	11.0	12.0
6-Aug	15.0	21.0	12.0	14.0	17.0	9.0	12.0	15.0	11.0	13.0
7-Aug	16.0	20.0	13.0	18.0	16.0	7.0	14.0	14.0	11.0	14.0
8-Aug	16.0	21.0	13.0	18.0	15.0	7.0	14.0	14.0	11.0	16.0
9-Aug	17.0	19.0	15.0	15.0	15.0	8.0	12.0	15.0	10.0	15.0
10-Aug	16.5	20.0	16.0	ND	ND	ND	ND	ND	ND	14.0

Table 7.–Percent of Gulkana River Chinook salmon run past the counting tower by 1 July and average maximum water temperature between 10 June and 30 June, 2002–2012, including the percent of return interpolated each year.

Year	Percent Return	Acsin ($\sqrt{\bar{Y}}$)	Average Max Temperature	Percent Return Interpolated
2002	49	ND	ND	6
2003	37	0.65	14.2	0
2004	82	1.13	18.1	0
2005	60	0.88	16.9	1
2006	28	0.56	13.4	15
2007	45	0.74	15.5	1
2008	30	0.58	10.4	26
2009	11	0.34	9.2	1
2010	26	0.54	12.4	6
2011	22	0.49	12.3	0
2012	18	0.44	11.6	6

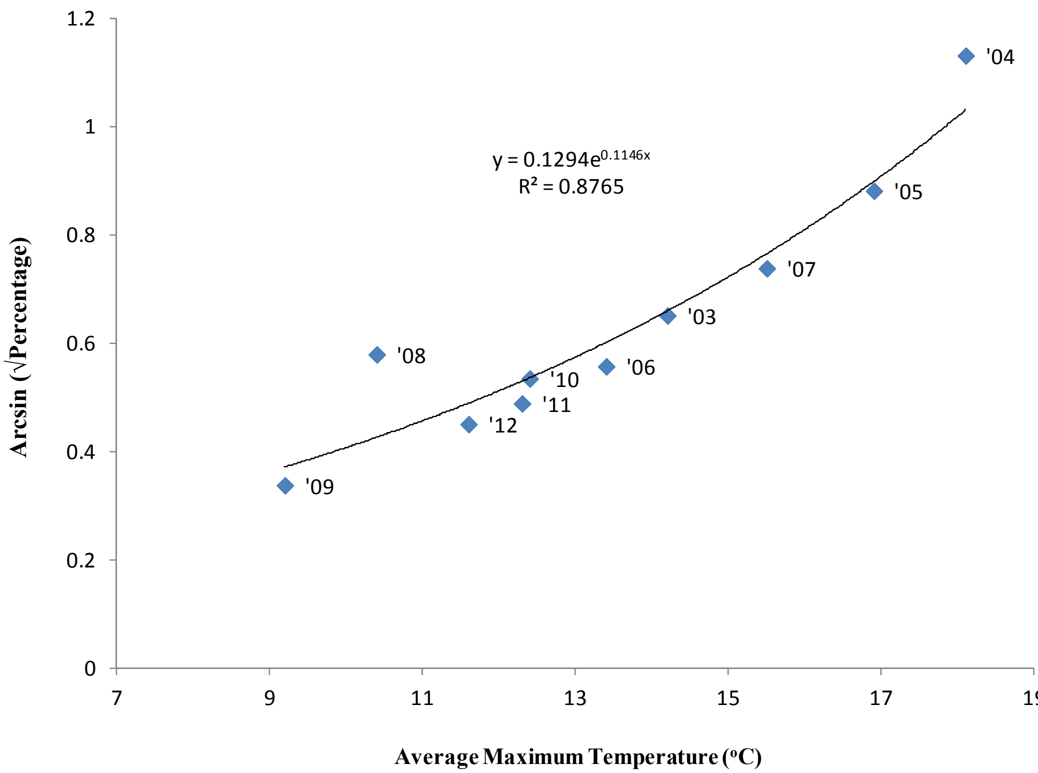

Figure 4.–June 10–30 average maximum water temperature and the arcsine transformed percentage of the Chinook salmon run on June 30 at the Gulkana River fish counting tower, 2003–2012. Note, the year 2008 had 20 days of very poor to no visibility resulting in interpolations for 25% of the return.

