Fishery Manuscript No. 10-03

Optimal Production of Chinook Salmon from the Taku River through the 2001 Year Class

by

Scott A. McPherson,

Edgar L. Jones III,

Steve J. Fleischman,

and

Ian M. Boyce

May 2010

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

Measures (fisheries)

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

Mathematics, statistics

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

FISHERY MANUSCRIPT SERIES NO. 10–03

OPTIMAL PRODUCTION OF CHINOOK SALMON FROM THE TAKU RIVER THROUGH THE 2001 YEAR CLASS

by
Scott A. McPherson
Alaska Department of Fish and Game, Division of Sport Fish, Douglas

Edgar L. Jones III
Alaska Department of Fish and Game, Division of Sport Fish, Douglas

Steve J. Fleischman
Alaska Department of Fish and Game, Division of Sport Fish, Anchorage

and

Ian M. Boyce
Fisheries and Oceans Canada, Whitehorse, Yukon Territory, Canada

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

May 2010

This investigation was made possible, in part, by funding under the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K).

The Fishery Manuscript series was established in 1987 by the Division of Sport Fish for the publication of technically oriented results of several years' work undertaken on a project to address common objectives, provide an overview of work undertaken through multiple projects to address specific research or management goal(s), or new and/or highly technical methods, and became a joint divisional series in 2004 with the Division of Commercial Fisheries. Fishery Manuscripts are intended for fishery and other technical professionals. Fishery Manuscripts are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

Scott A. McPherson[a,]
Alaska Department of Fish and Game, Division of Sport Fish
802 3rd St., Douglas, AK 99824, P.O. Box 110024, Juneau, AK 99811, USA

Edgar L. Jones III
Alaska Department of Fish and Game, Division of Sport Fish
802 3rd St., Douglas, AK 99824, P.O. Box 110024, Juneau, AK 99811, USA

Steve J. Fleischman
Alaska Department of Fish and Game, Division of Sport Fish
333 Raspberry Road, Anchorage, AK 99518-1599, USA

and
Ian M. Boyce
Fisheries and Oceans Canada, Stock Assessment Division
Suite 100, 419 Range Road, Whitehorse, Yukon Territory, Canada Y1A 3V1

[a]*Author to whom all correspondence should be addressed: Scott.McPherson@alaska.gov*

This document should be cited as:
McPherson, S.A., E. L. Jones III, S. J. Fleischman, and I. M. Boyce. 2010. Optimal Production of Chinook Salmon from the Taku River Through the 2001 Year Class. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-03, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES ii

LIST OF FIGURES iii

LIST OF APPENDICES iv

ABSTRACT 1

INTRODUCTION 1

Sources of Available Data 5

- Spawning Abundance 5
- Smolt Abundance 7
- Marine Harvests 8
- Inriver Harvests 12
- Annual Run Statistics 12
- Production by Year Class 12
- Exploitation Rate 17

RESULTS AND DISCUSSION 17

Smolt Production 17

Stock-Recruit Analysis 21

Other Stock-Recruit Analyses 27

CONCLUSIONS 29

RECOMMENDATIONS 30

ACKNOWLEDGMENTS 31

REFERENCES CITED 32

APPENDIX A. EXPANSION FACTORS AFFECTING ESCAPEMENTS AND PARAMETER ESTIMATES FOR CHINOOK SALMON FROM THE TAKU RIVER 35

APPENDIX B. ESTIMATES OF RELATIVE AGE-SEX COMPOSITION OF SPAWNING CHINOOK SALMON 51

APPENDIX C. ESTIMATING NUMBERS OF SPAWNING CHINOOK SALMON BY AGE AND SEX 57

APPENDIX D. ESTIMATES OF AGE COMPOSITION OF HARVESTED CHINOOK SALMON 63

APPENDIX E. ESTIMATES OF SMOLT ABUNDANCE 71

APPENDIX F. AGE-STRUCTURED BAYESIAN STATISTICAL ANALYSIS OF TAKU RIVER CHINOOK SALMON STOCK-RECRUIT DATA 83

APPENDIX G. MANAGEMENT OF TAKU RIVER CHINOOK SALMON 93

APPENDIX H. SECTIONS OF THE 2009–2018 PACIFIC SALMON TREATY RELEVANT TO TAKU RIVER CHINOOK SALMON 97

LIST OF TABLES

Table **Page**

1. Combined peak counts from aerial surveys, estimated total spawning abundance with associated standard errors and approximate 95% confidence intervals (CIs) for large (≥660 mm MEF) Chinook salmon spawning in the Taku River from 1973 through 2007. 6
2. Estimated numbers of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1981 through 2007, using the expansion factor of 10.86 for survey counts. 8
3. Estimated numbers of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 5.20 for survey counts.. 9
4. Estimated abundance of females, smolts, subsequent production of large adults, and estimated mean fork length for smolts and return rates for 16 year classes of Chinook salmon in the Taku River. 10
5. Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in commercial and aboriginal gillnet fisheries in Taku Inlet and in Canada, in the recreational fishery near Juneau and in the commercial troll fishery in Southeast Alaska. 13
6. Estimated harvest, escapement (Esc), total run and harvest rate (HR) of Taku River Chinook salmon from 1973–2007, segregated by large and age-1.2 fish. 14
7. Estimated production by age and year class for Chinook salmon in the Taku River, adding escapements by age in Table 2 to harvests by age in Table 5, using the expansion factor of 10.86. 16
8. Estimated production by age and year class for Chinook salmon in the Taku River, adding escapements by age in Table 3 to harvests by age in Table 5, using the expansion factor of 5.20. 17
9. Estimated large spawning Chinook salmon, large spawning female Chinook salmon, production of large (age-1.3 to -1.5) Chinook salmon return rate and exploitation rate by year class for Chinook salmon in the Taku River, using statistics from Table 7. 18
10. Estimated large spawning Chinook salmon, large spawning female Chinook salmon, production of large (age-1.3 to -1.5) Chinook salmon, return rate and exploitation rate by year class for Chinook salmon in the Taku River, using statistics from Table 8. 19
11. Estimated parameters for two time series from the log-linear transform of Ricker's model on estimates of production and spawning abundance of Chinook salmon in the Taku River. 22

LIST OF FIGURES

Figure		Page
1.	Taku Inlet and Taku River drainage.	2
2.	Timing of substocks of Chinook salmon in the Taku River past Canyon Island, based on uniquely numbered tag recoveries from spawning grounds sampling.	4
3.	Length-frequency polygons of age groups of Chinook salmon sampled in fish wheels at Canyon Island on the Taku River in 1988. The dashed vertical line marks the boundary segregating "large" fish (≥660 mm MEF).	5
4.	The total peak aerial count of Chinook salmon seen in 5 tributaries compared to the mark–recapture estimate of large Chinook salmon spawning abundance in the Taku River.	7
5.	Estimated calendar year harvests, escapements, total runs and exploitation rates for large (solid lines) and age-1.2 (dashed lines) Chinook salmon from the Taku River.	15
6.	Number of Chinook salmon smolt produced per spawning female across a range of spawning abundance.	20
7.	Chinook salmon smolt fork length (mm) across a range of female spawning abundances.	20
8.	Chinook salmon marine survival across a range of smolt abundances.	20
9.	Estimated smolt production and 95% confidence intervals against the estimated abundance of large parents for the 1975, 1976, 1979, and 1991–2003 year classes. Also shown is the curve corresponding to least-squares fit of the Beverton-Holt model.	21
10.	Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1983–2001 against the estimated abundance of large spawning Chinook salmon (Table 9), along with curves corresponding to least-squares fit of the Ricker model and the replacement line.	23
11.	Estimated residuals of the log-transformed fit of the Ricker model to production of age-1.3 to -1.5 Chinook salmon in year classes 1983–2001 against the estimated abundance of large spawning Chinook salmon.	23
12.	ACF and PACF plots for stock-recruit data in Figure 10.	24
13.	Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1973–2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line.	25
14.	Estimated residuals of the log-transformed fit of the Ricker model to production of age-1.3 to -1.5 Chinook salmon in year classes 1973–2001 against the estimated abundance of large spawning Chinook salmon.	25
15.	ACF and PACF plots for stock-recruit data in Figure 13.	26
16.	Probability that a specified spawning abundance will result in sustained yield exceeding 70%, 80%, and 90% of maximum sustained yield, Taku River Chinook salmon (solid lines).	28

LIST OF APPENDICES

Appendix **Page**

A1. Expansion factors affecting escapements and parameter estimates for Chinook salmon from the Taku River. 36
B1. Estimates of relative age-sex composition of spawning Chinook salmon. 52
C1. Estimating numbers of spawning Chinook salmon by age and sex. 58
D1. Estimates of age composition of harvested Chinook salmon. 64
E1. Estimates of smolt abundance. 72
F1. Bayesian age-structured spawner recruit mode[1] and MCMC methods. 84
F2. WinBUGS code for Bayesian age-structured spawner-recruit analysis of Taku River Chinook salmon data, 1983–2007. Prior distributions are in italics; sampling distributions of the data are in bold. 87
F3. Data for Bayesian age-structured spawner-recruit analysis, Taku River Chinook salmon 1983-2007. 89
F4. Results of Bayesian age-structured spawner-recruit analysis, Taku River Chinook salmon, 1983–2001 brood years. 90
G1. Management of Taku River Chinook salmon. 94
H1. Sections of the 2009–2018 Pacific Salmon Treaty relevant to Taku River Chinook Salmon. 98

ABSTRACT

The biological escapement goal for Chinook salmon Oncorhynchus tshawytscha from the Taku River was investigated with information from a stock assessment program (1973–2007), and catch sampling programs of the Canadian inriver gillnet fishery, U.S. commercial gillnet fishery in Taku Inlet, and troll fishery in Southeast Alaska, and the U.S. recreational fishery near Juneau. Stock assessment was based on aerial surveys and mark–recapture experiments to estimate abundance of large (≥660 mm MEF, mostly age-1.3 and age-1.4 fish) salmon on the spawning grounds. Relative age composition was estimated from 1973 through 2007 at a carcass weir on the Nakina River, and during mark–recapture experiments (1989, 1990 and 1995–2007) on other tributaries. Additional mark–recapture experiments using coded wire tags provided estimates of harvest in fisheries and abundance of emigrating smolts. Spawning abundance that would produce maximum sustained yield (NMSY) was estimated at 25,075 large Chinook salmon using the traditional Ricker exponential stock-recruit model fit to the production data for the 1983–2001 year classes, and at 25,686 fit to production data from the 1973–2001 year classes. From simulations of the production data incorporating measurement error from a Bayesian age-structured Ricker analysis, we estimated a 90% confidence interval of 18,470 to 36,530 around the point estimate of 25,075 above. No autocorrelation among residuals was detected in fitting these data sets. For the 1983–2001 year classes, the estimated range that will produce, on average, 95% of N_{MSY} is 18,675 to 32,094 large spawners, and that which will produce 90% of N_{MSY} is 16,178 to 35,203 large spawners. Results were corroborated by the Bayesian Markov chain Monte Carlo analysis, a Beverton-Holt model fit to the smolt production data, a Parken habitat model utilizing watershed characteristics, and Ricker models that included smaller, age-1.2 fish. We recommend that the Alaska Department of Fish and Game and the Department of Fisheries and Oceans (Canada) adopt a biological escapement goal range of 19,000 to 36,000 fish, with a point goal of 25,500 large spawning Chinook salmon, for management purposes for this Chinook salmon stock, as estimated from mark–recapture methods. We also make recommendations regarding continuation or modification of several stock assessment components to manage this stock.

Key words: Chinook salmon, Oncorhynchus tshawytscha, Taku River, smolt abundance, spawning abundance, mark–recapture, age, sex and length composition, escapement goal, stock-recruit analysis, measurement error, Ricker, Beverton-Holt, Parken.

INTRODUCTION

The Taku River is a relatively large watershed of over 17,000 km^2 that originates in northern British Columbia and drains into Taku Inlet south of Juneau in Southeast Alaska (SEAK, Figure 1). An estimated 17,094 km^2 is accessible to anadromous salmon *Oncorhynchus* sp., or almost all of the drainage (Chuck Parken, DFO, Nanaimo, BC, personal communication). The 2 main arteries of the Taku River are the Nakina and Inklin rivers, with the Inklin draining a larger area and comprised of several large tributaries that produce salmon, including Chinook salmon O. *tshawytscha*. Most of the tributaries are clear or slightly occluded by glacial flour, especially in the lower Nakina, Sheslay and Kowatua tributaries.

Chinook salmon from the Taku River are a “spring run” of salmon with adults passing through SEAK from late April through early July on their way to spawn in Canada from late July to mid-September. Almost all juveniles rear for 1 year in the Taku River after emergence. Young leave freshwater as yearling, 2-year-old (age-1. in European aging notation) smolt (Kissner and Hubartt 1986). From CWT recoveries captured as immature fish in marine waters, juveniles initially spend time in Taku Inlet for weeks, followed by months of residence in inside coastal areas near Juneau and in Chatham and Icy straits (Orsi et al. 2005). At least a portion of the population overwinter in these waters. Sometime in the late fall or following summer after leaving Taku River, almost all of a given cohort have reached the outer coast and begin a northwesterly migration along the continental shelf. They spend the remainder of the ocean-rearing portion of their life cycle west and north of SEAK in the Gulf of Alaska and the Bering Sea. Mature adults migrate back through SEAK after 1 to 5 years at sea. Fish maturing at a younger age (age-1.1 and -1.2 fish) are almost exclusively males, while older fish (age-1.3, -1.4. and -1.5 fish) are, on average, about 50% females (Jones III et al. *In prep*;Pahlke 2008). Age-1.2, -1.3, and -1.4 fish dominate the annual spawning population, while age-1.5 fish are uncommon (<52%) and age-1.1 fish are usually not enumerated by stock assessment.

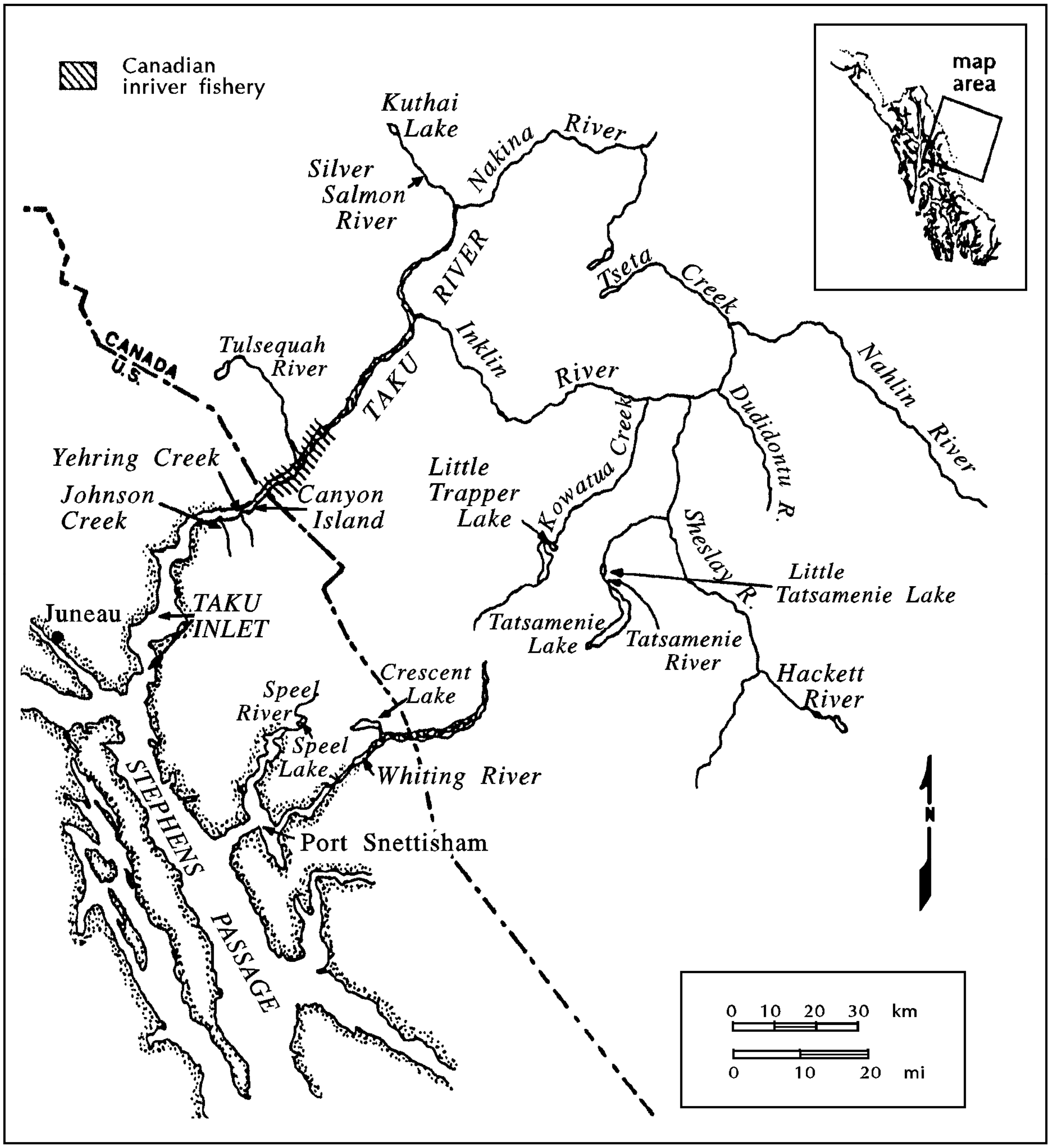


Figure 1.–Taku Inlet and Taku River drainage.

Most spawning occurs in upriver tributaries to the Taku River, which are not glacially influenced, such as the Nakina, Nahlin, Kowatua, Dudidontu, Tatsamenie, King Salmon, and Hackett rivers and Tseta Creek (Pahlke and Bernard 1996). The mainstem Taku River is turbid from late spring through late fall from silt flushed from glaciers in Alaska and British Columbia.

Taku River Chinook salmon have been harvested by aboriginal or native tribal groups from both Canada and Southeast Alaska for centuries, in both the mainstem and in tributaries such as the Nakina River. A commercial fishery for Chinook salmon has operated in Taku Inlet in U.S. waters since the late 1800s (Moser 1899). Recreational users have harvested this stock since the early 1900s.

In Alaskan waters, Chinook salmon from the Taku River have been important contributors to the recreational fishery and the commercial drift gillnet and troll fleets. Commercial harvests near the terminal area (troll and gillnet) in Taku Inlet averaged 10,000 to 15,000 Chinook salmon from 1900 through 1929 (Kissner 1982). Commercial gillnet harvests appear to have averaged 5,000 or fewer Chinook salmon since that time, except during the 1950s when harvests averaged about 14,000. These figures include harvests for the entire season and include harvests of other stocks. The Taku River Chinook salmon stock undoubtedly contributed substantial numbers to the spring troll fishery in SEAK since the early 1900s, but contribution rates are unknown prior to the late 1970s. Prior to 1976, annual commercial harvests of Chinook salmon from the Taku River were estimated to have reached approximately 15,000 or more, based on spring gillnet and troll harvests in or near Taku Inlet (Kissner 1976).

By the early 1970s, it was apparent that the Taku Chinook stock, like others in the region, were depleted from continued fishing at a time when survival of Chinook stocks over a broad area of the coast had declined, and regulatory changes were enacted. Beginning in 1976, commercial fishing for Chinook salmon in SEAK was reduced substantially in terminal areas as part of what subsequently became a coastwide, international rebuilding program under the Pacific Salmon Treaty (PST) signed in 1985. The spring troll fishery was closed in inside waters of SEAK in 1976, and in the same year, the regulatory opening date of the drift gillnet fishery in Taku Inlet was delayed until the third Sunday in June. The U.S. recreational fishery was closed around Taku Inlet in the spring from 1976–1988. An extensive regulatory history of management actions through 1998 for U.S. fisheries operating on Taku-bound Chinook salmon can be found in Appendix D in McPherson et al. (McPherson et al. 2000).

A very conservative management regime remained in place for 2 decades after the signing of the PST in 1985. In 2005, the U.S. and Canada reached agreement and implemented single-stock management on Taku River Chinook salmon under the Transboundary River portion of the 1999 PST (TTC 1999). This agreement covered the terminal run, and included the marine recreational fishery near Juneau and marine commercial drift gillnet and troll fisheries in Alaska District 111, as well as commercial gillnet, aboriginal and recreational harvests in Canada.

The management of Taku Chinook under the PST is for large Chinook (≥660 mm MEF). These fish are almost all age-1.3, -1.4 and -1.5 Chinook salmon and contain almost all female members of the population. This size corresponds closely with the legal size limit of 28 inches TL in the marine recreational and troll fisheries. Fish smaller than this size are taken in both gillnet fisheries and the aboriginal fishery and do not count against PST limits; these fish are generally harvested at rates less than those seen for large fish. The management approach is abundance-based in the spring before sockeye runs develop, when Chinook openings and liberalization of bag limits in the recreational fishery, if any, are determined by preseason and inseason abundance estimates. If forecasts are sufficiently high, directed fisheries will proceed (as in 2005 and 2006). Harvests are shared between the countries according to prescribed harvest-sharing agreements. The full PST language pertaining to management of Taku Chinook is found in Appendix G.

The transboundary annex of the PST does not cover marine recreational and commercial troll harvests of Taku-bound Chinook salmon outside of Alaskan District 111. The recreational harvests of the Taku River stock beyond District 111 occur from April to late June and are estimated to be less than 1,000 fish annually. The commercial troll fishery in SEAK harvests about 2,000 Chinook salmon bound for the Taku River annually outside of District 111, usually during openings in spring directed at Alaska hatchery fish.

Management of the resource is also aimed at spreading exploitation over the duration of the run. Regulatory schemes have been developed to determine the available surplus harvest and to structure openings to spread the harvest over the run segments. Canada has identified 3 run segments in the Wild Salmon Policy as the early, middle and late run components. The early run segment includes fish spawning in the Nahlin River and Tseta Creek, the middle includes the Nakina (historically the most numerous substock), and the late run, fish spawning in locations like the Tatsatua and Tatsamenie rivers (Figure 2). Other management considerations and the 2008 PST language pertaining to the Taku River are presented in Appendix G.

Attempts at establishing an escapement goal for the Taku River Chinook salmon stock go back to 1981 when the Alaska Department of Fish and Game (ADF&G) began an intensive rebuilding program for Chinook salmon in SEAK (ADF&G 1981). ADF&G set a survey count of 9,000 large spawning Chinook salmon in the Nakina River as the escapement goal, which was the previous high survey count in 1952. With the signing of the 1985 PST, a drainage-wide goal range of 25,600 (U.S.) to 30,000 (Canada) large spawning Chinook salmon was agreed to, because of differing opinions on a point estimate and an unknown expansion factor for survey counts. In 1991, the Transboundary Technical Committee (TTC) jointly agreed to an index survey goal of 13,200 large spawning Chinook salmon counted in the following 6 tributaries: Nahlin, Nakina, Dudidontu, Kowatua and Tatsamenie rivers, along with Tseta Creek (TTC 1991). None of these 3 previous escapement goals were based on analysis of production data because few were available, although the 1991 goal did incorporate spawning distribution determined from radio telemetry in 1990.

In 2000, the first stock-recruit analysis was used to recommend an escapement goal range of 30,000 to 55,000 large spawning Chinook salmon as measured by the annual mark–recapture program (McPherson et al. 2000). That goal was based on maximum production of smolt, which was the best available information at that time. It was adopted by Alaska and Canada and used to manage terminal fisheries through 2008.

The purpose of this analysis is to determine a biological escapement goal for the population of Chinook salmon from the Taku River based on the best available information. Ten years of stock assessment information have been added since the previous analysis was done.

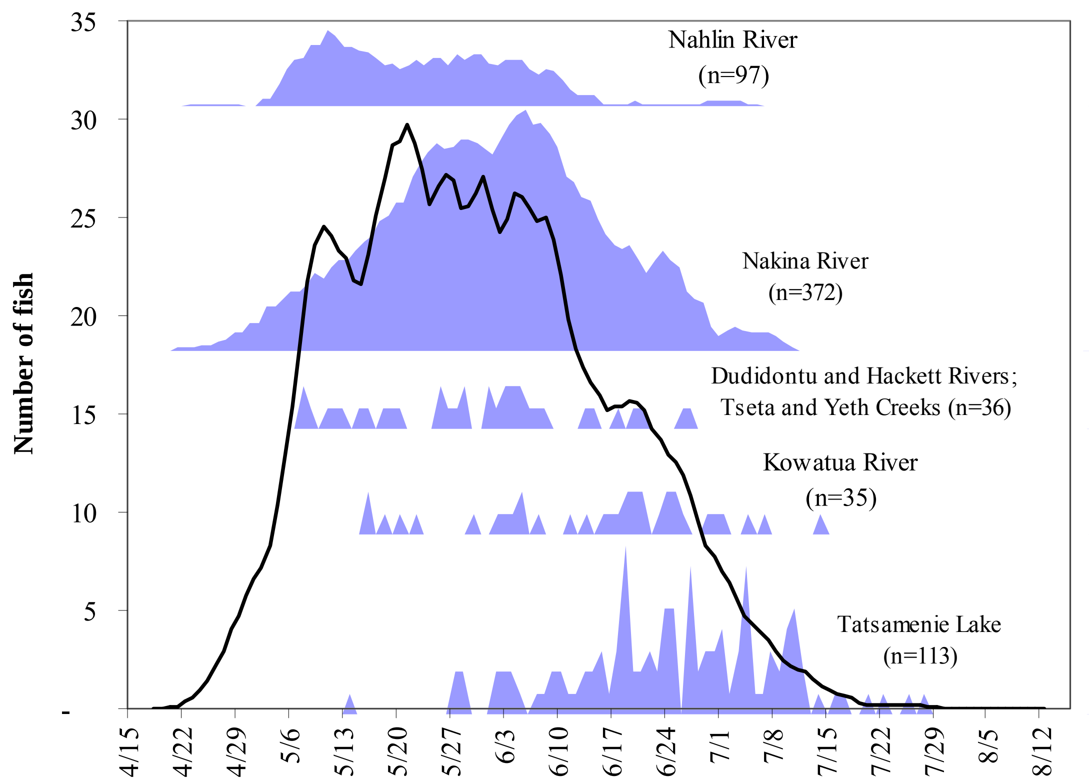


Figure 2.–Timing of substocks of Chinook salmon in the Taku River past Canyon Island, based on uniquely numbered tag recoveries from spawning grounds sampling.