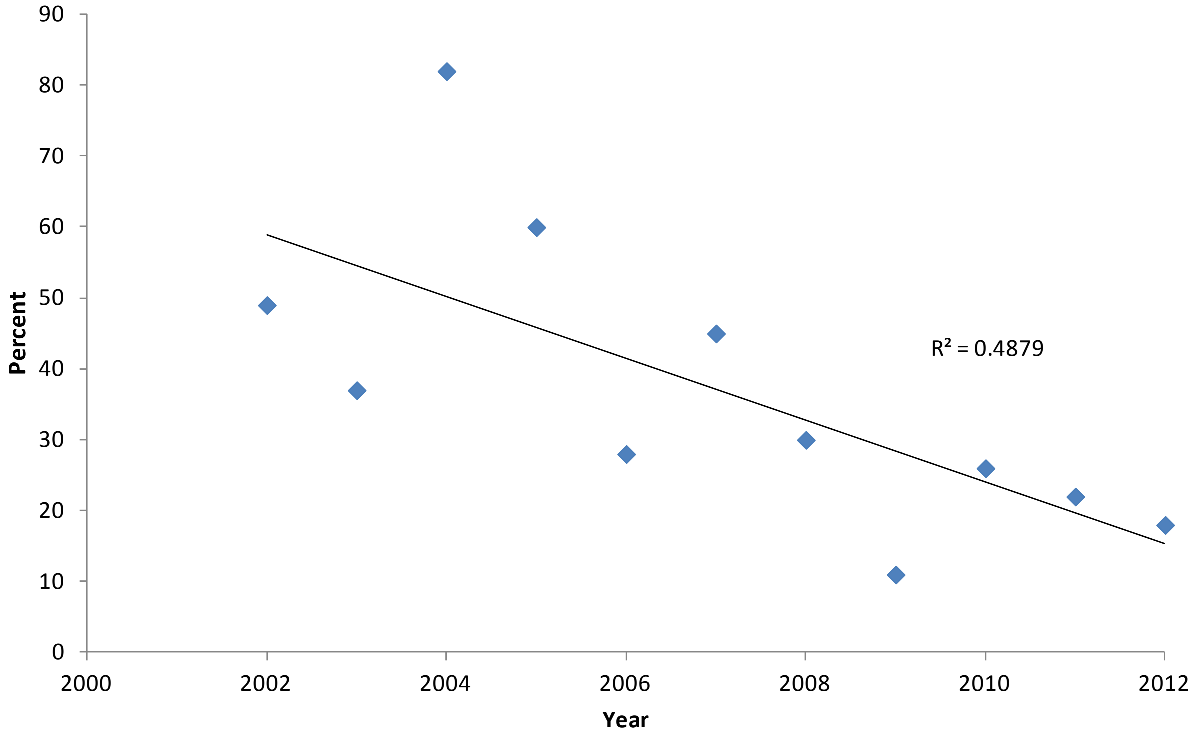

Figure 5.–Percent of Gulkana River Chinook salmon run past the counting tower by 1 July, 2002–2012.

Table 8.–Escapement, standard error (SE), aerial count, and proportion of escapement by survey date of Chinook salmon upstream of the tower in the Gulkana River, 2002–2012, excluding 2003 and 2008.

Year	Day/Month	Twr Esc	SE	Aerial Count	Proportion of Esc
2002	19-Jul	5448	340	2037	0.37
2004	24-Jul	4302	302	2014	0.47
2005	22-Jul	2370	174	804	0.34
2006	19-Jul	3808	279	1163	0.31
2007	21-Jul	3888	273	1131	0.29
2009	2-Aug	2696	179	623	0.23
2010	30-Jul	2117	130	716	0.34
2011	22-Jul	2604	228	493	0.19
2012	31-Jul	1646	154	445	0.27

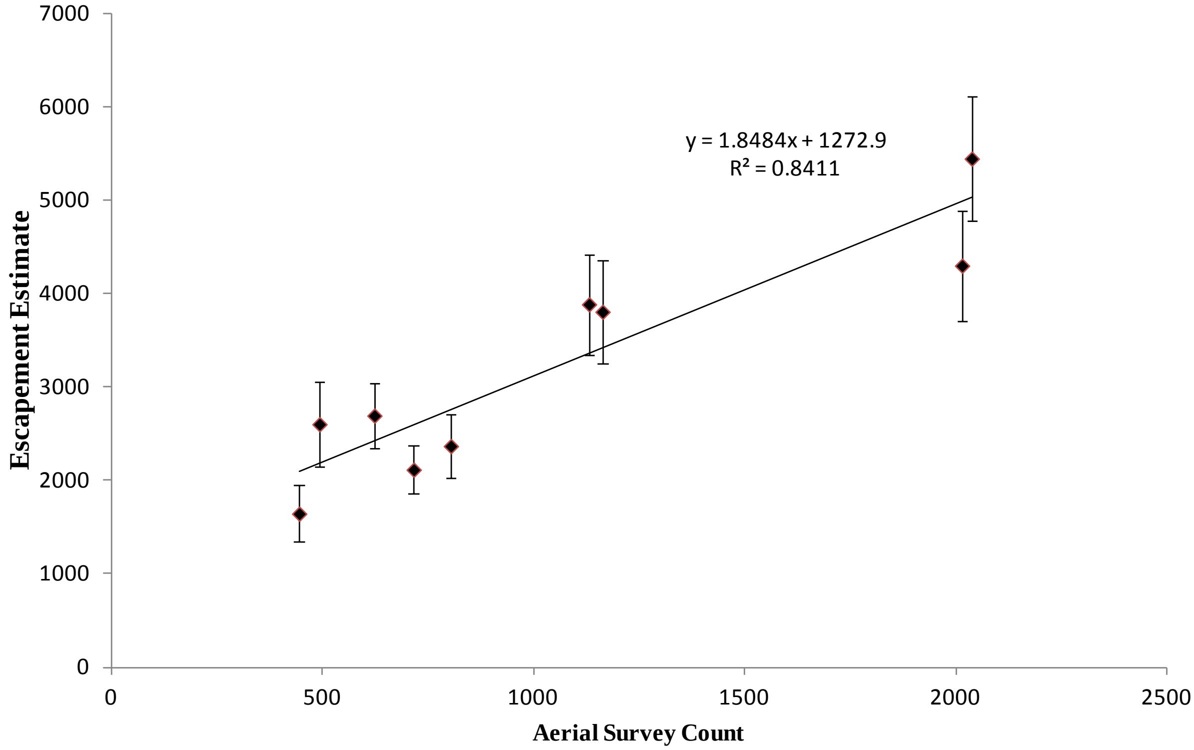

Figure 6.–Counting tower escapement estimates with 95% confidence intervals compared with aerial index counts for Gulkana River Chinook, 2002–2012 excluding 2003 and 2008.

Table 9.–Daily counts, expanded counts, and the cumulative estimated escapement of sockeye salmon at the Gulkana River tower, 2011.