A biological escapement goal range will be used to provide benchmarks for management of this population. We provide an overview of the stock assessment programs used to gain knowledge of population dynamics since 1973. Sources of information are cited and analyses described. Adjustments to annual estimates from stock assessment programs are described in appendices to focus attention on links between spawning abundance and subsequent production of smolts and adults.

SOURCES OF AVAILABLE DATA

Spawning Abundance

Since 1973, escapements to the Taku River have been assessed with aerial surveys from helicopters. Only "large" Chinook salmon, typically 3-ocean (age-1.3) and older (most ≥660 mm MEF), were counted annually by flying over stretches of the Nahlin, Nakina, Dudidontu, Kowatua, and Tatsamenie rivers, and beginning in 1981, Tseta Creek, according to fixed schedules and protocols (Pahlke 1998). Age-1.1 and age-1.2 salmon (1- and 2-ocean age) were not counted because Chinook salmon less than 660 mm MEF are difficult to distinguish from other species. Large Chinook salmon could be distinguished from smaller fish because there was little overlap in age and size distributions (Figure 3).

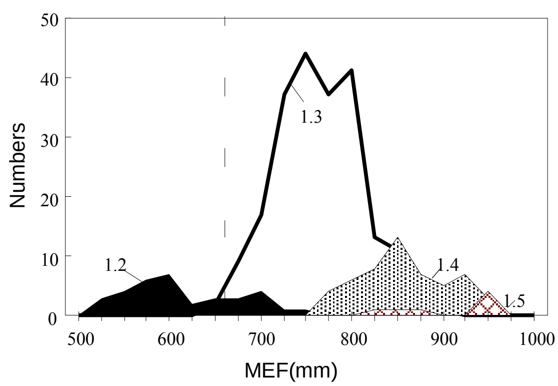


Figure 3.–Length-frequency polygons of age groups of Chinook salmon sampled in fish wheels at Canyon Island on the Taku River in 1988. The dashed vertical line marks the boundary segregating "large" fish (≥660 mm MEF).

Counts were highly correlated across 5 of the 6 tributaries in the previous stock-recruit analysis (McPherson et al. 2000), suggesting that the relative strength of year classes were similar throughout the Taku River. We found that the relationship among Taku River tributaries has changed since 2000 (see Appendix A for details), suggesting that spawning distribution may also have changed.

Abundance of large spawning Chinook salmon in the Taku River was directly estimated with mark–recapture experiments based on tagging and radio telemetry studies in 1989 and 1990 by the Commercial Fisheries Division (CFD) of ADF&G, the Department of Fisheries and Oceans Canada (DFO), and the U.S. National Marine Fisheries Service (NMFS) (Pahlke and Bernard 1996). Mark–recapture experiments have been conducted annually from 1995 to present; these have been cooperative efforts involving ADF&G, DFO, and the Taku River Tlingit First Nation (TRTFN), producing successful estimates of spawning abundance from 1995 through 1997 (McPherson et al. 1996-1998) and 1999–2007 (Boyce et al. 2006; Jones III et al. *In prep*). Adults were captured in fish wheels at Canyon Island (the first sampling event) and on the spawning grounds upriver in the Nakina, Nahlin, Tatsamenie, Kowatua and Dudidontu rivers and Tseta Creek (the second sampling event). Marked Chinook salmon subsequently captured in test, commercial or recreational fisheries were typically censored from the marked population, making the estimate germane to all Chinook salmon spawning in the Taku River. No spawning has been detected downstream or in the vicinity of Canyon Island (Eiler et al. *In prep*). Estimated abundance was stratified into 2 size/age groups, fish of age-1.2 and fish age-1.3 and older. Estimated abundance $\hat{N}_t$ for the latter group in year t is in Table 1. Direct abundance estimates of age-1.3 and older were closely related to aerial survey counts of large spawning Chinook salmon in 5 tributaries: Nahlin, Kowatua, Dudidontu, and Tatsamenie rivers plus Tseta Creek (Figure 4). We used this relationship to expand aerial survey counts in years without mark-recapture estimates (Appendix A). The mean expansion factor was $\overline{\pi} = 10.86$ (prediction error CV = 24.9%). We also ran comparative analyses using the expansion factor of 5.20 (prediction error CV = 38.2%) used in McPherson (2000). The resulting estimates of spawning escapement are listed in Table 1.

Table 1.–Combined peak counts from aerial surveys, estimated total spawning abundance $\hat{N}$ with associated standard errors and approximate 95% confidence intervals (CIs) for large (≥660 mm MEF) Chinook salmon spawning in the Taku River from 1973 through 2007. Statistics in bold face come directly from mark–recapture experiments.

Year	Counts[a]	$\hat{N}$	SE($\hat{N}$)	CV	Counts[b]	$\hat{N}$	SE($\hat{N}$)	CV
1973	2,800	14,564	5,565	38.2%				
1974	3,079	16,015	6,119	38.2%				
1975	2,484	12,920	4,937	38.2%				
1976	4,726	24,582	9,392	38.2%				
1977	5,671	29,497	11,270	38.2%				
1978	3,292	17,123	6,542	38.2%				
1979	4,156	21,617	8,259	38.2%				
1980	7,544	39,239	14,992	38.2%				
1981	9,528	49,559	18,935	38.2%	4,676	50,784	12,669	24.9%
1982	4,585	23,848	9,112	38.2%	2,280	24,762	6,177	24.9%
1983	1,883	9,794	3,742	38.2%	1,094	11,881	2,964	24.9%
1984	3,995	20,780	7,939	38.2%	2,284	24,805	6,188	24.9%
1985	6,905	35,916	13,722	38.2%	4,561	49,535	12,357	24.9%
1986	7,327	38,111	14,561	38.2%	3,652	39,663	9,895	24.9%
1987	5,563	28,935	11,055	38.2%	2,837	30,811	7,686	24.9%
1988	8,560	44,524	17,011	38.2%	4,126	44,810	11,179	24.9%
1989[c]	8,986	**40,329**	**5,646**	**14.0%**	4,339	**40,329**	**5,646**	**14.0%**
1990[c]	12,077	**52,142**	**9,326**	**17.9%**	4,332	**52,142**	**9,326**	**17.9%**
1991	9,929	51,645	19,732	38.2%	4,543	49,339	12,309	24.9%
1992	10,745	55,889	21,354	38.2%	5,308	57,647	14,381	24.9%
1993	12,713	66,125	25,265	38.2%	6,714	72,917	18,191	24.9%
1994	9,299	48,368	18,480	38.2%	5,121	55,617	13,875	24.9%
1995[d]	7,971	**33,805**	**5,060**	**15.0%**	4,814	**33,805**	**5,060**	**15.0%**
1996[e]	18,576	**79,019**	**9,048**	**11.5%**	12,057	**79,019**	**9,048**	**11.5%**
1997[f]	13,201	**114,938**	**17,888**	**15.6%**	7,754	**114,938**	**17,888**	**15.6%**
1998	5,969	31,039	11,862	38.2%	3,609	39,196	9,778	24.9%
1999[g]	3,951	**16,786**	**3,171**	**18.9%**	2,272	**16,786**	**3,171**	**18.9%**
2000[g]	5,772	**34,997**	**5,403**	**15.4%**	3,025	**34,997**	**5,403**	**15.4%**
2001[g]	5,040	**46,544**	**6,766**	**14.5%**	3,690	**46,544**	**6,766**	**14.5%**
2002[g]	8,089	**55,044**	**11,087**	**20.1%**	4,215	**55,044**	**11,087**	**20.1%**
2003[h]	5,481	**36,435**	**6,705**	**18.4%**	3,791	**36,435**	**6,705**	**18.4%**
2004[g]	9,138	**75,032**	**10,280**	**13.7%**	5,953	**75,032**	**10,280**	**13.7%**
2005[g]	3,981	**38,725**	**4,908**	**12.7%**	2,983	**38,725**	**4,908**	**12.7%**
2006[g]	5,338	**42,296**	**5,535**	**13.1%**	3,637	**42,296**	**5,535**	**13.1%**
2007[g]	NE	**14,854**	**3,277**	**22.1%**	NE	**14,854**	**3,277**	**22.1%**

[a] Counts from Nakina, Nahlin, Kowatua, Dudidontu and Tatsamenie rivers; expansion factor = 5.20.

[b] Counts from Nahlin, Kowatua, Dudidontu, and Tatsamenie rivers plus Tseta Creek; expansion factor = 10.86.

[c] Estimates from Pahlke and Bernard (1996).

[d] Estimates from McPherson et al. (1996).

[e] Estimates from McPherson et al. (1997).

[f] Estimates from McPherson et al. (1998).

[g] Estimates from Jones et al. (*In prep*).

[h] Estimates from Boyce et al. (2006).

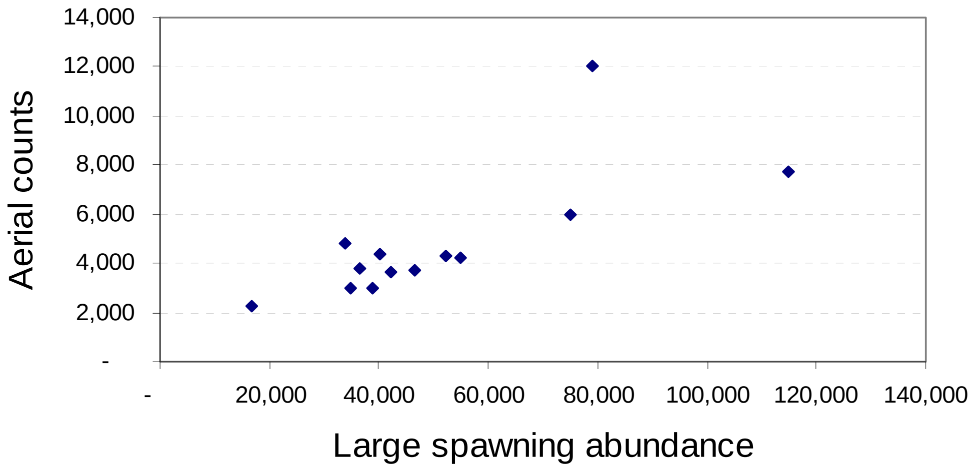


Figure 4.–The total peak aerial count of Chinook salmon seen in 5 tributaries compared to the mark–recapture estimate of large Chinook salmon spawning abundance in the Taku River. The tributaries include the Nahlin, Kowatua, Dudidontu, and Tatsamenie rivers plus Tseta Creek.

Age-sex composition of spawning Chinook salmon (for 1973–1988 and 1991–1994) was estimated from information gathered at a carcass weir on the Nakina River (1973–1997) and with a combination of carcass surveys, carcass weirs, and live weirs on the Nahlin, Kowatua, and Tatsamenie rivers (1989, 1990, 1995–1997). Mark–recapture experiments on the Taku River (Pahlke and Bernard. 1996; McPherson et al. 1996-98) indicated that samples taken from the latter set of 3 rivers were representative of all Chinook salmon spawning in the Taku River, while samples taken at the carcass weir on the Nakina River were skewed to males (over-representing age-.1 and -.2 jacks) and larger females in most years. Because a complete record is available only for the Nakina River, estimates of relative age and sex composition for that subpopulation were adjusted with information from the other tributaries to complete a set of estimates for 1973–1997 (Appendix B).

These adjusted estimates were combined to produce multipliers to transform estimated abundance for large fish into estimated abundance by age and sex. Estimated abundance in year *t* for age and sex group *a* and estimated variance was calculated as:

$$\hat{N}_{a,t} = \hat{N}_t \ \hat{p}_{a,t}$$

$$v(\hat{N}_{a,t}) = v(\hat{N}_t)\hat{p}_{a,t}^2 + v(\hat{p}_{a,t})\hat{N}_t^2 - v(\hat{N}_t)v(\hat{p}_{a,t}) \quad (1)$$

where estimated abundance $\hat{N}_t$ of large fish and estimated variance for year *t* were taken from Table 1 and $\hat{p}_{a,t}$ is the appropriate multiplier for age-sex group *a*. Calculations of the multipliers and their estimated variances are described in Appendix C.

Table 2 contains the adjusted estimates (1981–1988 and 1991–1994) and unbiased estimates of spawning abundance (1989–1990 and 1995–2007) by age for all adults and by sex for large Chinook salmon, using the non-Nakina 5-tributary expansion factor of 10.86. Table 3 contains the adjusted estimates (1973–1988 and 1991–1994) and unbiased estimates of spawning abundance (1989–1990 and 1995–2007) by age for all adults and by sex for large Chinook salmon using the non-Tseta 5-tributary expansion factor of 5.20 used in McPherson et al. (2000).

Smolt Abundance

Stock assessment included a tagging program to estimate smolt abundance. Smolts and/or fingerlings were implanted with coded wire tags (CWTs) from the 1975 through 1981 broods (year classes) and from the 1991 to 2003 broods. Note that smolts have been tagged for the 2004–2006 broods, but adults have yet to return to determine marked rates. Young fish were captured in the lower river near or downstream of the border with baited minnow traps (Kissner and Hubartt 1986) and in some later years with additional screw traps. The fraction of year class *y* tagged in year *y*+2 as smolts was estimated by summing data on adults of that year class sampled on the spawning grounds or caught at Canyon Island in years y+3, y+4, y+5, and/or y+6. Recovery of CWTs from adults on the spawning grounds showed that tagged smolts represented all subpopulations in the Taku River in near equal proportion (Appendix E). The estimated marked fraction of year class y and the number tagged in year y+2 were used to estimate the number of smolt emigrating that year per a simple, 2-event mark–recapture experiment on a closed population (Seber 1982: 60). Because too few smolt were recaptured later as adults for some year classes, estimates of smolt abundance are only available for the 1975, 1976, 1979, and 1991–2003 year classes. Table 4 is a compendium of smolt abundance estimates for these year classes, along with estimated abundance of the females that produced them and of the recruits of large adults (5- to 7-year old fish) they subsequently became.

Marine Harvests

The coded wire tagging program was also used to estimate likely harvests of Taku-origin Chinook salmon in the commercial gillnet fishery in Taku Inlet, in the recreational fishery near Juneau, and in the commercial troll fishery in SEAK. For year classes with tagged fish, CWTs recovered during catch sampling in the 3 fisheries were expanded for the fraction of the catch inspected and the estimated fraction of each year class marked asper procedures described in Bernard and Clark (1996).

Table 2.–Estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1981 through 2007, using the expansion factor of 10.86 for survey counts. Numbers by age are the product of the estimated abundance of large fish in Table 1 (EF=10.86) and the multipliers in Table C2 for years without mark–recapture estimates. Bold numbers came directly from mark–recapture experiments. Estimated SEs for these statistics are in Table C3.

Year	1.2	1.3	1.4	1.5	Large females	Large males
1981	15,982	28,828	21,955	0	25,642	25,141
1982	6,159	11,826	11,869	1,065	12,871	11,891
1983	5,545	7,200	4,495	188	4,998	6,883
1984	11,725	21,296	3,096	414	12,047	12,758
1985	17,823	35,473	13,877	185	24,063	25,472
1986	8,361	20,151	18,741	769	22,583	17,079
1987	8,215	21,144	8,829	839	13,424	17,387
1988	17,692	14,357	27,964	2,490	22,005	22,806
1989	**10,569**	**26,715**	**12,053**	**1,561**	**17,580**	**22,749**
1990	**7,095**	**20,848**	**30,124**	**1,171**	**26,749**	**25,394**
1991	20,738	23,014	21,986	4,339	26,210	23,129
1992	19,271	32,505	23,303	1,840	23,657	33,991
1993	12,369	38,147	32,819	1,951	33,055	39,862
1994	6,077	33,217	20,110	2,289	36,282	19,335
1995[a]	**30,884**	**14,606**	**19,950**	**612**	**19,705**	**14,100**
1996	**8,005**	**71,372**	**9,901**	**143**	**40,897**	**38,122**
1997	**2,652**	**43,757**	**71,071**	**0**	**70,691**	**44,247**
1998	**8,094**	11,101	26,617	980	21,732	17,577
1999	**10,394**	**11,668**	**3,246**	**203**	**6,948**	**9,838**
2000	**9,452**	**24,800**	**9,083**	**86**	**19,199**	**15,798**
2001	**5,075**	**36,504**	**9,760**	**25**	**23,110**	**23,434**
2002	**6,707**	**32,786**	**21,323**	**140**	**31,558**	**23,486**
2003	**16,357**	**22,799**	**12,951**	**106**	**19,089**	**17,346**
2004	**25,702**	**56,866**	**13,895**	**261**	**37,473**	**37,560**
2005	**6,574**	**27,570**	**9,459**	**47**	**19,257**	**19,198**
2006	**2,874**	**20,454**	**20,929**	**220**	**21,506**	**20,790**
2007	**6,949**	**8,556**	**5,776**	**201**	**6,290**	**8,564**

[a] Estimates of large fish from 1995 to 2007 include some age-1.2 fish.

Table 3.–Estimated numbers of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 5.20 for survey counts. Numbers by age are the product of the estimated abundance of large fish in Table 1 (EF=5.20) and the multipliers in Table C2 for years without mark–recapture estimates. Bold numbers came directly from mark–recapture experiments. Estimated SEs for these statistics are in Table C3.

Year	1.2	1.3	1.4	1.5	Large females	Large males
1973	8,553	7,966	6,427	172	8,929	5,635
1974	10,043	11,080	4,826	109	9,824	6,191
1975	25,074	7,998	4,800	122	4,593	8,327
1976	11,667	16,718	7,624	240	15,165	9,417
1977	4,678	12,716	16,091	689	20,466	9,031
1978	31,514	9,162	6,653	1,309	9,143	7,981
1979	28,620	18,790	2,530	297	10,997	10,620
1980	16,436	26,282	12,957	0	21,228	18,011
1981	15,597	28,133	21,426	0	25,024	24,535
1982	5,932	11,390	11,431	1,026	12,396	11,452
1983	4,571	5,935	3,705	155	4,120	5,674
1984	9,821	17,838	2,593	347	10,091	10,687
1985	12,923	25,720	10,062	134	17,447	18,469
1986	8,034	19,363	18,008	739	21,700	16,411
1987	7,715	19,856	8,291	788	12,607	16,328
1988	17,579	14,265	27,785	2,474	21,864	22,660
1989	**10,569**	**26,715**	**12,053**	**1,561**	**17,580**	**22,749**
1990	**7,095**	**20,848**	**30,124**	**1,171**	**26,749**	**25,394**
1991	21,707	24,090	23,013	4,542	27,435	24,210
1992	18,683	31,513	22,592	1,784	22,935	32,954
1993	11,217	34,594	29,762	1,769	29,976	36,149
1994	5,285	28,888	17,489	1,991	31,553	16,815
1995	**30,884**	**14,600**	**19,950**	**612**	**19,705**	**14,100**
1996	**8,005**	**71,372**	**9,901**	**143**	**40,897**	**38,122**
1997	**2,652**	**43,757**	**71,071**	**0**	**70,691**	**44,247**
1998	**8,094**	8,791	21,078	776	17,210	13,919
1999	**10,394**	**11,668**	**3,246**	**203**	**6,948**	**9,838**
2000	**9,452**	**24,800**	**9,083**	**86**	**19,199**	**15,798**
2001	**5,075**	**36,504**	**9,760**	**25**	**23,110**	**23,434**
2002	**6,707**	**32,786**	**21,323**	**140**	**31,558**	**23,486**
2003	**16,357**	**22,799**	**12,951**	**106**	**19,089**	**17,346**
2004	**25,702**	**56,866**	**13,895**	**261**	**37,473**	**37,560**
2005	**6,574**	**27,570**	**9,459**	**47**	**19,257**	**19,198**
2006	**2,874**	**20,454**	**20,929**	**220**	**21,506**	**20,790**
2007	**6,949**	**8,556**	**5,776**	**201**	**6,290**	**8,564**

Table 4.–Estimated abundance of females, smolts, subsequent production of large adults, and estimated mean fork length for smolts and return rates for 16 year classes of Chinook salmon in the Taku River. Standard errors for ratios (in parentheses) were approximated with the delta method (Seber 1982:7-9).

Year Class	Females		Smolts		Mean smolt FL (mm)	Smolts per female		Recruits of large adults		Adults per female	
1975	4,593	(1,959)	1,189,118	(174,197)	79	258.9	(117)	55,557	(13,665)	0.047	(0.0134)
1976	15,165	(6,002)	1,549,052	(374,227)	71	102.1	(47)	48,134	(12,337)	0.031	(0.0109)
1979	10,997	(4,586)	661,150	(97,648)	74	60.1	(27)	34,531	(8,155)	0.052	(0.0145)
1991	26,210	(7,280)	2,098,862	(295,390)	80	80.1	(25)	161,498	(13,618)	0.077	(0.0126)
1992	23,657	(7,172)	1,968,167	(438,569)	73	83.2	(31)	76,549	(9,418)	0.039	(0.0099)
1993	33,055	(10,036)	1,112,199	(391,128)	78	33.6	(16)	17,503	(2,969)	0.016	(0.0061)
1994	36,282	(10,001)	1,433,926	(251,389)	76	39.5	(130	25,938	(2,718)	0.018	(0.0037)
1995	19,705	(2,891)	1,242,135	(121,538)	76	63.0	(11)	39,208	(4,025)	0.032	(0.0045)
1996	40,897	(4,595)	1,917,024	(190,730)	71	46.9	(7)	66,971	(6,749)	0.035	(0.0049)
1997	70,691	(11,039)	1,923,651	(302,306)	75	27.2	(6)	55,050	(7,000)	0.029	(0.0058)
1998	21,732	(5,474)	1,194,260	(145,660)	79	55.0	(15)	43,785	(4,511)	0.037	(0.0059)
1999	6,948	(1,386)	1,738,624	(124,324)	75	250.2	(53)	84,703	(7,545)	0.049	(0.0056)
2000	19,199	(3,025)	1,984,004	(189,699)	71	103.3	(19)	82,253	(4,411)	0.041	(0.0045)
2001	23,110	(3,402)	2,116,807	(360,408)	73	91.6	(21)	39,049	(3,083)	0.018	(0.0035)
2002	31,558	(8,395)	1,462,461	(296,011)	75	46.3	(15)				
2003	19,089	(3,546)	1,043,352	(214,599)	75	54.7	(15)				

These CWT expansions showed that of the mature, age-1. wild Chinook salmon caught before 9 July in the commercial gillnet harvest, Chinook salmon bound for the Taku River represented, on average, most of the harvest. We estimated harvests of Taku-origin Chinook salmon in the commercial gillnet fishery by assuming that all age-1. fish caught during the first 3 or 4 weeks were Taku-origin (ADFG statistical weeks 25-28), except we subtracted CWT contributions of Alaska hatchery origin. This includes harvests from the third Sunday in June (average start date is 19 June) although, on average, 9 July. The gillnet harvest during these weeks averaged 2,381 Taku-origin Chinook salmon from 1977–2007, which represents about 67% of the season total in this fishery. Although some Taku-origin Chinook salmon are undoubtedly caught later than this in some years as evidenced by CWT recoveries, some harvest of other age-1. stocks is also included in our estimates and we expect these differences to be approximately equal and cancel out.

Estimated marine gillnet harvests were apportioned among year classes according to estimated relative age composition of the catches (Appendix D). Age samples collected from the gillnet fishery from 1973–1976, 1982–1992 and 1995–2007 were used to estimate age composition for those years (Appendix D). Age composition for 1977–1981 and 1993–1994 were estimated by adjusting estimates of relative age composition for the Nakina River (Appendix D). For years when information was available for both the gillnet fishery and the Nakina River, regression parameters were calculated to estimate proportions by age class in the gillnet fishery in years when this fishery was not sampled. Estimated standard errors for gillnet harvests are listed in Table D2.

The CWT expansions in the Juneau recreational fishery showed that of the mature, age-1. wild Chinook salmon caught before late-June in this fishery, Taku-origin fish represented most of the harvests in years when random CWTs were recovered. This fishery has been sampled at relatively low rates for CWTs (9% through 1997 and about 15% since) and, not surprisingly, few random CWTs have been recovered in this fishery (6 per brood for the 1991–2002 year classes). However, select CWT recoveries (heads turned in voluntarily by sport anglers), represented almost every year class marked by CWT on the Taku River. We estimated the number of Chinook salmon caught in the Juneau recreational fishery and bound for the Taku River by subtracting all age-0. fish and estimated harvests of other stocks from CWTs (hatchery and wild). Spring harvests in the Juneau area are defined as occurring from late April to late June. Chinook salmon bound for the Taku River harvested each spring in the Juneau recreational fishery averaged 2,381 from 1977–2007. Estimated sport harvests from CWT expansions averaged 2,412 fish for 1979–1987 and 1996–2008.

These estimated marine recreational harvests were then apportioned among year classes according to estimated relative age composition of the harvests (Appendix D). Age samples collected from the Juneau recreational fishery from 1983–2007 were used to estimate age composition for those years. Age compositions for 1977–1982 were estimated by adjusting estimates of relative age composition for the Nakina River (Appendix D). Estimated standard errors for recreational harvests are listed in Table D1.

Harvests of Taku-origin Chinook salmon in the commercial troll fishery in SEAK were estimated directly from CWT recoveries (Table D5). This fishery harvests myriad stocks and has been sampled at high rates for recovery of CWTs, averaging 40–45%. Given the magnitude of the harvest (over 200,000 per year average) and the high sampling rate, the likelihood of recovering CWTs from this fishery is higher than for the other 2 fisheries mentioned previously. This fishery has undergone large-scale changes in management; the fishery has been closed most of the spring troll period (April 16 to June 30) since 1981, when Taku-origin fish would have been harvested (McPherson et al. 2000; see Appendix D). Estimated harvests of Taku-origin Chinook salmon were low following the 1976 brood year returns. Additionally, there were no CWT estimates for the 1988–1995 calendar years, but we estimated troll harvests during this period using the average seen from 1996–2008 (2,034 age-1.3 and age-1.4 fish). This represents 4% of the estimated production of large fish for those years.