	West Channel		East Channel		Combined		Total
Date	Daily	Expanded	Daily	Expanded	Daily	Expanded	Escapement
2-Jun	0	0	0	0	0	0	0
3-Jun	0	0	1	6	1	6	6
4-Jun	0	0	0	0	0	0	6
5-Jun	0	0	0	0	0	0	6
6-Jun	0	0	1	6	1	6	12
7-Jun	35	210	2	12	37	222	234
8-Jun	105	630	15	90	120	720	954
9-Jun	35	210	10	60	45	270	1,224
10-Jun	32	192	49	294	81	486	1,710
11-Jun	153	918	62	372	215	1,290	3,000
12-Jun	53	318	36	216	89	534	3,534
13-Jun	20	120	20	120	40	240	3,774
14-Jun	60	360	40	240	100	600	4,374
15-Jun	144	864	68	408	212	1,272	5,646
16-Jun	399	2,394	144	864	543	3,258	8,904
17-Jun	345	2,070	161	966	506	3,036	11,940
18-Jun	164	984	78	468	242	1,452	13,392
19-Jun	209	1,254	150	900	359	2,154	15,546
20-Jun	201	1,206	186	1,116	387	2,322	17,868
21-Jun	192	1,152	129	774	321	1,926	19,794
22-Jun	220	1,320	207	1,242	427	2,562	22,356
23-Jun	80	480	105	630	185	1,110	23,466
24-Jun	45	270	70	420	115	690	24,156
25-Jun	60	360	177	1,062	237	1,422	25,578
26-Jun	30	180	102	612	132	792	26,370
27-Jun	13	78	91	546	104	624	26,994
28-Jun	13	78	131	786	144	864	27,858
29-Jun	4	24	36	216	40	240	28,098
30-Jun	14	84	44	264	58	348	28,446
1-Jul	2	12	27	162	29	174	28,620
2-Jul	10	60	80	480	90	540	29,160
3-Jul	11	66	74	444	85	510	29,670
4-Jul	11	66	55	330	66	396	30,066
5-Jul	3	18	15	90	18	108	30,174
6-Jul	4	24	40	240	44	264	30,438
7-Jul	4	24	83	498	87	522	30,960
8-Jul	17	102	73	438	90	540	31,500

-continued-

Table 9.–Page 2 of 2.

Date	West Channel Daily	West Channel Expanded	East Channel Daily	East Channel Expanded	Combined Daily	Combined Expanded	Total Escapement
9-Jul	12	72	39	234	51	306	31,806
10-Jul	4	24	13	78	17	102	31,908
11-Jul	1	6	52	312	53	318	32,226
12-Jul	9	54	47	282	56	336	32,562
13-Jul	3	18	14	84	17	102	32,664
14-Jul	0	0	27	162	27	162	32,826
15-Jul	7	42	16	96	23	138	32,964
16-Jul	0	0	14	84	14	84	33,048
17-Jul	0	0	17	102	17	102	33,150
18-Jul	16	96	53	318	69	414	33,564
19-Jul	2	12	34	204	36	216	33,780
20-Jul	8	48	2	12	10	60	33,840
21-Jul	26	156	26	156	52	312	34,152
22-Jul	3	18	40	240	43	258	34,410
23-Jul	1	6	20	120	21	126	34,536
24-Jul	18	108	51	306	69	414	34,950
25-Jul	5	30	20	120	25	150	35,100
26-Jul	1	6	9	54	10	60	35,160
27-Jul	4	24	21	126	25	150	35,310
28-Jul	8	48	41	246	49	294	35,604
29-Jul	11	66	31	186	42	252	35,856
30-Jul	3	18	11	66	14	84	35,940
31-Jul	9	54	21	126	30	180	36,120
1-Aug	24	144	18	108	42	252	36,372
2-Aug	13	78	11	66	24	144	36,516
3-Aug	17	102	21	126	38	228	36,744
4-Aug	5	30	27	162	32	192	36,936
5-Aug	15	90	31	186	46	276	37,212
6-Aug	0	0	17	102	17	102	37,314
7-Aug	3	18	13	78	16	96	37,410
8-Aug	4	24	27	162	31	186	37,596
9-Aug	3	18	19	114	22	132	37,728
10-Aug	12	72	41	246	53	318	38,046

Table 10.–Daily counts, expanded counts, interpolations, and the cumulative estimated escapement of sockeye salmon at the Gulkana River tower, 2012. Shading identifies days with counts that included interpolation.

	West Channel			East Channel			Combined			Cumulative
Date	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Escapement
6-Jun	0	0	0	3	18	18	3	18	18	18
7-Jun	0	0	0	6	36	36	6	36	36	54
8-Jun	1	6	6	1	6	6	2	12	12	66
9-Jun	7	42	42	4	24	24	11	66	66	132
10-Jun	3	18	18	3	18	18	6	36	36	168
11-Jun	6	36	36	3	18	18	9	54	54	222
12-Jun	0	0	0	2	12	12	2	12	12	234
13-Jun	0	0	25	0	0	57	0	0	87	321
14-Jun	0	0	67	0	0	117	0	0	170	491
15-Jun	0	0	105	0	0	194	0	0	278	769
16-Jun	0	0	205	0	0	235	0	0	468	1,237
17-Jun	0	0	346	0	0	293	0	0	654	1,891
18-Jun	0	0	684	0	0	301	0	0	1,059	2,950
19-Jun	12	72	72	0	0	321	33	198	393	3,343
20-Jun	49	294	294	54	324	324	103	618	618	3,961
21-Jun	45	270	270	83	498	498	128	768	768	4,729
22-Jun	124	744	744	108	648	648	232	1,392	1,392	6,121
23-Jun	168	1,008	1,008	56	336	336	224	1,344	1,344	7,465
24-Jun	400	2,400	2,400	81	486	486	481	2,886	2,886	10,351
25-Jun	47	282	282	14	84	84	61	366	366	10,717
26-Jun	34	204	204	30	180	180	64	384	384	11,101
27-Jun	31	186	186	9	54	54	40	240	240	11,341
28-Jun	29	174	174	0	0	0	29	174	174	11,515
29-Jun	55	330	330	50	300	300	105	630	630	12,145
30-Jun	109	654	654	141	846	846	250	1,500	1,500	13,645
1-Jul	62	372	372	55	330	330	117	702	702	14,347
2-Jul	67	402	402	60	360	360	127	762	762	15,109
3-Jul	67	402	402	77	462	462	144	864	864	15,973
4-Jul	18	108	108	15	90	90	33	198	198	16,171
5-Jul	27	162	162	16	96	96	43	258	258	16,429
6-Jul	47	282	282	40	240	240	87	522	522	16,951
7-Jul	91	546	546	39	234	234	130	780	780	17,731
8-Jul	77	462	462	48	288	288	125	750	750	18,481
9-Jul	54	324	324	9	54	54	63	378	378	18,859
10-Jul	46	276	276	21	126	126	67	402	402	19,261
11-Jul	33	198	198	7	42	42	40	240	240	19,501
12-Jul	20	120	120	12	72	72	32	192	192	19,693
13-Jul	26	156	156	16	96	96	42	252	252	19,945
14-Jul	40	240	240	10	60	60	50	300	300	20,245
15-Jul	74	444	444	19	114	114	93	558	558	20,803
16-Jul	41	246	246	12	72	72	53	318	318	21,121
17-Jul	45	270	270	13	78	78	58	348	348	21,469
18-Jul	105	630	630	29	174	174	134	804	804	22,273

-continued-

Table 10.–Page 2 of 2.

	West Channel			East Channel			Combined			Cumulative
Date	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Daily	Expanded	Interpolated	Escapement
19-Jul	158	948	948	31	186	186	189	1,134	1,134	23,407
20-Jul	175	1,050	1,050	60	360	360	235	1,410	1,410	24,817
21-Jul	144	864	864	36	216	216	180	1,080	1,080	25,897
22-Jul	83	498	498	30	180	180	113	678	678	26,575
23-Jul	155	930	930	37	222	222	192	1,152	1,152	27,727
24-Jul	72	432	432	13	78	78	85	510	510	28,237
25-Jul	147	882	882	27	162	162	174	1,044	1,044	29,281
26-Jul	467	2,802	2,802	212	1,272	1,272	679	4,074	4,074	33,355
27-Jul	195	1,170	1,170	181	1,086	1,086	376	2,256	2,256	35,611
28-Jul	94	564	564	129	774	774	223	1,338	1,338	36,949
29-Jul	161	966	966	20	120	120	181	1,086	1,086	38,035
30-Jul	27	162	162	2	12	12	29	174	174	38,209
31-Jul	21	126	126	3	18	18	24	144	144	38,353
1-Aug	42	252	252	-2	-12	-12	40	240	240	38,593
2-Aug	53	318	318	-1	-6	-6	52	312	312	38,905
3-Aug	49	294	294	3	18	18	52	312	312	39,217
4-Aug	75	450	450	7	42	42	82	492	492	39,709
5-Aug	20	120	120	0	0	0	20	120	120	39,829
6-Aug	41	246	246	4	24	24	45	270	270	40,099
7-Aug	55	330	330	2	12	12	57	342	342	40,441
8-Aug	92	552	552	3	18	18	95	570	570	41,011
9-Aug	134	804	804	3	18	18	137	822	822	41,833
10-Aug	20	120	120	0	0	0	20	120	120	41,953