Few other CWTs originally released in the Taku River were recovered in other marine fisheries. Where Taku-origin CWTs were found, these harvests were estimated from expansions of CWTs (Appendix D). Incidental mortality of Chinook salmon in marine fisheries was ignored in this analysis, including potential drop-out from commercial gillnets. Only the recreational fishery near Juneau is known to cover the migration window of Chinook salmon returning to the Taku River on an annual basis. Some fish caught in this fishery are most likely released and some of these released fish most likely die. However, the number of released, legal-sized Chinook salmon in this fishery is known to be minor, from annual creel sampling (Hubartt et al. 1999). Hence, the number of these incidentally killed Chinook salmon is negligible relative to the abundance of returning adults.

Inriver Harvests

Age compositions of Chinook salmon caught in the Canadian inriver commercial and aboriginal fisheries (managed for sockeye salmon in all years except 2005 and 2006) were estimated from samples taken from these fisheries in 1983–1987 and 1997–2007. Age compositions in 1979–1982 and 1988–1996 were estimated by adjusting estimates of relative age composition for the Nakina River (Appendix D). For years when information is available for both the fisheries and the Nakina River, regression parameters were calculated to estimate proportions by age class in the inriver fishery in years when this fishery was not sampled. Estimated standard errors for inriver gillnet harvests are listed in Table D3. Age compositions in the test fishery were estimated from samples taken each year from 1999-2007 (Table D4). The marine harvest estimates were combined with those from the inriver commercial and aboriginal fisheries, and the test fishery (Tables D3 and D4). All Chinook salmon caught in the inriver fisheries were considered Taku-origin.

Because catches in the inriver recreational fishery and the U.S. personal use fishery are believed to be less than 100 Chinook salmon for each fishery, these fish are not considered further in this analysis.

Annual Run Statistics

Annual total run is the sum of estimates of escapements (Table 2 and Table 3 for 1973–1980) and estimates of harvests (Table 5). Estimated annual abundance of Chinook salmon from the Taku River is presented in Table 6. Annual total runs of large Chinook salmon have averaged about 48,000 fish since 1973 and about 14,000 fish for smaller age-1.2 fish (almost all males) since 1973. Total runs of large fish increased through the 1990s and then leveled off, averaging about 28,000 in the 1970s, 40,000 in the 1980s, 65,000 in the 1990s and 56,000 since 2000 (Table 6; Figure 5). Estimated exploitation rates of large fish averaged 18% over the time series, but were highest in the 1970s at 32% when stock size was lower (Table 6; Figure 5). After conservative management actions were taken, exploitation rates dropped to 11% in the 1980s and 13% in the 1990s. Since 2000, exploitation rates have averaged 22%. Exploitation rates for smaller age-1.2 fish were very low throughout the time series, averaging 4% in the 1970s, 7% in the 1980s, 10% in the 1990s and 19% since 2000.

Production by Year Class

Estimated production of adults from year class y and the estimated variance were calculated as:

$$\hat{R}_y = \sum_{i=3}^{5} \hat{N}_{1.i,y+i+2} + \sum_{i=3}^{5} \hat{H}_{1.i,y+i+2} \qquad (2)$$

$$v(\hat{R}_y) = \sum_{i=3}^{5} v(\hat{N}_{1.i,y+i+2}) + \sum_{i=3}^{5} v(\hat{H}_{1.i,y+i+2}) \qquad (3)$$

where $\hat{N}_{1.i,y+i+2}$ is the estimated number of spawning Chinook salmon and $\hat{H}_{1.i,y+i+2}$ the estimated harvest of Chinook salmon age-1.i in year y+i+2. Estimated total production and associated SEs by age are in Table 7 for year classes 1981–2001, and Table 8 for year classes 1973–2001. Estimated production for age-1.5 salmon in the 2001 year class was not available at this writing, making the overall estimate of production for this year class slightly conservative.

Table 5.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in commercial and aboriginal gillnet fisheries in Taku Inlet and in Canada, in the recreational fishery near Juneau and in the commercial troll fishery in Southeast Alaska. Standard errors are in parentheses.

Year	1.2		1.3		1.4		1.5		Age-.2-.5 total	Age-.3-.5 total	
1977	183	(90)	1,105	(330)	1,848	(360)	0	(0)	3,136	2,953	(292)
1978	1,403	(278)	3,053	(1,741)	1,021	(261)	0	(0)	5,476	4,073	(1,737)
1979	3,297	(710)	3,862	(1,794)	2,794	(1,743)	0	(0)	9,953	6,656	(2,575)
1980	937	(204)	3,769	(1,023)	3,866	(1,751)	0	(0)	8,572	7,635	(1,975)
1981	543	(148)	4,930	(1,905)	3,042	(1,027)	0	(0)	8,514	7,971	(2,143)
1982	955	(52)	1,668	(445)	3,485	(969)	12	(8)	6,120	5,165	(1,039)
1983	795	(37)	649	(79)	1,072	(325)	0	(0)	2,516	1,721	(345)
1984	796	(65)	4,170	(926)	344	(60)	9	(9)	5,320	4,524	(933)
1985	757	(59)	1,970	(179)	1,699	(419)	30	(20)	4,456	3,699	(472)
1986	458	(85)	1,638	(814)	1,049	(116)	22	(12)	3,167	2,708	(820)
1987	396	(49)	931	(101)	1,005	(407)	116	(39)	2,448	2,051	(422)
1988	671	(122)	1,517	(887)	1,886	(660)	25	(14)	4,099	3,428	(1,107)
1989	817	(157)	3,510	(918)	1,746	(662)	115	(38)	6,188	5,371	(1,152)
1990	1,048	(269)	2,800	(924)	3,384	(720)	48	(22)	7,279	6,232	(1,185)
1991	2,023	(278)	3,283	(940)	4,384	(756)	299	(72)	9,988	7,966	(1,280)
1992	1,078	(249)	3,483	(948)	3,366	(739)	37	(21)	7,964	6,887	(1,257)
1993	1,336	(481)	4,707	(1,024)	6,574	(906)	170	(50)	12,786	11,450	(1,422)
1994	756	(420)	3,942	(977)	3,754	(722)	108	(33)	8,559	7,804	(1,219)
1995	3,587	(410)	3,128	(981)	3,020	(686)	141	(47)	9,875	6,288	(1,209)
1996	680	(557)	9,342	(1,115)	1,068	(309)	71	(30)	11,160	10,480	(1,143)
1997	228	(50)	3,624	(257)	8,649	(1,132)	0	(0)	12,501	12,273	(1,190)
1998	669	(67)	1,365	(114)	2,298	(673)	84	(24)	4,416	3,748	(699)
1999	1,696	(123)	2,887	(347)	1,687	(409)	50	(16)	6,320	4,624	(585)
2000	1,326	(92)	3,042	(229)	2,220	(444)	18	(9)	6,606	5,280	(536)
2001	843	(58)	5,572	(574)	1,360	(188)	55	(17)	7,830	6,987	(611)
2002	1,514	(107)	5,250	(682)	3,280	(491)	107	(41)	10,151	8,637	(863)
2003	2,485	(128)	3,563	(472)	3,411	(504)	185	(160)	9,644	7,159	(738)
2004	1,760	(102)	7,704	(641)	3,333	(638)	391	(322)	13,189	11,429	(982)
2005	3,771	(355)	21,749	(692)	10,207	(569)	147	(57)	35,874	32,103	(948)
2006	1,489	(183)	10,214	(632)	11,722	(571)	247	(59)	23,672	22,183	(802)
2007	1,542	(157)	3,735	(568)	2,604	(474)	82	(18)	7,963	6,421	(824)

Table 6.–Estimated harvest, escapement (Esc), total run and harvest rate (HR) of Taku River Chinook salmon from 1973–2007, segregated by large and age-1.2 fish.

	Large Chinook salmon (≥660 mm MEF)				Age-1.2 Chinook salmon			
Year	Havest[a]	Esc	Total run[b]	HR	Havest[a]	Esc	Total run[b]	HR
1973	14,951	14,564	29,515	0.507	239	8,553	8,792	0.027
1974	9,349	16,015	25,364	0.369	35	10,043	10,078	0.003
1975	8,807	12,920	21,727	0.405	69	25,074	25,143	0.003
1976	7,472	24,582	32,054	0.233	834	11,667	12,501	0.067
1977	7,498	29,497	36,995	0.203	183	4,678	4,861	0.038
1978	6,346	17,123	23,469	0.270	1,403	31,514	32,917	0.043
1979	6,656	21,617	28,273	0.235	3,297	28,620	31,917	0.103
1980	7,635	39,239	46,874	0.163	937	16,436	17,373	0.054
1981	7,971	50,784	58,755	0.136	543	15,982	16,525	0.033
1982	5,165	24,762	29,927	0.173	955	6,159	7,115	0.134
1983	1,721	11,881	13,603	0.127	795	5,545	6,340	0.125
1984	4,524	24,805	29,329	0.154	796	11,725	12,521	0.064
1985	3,699	49,535	53,234	0.069	757	17,823	18,580	0.041
1986	2,708	39,663	42,371	0.064	458	8,361	8,819	0.052
1987	2,051	30,811	32,863	0.062	396	8,215	8,611	0.046
1988	3,428	44,810	48,238	0.071	671	17,692	18,363	0.037
1989	5,371	40,329	45,700	0.118	817	10,569	11,386	0.072
1990	6,232	52,142	58,374	0.107	1,048	7,095	8,143	0.129
1991	7,966	49,339	57,305	0.139	2,023	20,738	22,761	0.089
1992	6,887	57,647	64,534	0.107	1,078	19,271	20,348	0.053
1993	11,450	72,917	84,368	0.136	1,336	12,369	13,705	0.097
1994	7,804	55,617	63,420	0.123	756	6,077	6,833	0.111
1995	6,288	33,805	40,093	0.157	3,587	30,884	34,471	0.104
1996	10,480	79,019	89,499	0.117	680	8,005	8,685	0.078
1997	12,273	114,938	127,211	0.096	228	2,652	2,880	0.079
1998	3,748	39,196	42,943	0.087	669	8,094	8,763	0.076
1999	4,624	16,786	21,410	0.216	1,696	10,394	12,090	0.140
2000	5,280	34,997	40,277	0.131	1,326	9,452	10,778	0.123
2001	6,987	46,544	53,531	0.131	843	5,075	5,918	0.142
2002	8,637	55,044	63,681	0.136	1,514	6,707	8,221	0.184
2003	7,159	36,435	43,594	0.164	2,485	16,357	18,842	0.132
2004	11,429	75,032	86,461	0.132	1,760	25,702	27,462	0.064
2005	32,103	38,725	70,828	0.453	3,771	6,574	10,345	0.365
2006	22,183	42,296	64,479	0.344	1,489	2,874	4,363	0.341
2007	6,421	14,854	21,275	0.302	1,542	6,949	8,491	0.182
Average	8,094	40,236	48,331	0.184	1,172	12,684	13,855	0.098

[a] Large totals include approximated troll harvests for 1973–1977 based on averages for 1978–1981 and approximated sport harvests for 1973–1976 based on averages for 1977–1981.

[b] Total runs for individual estimates of large and age-1.2 fish for 1995–2007 will not add up to the correct total due to a small number of age-1.2 fish included in the large total and a small number of age-1.3 fish <660 mm MEF excluded from the large total.

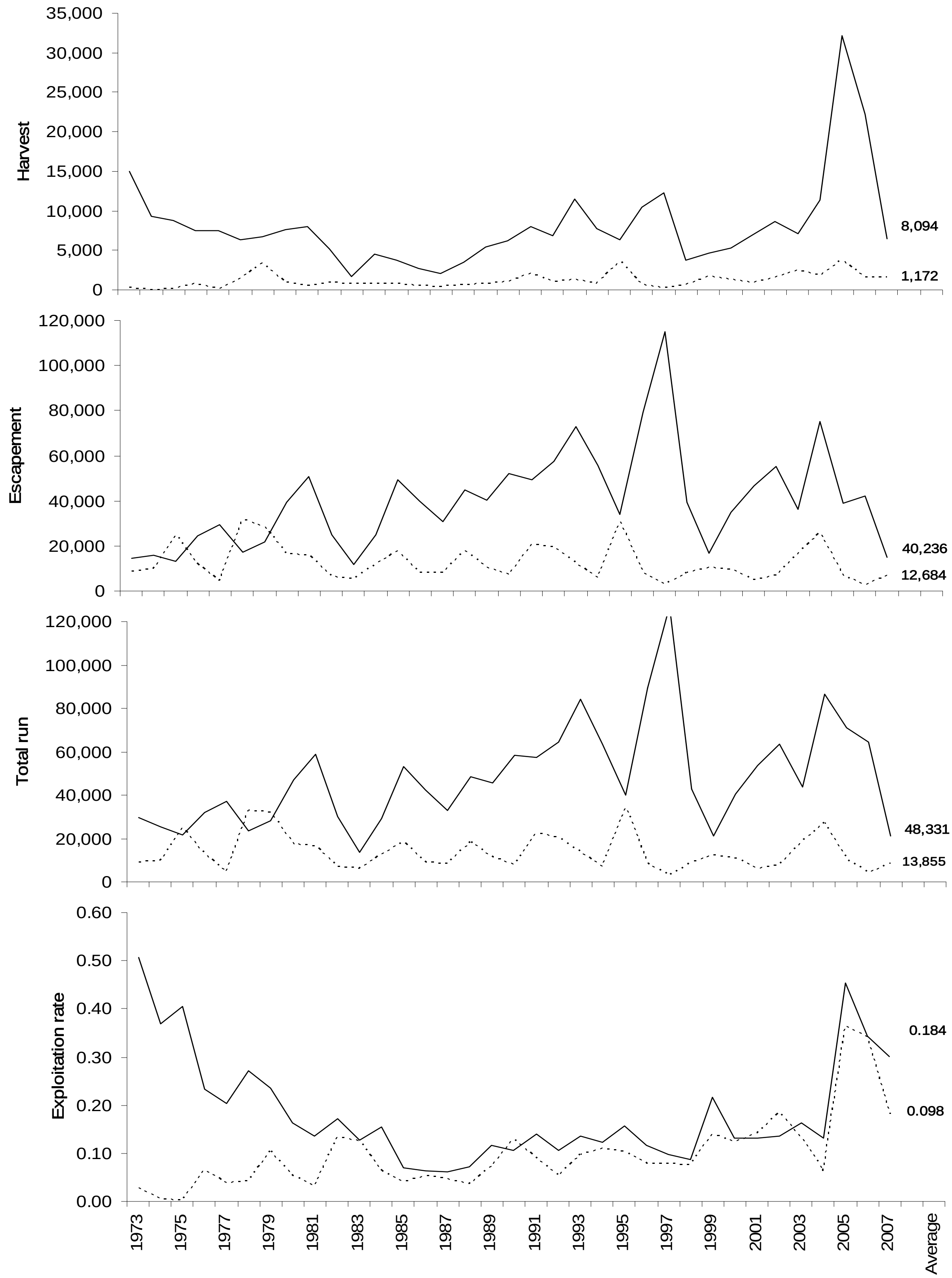


Figure 5.–Estimated calendar year harvests, escapements, total runs and exploitation rates for large (solid lines) and age-1.2 (dashed lines) Chinook salmon from the Taku River.

Table 7.–Estimated production $\hat{R}_y$ by age and year class for Chinook salmon in the Taku River, adding escapements by age in Table 2 to harvests by age in Table 5, using the expansion factor of 10.86. Standard errors are in parentheses. Estimates in bold include production estimated from mark–recapture in the escapements.

Year class	1.2		1.3		1.4		1.5		Age-.2-.5 total	Age-.3-.5 total	
1981	18,580	(8,746)	21,789	(5,832)	9,834	(2,849)	2,514	(1,139)	52,717	34,137	(6,590)
1982	8,819	(4,271)	22,074	(5,534)	29,850	(7,672)	**1,676**	**(296)**	62,420	53,600	(9,464)
1983	8,611	(4,178)	15,874	(4,466)	**13,799**	(1,890)	**1,219**	**(265)**	39,503	30,892	(4,857)
1984	18,363	(9,506)	**30,225**	(3,928)	**33,508**	(5,482)	4,638	(1,686)	86,734	68,371	(6,951)
1985	**11,386**	**(1,597)**	**23,648**	(3,890)	26,369	(6,518)	1,877	(812)	63,280	51,894	(7,634)
1986	**8,143**	**(1,365)**	26,298	(6,364)	26,669	(6,922)	2,120	(802)	63,230	55,087	(9,437)
1987	22,761	(10,702)	35,988	(8,846)	39,393	(9,755)	2,398	(786)	100,539	77,779	(13,192)
1988	20,348	(10,344)	42,854	(10,740)	23,864	(6,448)	**753**	**(180)**	87,819	67,470	(12,528)
1989	13,705	(6,579)	37,159	(9,049)	**22,970**	(2,689)	**214**	**(89)**	74,048	60,343	(9,440)
1990	6,833	(3,119)	**17,728**	(2,185)	**10,969**	(1,324)	**0**	**(0)**	35,529	28,697	(2,554)
1991	**34,471**	**(3,870)**	**80,714**	(7,772)	**79,720**	(11,177)	1,064	(310)	195,969	161,498	(13,618)
1992	**8,685**	**(1,230)**	**47,381**	(6,605)	28,915	(6,713)	**253**	**(105)**	85,234	76,549	(9,418)
1993	**2,880**	**(641)**	12,466	(2,855)	**4,933**	(813)	**104**	**(62)**	20,384	17,503	(2,969)
1994	**8,763**	**(2,006)**	**14,555**	(2,235)	**11,303**	(1,547)	**80**	**(30)**	34,701	25,938	(2,718)
1995	**12,090**	**(1,478)**	**27,842**	(3,752)	**11,120**	(1,454)	**247**	**(82)**	51,298	39,208	(4,025)
1996	**10,778**	**(1,768)**	**42,076**	(5,222)	**24,603**	(4,273)	**291**	**(169)**	77,749	66,971	(6,749)
1997	**5,918**	**(908)**	**38,036**	(6,561)	**16,362**	(2,418)	**652**	**(340)**	60,968	55,050	(7,000)
1998	**8,221**	**(1,139)**	**26,362**	(4,009)	**17,228**	(2,067)	**194**	**(66)**	52,005	43,785	(4,511)
1999	**18,842**	**(1,994)**	**64,570**	(7,421)	**19,666**	(1,361)	**467**	**(100)**	103,545	84,703	(7,545)
2000	**27,462**	**(2,318)**	**49,319**	(3,396)	**32,651**	(2,812)	**283**	**(119)**	109,715	82,253	(4,411)
2001	**10,345**	**(870)**	**30,668**	(2,741)	**8,380**	(1,412)	0	(0)	49,393	39,049	(3,083)

Table 8.–Estimated production $\hat{R}_y$ by age and year class for Chinook salmon in the Taku River, adding escapements by age in Table 3 to harvests by age in Table 5, using the expansion factor of 5.20. Standard errors are in parentheses. Estimates in bold include production estimated from mark–recapture in the escapements.

Year class	1.2		1.3		1.4		1.5		Age-.2-.5 total	Age-.3-.5 total	
1973	4,861	(2,842)	12,215	(4,046)	5,324	(2,093)	0	0	22,399	17,539	(4,556)
1974	32,917	(18,328)	22,652	(7,424)	16,823	(5,817)	0	0	72,392	39,475	(9,432)
1975	31,917	(16,108)	30,051	(10,399)	24,468	(8,851)	1,038	(486)	87,474	55,557	(13,665)
1976	17,373	(8,879)	33,063	(11,377)	14,916	(4,769)	155	(75)	65,506	48,134	(12,337)
1977	16,140	(8,755)	13,058	(4,603)	4,777	(1,564)	356	(153)	34,331	18,191	(4,864)
1978	6,887	(3,450)	6,584	(2,335)	2,937	(1,199)	164	(64)	16,572	9,685	(2,626)
1979	5,366	(2,663)	22,008	(6,908)	11,761	(4,320)	761	(353)	39,897	34,531	(8,155)
1980	10,617	(5,261)	27,690	(10,009)	19,057	(7,409)	904	(371)	58,267	47,650	(12,459)
1981	13,680	(7,179)	21,001	(7,886)	9,296	(3,562)	2,499	(1,309)	46,475	32,795	(8,752)
1982	8,492	(4,594)	20,787	(7,734)	29,671	(11,041)	**1,676**	**(296)**	60,626	52,134	(13,484)
1983	8,111	(4,397)	15,782	(6,016)	**13,799**	**(1,890)**	**1,219**	**(265)**	38,911	30,800	(6,311)
1984	18,250	(10,433)	**30,225**	**(3,928)**	**33,508**	**(5,482)**	4,841	(2,163)	86,824	68,574	(7,082)
1985	**11,386**	**(1,597)**	**23,648**	**(3,890)**	27,397	(9,471)	1,821	(922)	64,251	52,865	(10,280)
1986	**8,143**	**(1,365)**	27,373	(9,604)	25,958	(9,310)	1,939	(873)	63,413	55,270	(13,404)
1987	23,730	(12,505)	34,996	(12,482)	36,336	(12,271)	2,099	(883)	97,161	73,432	(17,526)
1988	19,761	(11,080)	39,301	(13,912)	21,243	(7,491)	**753**	**(180)**	81,057	61,296	(15,801)
1989	12,553	(6,611)	32,830	(11,455)	**22,970**	**(2,689)**	**214**	**(89)**	68,567	56,014	(11,767)
1990	6,041	(3,041)	**17,728**	**(2,185)**	**10,969**	**(1,324)**	**0**	**0**	34,737	28,697	(2,554)
1991	**34,471**	**(3,870)**	**80,714**	**(7,772)**	**79,720**	**(11,177)**	860	(271)	195,765	161,294	(13,617)
1992	**8,685**	**(1,230)**	**47,381**	**(6,605)**	23,376	(7,162)	**253**	**(105)**	79,695	71,010	(9,743)
1993	**2,880**	**(641)**	10,156	(2,902)	**4,933**	**(813)**	**104**	**(62)**	18,074	15,193	(3,014)
1994	**8,763**	**(2,006)**	**14,555**	**(2,235)**	**11,303**	**(1,547)**	**80**	**(30)**	34,701	25,938	(2,718)
1995	**12,090**	**(1,478)**	**27,842**	**(3,752)**	**11,120**	**(1,454)**	**247**	**(82)**	51,298	39,208	(4,025)
1996	**10,778**	**(1,768)**	**42,076**	**(5,222)**	**24,603**	**(4,273)**	**291**	**(169)**	77,749	66,971	(6,749)
1997	**5,918**	**(908)**	**38,036**	**(6,561)**	**16,362**	**(2,418)**	**652**	**(340)**	60,968	55,050	(7,000)
1998	**8,221**	**(1,139)**	**26,362**	**(4,009)**	**17,228**	**(2,067)**	**194**	**(66)**	52,005	43,785	(4,511)
1999	**18,842**	**(1,994)**	**64,570**	**(7,421)**	**19,666**	**(1,361)**	**467**	**(100)**	103,545	84,703	(7,545)
2000	**27,462**	**(2,318)**	**49,319**	**(3,396)**	**32,651**	**(2,812)**	**283**	**(119)**	109,715	82,253	(4,411)
2001	**10,345**	**(870)**	**30,668**	**(2,741)**	**8,380**	**(1,412)**	0	0	49,393	39,049	(3,083)

Exploitation Rate

The estimated exploitation rates (Tables 9 and 10) and the estimated variances were calculated as:

$$\hat{E}_y = \frac{\hat{H}_y}{\hat{R}_y} \qquad (4)$$

$$v\left[\hat{E}_y\right] \approx \frac{v[\hat{H}_y]\hat{N}_y^2}{\hat{R}_y^4} + \frac{v[\hat{N}_y]\hat{H}^2}{\hat{R}_y^4} \qquad (5)$$

The variance above was approximated with the delta method (Seber 1982).

RESULTS AND DISCUSSION

Smolt Production

An analysis of the statistics on production and the auxiliary data in Table 4 reveals evidence to support the following:

- density-dependent survival in the early freshwater life of young Chinook salmon;
- an upper bound on the production of smolts from the Taku River at about 2.1 million; and
- density-independent survival of smolts at sea.

Table 9.–Estimated large spawning Chinook salmon $\hat{N}_y$, large spawning female Chinook salmon $\hat{N}_{y,F}$, production of large (age-1.3 to -1.5) Chinook salmon $\hat{R}_y$, return rate ($\hat{R}_y$ / $\hat{N}_y$) and exploitation rate $\hat{E}_y$ by year class for Chinook salmon in the Taku River, using statistics from Table 7. Standard errors are in parentheses.

Year class	$\hat{N}_y$		$\hat{N}_{y,F}$		$\hat{R}_y$		$\frac{\hat{R}_y}{\hat{N}_y}$		$\hat{E}_y$	
1981	50,784	(12,669)	25,642	(7,536)	34,137	(6,590)	0.7	(0.21)	0.078	(0.029)
1982	24,762	(6,177)	12,871	(3,669)	53,600	(9,464)	2.2	(0.66)	0.055	(0.015)
1983	11,881	(2,964)	4,998	(1,571)	30,892	(4,857)	2.6	(0.77)	0.107	(0.036)
1984	24,805	(6,188)	12,047	(3,862)	68,371	(6,951)	2.8	(0.74)	0.105	(0.019)
1985	49,535	(12,357)	24,063	(7,177)	51,894	(7,634)	1.0	(0.30)	0.139	(0.028)
1986	39,663	(9,895)	22,583	(6,473)	55,087	(9,437)	1.4	(0.42)	0.124	(0.028)
1987	30,811	(7,686)	13,424	(4,165)	77,779	(13,192)	2.5	(0.76)	0.131	(0.026)
1988	44,810	(11,179)	22,005	(6,495)	67,470	(12,528)	1.5	(0.47)	0.127	(0.029)
1989	40,329	(5,646)	17,580	(4,827)	60,343	(9,440)	1.5	(0.31)	0.117	(0.025)
1990	52,142	(9,326)	26,749	(5,831)	28,697	(2,554)	0.6	(0.11)	0.146	(0.033)
1991	49,339	(12,309)	26,210	(7,280)	161,498	(13,618)	3.3	(0.86)	0.112	(0.013)
1992	57,647	(14,381)	23,657	(7,172)	76,549	(9,418)	1.3	(0.37)	0.078	(0.013)
1993	72,917	(18,191)	33,055	(10,036)	17,503	(2,969)	0.2	(0.07)	0.175	(0.036)
1994	55,617	(13,875)	36,282	(10,001)	25,938	(2,718)	0.5	(0.13)	0.199	(0.027)
1995	33,805	(5,060)	19,705	(2,891)	39,208	(4,025)	1.2	(0.21)	0.115	(0.014)
1996	79,019	(9,048)	40,897	(4,595)	66,971	(6,749)	0.8	(0.13)	0.135	(0.017)
1997	114,938	(17,888)	70,691	(11,039)	55,050	(7,000)	0.5	(0.10)	0.164	(0.025)
1998	39,196	(9,778)	21,732	(5,474)	43,785	(4,511)	1.1	(0.30)	0.161	(0.022)
1999	16,786	(3,171)	6,948	(1,386)	84,703	(7,545)	5.0	(1.05)	0.214	(0.021)
2000	34,997	(5,403)	19,199	(3,025)	82,253	(4,411)	2.4	(0.38)	0.408	(0.022)
2001	46,544	(6,766)	23,110	(3,402)	39,049	(3,083)	0.8	(0.14)	0.335	(0.029)
Average	47,094		24,470		59,634		1.6		0.163	
Contrast	9.7		14.1		9.2		21.0		5.2	

Density-dependent survival of young in their early freshwater existence is indicated by the decline in smolts per female with increasing numbers of spawning Chinook salmon (Figure 6). On the other hand, smolt length varied little, averaging 71 to 80 mm FL, and showed no evidence of density dependence (Figure 7). Marine survival, on the other hand, appears to be density-independent (Figure 8).