when average maximum water temperatures are considered warm (16°–18°C) versus a smaller proportion when the water temperatures are considered cool (9°–14°C). This could be an expected behavioral response of an ectothermic organism such as salmon. In which water temperature can greatly affect metabolic rate, maturation and activity that influences their migration timing past the counting tower.

Not surprisingly, salmon adapt their migration patterns to minimize energy expenditure. For example, adult salmon swim along shore to avoid stronger currents and select water depths that maximize swimming efficiency during their upstream migration (Brett 1995; Hinch and Rand 2000; Hughes 2004). Therefore, one would expect a similar behavioral response in salmon to temperature; especially, in a river like the Gulkana where Chinook salmon may be residing for a month or more before spawning.

Brett (1995) determined that metabolic energy demand of salmon increases as the water temperature increases above an optimum around 15°C. Temperatures greater than 15°C can also increase susceptibility to disease (Kocan et al. 2003), increase prespawning mortality (Keefer et al. 2010) and decrease gamete quality and viability during migration (Beacham and Murray, 1990). Migration delays and blockages occur consistently in the temperature range of 19°–23°C (McCullough et al. 2001; Goniea et al. 2006).

Drought conditions existed during 2004 and a significantly smaller proportion (50%) of radiotagged spawners was recorded upstream of the tower compared to 81% in 2002 and 86% in 2003 (Savereide 2005). Although low water is a likely reason for the smaller proportion of spawners above the tower, high water temperatures were also prevalent. During 2004, water temperatures exceeded 19°C for 33 days during the spawning migration and were consistently the highest recorded among the past ten years, peaking at 24°C. Despite the warm water temperatures experienced during 2004, over 700 Chinook salmon continued to migrate upstream of the tower after 1 July.

It's plausible that Chinook salmon are moving upstream in response to the elevated water temperatures to seek an optimal temperature. For example, adult Chinook salmon in the Columbia River were found holding near cool water tributaries during their upstream migration in response to high water temperatures (Goniea et al. 2006). However, there are no substantial tributaries on the lower 68 river kilometers of the Gulkana River, downstream of the West Fork. The Middle Fork Gulkana River was found to be 2°C cooler on average during the month of July 2011 compared to the mainstem Gulkana River at the fish counting tower (ADF&G, unpublished data). This difference in water temperature may be more pronounce during warm years, in particular in the lower reaches of the Gulkana River, and warrants a drainage wide temperature investigation.

Quinn and Adams (1996) found a trend in the median passage date of adult sockeye salmon at Bonneville Dam, Columbia River, with the first day of the year when the river warmed to 15.5°C. Similar analyses showed shifts in earlier migration timing of steelhead over the past decades (Robards and Quinn 2002). In contrast, the Gulkana River has not been modified by the construction of storage dams and the Chinook salmon run timing at the tower has been trending later in recent years and experiencing cooler temperatures.

It is essential to identify environmental conditions that influence timing to implement effective management measures because management of fisheries for anadromous species is based on expected time of arrival in harvest areas (Mundy 1982; Quinn and Adams 1996; Cooke et al. 2004; Keefer et al. 2010; Anderson and Beer 2009). A delay in the arrival of migrating Yukon River Chinook salmon was found to coincide with cold spring temperatures, shorten the time interval of migrations, and reduce the effect of daily environmental changes on migratory behavior. Whereas, warm springs portended an early arrival and an extended migration. Recent investigations by Mundy and Evenson (2011) combined sea surface and air temperatures to explain 59% of the annual variation in migratory timing of Chinook salmon at the mouth of the Yukon River.