For example, estimates of smolt abundance from the 1976 and 1991 year classes (1.55 vs. 2.10 million from Table 4) were not significantly different ($P > 0.20$); an estimated 3.1% returned as adults for the earlier year class and 7.7% for the later year class. While the estimated numbers of smolt are not statistically different, the return rates are statistically different ($P < 0.01$). The estimated size of smolts for these year classes (71 and 80 mm FL) cover the observed range.

The evidence in the smolt information underpinning a ceiling on the number of smolts produced each year by the Taku River is supported by the body of estimates available since 1975. Early density-dependence in the freshwater existence of Chinook salmon is the result of limited, high quality spawning habitat or limited rearing habitat for young in the year up until smolt emigration. If there is a ceiling on smolt production in the Taku River, smolt production for the year classes with the highest production rates should follow an asymptotic, density-dependent relationship. Estimates of smolt production, precision, and associated large females that produced each brood, shows relatively similar smolt production across a broad range of spawning female Chinook salmon (Figure 9). Six year classes (1991, 1992, 1996, 1997, 2000 and 2001) produced between 1.9 and 2.1 million smolt, averaging 2.0 (SE = 309,907) smolt. None are significantly different from one another ($P > 0.50$).

Table 10.–Estimated large spawning Chinook salmon $\hat{N}_y$, large spawning female Chinook salmon $\hat{N}_{y,F}$, production of large (age-1.3 to -1.5) Chinook salmon $\hat{R}_y$, return rate ($\hat{R}_y$ / $\hat{N}_y$) and exploitation rate $\hat{E}_y$ by year class for Chinook salmon in the Taku River, using statistics from Table 8. Standard errors are in parentheses.

Year class	$\hat{N}_y$	$\hat{N}_{y,F}$	$\hat{R}_y$	$\frac{\hat{R}_y}{\hat{N}_y}$	$\hat{E}_y$
1973	14,564 (5,565)	8,929 (3,573)	17,539 (4,556)	1.2 (0.56)	0.333 (0.119)
1974	16,015 (6,119)	9,824 (3,918)	39,475 (9,432)	2.5 (1.11)	0.196 (0.068)
1975	12,920 (4,937)	4,593 (1,959)	55,557 (13,665)	4.3 (1.95)	0.123 (0.038)
1976	24,582 (9,392)	15,165 (6,002)	48,134 (12,337)	2.0 (0.90)	0.175 (0.057)
1977	29,497 (11,270)	20,466 (8,049)	18,191 (4,864)	0.6 (0.29)	0.151 (0.048)
1978	17,123 (6,542)	9,143 (3,689)	9,685 (2,626)	0.6 (0.26)	0.106 (0.030)
1979	21,617 (8,259)	10,997 (4,586)	34,531 (8,155)	1.6 (0.72)	0.171 (0.047)
1980	39,239 (14,992)	21,228 (8,703)	47,650 (12,459)	1.2 (0.56)	0.066 (0.018)
1981	49,559 (18,935)	25,024 (10,255)	32,795 (8,752)	0.7 (0.31)	0.081 (0.033)
1982	23,848 (9,112)	12,396 (5,009)	52,134 (13,484)	2.2 (1.01)	0.056 (0.019)
1983	9,794 (3,742)	4,120 (1,744)	30,800 (6,311)	3.1 (1.36)	0.107 (0.039)
1984	20,780 (7,939)	10,091 (4,316)	68,574 (7,082)	3.3 (1.31)	0.105 (0.019)
1985	35,916 (13,722)	17,447 (7,200)	52,865 (10,280)	1.5 (0.63)	0.137 (0.033)
1986	38,111 (14,561)	21,700 (8,791)	55,270 (13,404)	1.5 (0.66)	0.123 (0.035)
1987	28,935 (11,055)	12,607 (5,304)	73,432 (17,526)	2.5 (1.14)	0.138 (0.036)
1988	44,524 (17,011)	21,864 (8,979)	61,296 (15,801)	1.4 (0.63)	0.140 (0.040)
1989	40,329 (5,646)	17,580 (4,827)	56,014 (11,767)	1.4 (0.35)	0.126 (0.032)
1990	52,142 (9,326)	26,749 (5,831)	28,697 (2,554)	0.6 (0.11)	0.146 (0.033)
1991	51,645 (19,732)	27,435 (10,959)	161,294 (13,617)	3.1 (1.22)	0.112 (0.013)
1992	55,889 (21,354)	22,935 (9,540)	71,010 (9,743)	1.3 (0.52)	0.084 (0.015)
1993	66,125 (25,265)	29,976 (12,477)	15,193 (3,014)	0.2 (0.10)	0.202 (0.046)
1994	48,368 (18,480)	31,553 (12,562)	25,938 (2,718)	0.5 (0.21)	0.199 (0.027)
1995	33,805 (5,060)	19,705 (2,891)	39,208 (4,025)	1.2 (0.21)	0.115 (0.014)
1996	79,019 (9,048)	40,897 (4,595)	66,971 (6,749)	0.8 (0.13)	0.135 (0.017)
1997	114,938 (17,888)	70,691 (11,039)	55,050 (7,000)	0.5 (0.10)	0.164 (0.025)
1998	31,039 (11,862)	17,210 (5,877)	43,785 (4,511)	1.4 (0.56)	0.161 (0.022)
1999	16,786 (3,171)	6,948 (1,386)	84,703 (7,545)	5.0 (1.05)	0.214 (0.021)
2000	34,997 (5,403)	19,199 (3,025)	82,253 (4,411)	2.4 (0.38)	0.408 (0.022)
2001	46,544 (6,766)	23,110 (3,402)	39,049 (3,083)	0.8 (0.14)	0.335 (0.029)
Average	37,885	19,986	50,589	1.7	0.159
Contrast	11.7	17.2	16.7	22.0	7.3

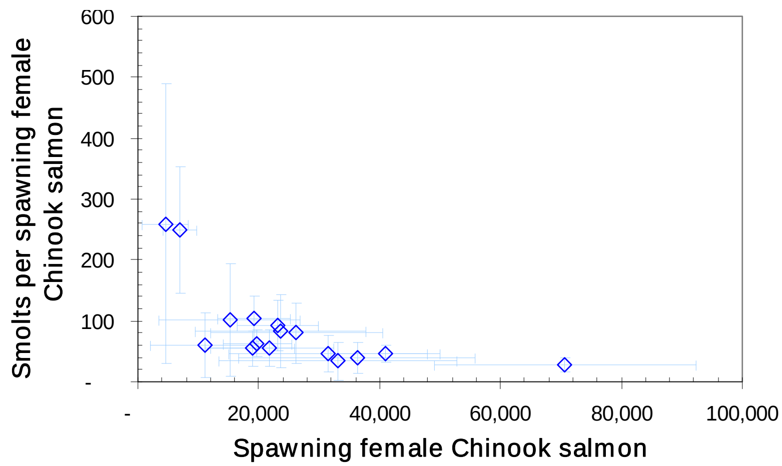


Figure 6.–Number of Chinook salmon smolt produced per spawning female across a range of spawning abundance.

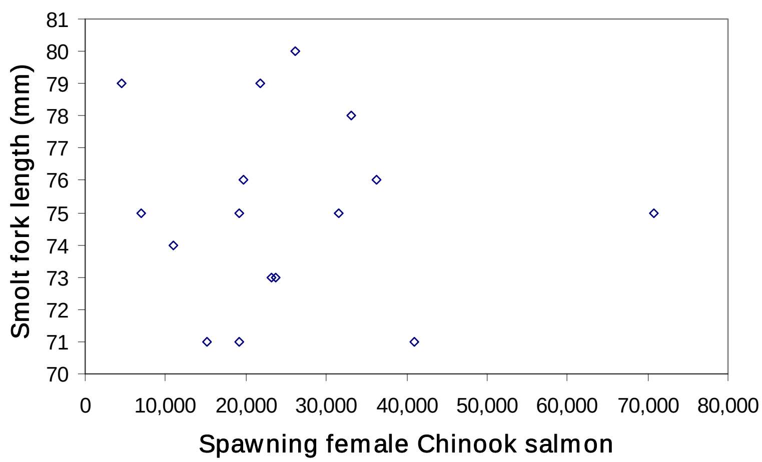


Figure 7.–Chinook salmon smolt fork length (mm) across a range of female spawning abundances.

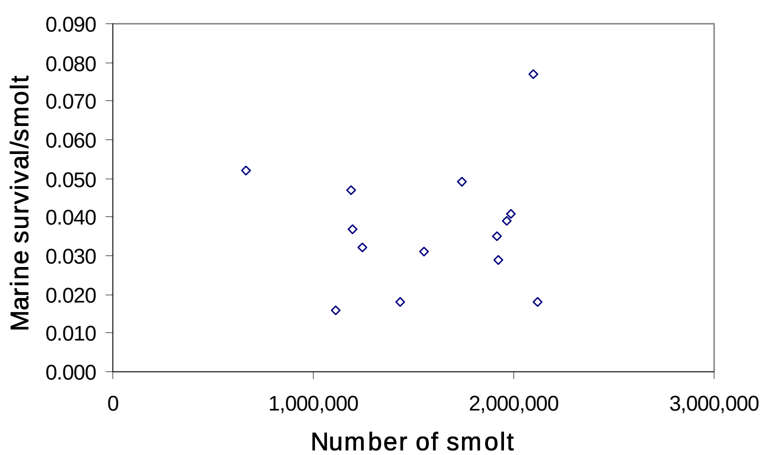


Figure 8.–Chinook salmon marine survival across a range of smolt abundances.

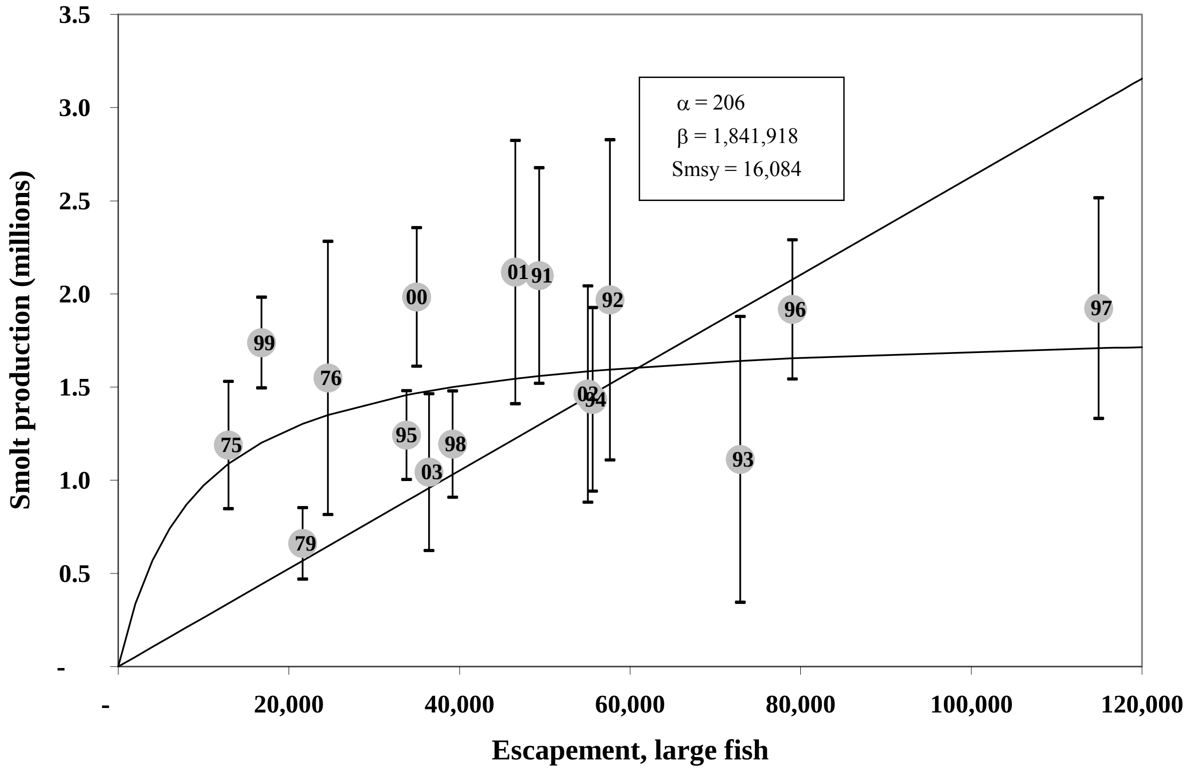


Figure 9.–Estimated smolt production and 95% confidence intervals against the estimated abundance of large parents for the 1975, 1976, 1979, and 1991–2003 year classes. Also shown is the curve corresponding to least-squares fit of the Beverton-Holt model.

Production of smolt appears not to increase with large escapements, when the estimated smolt production is plotted against the large spawning parents (males and females; Figure 9). Amongst the 16 year classes with estimates, the 6 highest levels of smolt production (1.9 to 2.1 million) were produced from spawning levels between 35,000 and 115,000 large spawning Chinook salmon (Table 1) or between 19,000 and 71,000 females (Table 4). Production did not increase at higher escapements, including 115,000 large spawning Chinook salmon from the 1997 year class. Smolt production below 19,000 females was lower, on average, however the 1.7 million smolt produced by the 1999 brood from 16,786 large parents (6,948 females) was not significantly different from the 6 highest estimates ($P > 0.25$).

STOCK-RECRUIT ANALYSIS

Two time series were selected for analysis, 1973–2001 and 1983–2001. Beginning with returns in 1983, most are based on mark–recapture estimates of escapement making up the bulk of returns, and have unbiased sampling of escapements for age and other biological data. The shorter time series eliminated many data pairs containing expanded survey counts, but also eliminated most of the year classes with the smallest spawning stock sizes (see Tables 7 and 8).

One model was used in this analysis: Ricker's exponential function (Ricker 1975):

$$R_y = \alpha S_y \exp(-\beta N_y)\exp(\varepsilon_y) \tag{6}$$

Parameters were estimated for the linear form of Ricker's model (Table 11):

$$\ln(R_y / N_y) = \ln(\alpha) - \beta N_y + \varepsilon_y, \tag{7}$$

by simple linear regression of the left-hand side on N_y. Predictions by the fitted, untransformed model and the original data for the 1983–2001 year classes are given in Figure 10, the residuals from that fit are in Figure 11, and autocorrelation (ACF) and partial autocorrelation plots (PACF) are in Figure 12. The predictions and original data for the 1973–2001 year classes are shown in Figure 13, the residuals from that fit are in Figure 14, and ACF and PACF plots are in Figure 15. No autocorrelation among residuals (Durbin-Watson test = 1.91 for 1983–2001 year classes, and 1.54 for the 1973–2001 year classes) or higher order influence of spawning abundance for either data set was found (see the ACF and PACF plots in Figures 12 and 15).

Spawning abundance that on average produces maximum sustained yield (N_{MSY}) was estimated with Hilborn's (1985) approximation:

$$\hat{N}_{msy} \doteq \ln\hat{\alpha}/\hat{\beta}\left(0.5-0.07(\ln\hat{\alpha}+\hat{\sigma}_{\varepsilon}^{2}/2)\right) \qquad (8)$$

where $\hat{\sigma}_{\varepsilon}^{2}$ is the mean square error from the fitted regression. Regression residuals were bootstrapped (resampled with replacement) to obtain confidence intervals for N_{MSY}.

Little difference was seen between estimates of $\hat{N}_{MSY}$ for the 2 data sets ($\hat{N}_{MSY}$ = 25,075 and 25,686) and the associated confidence intervals and estimated ranges that produce 90% or 95% of *MSY*, nor replacement (63,185 for 1983–2001 vs 61,553; Table 11). The fit of the longer time series produced parameters indicating a slightly less productive stock, with $\hat{\alpha}$ =3.4 (vs. 4.5) and $\hat{E}_{MSY}$ = 0.51 (vs. 0.59).

Table 11.–Estimated parameters for two time series from the log-linear transform of Ricker's model on estimates of production and spawning abundance of Chinook salmon in the Taku River.

Parameter	**1983–2001**[a]	**1973–2001**[b]
$\ln(\hat{\alpha})$	1.35 (P < 0.00020)	1.04 (P = 0.00006)
$\ln(\hat{\alpha})+\sigma_{\varepsilon}^{2}/2$	1.50	1.22
$\hat{\alpha}$	4.48	3.38
$\hat{\beta}$	0.00002373 (P=0.00046)	0.00001978 (P=0.00052)
$1/\hat{\beta}=\hat{N}_{MAX}$	42,142	50,553
$\hat{N}_{EQ}$	63,185	61,553
R^2(corrected)	0.4962	0.3408
$\hat{\sigma}_{\varepsilon}^{2}$	0.30	0.36
$\hat{\sigma}_{u}^{2}$	0.05	0.11
$\hat{\sigma}_{v}^{2}$	0.02	0.04
$\hat{N}_{MSY}$ (large spawning Chinook salmon)	25,075	25,686
90% CI from simulation 90% CI from simulation with ME [c]	20,655 to 30,669 [c] 18,470 to 36,530	22,671 to 33,862
$\hat{N}_{MSY}$ producing 90% of *MSY*	16,178 to 35,203	16,740 to 35,611
$\hat{N}_{MSY}$ producing 95% of *MSY*	18,675 to 32,094	19,269 to 32,592
$\hat{E}_{MSY}$	0.59	0.51

[a] Includes escapement estimates in years without capture-recapture estimates from EF of 10.86 in Appendix A for Nahlin, Kowatua, Dudidontu, and Tatsamenie rivers plus Tseta Creek.

[b] Includes escapement estimates in years without capture-recapture estimates from EF of 5.20 in Appendix A for Nahlin, Nakina, Kowatua, Dudidontu, and Tatsamenie rivers.

[c] Bootstrap confidence intervals understate the uncertainty around the parameter estimates because they ignore measurement error. See Appendix F for Bayesian intervals that are more realistic (18,470 to 36,530 for the 1983–2001 year classes).

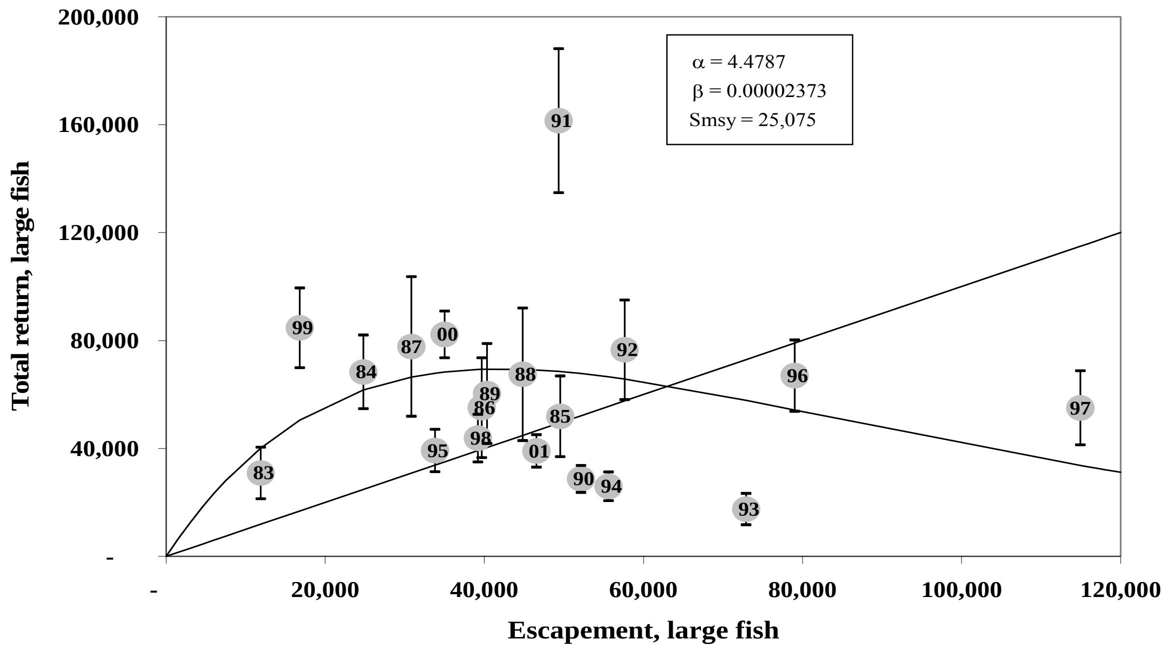


Figure 10.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1983–2001 against the estimated abundance of large spawning Chinook salmon (Table 9), along with curves corresponding to least-squares fit of the Ricker model and the replacement line. Spawners and recruits are from Table 7 for the EF = 10.86 for survey counts.

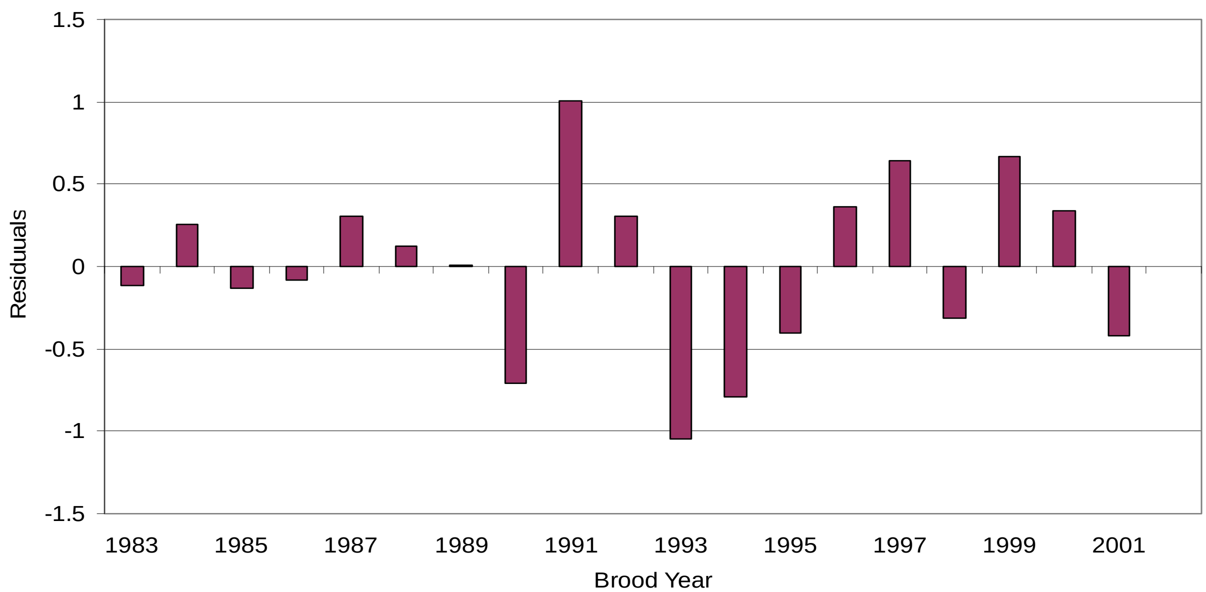
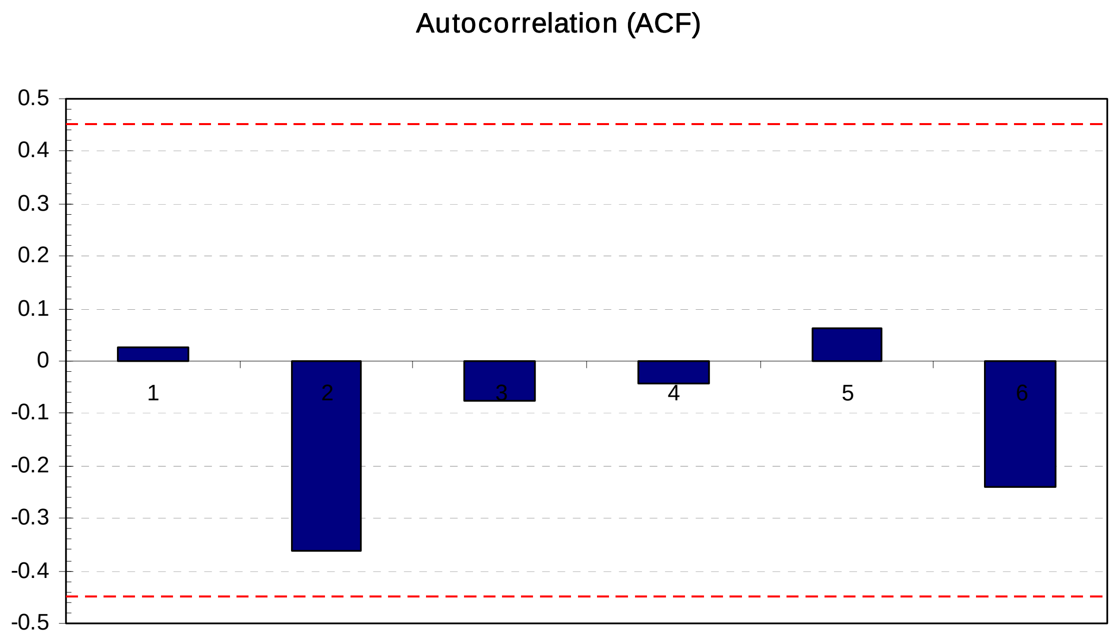


Figure 11.–Estimated residuals of the log-transformed fit of the Ricker model to production of age-1.3 to -1.5 Chinook salmon in year classes 1983–2001 against the estimated abundance of large spawning Chinook salmon. Data set used is from Table 7 for the EF = 10.86 in years without mark–recapture estimates.