Results here indicate 88% of the variation in run timing prior to 1 July can be explained by average maximum water temperature. The current results also suggest actively migrating Chinook salmon are selecting for optimal temperatures. Additional years of data should test the integrity of the relationship between average maximum water temperature and run timing. Additional years of data will also clarify the type of relationship (e.g., polynomial or exponential). This relationship may aid managers when making inseason decisions about the Gulkana River Chinook salmon sport fishery.

Aerial surveys during peak spawning in late July are good indices of the magnitude of escapement in the Gulkana River. On average one third of the Chinook salmon are counted during aerial surveys. Additional years of data should test the integrity of the relationship between aerial counts and escapement of Chinook salmon upstream of the tower. In particular, years with high escapement, such as 1996 when 11,684 Chinook salmon were counted through a weir on the Gulkana River near Sourdough (LaFlamme 1997).

To establish a Chinook salmon escapement goal for the Gulkana River a long time series of escapement, total run, and age composition estimates are required. Estimates of escapement are available from 2002–2011; however, Copper River Chinook salmon range from age 1.1 to age 1.6 and 10 years of escapement information is only equivalent to five complete brood year returns. Stock specific estimates of harvest in the mixed stock commercial, PU, or subsistence fisheries are required to estimate the total run. Currently, there are no such estimates but a recent genetic study has provided the means to derive these estimates (Seeb et. al 2009). These methods will be used to obtain stock-specific estimates of the harvest and age composition. Age composition estimates of the escapement are not available, but they can be inferred from previous age composition estimates of the sport fishery.

CONCLUSION

Even though all of the information needed to establish an escapement goal is limited at this time, an escapement goal analysis should be conducted and enumeration of Chinook salmon migrating upstream of the counting tower should continue.

In the absence of an escapement goal, another objective of area sport fish management is to establish an inseason guideline to use for making a determination as to whether a management action (e.g., close the fishery) is needed to address low numbers of Chinook salmon. Continued estimates of escapement and run timing may indicate a number and corresponding date that could be used as a guideline. For example, the water temperature in June may prove to be a predictor of run timing and escapement.

ACKNOWLEDGMENTS

Partial funding for this project was provided by the Bureau of Land Management. The author would like to thank the ADF&G field crew: Mark Schlenker, Ben Tyler, Mark Roti, and Dustin Canniff. Thanks also go to BLM, for their assistance with project logistics, student technicians and volunteer: Ellie Bowman, Eli Morse, and Willow Schlenker. The author is grateful for the support and lease of the cabin from Bruce and Ian Griggs. Jiaqi Huang completed the biometric review and Rachael Kvapil finalized the report for publication.

REFERENCES CITED

Anderson, J. J., and W. N. Beer. 2009. Oceanic, riverine, and genetic influences on spring Chinook salmon migration timing. Ecological Applications, 19: 1989–2003.

Beacham, T. D., and C. B. Murray. 1990. Temperature, egg size, and development of embryos and alevins of five species of Pacific Salmon; a comparative analysis. Trans. Am. Fish. Soc. 119: 927-945.

Botz, J., and M. A. Somerville. 2011. Management of salmon stocks in the Copper River, Report to the Alaska Board of Fisheries: December 2-7, 2011, Valdez, Alaska. Alaska Department of Fish and Game, Special Publication No. 11-13, Anchorage.

Brett, J. R. 1995. Energetics in Physiological ecology of Pacific salmon. Edited by C. Groot, L. Margolis, and W.C. Clarke. University of British Columbia Press, Vancouver. pp. 3–68.

Cochran, W. G. 1977. Sampling Techniques. 3rd edition, John Wiley, New York.

Cooke, S. J., S. G. Hinch, A. P. Farrell, M. F. Lapointe, S. R. M. Jones, J. S. Macdonald, D. A. Patterson, et al. 2004. Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, BC. Fisheries, 29: 22–33.

Goniea, T., M. L. Keefer, T. C. Bjornn, C. A. Peery, and D. H. Bennett. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Trans. Am. Fish. Soc. 135: 408-419.

Hinch, S. G., and P. S. Rand. 2000. Optimal swimming speeds and forward-assisted propulsion: energy-conserving behaviours of upriver-migrating adult salmon. Can. J. Fish. Aquat. Sci. 57: 2470–2478.

Hughes, N. F., 2004. The wave-drag hypothesis: An explanation for size-biased lateral segregation during the upstream migration of salmonids. Can. J. Fish. Aquat. Sci. 61: 103–109.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2005. Alaska Department of Fish and Game, Fishery Data Series No. 09-47 Anchorage.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009b. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2006. Alaska Department of Fish and Game, Fishery Data Series No. 09-54, Anchorage.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2010. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2007. Alaska Department of Fish and Game, Fishery Data Series No. 10-02, Anchorage.

Keefer, M. L., G. A. Taylor, D. F. Garletts, G. A. Gauthier, T. M. Pierce, and C. C. Caudill, 2010. Prespawn mortality in adult spring Chinook salmon outplanted abouve barrier dams. Ecology of Freshwater Fish, 19:361-372. John Wiley & Sons.

Kocan, R., P. Hershberger, and J. Winton. 2003. Effects of *Ichthyophonus* on Survival and Reproductive Success of Yukon River Chinook Salmon. Federal Subsistence Fisheries Resource Monitoring Program, Final Project Report No. FIS 01-200. U. S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Information Services Division, Anchorage.

LaFlamme, T. R. 1997. Creel and escapement estimates for Chinook salmon on the Gulkana River, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-12, Anchorage.

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Summary of technical literature examining the physiological effects of temperature on salmonids. U.S. Environmental Protection Agency, Report EPA-910-D-01-005, Seattle.

Mills, M. J. 1979. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1978-1979, Project F-9-11, 20 (SW-I-A), Juneau.

Mundy, P. R. 1982. Computation of migratory timing statistics for adult chinook salmon in the Yukon River, Alaska, and their relevance to fisheries management. North American Journal of Fisheries Management, 4: 359–370.

REFERENCES CITED (Continued)

Mundy, P. R., and D. F. Evenson. 2011. Environmental controls of phenology of high-latitude Chinook salmon populations of the Yukon River, North America, with application to fishery management. ICES Journal of Marine Science, 68: 1155–1164.

Quinn, T. P., and D. J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology, 77: 1151–1162.

Robards, M. D., and T. P. Quinn. 2002. The migratory timing of adult summer-run steelhead trout (*Oncorhynchus mykiss*) in the Columbia River: Six decades of environmental change. Trans. Am. Fish. Soc. 131: 523-536.

Savereide, J. W. 2005. Inriver Abundance, Spawning Distribution and Run Timing of Copper River Chinook Salmon, 2002-2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-50, Anchorage.

Seeb, L. W., N. A. DeCovich, A. W. Barclay, C. T. Smith, and W. D. Templin. 2009. Timing and origin of Chinook salmon stocks in the Copper River and adjacent ocean fisheries using DNA markers. Alaska Department of Fish and Game, Fishery Data Series No. 09-58, Anchorage.

Somerville, M. A. 2011. Fishery management report for the recreational fisheries of the Upper Copper/Upper Susitna River management area, 2009. Alaska Department of Fish and Game, Fishery Management Report No. 11-38, Anchorage.

Taras, B. D., and D. R. Sarafin. 2005. Chinook salmon escapement in the Gulkana River, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 05-02, Anchorage.

Taube, T. T. 2002. Area management report for the recreational fisheries of the Upper Copper/Upper Susitna river management area, 2000-2001. Alaska Department of Fish and Game, Fishery Data Series No. 02-7, Anchorage.

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.