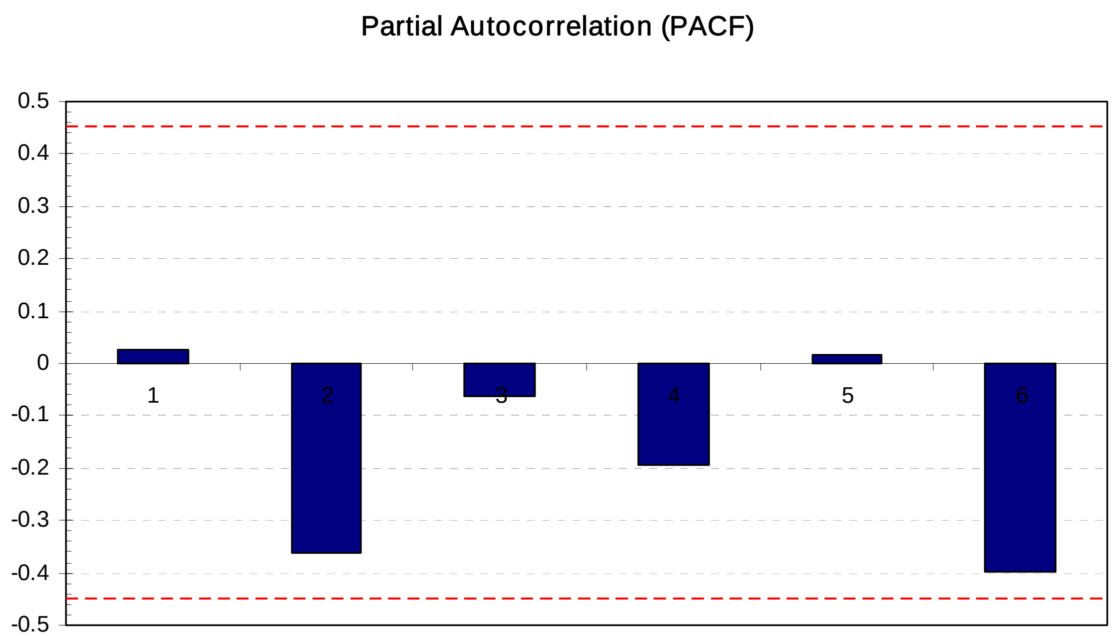


Figure 12.–ACF and PACF plots for stock-recruit data in Figure 10.

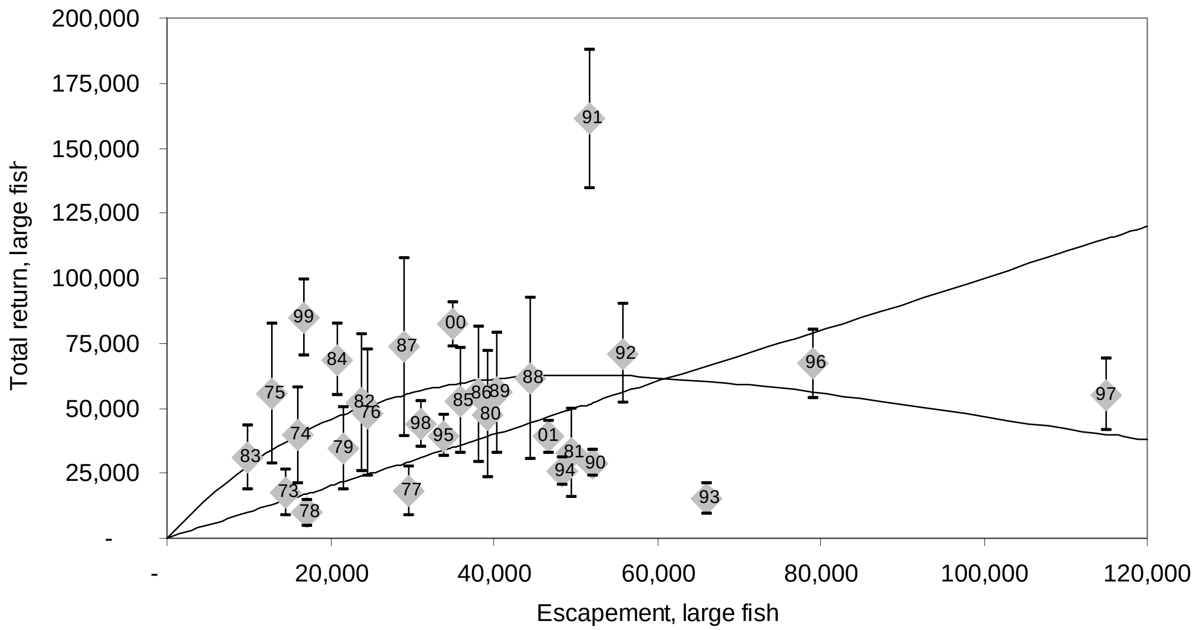


Figure 13.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1973–2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line. Spawners and recruits are from Table 8 for the EF = 5.20 for survey counts.

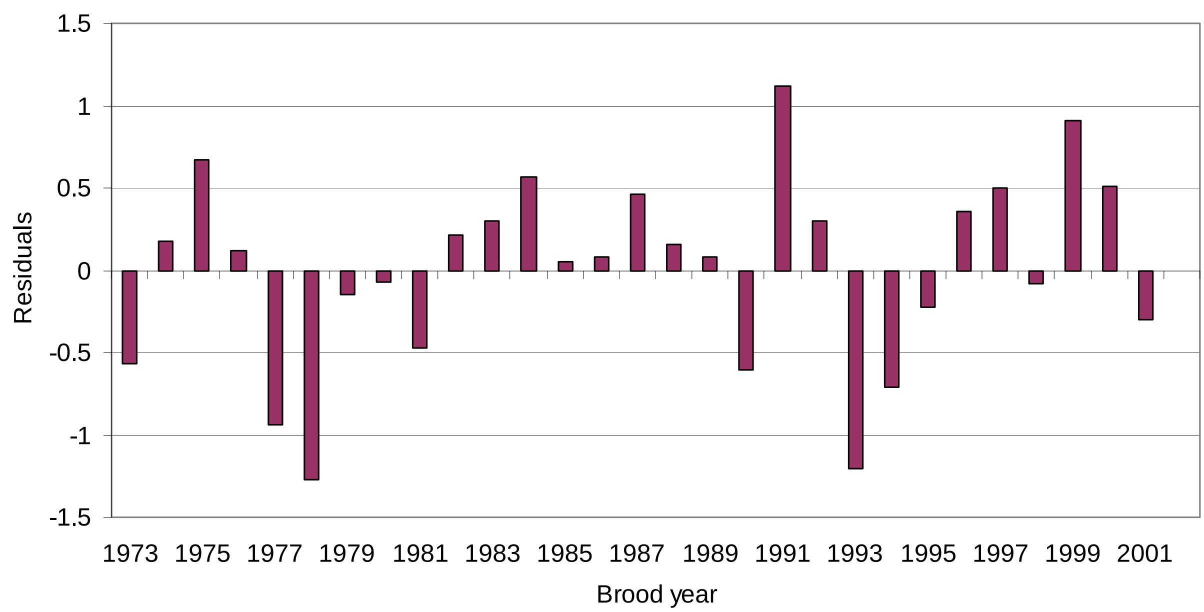


Figure 14.–Estimated residuals of the log-transformed fit of the Ricker model to production of age-1.3 to -1.5 Chinook salmon in year classes 1973–2001 against the estimated abundance of large spawning Chinook salmon. Data set used is from Table 8 for the EF = 5.20 in years without mark–recapture estimates.

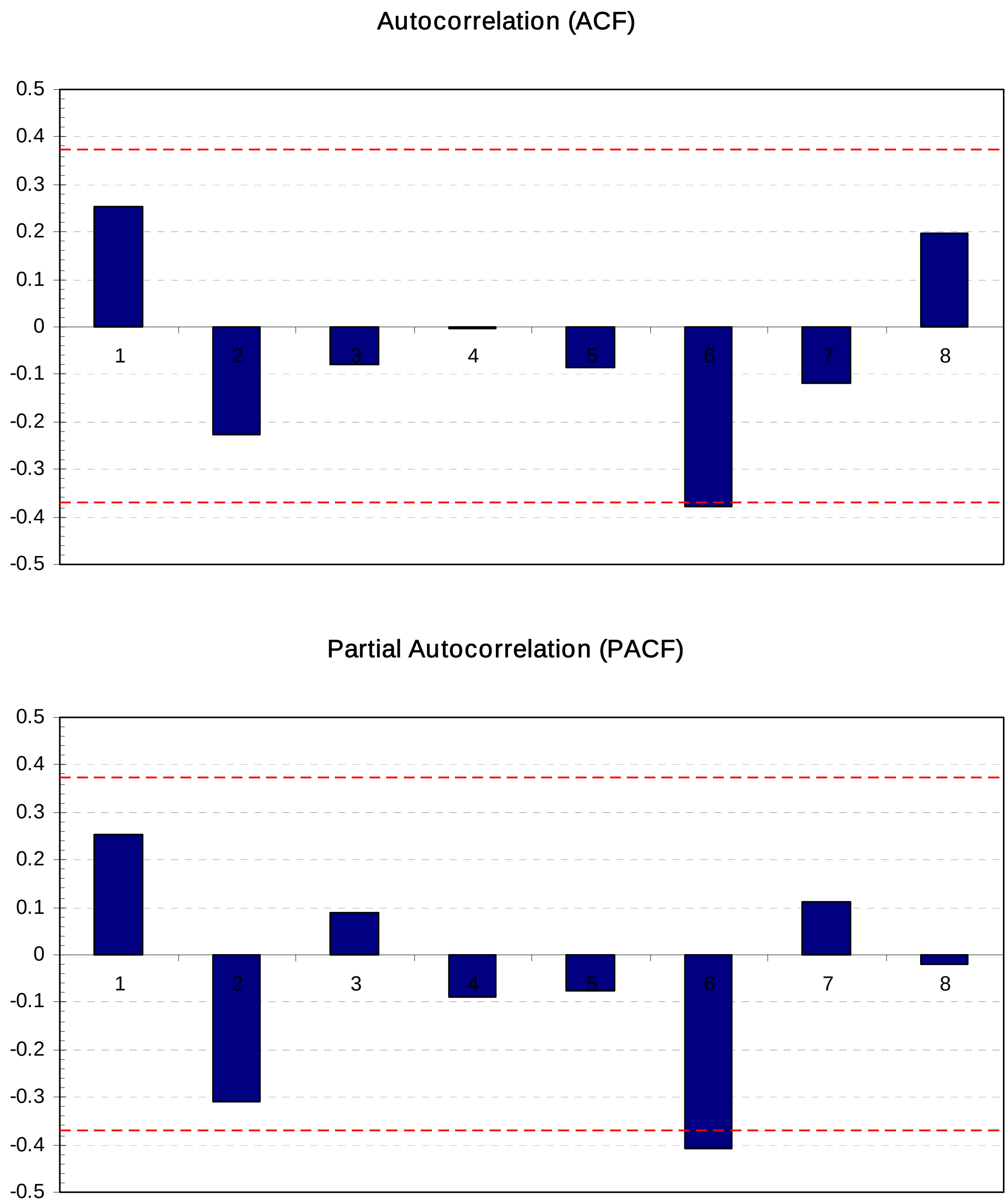


Figure 15.–ACF and PACF plots for stock-recruit data in Figure 13.

Estimation of Ricker parameters via simple linear regression (SLR) assumes known values of the independent variable N_y. However estimates of N_y are subject to measurement error. As per Bernard et al. (2000), log-normal measurement error can be estimated when sampling variances are calculated. For measurement error in spawning abundance

$$V[\ln(\hat{N})] = V[\ln(\hat{N})] + \sigma_u^2 . \qquad (9)$$

These variances are unknown, but can be estimated as $v[\ln(\hat{N})]$ and $\hat{\sigma}_u^2$ such that:

$$v[\ln(\hat{N})] = \frac{\sum[\ln(\hat{N}_y) - \overline{\ln(\hat{N})}]^2}{n-1} = 0.2728$$

$$\hat{\sigma}_u^2 = \frac{\sum \hat{\sigma}_{u,y}^2}{n} = \frac{cv^2(\hat{N}_y)}{n} = 0.0461.$$

Note these calculations show estimated measurement error, for the 1983–2001 year classes, composed 17% (= 0.0461/0.2728) of all variation in estimated spawning abundance. Log-normal measurement error in estimates of production was estimated as (Bernard et al. 2000):

$$\hat{\sigma}_v^2 = \frac{\sum \hat{\sigma}_{v,y}^2}{n} \qquad (10)$$

$$\hat{\sigma}_{v,y}^2 = v[\ln(\hat{R}_y)] \cong v(\hat{R}_y)\hat{R}_y^{-2} = cv^2(\hat{R}_y) .$$

for the population in the Taku River, $\hat{\sigma}_v^2 =$ 0.0162 for the 1983–2001 year classes. Estimated measurement error for the estimated log of the production-to-spawner ratio $\hat{R}_y \big/ \hat{N}_y$ is $\hat{\sigma}_{uv,y}^2 = cv^2(\hat{R}_y) + cv^2(\hat{N}_y)$. The average for the 1983–2001 year classes is $\hat{\sigma}_{uv}^2 = 0.0624$.

The magnitude of measurement error in estimates of production and spawning abundance for this stock has dropped substantially for all 3 calculations when compared to the values in McPherson et al. (2000). Corresponding values for the 1973–1991 dataset were 60% (=0.1832/0.3033), 0.0583, and 0.2415.

Despite the improvement, the measurement error CV in the spawning abundance estimates is 25% for years with aerial survey counts but no direct estimates (Table 1). This level of error has some potential to affect the stock-recruit analysis by biasing the estimate of optimal escapement and underestimating the associated uncertainty. Depending on factors like historical harvest rate, serial correlation, and the amount of measurement error, the bias can be in either direction (Kehler et al. 2002; Kope 2006). For this reason, we conducted an age-structured Bayesian analysis of the stock-recruit data using Markov chain Monte Carlo (MCMC) techniques (Appendix F). This analysis explicitly specifies the existence of measurement error in the statistical model and thereby produces estimates that take such error into consideration.

In our case, the MCMC analysis corroborated the results of the simpler analysis, suggesting that measurement error does not wield major influence for this data set. Based on the Bayesian analysis, the proposed escapement goal of 19,000 to 36,000 is 90% certain to achieve >90% of *MSY* at the lower end, and about 25% certain to exceed 90% of *MSY* at the upper end of the escapement goal range (Figure 16; see Appendix F for details).

OTHER STOCK-RECRUIT ANALYSES

Spawner-recruit models were fit to the smolt data. This subset of 14 or 16 of the 29 available year classes (the others do not have smolt information) showed varying results. A Beverton-Holt model was fit to the smolt data set with 16 year classes using a least squares approach and is shown in Figure 9 using methods in Quinn and Deriso (1999). The point estimate was 16,084 large spawners using an empirical fit, and 20,720 when measurement error was incorporated. This latter estimate is below the point estimate from the Ricker model, which is typical, by about 20% in this case. Fourteen of these year classes, excluding 2002 and 2003, have observed adult returns. When these are fit using a 2-parameter Ricker lognormal model (see section below for methods), $\hat{N}_{MSY}$ is 27,019 fish, which is slightly higher than estimates from the longer time series because of exclusion of the earlier year classes with smaller parent-year escapements. Incorporation of a marine survival covariate yields an $\hat{N}_{MSY}$ estimate of 29,667 fish. This subset of 14 year classes excludes over half of the total time series.

Questions were raised during review regarding an analysis using females as the parent stock versus adult returns of large fish, and analyses utilizing large spawners versus large fish plus age-1.2 males in recruitment. Using females as the spawning stock with the 1983–2001 year classes, $\hat{N}_{MSY.females}$ is 13,331 females. Because females average 51.9% of the large spawning population from 1983–2007, this translates to $\hat{N}_{MSY}$ of 25,703 large spawners. This is very close the estimate for this time series without segregating females. The point of consideration in this exercise is that management of the resource should be prosecuted to maintain the approximate 1:1 rate of large females to large males in the spawning population. Analyses that included age-1.2 fish (almost all males) were done for both the 1973–2001 and 1983–2001 year classes. The estimated $\hat{N}_{MSY}$ was 23,144 large spawners for the 1973–2001 year classes, and 24,779 large spawners for the shorter time series. Age-1.2 fish comprised an estimated 22% of returns in the longer times series and 19% of the shorter times series.

Parken et al. (2006) conducted a meta-analysis of 25 Chinook salmon stocks distributed from central Alaska to northern Oregon, and developed an allometric model to predict N_{MSY} from the watershed area. The Taku watershed area is estimated to be 17,097 km^2 after accounting for blockages in the Taku River, which are few (described in Parken et al. 2006, p. 59). This translates to an N_{MSY} estimate of 16,964 age-1.2 and older fish, with a 90% interval estimate of 6,262 to 45,955. Inherently, the watershed-based estimate is inflated through inclusion of age-1.2 fish, yet there is still substantial potential for overlap with the current 90% interval estimate of 18,470 to 36,530 large spawning Chinook salmon from Table F4.1. We conclude that our results are consistent with the watershed model of Parken et al. (2006), considering the confidence intervals of both methods.

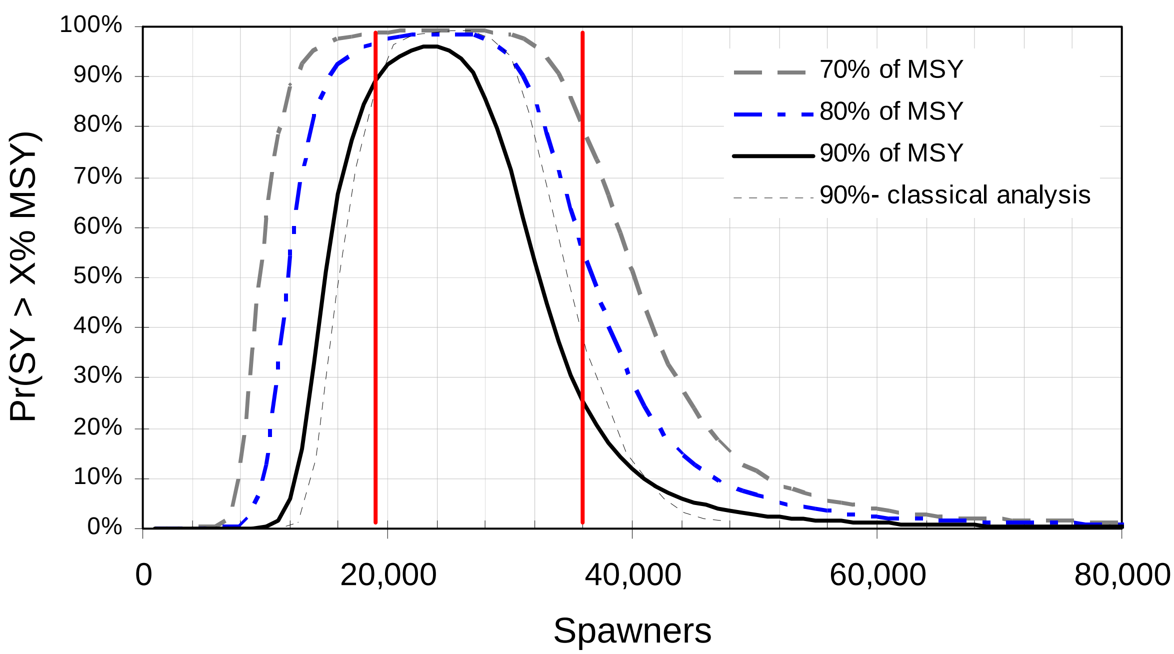


Figure 16.–Probability that a specified spawning abundance will result in sustained yield exceeding 70%, 80%, and 90% of maximum sustained yield, Taku River Chinook salmon (solid lines). The equivalent 90% profile from the classical (non-Bayesian) analysis is shown for comparison as a dashed line. Vertical lines bracket the proposed escapement goal range.

Stability of environment, at least around average conditions, is presumed under traditional statistical analysis of stock-recruit data; the same is true for this scientific analysis of information for the stock of Chinook salmon from the Taku River. Evidence in our data for such stability is that:

- Smolt sizes were essentially the same for early and late year classes in the series;
- Maximum production of smolt is similar across both time and a large range of spawning abundance; and
- There was negligible or no loss of habitat during our series from land development, land use, or human habitation.
- No autocorrelation was present in either data set of adult production data, 1973–2001 or 1983–2001, indicating stationarity in the production regime.

Evidence in our data against such stability of environment can be found in the marine survival for the 1991 year class (0.077) which was 77% higher ($P < 0.02$) than the average for year classes 2 decades earlier (0.039). However, the 1991 year class is an outlier and other year classes from 1992 to 2007 have not returned at the same rate as the 1991 year class; average survival has been 3.5% since 1991. Hence, we see no evidence that survival rates have changed over the 2 decades in this data set.

All ongoing scientific investigations improve with the addition of new information; this was indeed true for this investigation, as predicted in McPherson et al. (2000). The completion of returns from the 1996 and 1997 year classes doubled the contrast in spawning escapements (9.7 vs. 5.3). Precision of all statistics for adults has markedly improved with the inclusion of an additional 10 years of data with mark–recapture estimates of escapement, improved sampling of fisheries for age structure, and higher numbers of CWT smolt each spring for estimating smolt and harvest magnitude. We found that the very large escapement seen in 1997 did not increase smolt production over what was seen in the previous stock-recruit analysis.

The addition of more precise data, along with large escapements, did not result in an increase in the prescribed escapement goal and range. Rather it did the opposite, as the large escapements failed to replace themselves. The previous goal essentially maximized smolt production and theoretically adult production. The current analysis estimates that maximum production occurs at about 42,000 large spawning Chinook salmon, which is centered in the existing range of 30,000 to 55,000. Additionally, the exploitation rate on this stock has been low, averaging 16%, which would produce a stock varying about equilibrium and is likely responsible for the relatively low return-per-spawner rates, which average 1.6:1. This indicates that this stock can support additional harvest, although natural fluctuations in abundance may preclude additional harvests in some future years.

Managing for the recommended escapement goal range of 19,000 to 36,000 large spawning Chinook salmon is not beyond the capability of ADF&G and DFO, given refinement of our stock assessment program. Preseason forecasts of terminal run are completed by December 1. Inseason estimates of the terminal run abundance are made on a weekly basis beginning in the middle of May, using information from terminal fisheries and inriver gillnet commercial or assessment fisheries. These methods are proven, correctly allowing directed fisheries in 2005 and 2006 and not allowing directed fisheries in 2007 and 2008.

CONCLUSIONS

Given 10 additional years of adult spawner-recruit data since the previous analysis, the most defensible estimate for N_{MSY} is a range from 19,000 to 36,000 large spawning Chinook salmon and a point estimate of 25,500, estimated as total escapement using mark–recapture methods. The lower end of the range is similar to the numeric values estimated to produce 95% of *MSY*; the upper end is similar to the numeric values estimated to produce 90% of *MSY* (Table 11). Both ends of the range match closely to the 90% confidence interval estimated from simulation incorporating measurement error in statistics for spawners and recruits (Table 11 and Appendix F).

Measurement error in spawning abundance for this data set accounts for 17% of all variation in spawning abundance, compared to 60% estimated 10 years ago (McPherson et al. 2000). Estimated log-normal measurement error in adult returns has dropped to $\hat{\sigma}_v^2$ = 0.0162 for this time series versus 0.0583 as seen 10 years ago, or an average CV of 12%. Likewise, the estimated measurement error for the log of the production-to-spawning Chinook salmon ratio is 0.0624 for the 1983–2001 year classes versus 0.2415 seen 10 years ago. An important aspect of this analysis was the addition of the 1996 and 1997 year classes. Both data points were measured precisely for large spawning Chinook salmon and returns, increased the contrast in spawning escapements to 10:1 (114,938/11,881), and helped define the right side of the production relationship and balance the high production from the 1991 year class. Results of an age-structured Bayesian analysis that considered the effect of measurement error corroborated the results (Appendix F).

Inspection of the empirical data in Figure 10 supports the recommendations. The estimated escapement in 1988 was 44,819 large fish, very close to the number of large spawning Chinook salmon estimated to produce maximum production (42,142) from the fit. Beyond this spawning level are 9 empirical data points, 7 of which did not replace themselves. Beneath this spawning level are 16 data points, of which 14 were above replacement. Escapement levels below 16,000 large spawning Chinook salmon are considered risky because survival in freshwater has a significant density-independent component.

The historical data for the 1973–2001 year classes contains 29 data points within and outside of the recommended escapement goal range (see below).

Esc range	Large spawners	Large total return	Return per spawner	n years
<19,000	14,882	40,040	2.7	6
19K to 36K	28,110	53,979	1.9	8
>36,000	55,448	56,144	1.1	15

The 6 escapements below 19,000 large spawners produced an average total return of 40,000 large fish and 2.7 returns per spawner. The 8 escapements within the recommended range produced total returns averaging 54,000 large fish and about double the parent escapements. For the 15 escapements above the recommended range, total returns averaged about 56,000 large fish, or about replacement.The estimated exploitation rate associated with N_{MSY} is 0.59 (= $\hat{E}_{MSY}$) for the 1983–2001 year classes, and 0.51 for 1973–2001. These are similar to the rate reported in McPherson et al. (2000). The average estimated exploitation rate for the Taku River stock is 16% (Table 9), substantially less than the above rate. Experience has shown that due to variation in run strength, coupled with errors in forecasts and management, that observed exploitation rates in an intensively managed stock will average less than the rate associated with N_{MSY}.

The deterioration in the relationship between Nakina-inclusive survey counts and the mark–recapture estimates (i.e., the expansion factors) was disappointing. The primary reason is a decrease in counts on the Nakina River relative to counts in the other 5 tributaries. Though use of different expansion factors for years without mark–recapture estimates had little effect on estimates of N_{MSY}, there has been an apparent shift in spawning distribution in the Taku River. This shift occurred before the directed commercial fisheries were in place in 2004 and 2005, but management should continue to spread harvest of surplus production across all run segments. The aerial survey counts should continue as well, to track the substock abundance. In future analyses, it may be most appropriate to use the expansion factor of 5.20 for years without mark–recapture estimates (1993–1988, 1991–1994 and 1998) because we believe it to best represent the relationship between observer counts and total escapement prior to 2000. We conclude that the Taku River Chinook salmon stock has recovered from the low levels of escapement seen in the 1970s and for the past 2 decades has been at levels adequate to support an increase in exploitation rate. Escapements in the 1970s likely averaged about 20,000 large spawning Chinook salmon. In contrast, estimated escapements from 1990–2007 have averaged 50,000 large spawning Chinook salmon, a 2.5 fold increase.

RECOMMENDATIONS

Since this analysis will set the stage for future analysis and management, we recommend some strategies to support these endeavors.

We believe that long-term stock assessment programs should continue to be one of the highest priorities for ADF&G, DFO, TRTFN and the PSC. These types of programs provide essential information on the population dynamics of the resource. For the stock of Chinook salmon from the Taku River, we make the following recommendations:

- Enumeration of total spawning abundance from mark–recapture studies continue each year along with sampling on the spawning grounds.
- Aerial surveys be continued because they provide an important gauge of relative substock abundance.
- Biological sampling continue (and be improved in some cases) annually for all fisheries and during mark–recapture sampling for age, sex and length information as well as recovery of CWTs and other tags.
- Chinook salmon smolt continue to be CWT-marked each year with a target of 35,000 to 50,000, in order to provide the necessary levels of precision for estimating harvest, smolt abundance and survival.
- ADF&G and DFO adopt the range of 19,000 to 36,000 (point estimate = 25,500) large spawning Chinook salmon as the biological escapement goal for management of this stock.
- Preseason and inseason estimates of terminal run size and escapement continue with or without directed fisheries.
- Management actions conserve the early, middle and late run segments, and maintain the 1:1 ratio of females to males in large spawners, on average.

This escapement goal be reviewed in the next 5–10 years, incorporating additional data available.

ACKNOWLEDGMENTS

The authors thank Paul Kissner, formerly of ADF&G, for implementing the stock assessment program for Chinook salmon on the Taku River in the early 1970s. He standardized the aerial surveys in 1973, initiated age/sex/size sampling on the tributaries, and was responsible for the coded wire tagging and most of the adult recovery efforts for the 1975–1981 year classes. Sandy Johnston and Pat Milligan of DFO and Andy McGregor and Scott Kelley of ADF&G helped develop the current Chinook salmon stock assessment program on the Taku River. We thank Phil Timpany of TRTFN for his 30 years of participation in Chinook salmon stock assessment on the Taku River in various capacities for ADF&G, TRTFN and DFO. We thank Keith Pahlke for aerial surveys, assistance in field sampling and project design in the 1990s, and completion of the 1989 and 1990 mark–recapture analyses. The authors thank Dave Bernard for his assistance in analysis and reporting of the 1989 and 1990 mark–recapture studies; planning and analysis assistance with the 1995–1998 and 2003 studies and completion of previous stock-recruit analysis published in 2000. We thank Dan Reed for analysis assistance and reporting of the 1999–2002 and 2004–2007 mark–recapture studies and for providing variances for the expansion factors for aerial surveys used in this document. We thank Chuck Parken (DFO) for applying the habitat-based approach to the Taku River watershed. We thank the following project leaders for their efforts in stock assessment: Richard Yanusz, Dave Magnus, and James Andel (ADF&G); Richard Erhardt (TRTFN); contractor Brian Mercer (DFO); crew leaders Heather Stilwell, Jerry Owens, James Lobdell, and Mike Lafollette (ADF&G); Patrick Jackson, Rick Ferguson, Marty Strachan, Sean Stark, Scott Herron, Matt Waugh, Al Mcleod, Tyler Rudolph, and Lars Jessup (DFO); Mark Connor, Terry Jack and Mike Smarch (TRTFN). We thank Dale Brandenburger, Al Demartini, Mark Olsen, Jarbo Crete, David Dreyer, Shane Rear, Krista Kissner, Jaime Kissner, Christie Hendrich, Kercia Schroeder (Rear), and Nicole Zeiser (ADF&G) and Kirstie Falkevitch and Mark McFarland (DFO) for smolt tagging since 1993. Sue Millard, Mark Olsen, and Darlene Gillespie, along with and other personnel from the DFO Nanaimo Lab, performed most of the scale age analyses over the years. Brian Riddell, Dave Bernard, Blair Holtby and members of the PSC Chinook Technical and Transboundary Technical committees and Transboundary panel provided helpful review comments on this manuscript. The assistance of John Clark and Frank Quinn in the review process is appreciated. Joanne MacClellan prepared the final layout of this manuscript. This work was partially funded by aid authorized under the U.S. Federal Sport Fish Restoration Act, by Canadian funding through DFO and TRTFN, and by recreational anglers fishing in Alaska. We also extend our sincere appreciation to the local residents, industry representatives and others who have asked for responsible stewardship of the salmon resources produced by the Taku River.

REFERENCES CITED

ADF&G (Alaska Department of Fish and Game). 1981. Proposed management plan for Southeast Alaska Chinook salmon runs in 1981. Southeast Region, Alaska Department of Fish and Game Division of Commercial Fisheries. Regional Report 1J81-3, Juneau.

Bernard, D. R., and J. E. Clark. 1996. Estimating salmon harvest based on return of coded-wire tags. Canadian Journal of Fisheries and Aquatic Sciences 53:2323-2332.

Bernard, D. R., S. A. McPherson, K. A. Pahlke, and P. Etherton. 2000. Optimal production of Chinook salmon from the Stikine River. Alaska Department of Fish and Game, Fishery Manuscript No. 00-1, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fms00-01.pdf

Boyce, I. M., S. A. McPherson, D. R. Bernard, and E. L. J. III. 2006. Spawning abundance of Chinook salmon in the Taku River in 2003. Alaska Department of Fish and Game, Fishery Data Series No. 06-16, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds06-16.pdf

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1:131-160.

Draper, N. R., and H. Smith. 1981. Applied regression analysis, 2nd edition. John Wiley and Sons, New York

Efron, B., and R. J. Tibshirani. 1993. 1st edition. An introduction to the bootstrap. Chapman and Hall, New York, NY

Eiler, J., M. M. Masuda, J. Pella, H. R. Carlson, R. F. Bradshaw, and B. D. Nelson. In prep. Stock composition, escapement estimate, and timing of Chinook salmon returns in the Taku River, Alaska and British Columbia. National Marine Fisheries Service Technical Report, Juneau.

Ericksen, R. P., and S. J. Fleischman. 2006. Optimal production of coho salmon from the Chilkat River. Alaska Department of Fish and Game, Fishery Manuscript No. 06-06, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fms06-06.pdf

Gilks, W. R., A. Thomas, and D. J. Spiegelhalter. 1994. A language and program for complex Bayesian modeling. The Statistician 43:169-178. http://www.mrc-bsu.cam.ac.uk/bugs Accessed 01/2010.

Hilborn, R. 1985. Simplified calculation of optimum spawning stock size from Ricker's stock-recruitment curve. Canadian Journal of Fisheries and Aquatic Sciences 42:1833-4.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York.

Hubartt, D. J., A. E. Bingham, and P. M. Suchanek. 1999. Harvest estimates for selected marine sport fisheries in Southeast Alaska during 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-15, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds99-15.pdf

Jones III, E. L., S. A. McPherson, D. R. Bernard, and I. Boyce. In prep. Spawning abundance of Chinook salmon in the Taku River 1999-2007. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

Kehler, D. G., R. A. Myers, and C. A. Field. 2002. Measurement error and bias in the maximum reproductive rate for the Ricker model. Canadian Journal of Fisheries and Aquatic Sciences 59:854-864

Kissner, P. D. 1976. Status of important native Chinook salmon stocks in Southeastern Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1976-1977, Project F-9-8(17) AFS 41-4b, Juneau.

Kissner, P. D. 1982. A study of Chinook salmon in Southeast Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1981-1982, Project F-9-14(23)AFS-41-1, Juneau.

Kissner, P. D., and D. J. Hubartt. 1986. Status of important native Chinook salmon stocks in Southeast Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27 (AFS-41-13), Juneau. http://www.sf.adfg.state.ak.us/FedAidPDFs/FREDf-10-1(27)AFS-41-13.pdf

REFERENCES CITED (Continued)

Kope, R. 2006. Cumulative effects of multiple sources of bias in estimating spawner–recruit parameters with application to harvested stocks of Chinook salmon (Oncorhynchus tshawytscha). Fisheries Research 82:101-110.

McPherson, S. A., D. R. Bernard, and J. H. Clark. 2000. Optimal production of Chinook salmon from the Taku River. Alaska Department of Fish and Game, Fishery Manuscript No. 00-2, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fms00-02.pdf

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1996. Spawning abundance of Chinook salmon in the Taku River in 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-36, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds96-36.pdf

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1997. Spawning abundance of Chinook salmon in the Taku River in 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-14, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds97-14.pdf

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1998. Spawning abundance of Chinook salmon in the Taku River in 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-41, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds98-41.pdf

Millar, R. B. 2002. Reference priors for Bayesian fisheries models. Canadian Journal of Fisheries and Aquatic Sciences 59:1492-1502.

Moser, J. F. 1899. The salmon and salmon fisheries of Alaska. Report of the operations of the United States fish commission steamer Albatross for the year ending June 30, 1898. U.S. Fisheries Commission, Vol. 18. Washington, Govt. Print Office, Washington D.C.

Orsi, J. A., E. A. Fergusson, M. V. Sturdevant, B. L. Wing, A. C. Wertheimer, and W. R. Heard. 2005. Survey of juvenile salmon and associated epipelagic ichtyofauna in the marine waters of southeastern Alaska, May-August 2004. North Pacific Anadromous Fish Commission, Doc. 871. Auke Bay Lab., Alaska Fisheries Science Center, NMFS, NOAA, Juneau.

Pahlke, K. A. 1998. Escapements of Chinook salmon in Southeast Alaska and transboundary rivers in 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-33, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds98-33.pdf

Pahlke, K. A. 2008. Escapements of Chinook salmon in Southeast Alaska and transboundary rivers in 2006. Alaska Department of Fish and Game, Fishery Data Series No. 08-20, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds08-20.pdf

Pahlke, K. A., and D. R. Bernard. 1996. Abundance of the Chinook salmon escapement in the Taku River, 1989 to 1990. Alaska Fishery Research Bulletin 3(1):8-19, Juneau.

Pahlke, K. A., and D. R. Bernard. 1996. Abundance of the Chinook salmon escapement into the Taku River, 1989-1990., Alaska Fisheries Research Bulletin 3:9-20.

Parken, C. K., R. E. McNicol, and J. R. Irvine. 2006. Habitat-based methods to estimate escapement goals for data limited Chinook salmon stocks in British Columbia, 2004. Department of Fisheries and Oceans, Canadian Scientific Advisory Secretariat Research Document 2006/083.

Quinn, T. J., II, and R. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:382.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, 2nd edition. Griffin and Company, Ltd. London.

Szarzi, N. J., S. J. Fleischman, R. A. Clark, and C. M. Kerkvliet. 2007. Stock status and recommended escapement goal for Anchor River Chinook salmon. Alaska Department of Fish and Game, Fishery Manuscript No. 07-05, Anchorage. http://www.sf.adfg.state.ak.us/FedAidpdfs/fms07-05

TTC (Transboundary Technical Committee). 1991. Escapement goals for Chinook salmon in the Alsek, Taku, and Stikine rivers. Transboundary Technical Committee of the Pacific Salmon Commission, Vancouver, British Columbia. Report TCTR (91)-4.

TTC (Transboundary Technical Committee). 1999. Salmon management and enhancement plans for the Stikine, Taku and Alsek rivers, 1999. Pacific Salmon Commission, Transboundary Technical Committee Report, TCTR (99)-2.

APPENDIX A.
EXPANSION FACTORS AFFECTING ESCAPEMENTS AND PARAMETER ESTIMATES FOR CHINOOK SALMON FROM THE TAKU RIVER

As mentioned above, since 1973, escapements to the Taku River have been assessed with aerial surveys from helicopters by counting large Chinook salmon by flying over sections of the Nakina, Nahlin, Kowatua, Tatsamenie, and Dudidontu rivers, and after 1981, Tseta Creek, according to fixed schedules and protocols (Pahlke 1998). Peak counts for the 6 tributaries have historically been dominated by the Nakina count (Table A1). Peak counts were found to be highly correlated across 5 of the 6 tributaries in the previous stock-recruit analysis (McPherson et al. 2000), indicating the relative strengths of year classes were the same throughout the Taku River. At that time, the sum of peak counts from the Nakina, Nahlin, Kowatua, Tatsamenie and Dudidontu rivers was used to develop an expansion factor of 5.20 for that sum to estimate escapements in years without capture-recapture studies. In the succeeding years, we have found that the previous relationship has deteriorated, with the Nakina River count a smaller fraction of surveys counts and mark–recapture estimates (Table A2, Figure A1). This change could be due to multiple factors, including a change in spawning distribution, changes in environment, and factors affecting the efficiency of counting Chinook salmon. The Nakina is the most challenging of the 6 surveys conducted annually on the Taku River (K. Pahlke, ADF&G, Division of Sport Fish, Douglas, personal communication).

We developed an alternate index that includes survey counts from 5 tributaries: Nahlin, Kowatua, Tatsamenie and Dudidontu rivers plus Tseta Creek. Nakina River counts were removed from this index, while Tseta Creek was added. Equations used for expansion factors are in Table A3, using methods in Pahlke (2008), Appendix B1. The alternate (non-Nakina) index, resulting in an expansion factor of 10.86 (SE = 2.71), was more stable (slope not significantly different from zero) and had better precision than the previous (non-Tseta) expansion factor of 5.20 (SE = 1.99) used in McPherson et al. (2000) for the first 5 years with mark–recapture estimates (Figure A2, Tables A4 and A5). Because surveys over Tseta Creek began in 1981, 8 years after the start of surveys elsewhere, we cannot provide consistent estimates of escapement from 1973–1980 using the expansion factor of 10.86 for the non-Nakina index. Our preferred estimates of escapement for 1973–1980 are those derived from the non-Tseta expansion factor of 5.20, and though these estimates are apparently less precise, they may be more accurate.

We also updated the non-Tseta expansion factor to include the 8 recent mark–recapture studies, even though we are aware of its increased variability. The average expansion factor climbed to 6.53 (SE = 2.15) over the previous 5.20 (Table A4). Our intention was to create a different production data set and determine what the magnitude of change was on stock-recruit parameter estimates. Results are presented in Table A6. We do not recommend use of this expansion factor nor the resultant parameter estimates for setting management benchmarks for this stock.

Estimated Spawning Escapement and Production

The estimated spawning abundances of large Chinook salmon from 1981–2007, using the non-Nakina expansion factor of 10.86, is shown in Table 2 of this report. Spawning abundance by age based on an expansion factor of 5.20 is shown in Table 3, and the associated SEs by age are shown in Table C3 of this report. The estimated spawning abundances of large Chinook salmon for 1973–2007, using both of the non-Tseta expansion factors of 5.20 and 6.53 are in Table A7 below. Estimated stock-recruit data for all 3 expansion factors are in Table A8 and the data sources for each are cited. The returns of large fish for all 3 data sets all use the harvests in Table 5. The year class production (returns) is different for each data set because estimated escapement is estimated differently for years without mark–recapture estimates. Estimates of returns in escapements by age for the data sets with the non-Tseta expansion factors are shown in Tables A9 and A11 and their associated SEs in Tables A10 and A12. Escapements by age were all estimated by the product of the estimated large spawners and the multipliers in Table C2; the magnitude of associated SEs by age were a function of the variance of the escapement estimates and the SEs in Table C2.

Estimated Stock-Recruit Parameters

We fit the log-normal Ricker curve to the data sets created from the 3 expansion factors. Because of the different initial years for the non-Nakina and non-Tseta expansion factors, we fit 2 time series to determine the net effect of differing time series and production estimates on stock-recruit parameter estimates. We recognize that none of these data sets are independent as the mark–recapture estimates do not vary between them and the 1973–2001 and 1983–2001 time series overlap.

Some stock-recruit parameters were relatively insensitive to changes in expansion factors, while others were not (Table A8). For example, point estimates of $\hat{N}_{MSY}$ varied between 25,075 and 26,482 over the 5 fits, and estimated replacement ranged between 63,185 and 66,147 large fish. Estimated productivity differed between the fits for the 1973–2001 vs. 1983–2001 year classes. For example, the productivity parameter alpha averaged about 4.5 for the 3 fits to the 1983–2001 year classes versus 3.5 for the longer, less precise, time series. Additionally, our test of using the EF = 6.53 resulted in higher estimates of production for years without mark–recapture estimates vs. the other 2 expansion factors, but did not change estimated $\hat{N}_{MSY}$ (see Figures A3 and A4, compared to Figure 10 in the main body of the report), for the 1983–2001 year classes. The same is true for the 1973–2001 year classes, as shown in Figures A5 and A6.

In conclusion, we believe that the expansion factors of 5.20 (without Tseta Creek) and 10.86 (without Nakina) both have merit for estimating escapements in years without mark–recapture estimates. The expansion factor of 10.86 is statistically more precise than the expansion factor of 5.20; however, it produces higher estimates in most years, particularly in 1998, and therefore may overestimate productivity, though differences are slight in most years. Use of the above 2 expansion factors produced similar estimates for management of the stock and is the best production data set available to develop stock-recruit parameters for Chinook salmon spawning in the Taku River. Measurement error has been minimized to the extent possible, most of the range in spawning stock size is well represented (particularly with the 1973–2001 time series). With either expansion factor, a high level of spawning contrast was achieved (10:1 and 12:1), which is desirable in any spawner-recruit analysis.

Table A1.–Peak counts of Chinook salmon from standardized aerial surveys by year in 6 tributaries of the Taku River. Estimates in italics are imputed.

Year	Nakina River	Nahlin River	Kowatua River	Tatsamenie River	Dudidontu River	Tseta Creek	Total	Total without Tseta	Total without Nakina
1973	2,000	300	100	200	200		2,800	2,800	
1974	1,800	900	235	120	24		3,079	3,079	
1975	1,800	274	*157*	*235*	15		2,481	2,481	
1976	3,000	725	341	620	40		4,726	4,726	
1977	3,850	650	580	573	18		5,671	5,671	
1978	1,620	624	490	550	*8*		3,292	3,292	
1979	2,110	857	430	750	9		4,156	4,156	
1980	4,500	1,531	450	905	158		7,544	7,544	
1981	5,110	2,945	560	839	74	258	9,786	9,528	4,676
1982	2,533	1,246	289	387	130	228	4,813	4,585	2,280
1983	968	391	171	236	117	179	2,062	1,883	1,094
1984	1,887	951	279	616	*262*	176	4,171	3,995	2,284
1985	2,647	2,236	699	848	475	303	7,208	6,905	4,561
1986	3,868	1,612	548	886	413	193	7,520	7,327	3,652
1987	2,906	1,122	570	678	287	180	5,743	5,563	2,837
1988	4,500	1,535	1,010	1,272	243	66	8,626	8,560	4,126
1989	5,141	1,812	601	1,228	204	494	9,480	8,986	4,339
1990	7,917	1,658	614	1,068	820	172	12,249	12,077	4,332
1991	5,610	1,781	570	1,164	804	224	10,153	9,929	4,543
1992	5,750	1,821	782	1,624	768	313	11,058	10,745	5,308
1993	6,490	2,128	1,584	1,491	1,020	491	13,204	12,713	6,714
1994	4,792	2,418	410	1,106	573	614	9,913	9,299	5,121
1995	3,943	2,069	550	678	731	786	8,757	7,971	4,814
1996	7,720	5,415	1,620	2,011	1,810	1,201	19,777	18,576	12,057
1997	6,095	3,655	1,360	1,148	943	648	13,849	13,201	7,754
1998	2,720	1,294	473	675	807	360	6,329	5,969	3,609
1999	1,900	532	561	431	527	221	4,172	3,951	2,272
2000	2,907	728	702	953	482	160	5,932	5,772	3,025
2001	1,552	935	1,050	1,024	479	202	5,242	5,040	3,690
2002	4,066	1,099	945	1,145	834	192	8,281	8,089	4,215
2003	2,126	861	850	1,000	644	436	5,917	5,481	3,791
2004	4,091	1,787	828	1,396	1,036	906	10,044	9,138	5,953
2005	1,213	471	833	1,146	318	215	4,196	3,981	2,983
2006	1,900	955	1,180	908	395	199	5,537	5,338	3,637
2007[a]	77	277	262	390	4	-	1,010	1,010	933
2008	1,437	1,185	632	1,083	480	497	5,314	4,817	3,877
Averages									
1973–2006	3,560	1,451	659	880	461	362	7,287	7,010	
1981–2006	3,860	1,671	755	998	584	362	8,232	7,869	4,372
1999–2006	2,469	921	869	1,000	589	316	6,165	5,849	3,696

[a] The 2007 counts were severely hampered by snow-melt levels higher than any recorded in this time series and were not used in calculating expansion factors.

Table A2.–Two combined index counts of Chinook salmon in the Taku River, the percent of escapement represented by them and the Nakina count.

Year	Five tributary index total (without Tseta)	Five tributary index total (without Nakina)	Estimated escapement[a]	Percent escapement without Tseta	Percent escapement without Nakina	Nakina count as percent of escapement
1973	2,800		14,564	19%		14%
1974	3,079		16,015	19%		11%
1975	2,481		12,920	19%		14%
1976	4,726		24,582	19%		12%
1977	5,671		29,497	19%		13%
1978	3,292		17,124	19%		9%
1979	4,156		21,617	19%		10%
1980	7,544		39,239	19%		11%
1981	9,528	4,676	49,559	19%		10%
1982	4,585	2,280	23,848	19%	10%	11%
1983	1,883	1,094	9,794	19%	11%	10%
1984	3,995	2,284	20,778	19%	11%	9%
1985	6,905	4,561	35,916	19%	13%	7%
1986	7,327	3,652	38,111	19%	10%	10%
1987	5,563	2,837	28,935	19%	10%	10%
1988	8,560	4,126	44,524	19%	9%	10%
1989	8,986	4,339	**40,329**	22%	11%	13%
1990	12,077	4,332	**52,142**	23%	8%	15%
1991	9,929	4,543	51,645	19%	9%	11%
1992	10,745	5,308	55,889	19%	9%	10%
1993	12,713	6,714	66,125	19%	10%	10%
1994	9,299	5,121	48,368	19%	11%	10%
1995	7,971	4,814	**33,805**	24%	14%	12%
1996	18,576	12,057	**79,019**	24%	15%	10%
1997	13,201	7,754	**114,938**	11%	7%	5%
1998	5,969	3,609	31,039	19%	12%	9%
1999	3,951	2,272	**16,786**	24%	14%	11%
2000	5,772	3,025	**34,997**	16%	9%	8%
2001	5,040	3,690	**46,544**	11%	8%	3%
2002	8,089	4,215	**55,044**	15%	8%	7%
2003	5,481	3,791	**36,435**	15%	10%	6%
2004	9,138	5,953	**75,032**	12%	8%	5%
2005	3,981	2,983	**38,725**	10%	8%	3%
2006	5,338	3,637	**42,296**	13%	9%	4%
2007	1,010	933	**14,854**			
Averages						
1973–2006	7,010	4,372	39,594	18%		10%
1981–2006	7,869	4,372	45,024	18%	10%	9%
2000–2006	6,120	3,899	**47,010**	13%	8%	5%

[a] For purposes of illustration, estimated escapements in this table are those from McPherson et al. (2000) for 1973–1988, 1991–1994 and 1998, using the expansion factor of 5.20 in that report. Estimated escapements in bold are mark–recapture estimates.

Table A3.–Equations used to expand counts C_t into estimates of abundance N_t of large (≥660 mm MEF) Chinook salmon spawning in the Taku River, where t is year, k is the number of years with mark–recapture experiments, π is the ratio (expansion factor) N_i/C_i where i denotes years with mark–recapture experiments.

	Statistic	Estimated variance
Expansion	$\hat{N}_t = C_t\,\bar{\pi}$	$v(\hat{N}_t) = C_t^2 v(\pi)$
Mean expansion factor[a]	$\bar{\pi} = \frac{\sum_{i=1}^{k} \hat{\pi}_i}{k}$	$v\hat{a}r(\pi_p) = v\hat{a}r_B(\hat{\pi}) - \frac{\sum_{y=1}^{k} v\hat{a}r(\hat{\pi}_y)}{k} + v\hat{a}r_B(\bar{\pi})$
Estimated expansion factor for year *i*	$\hat{\pi}_i = \hat{N}_i C_i^{-1}$	$v(\hat{\pi}_i) = v(\hat{N}_i) C_i^{-2}$

[a] Methods for this variance calculation are detailed in Pahlke (2008), Appendix B1, developed by D. Reed, ADF&G, Division of Sport Fish, Nome.

Table A4.–Peak survey counts, mark–recapture (M-R) estimates, expansion factors (EFs) and for the escapement of large-sized Chinook salmon (≥660 mm MEF) in the Taku River, using the 5-tributary index without the Tseta Creek count.

Year	Survey count	(M-R) estimate	SE [M-R]	CV [M-R]	Percent counted	EF	SE[EF]	CV [EF]
1989	8,986	40,329	5,646	14.0%	22.3%	4.49	0.63	14.0%
1990	12,077	52,142	9,326	17.9%	23.2%	4.32	0.77	17.9%
1995	7,971	33,805	5,060	15.0%	23.6%	4.24	0.63	15.0%
1996	18,576	79,019	9,048	11.5%	23.5%	4.25	0.49	11.5%
1997	13,201	114,938	17,888	15.6%	11.5%	8.71	1.36	15.6%
1998	5,969	NE						
1999	3,951	16,786	3,171	18.9%	23.5%	4.25	0.80	18.9%
2000	5,772	34,997	5,403	15.4%	16.5%	6.06	0.94	15.4%
2001	5,040	46,544	6,766	14.5%	10.8%	9.23	1.34	14.5%
2002	8,089	55,044	11,087	20.1%	14.7%	6.80	1.37	20.1%
2003	5,481	36,435	6,705	18.4%	15.0%	6.65	1.22	18.4%
2004	9,138	75,032	10,280	13.7%	12.2%	8.21	1.12	13.7%
2005	3,981	38,725	4,908	12.7%	10.3%	9.73	1.23	12.7%
2006	5,338	42,296	5,535	13.1%	12.6%	7.92	1.04	13.1%
2007	NE	14,854	3,277	22.1%				
Averages								
1989, 90, 95–97	11,903	51,324		14.8%	20.8%	**5.20**	**1.99**[a]	38.2%
1999–2006	5,849	43,232		15.9%	14.5%	7.36		
1989–2006	8,277	51,238		15.4%	16.9%	6.53	2.15[a]	32.9%

[a] Standard error from D. Reed (ADF&G, Division of Sport Fish, Nome; Appendix B1 in Pahlke (2008)).

Table A5.–Peak survey counts, mark–recapture (M-R) estimates, expansion factors (EFs) and for the escapement of large-sized Chinook salmon (≥660 mm MEF) in the Taku River, using the 5-tributary index without the Nakina River count.

Year	Survey count	(M-R) estimate	SE [M-R]	CV [M-R]	Percent counted	EF	SE[EF]	CV [EF]
1989	4,339	40,329	5,646	14.0%	10.8%	9.29	1.30	14.0%
1990	4,332	52,142	9,326	17.9%	8.3%	12.04	2.15	17.9%
1995	4,814	33,805	5,060	15.0%	14.2%	7.02	1.05	15.0%
1996	12,057	79,019	9,048	11.5%	15.3%	6.55	0.75	11.5%
1997	7,754	114,938	17,888	15.6%	6.7%	14.82	2.31	15.6%
1998	3,609	NE						
1999	2,272	16,786	3,171	18.9%	13.5%	7.39	1.40	18.9%
2000	3,025	34,997	5,403	15.4%	8.6%	11.57	1.79	15.4%
2001	3,690	46,544	6,766	14.5%	7.9%	12.61	1.83	14.5%
2002	4,215	55,044	11,087	20.1%	7.7%	13.06	2.63	20.1%
2003	3,791	36,435	6,705	18.4%	10.4%	9.61	1.77	18.4%
2004	5,953	75,032	10,280	13.7%	7.9%	12.60	1.73	13.7%
2005	2,983	38,725	4,908	12.7%	7.7%	12.98	1.65	12.7%
2006	3,637	42,296	5,535	13.1%	8.6%	11.63	1.52	13.1%
2007	NE	14,854	3,277	22.1%				
Averages								
1989–2006	4,836	51,238		15.4%	9.8%	**10.86**	**2.71**[a]	24.9%

[a] Standard error from D. Reed (ADF&G, Division of Sport Fish, Fairbanks; Appendix B1 in Pahlke (2008)).

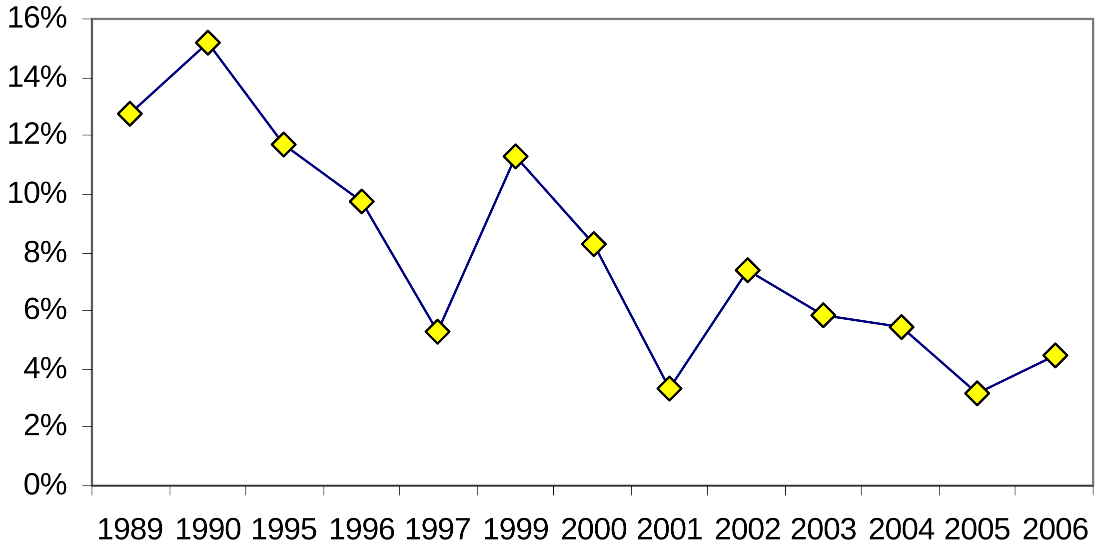


Figure A1.–Estimated percentage of the Nakina peak survey count against the abundance of large spawning Chinook salmon estimated from mark–recapture studies, 1989–2006.

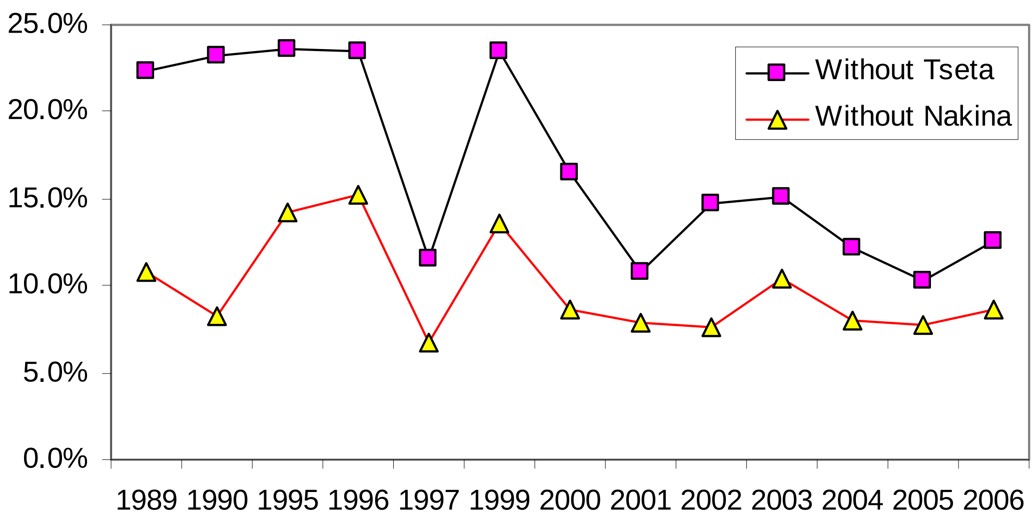


Figure A2.–Estimated percentage of the 2 survey indices against the abundance of large spawning Chinook salmon estimated from mark-recapture studies, 1989–2006.

Table A6.–Estimated parameters for 3 expansion factors (EFs) and 2 time series from the log-linear transform of Ricker's model on estimates of production and spawning abundance of large Chinook salmon in the Taku River. Production data are from Table A7 for the respective EFs.

Time Series >	1983–2001	1983–2001	1983–2001	1973–2001	1973–2001
EF	10.86[a]	5.20[b]	6.53[c]	5.20[b]	6.53[c]
$\ln(\hat{\alpha})$	1.3502 (P < 0.00020)	1.3133 (P = 0.00025)	1.3616 (P < 0.00026)	1.0408 (P = 0.00006)	1.1041 (P = 0.00005)
$\ln(\hat{\alpha})+\sigma_{\varepsilon}^2/2$	1.4993	1.4762	1.5124	1.2176	1.2683
$\hat{\alpha}$	4.4787	4.3761	4.5377	3.3791	3.5547
$\hat{\beta}$	0.00002373 (P=0.00046)	0.00002318 (P=0.00075)	0.00002286 (P=0.00043)	0.00001978 (P=0.00052)	0.00001981 (P=0.00021)
$1/\hat{\beta}$	42,142	43,132	43,736	50,553	50,478
$\hat{N}_{REPL}$	63,185	63,670	66,147	61,553	64,019
R^2(corrected)	0.4962	0.4673	0.4996	0.3408	0.3822
$\hat{\sigma}_{\varepsilon}^2$	0.2963	0.3257	0.3017	0.3586	0.3283
$\hat{\sigma}_{u}^2$	0.0461	0.0931	0.0729	0.1113	0.0852
$\hat{\sigma}_{v}^2$	0.0162	0.0245	0.0230	0.0387	0.0335
$\hat{N}_{MSY}$	25,075	25,379	26,193	25,686	26,482
90% CI	20,655 to 30,669	20,798 to 32,335		22,671 to 33,862	22,020 to 32,333
$\hat{N}_{MSY}$ (90% MSY)	16,178 to 35,203	16,384 to 35,588	16,911 to 36,838	16,740 to 35,611	17,247 to 36,849
Contrast $\hat{N}$	9.7	11.7	9.4	11.7	9.4
$\hat{E}_{MSY}$	0.59	0.59	0.60	0.51	0.51

[a] Includes escapement estimates in years without mark–recapture estimates from EF of 10.86 in Table A5 for Nahlin, Kowatua, Tatsamenie and Dudidontu rivers plus Tseta Creek, based on 13 years with mark–recapture.

[b] Includes escapement estimates in years without mark–recapture estimates from EF of 5.20 in Table A4 for Nakina, Nahlin, Kowatua, Tatsamenie and Dudidontu rivers, based on the first 5 years of mark–recapture estimates (McPherson et al. 2000).

[c] Includes escapement estimates in years without mark–recapture estimates from EF of 6.53 in Table A4 for Nakina, Nahlin, Kowatua, Tatsamenie and Dudidontu rivers, based on 13 years with mark–recapture estimates.

Table A7.–Combined peak counts from aerial surveys, estimated total spawning abundance $\hat{N}$ with associated standard errors for 2 expansion factors for large (≥660 mm FL) Chinook salmon spawning in the Taku River from 1973 through 2007. Statistics in bold face come directly from mark–recapture experiments; all other statistics are expanded from counts based either on the expansion factor of 5.20 (SE=1.99) or 6.53 (SE=2.15) for the 5-tributary index without the Tseta River count in Table A4 above.

		Expansion factor = 5.20			Expansion factor = 6.53		
Year	Counts	$\hat{N}$	SE($\hat{N}$)	CV	$\hat{N}$	SE($\hat{N}$)	CV
1973	2,800	14,564	5,565	38.2%	18,279	6,022	32.9%
1974	3,079	16,015	6,119	38.2%	20,101	6,622	32.9%
1975	2,484	12,920	4,937	38.2%	16,216	5,343	32.9%
1976	4,726	24,582	9,392	38.2%	30,853	10,165	32.9%
1977	5,671	29,497	11,270	38.2%	37,022	12,197	32.9%
1978	3,292	17,123	6,542	38.2%	21,491	7,081	32.9%
1979	4,156	21,617	8,259	38.2%	27,132	8,939	32.9%
1980	7,544	39,239	14,992	38.2%	49,250	16,226	32.9%
1981	9,528	49,559	18,935	38.2%	62,202	20,493	32.9%
1982	4,585	23,848	9,112	38.2%	29,932	9,862	32.9%
1983	1,883	9,794	3,742	38.2%	12,293	4,050	32.9%
1984	3,995	20,780	7,939	38.2%	26,081	8,593	32.9%
1985	6,905	35,916	13,722	38.2%	45,078	14,852	32.9%
1986	7,327	38,111	14,561	38.2%	47,833	15,759	32.9%
1987	5,563	28,935	11,055	38.2%	36,317	11,965	32.9%
1988	8,560	44,524	17,011	38.2%	55,882	18,411	32.9%
1989	8,986	**40,329**	**5,646**	**14.0%**	**40,329**	**5,646**	**14.0%**
1990	12,077	**52,142**	**9,326**	**17.9%**	**52,142**	**9,326**	**17.9%**
1991	9,929	51,645	19,732	38.2%	64,820	21,356	32.9%
1992	10,745	55,889	21,354	38.2%	70,147	23,111	32.9%
1993	12,713	66,125	25,265	38.2%	82,994	27,344	32.9%
1994	9,299	48,368	18,480	38.2%	60,707	20,001	32.9%
1995	7,971	**33,805**	**5,060**	**15.0%**	**33,805**	**5,060**	**15.0%**
1996	18,576	**79,019**	**9,048**	**11.5%**	**79,019**	**9,048**	**11.5%**
1997	13,201	**114,938**	**17,888**	**15.6%**	**114,938**	**17,888**	**15.6%**
1998	5,969	31,039	11,862	38.2%	38,967	12,838	32.9%
1999	3,951	**16,786**	**3,171**	**18.9%**	**16,786**	**3,171**	**18.9%**
2000	5,772	**34,997**	**5,403**	**15.4%**	**34,997**	**5,403**	**15.4%**
2001	5,040	**46,544**	**6,766**	**14.5%**	**46,544**	**6,766**	**14.5%**
2002	8,089	**55,044**	**11,087**	**20.1%**	**55,044**	**11,087**	**20.1%**
2003	5,481	**36,435**	**6,705**	**18.4%**	**36,435**	**6,705**	**18.4%**
2004	9,138	**75,032**	**10,280**	**13.7%**	**75,032**	**10,280**	**13.7%**
2005	3,981	**38,725**	**4,908**	**12.7%**	**38,725**	**4,908**	**12.7%**
2006	5,338	**42,296**	**5,535**	**13.1%**	**42,296**	**5,535**	**13.1%**
2007	NE	**14,854**	**3,277**	**22.1%**	**14,854**	**3,277**	**22.1%**

Table A8.–Estimated numbers of spawners $\hat{N}_y$ and recruits $\hat{R}_y$ of large Chinook salmon, from the Taku River for year classes 1973–2001, from the 3 expansion factors for survey counts. The expansion factor of 10.86 (SE=2.71) is from Table A5 and the expansion factors of 5.20 (SE=1.99) and 6.53 (SE=2.15) are from Table A4. Data sources for spawners and recruits are footnoted.

	EF = 10.86 (without Nakina)[a]		EF = 5.20 (without Tseta)[b]		EF = 6.53 (without Tseta)[c]	
Year class	$\hat{N}_y$	$\hat{R}_y$	$\hat{N}_y$	$\hat{R}_y$	$\hat{N}$	$\hat{R}_y$
1973			14,564	17,539	18,279	20,521
1974			16,015	39,475	20,101	47,574
1975			12,920	55,557	16,216	67,990
1976		49,300	24,582	48,134	30,853	58,267
1977		19,485	29,497	18,191	37,022	22,131
1978		11,503	17,123	9,685	21,491	11,895
1979		41,834	21,617	34,531	27,132	41,839
1980		58,187	39,239	47,650	49,250	59,006
1981	50,784	34,137	49,559	32,795	62,202	40,481
1982	24,762	53,600	23,848	52,134	29,932	64,288
1983	11,881	30,892	9,794	30,800	12,293	34,439
1984	24,805	68,371	20,780	68,574	26,081	69,733
1985	49,535	51,894	35,916	52,865	45,078	59,191
1986	39,663	55,087	38,111	55,270	47,833	67,630
1987	30,811	77,779	28,935	73,432	36,317	89,571
1988	44,810	67,470	44,524	61,296	55,882	74,583
1989	40,329	60,343	40,329	56,014	40,329	63,383
1990	52,142	28,697	52,142	28,697	52,142	28,697
1991	49,339	161,498	51,645	161,294	64,820	161,493
1992	57,647	76,549	55,889	71,010	70,147	76,394
1993	72,917	17,503	66,125	15,193	82,994	17,439
1994	55,617	25,938	48,368	25,938	60,707	25,938
1995	33,805	39,208	33,805	39,208	33,805	39,208
1996	79,019	66,971	79,019	66,971	79,019	66,971
1997	114,938	55,050	114,938	55,050	114,938	55,050
1998	39,196	43,785	31,039	43,785	38,967	43,785
1999	16,786	84,703	16,786	84,703	16,786	84,703
2000	34,997	82,253	34,997	82,253	34,997	82,253
2001	46,544	39,049	46,544	39,049	46,544	39,049

[a] Escapement and return estimates are extracted from Table 7 in the main body of the report.

[b] Escapement and return estimates are extracted from Table 8 in the main body of the report.

[c] Escapement estimates are from Table A7. Return estimates are the sum of escapement estimates from Table A11 and harvest estimates from Table 5, assigned to the respective year classes.

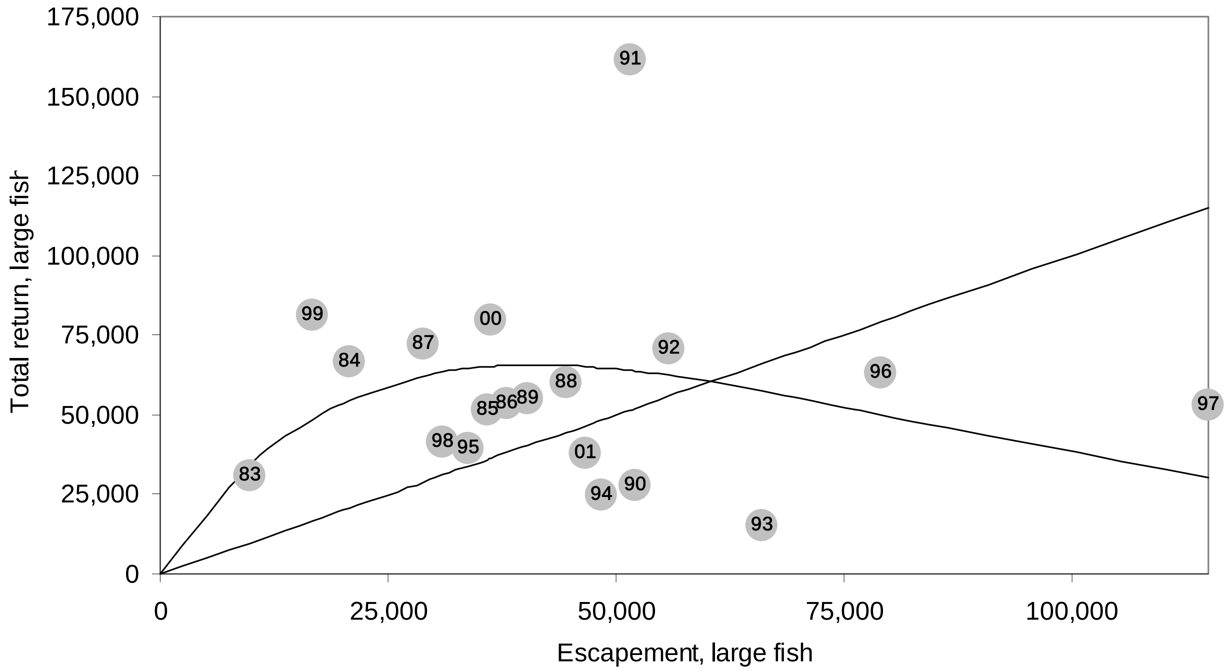


Figure A3.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1983 through 2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line, for the EF = 5.20 using the index without Tseta Creek.

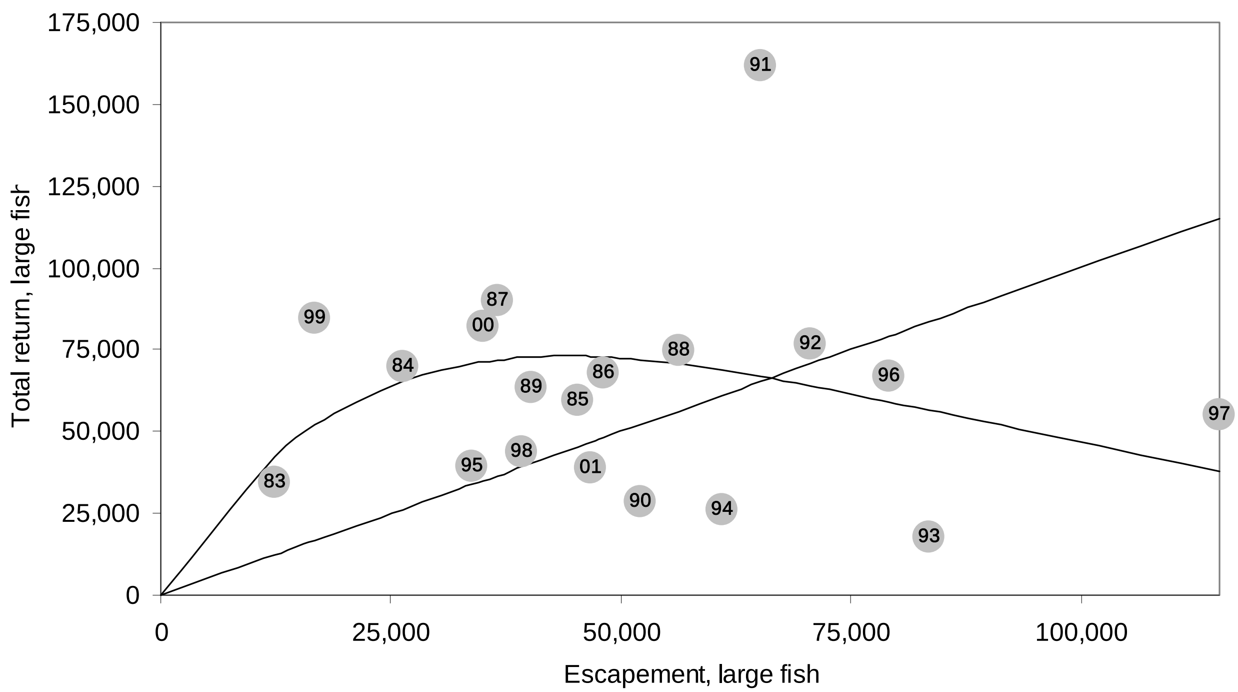


Figure A4.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1983 through 2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line, for the EF = 6.53 using the index without Tseta Creek.

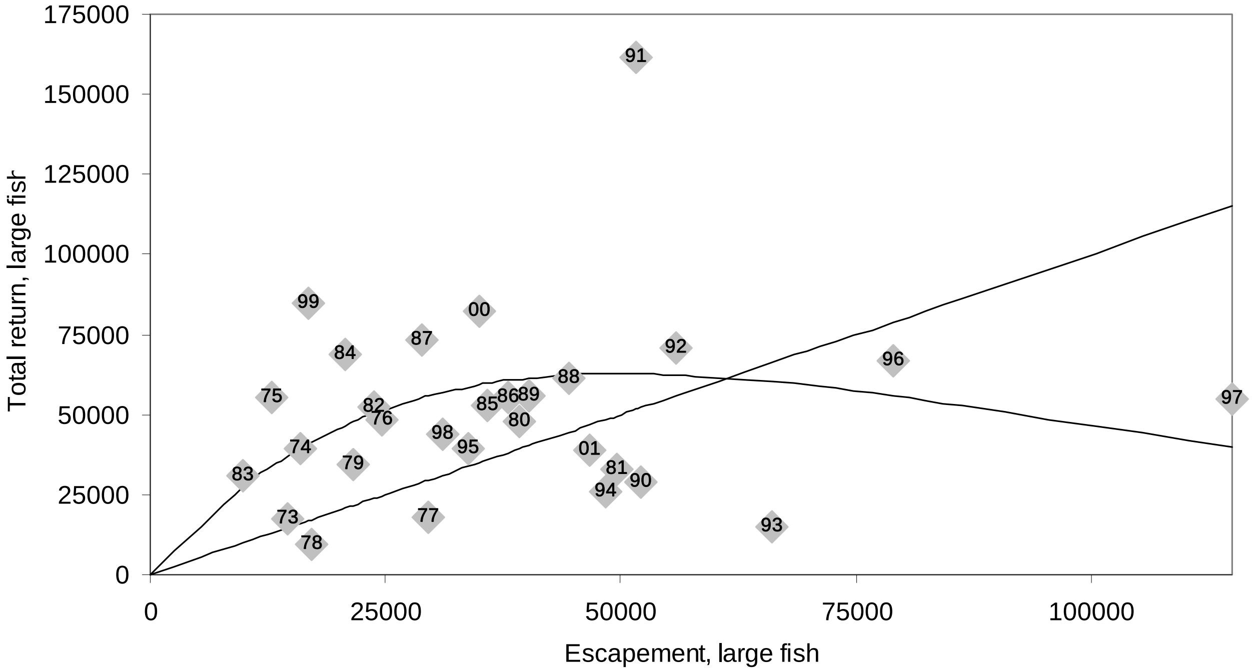


Figure A5.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1973 through 2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line, for the EF = 5.20 using the index without Tseta Creek.

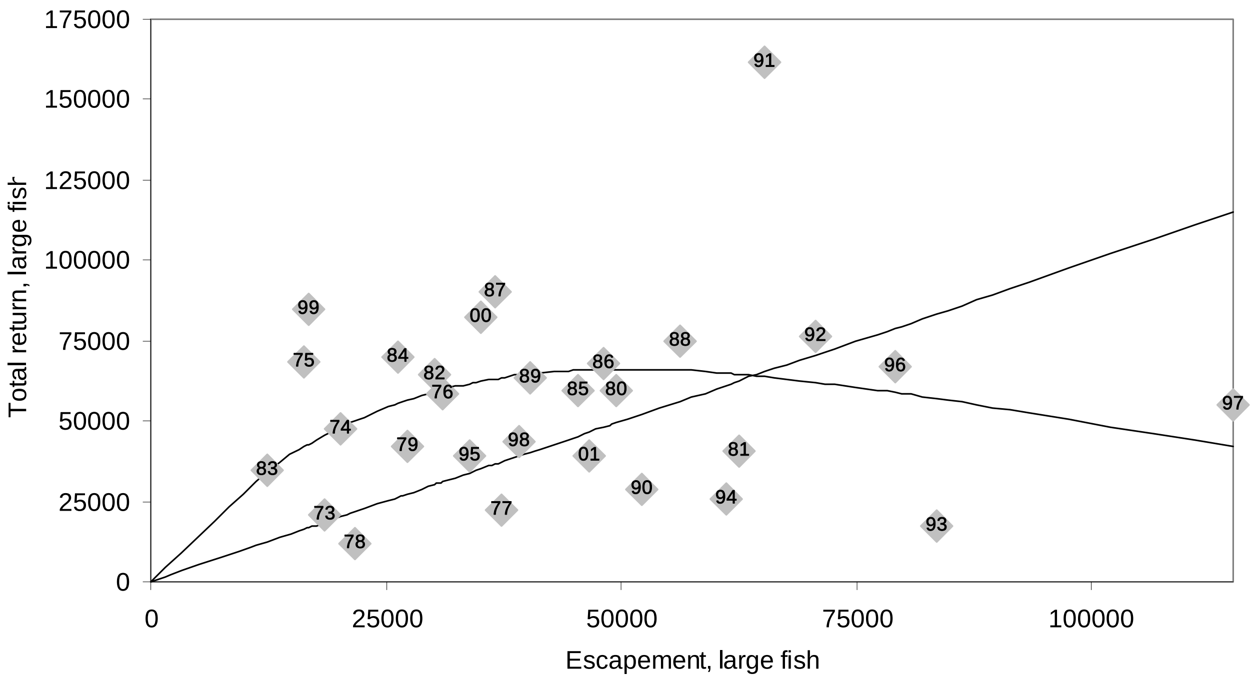


Figure A6.–Estimated production of age-1.3 to -1.5 Chinook salmon in year classes 1973 through 2001 against the estimated abundance of large spawning Chinook salmon, along with curves corresponding to least-squares fit of the Ricker model and the replacement line, for the EF = 6.53 using the index without Tseta Creek.

Table A9.–Estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 5.20 in Table A4. Numbers by age are the product of the estimated abundance of large fish in Table A6 and the multipliers in Table C1 for years without mark–recapture estimates. Bold numbers came directly from mark–recapture experiments. Estimated SEs for these statistics are in Table A10.

Year	1.2	1.3	1.4	1.5	Large females	Large males
1973	8,553	7,966	6,427	172	8,929	5,635
1974	10,043	11,080	4,826	109	9,824	6,191
1975	25,074	7,998	4,800	122	4,593	8,327
1976	11,667	16,718	7,624	240	15,165	9,417
1977	4,678	12,716	16,091	689	20,466	9,031
1978	31,514	9,162	6,653	1,309	9,143	7,981
1979	28,620	18,790	2,530	297	10,997	10,620
1980	16,436	26,282	12,957	0	21,228	18,011
1981	15,597	28,133	21,426	0	25,024	24,535
1982	5,932	11,390	11,431	1,026	12,396	11,452
1983	4,571	5,935	3,705	155	4,120	5,674
1984	9,821	17,838	2,593	347	10,091	10,687
1985	12,923	25,720	10,062	134	17,447	18,469
1986	8,034	19,363	18,008	739	21,700	16,411
1987	7,715	19,856	8,291	788	12,607	16,328
1988	17,579	14,265	27,785	2,474	21,864	22,660
1989	**10,569**	**26,715**	**12,053**	**1,561**	**17,580**	**22,749**
1990	**7,095**	**20,848**	**30,124**	**1,171**	**26,749**	**25,394**
1991	21,707	24,090	23,013	4,542	27,435	24,210
1992	18,683	31,513	22,592	1,784	22,935	32,954
1993	11,217	34,594	29,762	1,769	29,976	36,149
1994	5,285	28,888	17,489	1,991	31,553	16,815
1995	**30,884**	**14,600**	**19,950**	**612**	**19,705**	**14,100**
1996	**8,005**	**71,372**	**9,901**	**143**	**40,897**	**38,122**
1997	**2,652**	**43,757**	**71,071**	**0**	**70,691**	**44,247**
1998	**8,094**	8,791	21,078	776	17,210	13,919
1999	**10,394**	**11,668**	**3,246**	**203**	**6,948**	**9,838**
2000	**9,452**	**24,800**	**9,083**	**86**	**19,199**	**15,798**
2001	**5,075**	**36,504**	**9,760**	**25**	**23,110**	**23,434**
2002	**6,707**	**32,786**	**21,323**	**140**	**31,558**	**23,486**
2003	**16,357**	**22,799**	**12,951**	**106**	**19,089**	**17,346**
2004	**25,702**	**56,866**	**13,895**	**261**	**37,473**	**37,560**
2005	**6,574**	**27,570**	**9,459**	**47**	**19,257**	**19,198**
2006	**2,874**	**20,454**	**20,929**	**220**	**21,506**	**20,790**
2007	**6,949**	**8,556**	**5,776**	**201**	**6,290**	**8,564**

Table A10.–Estimated SEs for estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 5.20 in Table A4. Standard errors of the multipliers in Table C2 were used in this estimation. Bold numbers came directly from mark–recapture experiments.

Calendar Year	1.2	1.3	1.4	1.5	Large Females	Large Males
1973	4,948	3,194	2,655	77	3,573	2,401
1974	5,713	4,358	2,122	51	3,918	2,619
1975	13,930	3,171	2,025	59	1,959	3,299
1976	6,463	6,561	3,297	102	6,002	3,925
1977	2,841	5,418	6,671	342	8,049	3,943
1978	18,325	3,653	2,854	619	3,689	3,272
1979	16,092	7,204	1,159	128	4,586	4,454
1980	8,876	10,349	5,547	0	8,703	7,570
1981	8,754	11,217	8,792	0	10,255	10,082
1982	3,450	4,582	4,670	486	5,009	4,670
1983	2,662	2,334	1,530	75	1,744	2,294
1984	5,261	6,845	1,197	153	4,316	4,521
1985	7,179	10,007	4,299	61	7,200	7,563
1986	4,593	7,844	7,408	353	8,791	6,918
1987	4,397	7,733	3,539	369	5,304	6,622
1988	10,432	5,950	11,022	1,309	8,979	9,262
1989	**1,589**	**3,819**	**1,770**	**294**	**4,827**	**4,191**
1990	**1,338**	**3,779**	**5,434**	**264**	**5,831**	**3,218**
1991	12,502	9,558	9,440	2,161	10,959	9,787
1992	11,077	12,446	9,281	921	9,540	13,143
1993	6,594	13,874	12,238	871	12,477	14,672
1994	3,012	11,413	7,456	882	12,562	7,331
1995	**3,848**	**1,952**	**2,600**	**174**	**2,891**	**2,295**
1996	**1,097**	**7,692**	**1,287**	**84**	**4,595**	**4,588**
1997	**639**	**6,600**	**11,120**	**0**	**11,039**	**7,032**
1998	**2,005**	2,899	7,130	270	5,877	4,790
1999	**1,473**	**2,208**	**703**	**104**	**1,386**	**1,911**
2000	**1,766**	**3,745**	**1,482**	**61**	**3,025**	**2,513**
2001	**906**	**5,190**	**1,442**	**25**	**3,402**	**3,448**
2002	**1,134**	**6,525**	**4,245**	**71**	**8,395**	**7,242**
2003	**1,990**	**3,981**	**2,365**	**54**	**3,546**	**3,228**
2004	**2,316**	**7,393**	**1,966**	**108**	**7,265**	**7,273**
2005	**794**	**3,325**	**1,236**	**33**	**2,519**	**2,497**
2006	**505**	**2,667**	**2,753**	**80**	**2,875**	**2,783**
2007	**1,480**	**1,774**	**1,330**	**118**	**1,469**	**1,950**

.

Table A11.–Estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 6.53 in Table A4. Numbers by age are the product of the estimated abundance of large fish in Table A6 and the multipliers in Table C1 for years without mark–recapture estimates. Bold numbers came directly from mark–recapture experiments. Estimated SEs for these statistics are in Table A12.

Year	1.2	1.3	1.4	1.5	Large females	Large males
1973	10,735	9,998	8,067	216	11,207	7,072
1974	12,605	13,907	6,057	137	12,330	7,770
1975	31,471	10,039	6,025	153	5,765	10,451
1976	14,643	20,983	9,569	301	19,034	11,819
1977	5,871	15,960	20,196	865	25,687	11,335
1978	39,551	11,499	8,350	1,643	11,475	10,016
1979	35,921	23,583	3,175	373	13,802	13,329
1980	20,629	32,987	16,263	0	26,644	22,606
1981	19,576	35,310	26,892	0	31,408	30,794
1982	7,445	14,296	14,347	1,288	15,559	14,374
1983	5,737	7,449	4,650	195	5,171	7,122
1984	12,327	22,390	3,255	436	12,666	13,414
1985	16,220	32,281	12,629	168	21,898	23,180
1986	10,083	24,302	22,602	928	27,236	20,597
1987	9,683	24,922	10,406	989	15,823	20,494
1988	22,064	17,904	34,873	3,105	27,442	28,441
1989	**10,569**	**26,715**	**12,053**	**1,561**	**17,580**	**22,749**
1990	**7,095**	**20,848**	**30,124**	**1,171**	**26,749**	**25,394**
1991	27,244	30,235	28,884	5,701	34,434	30,386
1992	23,449	39,552	28,355	2,239	28,786	41,361
1993	14,079	43,419	37,355	2,220	37,623	45,371
1994	6,633	36,257	21,950	2,499	39,602	21,105
1995	**30,884**	**14,600**	**19,950**	**612**	**19,705**	**14,100**
1996	**8,005**	**71,372**	**9,901**	**143**	**40,897**	**38,122**
1997	**2,652**	**43,757**	**71,071**	**0**	**70,691**	**44,247**
1998	**8,094**	11,037	26,462	974	21,606	17,474
1999	**10,394**	**11,668**	**3,246**	**203**	**6,948**	**9,838**
2000	**9,452**	**24,800**	**9,083**	**86**	**19,199**	**15,798**
2001	**5,075**	**36,504**	**9,760**	**25**	**23,110**	**23,434**
2002	**6,707**	**32,786**	**21,323**	**140**	**31,558**	**23,486**
2003	**16,357**	**22,799**	**12,951**	**106**	**19,089**	**17,346**
2004	**25,702**	**56,866**	**13,895**	**261**	**37,473**	**37,560**
2005	**6,574**	**27,570**	**9,459**	**47**	**19,257**	**19,198**
2006	**2,874**	**20,454**	**20,929**	**220**	**21,506**	**20,790**
2007	**6,949**	**8,556**	**5,776**	**201**	**6,290**	**8,564**

Table A12.–Estimated SEs for estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1973 through 2007, using the expansion factor of 6.53 in Table A4. Standard errors of the multipliers in Table C2 were used in this estimation. Bold numbers came directly from mark–recapture experiments.

Calendar Year	1.2	1.3	1.4	1.5	Large Females	Large Males
1973	5,933	3,521	2,956	88	3,936	2,700
1974	6,834	4,770	2,408	59	4,311	2,938
1975	16,604	3,481	2,270	68	2,204	3,620
1976	7,700	7,175	3,723	115	6,585	4,382
1977	3,429	6,092	7,436	399	8,810	4,465
1978	21,991	4,018	3,215	715	4,075	3,634
1979	19,216	7,808	1,329	145	5,122	4,984
1980	10,531	11,332	6,245	0	9,666	8,476
1981	10,450	12,338	9,767	0	11,389	11,205
1982	4,140	5,056	5,180	561	5,536	5,177
1983	3,196	2,554	1,703	86	1,957	2,536
1984	6,233	7,421	1,376	174	4,858	5,071
1985	8,556	10,909	4,838	70	8,014	8,397
1986	5,498	8,676	8,238	408	9,725	7,753
1987	5,261	8,432	3,981	426	5,940	7,327
1988	12,554	6,645	12,101	1,547	9,978	10,277
1989	**1,589**	**3,819**	**1,770**	**294**	**4,827**	**4,191**
1990	**1,338**	**3,779**	**5,434**	**264**	**5,831**	**3,218**
1991	14,982	10,495	10,487	2,502	12,063	10,818
1992	13,329	13,643	10,314	1,084	10,645	14,459
1993	7,925	15,293	13,605	1,016	13,926	16,240
1994	3,604	12,513	8,384	1,003	13,811	8,298
1995	**3,848**	**1,952**	**2,600**	**174**	**2,891**	**2,295**
1996	**1,097**	**7,692**	**1,287**	**84**	**4,595**	**4,588**
1997	**639**	**6,600**	**11,120**	**-**	**11,039**	**7,032**
1998	**2,005**	3,696	8,746	370	7,156	5,804
1999	**1,473**	**2,208**	**703**	**104**	**1,386**	**1,911**
2000	**1,766**	**3,745**	**1,482**	**61**	**3,025**	**2,513**
2001	**906**	**5,190**	**1,442**	**25**	**3,402**	**3,448**
2002	**1,134**	**6,525**	**4,245**	**71**	**8,395**	**7,242**
2003	**1,990**	**3,981**	**2,365**	**54**	**3,546**	**3,228**
2004	**2,316**	**7,393**	**1,966**	**108**	**7,265**	**7,273**
2005	**794**	**3,325**	**1,236**	**33**	**2,519**	**2,497**
2006	**505**	**2,667**	**2,753**	**80**	**2,875**	**2,783**
2007	**1,480**	**1,774**	**1,330**	**118**	**1,469**	**1,950**

APPENDIX B.
ESTIMATES OF RELATIVE AGE-SEX COMPOSITION OF SPAWNING CHINOOK SALMON

Appendix B1.–Estimates of relative age-sex composition of spawning Chinook salmon.

Relative age-sex composition of spawning Chinook salmon was estimated from information gathered at a carcass weir on the Nakina River (1973–1997), and with a combination of carcass surveys, carcass weirs, and live weirs on the Nahlin, Kowatua, and Tatsamenie rivers. Mark–recapture experiments on the Taku River (Pahlke and Bernard 1996; McPherson et al. 1996-98) indicated that samples taken from the latter set of 3 rivers were representative, while samples taken at the carcass weir on the Nakina River were skewed to males and larger females in most years. Because a complete record is available only for the Nakina River, estimates of relative age-sex composition for that population were adjusted with information from the other tributaries to complete a set of estimates for 1973–1997.

The adjustment is based on the assumption that populations in all tributaries have the same relative age-sex composition. Comparison of statistics shows strong and weak year classes are repeated across tributaries (see Pahlke and Bernard 1996: Figure 5), and trends in counts are correlated across populations (McPherson et al. 2000). If these populations have the same relative age-sex compositions:

$$\theta_a = \frac{N_a}{N} = \frac{M_a}{M}$$

where M is the number of spawning Chinook salmon in Nakina River, M_a is the subset of that population in age-sex group a, and N and N_a are the corresponding numbers for the other populations. If ρ_a is the probability of sampling a fish in group a on the Nakina River, the expected number of Chinook salmon of that group in a randomly drawn sample from the Nakina River is:

$$\mathrm{E}[m_a] = M_a \rho_a$$

Similar equations exist for all age-sex groups. Because $M_a = M\,\theta_a$, $M_b = M\,\theta_b$, etc:

$$\mathrm{E}[m_a] = M\theta_a \rho_a$$

$$\mathrm{E}[m_b] = M\theta_b \rho_b$$

and so forth. If the equation for group a is divided into the equation for group b and rearranged:

$$\frac{\rho_b}{\rho_a} = \frac{\theta_a \mathrm{E}[m_b]}{\theta_b \mathrm{E}[m_a]}$$

If ρ_a is arbitrarily set to 1 and estimates plugged into the equation above:

$$\hat{w}_b = \frac{\hat{\theta}_a m_b}{\hat{\theta}_b m_a}$$

where $\hat{w}_b$ is the estimate of ρ_b relative to ρ_a. Weighted estimates for other groups can be calculated in the same way. Because estimates of relative age-sex composition are a function of the relative magnitudes of the probabilities of capture, scaling all probabilities to that for a single group has no effect on the estimates.

Solutions to $\{\boldsymbol{w}\}$ were calculated for years with mark–recapture experiments (1989, 1990, 1995–1997), then elements averaged across years to produce expansion factors (Table B1). Relative age-sex composition for all Chinook salmon age-1.2 through -1.4 were estimated from pooled samples drawn from Nahlin, Tatsamenie, and Kowatua rivers:

$$\hat{\theta}_{a,t} = \frac{n_{a,t}}{n_t}$$

where n_t is the pooled number of samples, $n_{a,t}$ the number of those samples from age-sex group a, and t is the year of sampling. The few sampled fish that were age 2. were considered inconsequential and were lumped with those age 1. Because sampling age-1.1 jacks was problematical over the years, these fish were ignored as an age-sex group. So few age-1.2 females were found (<0.01%) that these fish were also ignored. Samples for age-1.5 Chinook salmon of both sexes were not adjusted because their representation in samples was so low (≤2%). The remaining 5 age-sex groups in the adjustment are age-1.3 females (considered group a), -1.4 females, -1.2 males, -1.3 males, and -1.4 males.

Table B2 contains the adjusted estimates for relative age-sex composition for Chinook salmon spawning in the Taku River from 1973–1997. For years with mark–recapture experiments, estimates of relative age-sex composition for spawning Chinook salmon in the river were calculated directly from samples taken at on the Nahlin, Kowatua, and Tatsamenie rivers. In other years, estimates were calculated as adjustments of statistics based on samples from the Nakina River:

$$\hat{\theta}_a = \frac{m_a}{m_a + m_b \overline{w}_b^{-1} + m_c \overline{w}_c^{-1} + \ldots}$$

$$\hat{\theta}_b = \frac{m_b \overline{w}_b^{-1}}{m_a + m_b \overline{w}_b^{-1} + m_c \overline{w}_c^{-1} + \ldots}$$

and so forth. Estimated variances for $\{\hat{\boldsymbol{\theta}}_t\}$ in year t were obtained through simulation (Table B3). During the kth iteration of a simulation, 2 vectors of new sample sizes $\{\mathbf{n}_i'\}_k$ and $\{\mathbf{m}_t'\}_k$ were generated from the probability distributions multinom (n_i, $\{\hat{\boldsymbol{\theta}}_i\}$) and multinom ($m_t$, $\{\hat{\boldsymbol{\phi}}_t\}$), where i represents one of the years with mark–recapture experiments drawn at random with replacement. Elements of the vector $\{\hat{\boldsymbol{\phi}}_t\}$ are estimates of relative age-sex composition from the sampling program on the Nakina River in year t:

$$\hat{\phi}_{a,t} = \frac{m_{a,t}}{m_{a,t} + m_{b,t} + m_{c,t} + \ldots}$$

and so forth. A new set of weights were calculated for each vector of simulated sample sizes:

$$\hat{w}'_{b,t(k)} = \frac{\hat{\theta}'_{a,i(k)} m'_{b,t(k)}}{\hat{\theta}'_{b,i(k)} m'_{a,t(k)}}$$

and so forth for the other groups. Simulated estimates of relative age-sex composition were then calculated as:

$$\hat{\theta}'_{a,t(k)} = \frac{m'_{a,t(k)}}{m'_{a,t(k)} + m'_{b,t(k)} \hat{w}'^{-1}_{b,t(k)} + m'_{c,t(k)} \hat{w}'^{-1}_{c,t(k)} + \ldots}$$

$$\hat{\theta}'_{b,t(k)} = \frac{m'_{b,t(k)} \hat{w}'^{-1}_{b,t(k)}}{m'_{a,(k)} + m'_{b,t(k)} \hat{w}'^{-1}_{b,t(k)} + m'_{c(k)} \hat{w}'^{-1}_{c,t(k)} + \ldots}$$

and so forth. Variance for each element in $\{\hat{\boldsymbol{\theta}}_t\}$ was approximated as follows:

$$v(\hat{\theta}_{a,t}) \cong \frac{\sum_{k=1}^{K} (\hat{\theta}'_{a,t(k)} - \overline{\theta}'_{a,t})^2}{K-1}$$

$$v(\hat{\theta}_{b,t}) \cong \frac{\sum_{k=1}^{K} (\hat{\theta}'_{b.t(k)} - \overline{\theta}'_{b.t})^2}{K-1}$$

and so forth with K (=100) the number of iterations. The process was repeated for the next year. These calculations of estimated variance represent both the measurement (sampling error) at the carcass weir on the Nakina River, the measurement error from sampling on the Nahlin, Kowatua, and Tatsamenie rivers during mark–recapture experiments, and the process error (interannual variation) among the $\{\mathbf{w}_t\}$.

Simulation also provided a means of estimating the statistical bias in the procedures used to estimate $\{\boldsymbol{\theta}\}$ (Table B4). Relative statistical bias was estimated by subtracting estimates of $\hat{\theta}_{a,t}$ from the mean $\overline{\theta}'_{a,t}$ of simulated values $\hat{\theta}'_{a,t(k)}$ and dividing the difference by $\hat{\theta}_{a,t}$ (from Efron and Tibshirani 1993:124-6).

Table B1.–Solutions to {w} for years with mark–recapture experiments.

Sex	Age	1989	1990	1995	1996	1997	Average
Females	1.3	1.000	1.000	1.000	1.000	1.000	1.000
Females	1.4	1.835	5.289	2.629	2.032	1.649	2.687
Males	1.2	1.784	2.031	4.056	3.716	1.303	2.578
Males	1.3	0.999	2.507	2.839	1.896	1.585	1.965
Males	1.4	1.647	5.525	5.799	3.082	2.726	3.756

Table B2.–Estimates of relative age and sex composition for spawning Chinook salmon in the Taku River adjusted for bias arising from collecting samples with a carcass weir on the Nakina River in years without mark–recapture experiments.

Year	Sex	1.2	1.3	1.4	1.5
1973	Females	-	0.181	0.216	-
	Males	0.353	0.172	0.070	0.008
1974	Females	-	0.236	0.153	-
	Males	0.368	0.200	0.039	0.004
1975	Females	-	0.047	0.083	-
	Males	0.633	0.178	0.055	0.003
1976	Females	-	0.253	0.174	-
	Males	0.309	0.215	0.042	0.007
1977	Females	-	0.203	0.387	0.012
	Males	0.133	0.168	0.089	0.008
1978	Females	-	0.077	0.114	0.013
	Males	0.619	0.124	0.038	0.015
1979	Females	-	0.193	0.036	0.004
	Males	0.546	0.202	0.018	0.002
1980	Females	-	0.220	0.167	-
	Males	0.285	0.258	0.070	-
1981	Females	-	0.181	0.207	-
	Males	0.231	0.254	0.127	-
1982	Females	-	0.153	0.248	0.020
	Males	0.192	0.230	0.142	0.015
1983	Females	-	0.114	0.173	0.005
	Males	0.305	0.305	0.092	0.005
1984	Females	-	0.256	0.071	0.009
	Males	0.310	0.336	0.016	0.002
1985	Females	-	0.225	0.135	0.003
	Males	0.255	0.307	0.075	0.000
1986	Females	-	0.185	0.277	0.011
	Males	0.169	0.235	0.118	0.005
1987	Females	-	0.185	0.146	0.016
	Males	0.204	0.361	0.083	0.005
1988	Females	-	0.065	0.275	0.020
	Males	0.271	0.166	0.184	0.020
1991	Females	-	0.126	0.216	0.041
	Males	0.284	0.207	0.105	0.022
1992	Females	-	0.091	0.210	0.012
	Males	0.240	0.336	0.099	0.012
1993	Females	-	0.126	0.251	0.013
	Males	0.141	0.321	0.138	0.010
1994	Females	-	0.338	0.229	0.022
	Males	0.097	0.201	0.098	0.015

Table B3.–Simulated SEs for estimates of relative age and sex composition for spawning Chinook salmon in the Taku River adjusted for bias arising from collecting samples with a carcass weir on the Nakina River in years without mark–recapture experiments.

Year	Sex	1.2	1.3	1.4	1.5
1973	Females	-	0.056	0.060	-
	Males	0.098	0.042	0.024	0.002
1974	Females	0.000	0.063	0.053	-
	Males	0.099	0.047	0.013	0.001
1975	Females	-	0.020	0.035	-
	Males	0.098	0.051	0.023	0.001
1976	Females	-	0.061	0.053	-
	Males	0.091	0.046	0.015	0.002
1977	Females	-	0.067	0.094	0.004
	Males	0.057	0.040	0.029	0.003
1978	Females	-	0.027	0.047	0.004
	Males	0.099	0.036	0.018	0.005
1979	Females	-	0.063	0.015	0.001
	Males	0.099	0.053	0.008	0.001
1980	Females	-	0.075	0.046	-
	Males	0.082	0.054	0.026	-
1981	Females	-	0.055	0.056	-
	Males	0.077	0.050	0.038	-
1982	Females	-	0.048	0.065	0.006
	Males	0.072	0.039	0.043	0.004
1983	Females	-	0.041	0.054	0.002
	Males	0.091	0.057	0.030	0.002
1984	Females	-	0.079	0.025	0.003
	Males	0.082	0.075	0.006	0.001
1985	Females	-	0.066	0.042	0.001
	Males	0.080	0.055	0.025	0.000
1986	Females	-	0.063	0.072	0.004
	Males	0.063	0.045	0.038	0.001
1987	Females	-	0.059	0.046	0.005
	Males	0.073	0.064	0.026	0.002
1988	Females	-	0.029	0.077	0.007
	Males	0.092	0.033	0.048	0.007
1991	Females	-	0.041	0.059	0.012
	Males	0.091	0.040	0.028	0.007
1992	Females	-	0.033	0.060	0.004
	Males	0.085	0.055	0.031	0.004
1993	Females	-	0.046	0.073	0.004
	Males	0.057	0.051	0.039	0.003
1994	Females	-	0.083	0.062	0.005
	Males	0.039	0.049	0.031	0.004

Table B4.–Estimated relative statistical bias in $\{\hat{\theta}\}$ by age-sex groups of spawning Chinook salmon across years without mark–recapture experiments.

	Female 1.3	Female 1.4	Female 1.5	Male 1.2	Male 1.3	Male 1.4	Male 1.5
Average	-4%	6%	-2%	2%	-1%	4%	-4%
Minimum	-10%	-1%	-8%	-3%	-6%	-7%	-10%
Maximum	7%	12%	7%	13%	1%	11%	7%

APPENDIX C.
ESTIMATING NUMBERS OF SPAWNING CHINOOK SALMON BY AGE AND SEX

Abundances for age groups and for large females over the spawning grounds were estimated as the product of the estimated abundance of large Chinook salmon and either an estimated fraction or a simulated factor. Estimated abundance by age group was used to calculate production from a year class; estimated abundance of large females constituted the spawning abundance (S) for analysis of production. For years with mark–recapture experiments (1989, 1990, 1995–1997), estimates were taken directly from Pahlke and Bernard (1996) and from McPherson et al. (1996-98).

For years without mark–recapture experiments, abundance estimates were derived from adjusted estimates of relative age composition (see Appendix B). Estimated abundance for group a and its estimated variance were calculated as:

$$\hat{N}_a = \hat{N}\ \hat{p}_a$$

$$v(\hat{N}_a) = v(\hat{N})\hat{p}_a^2 + v(\hat{p}_a)\hat{N}^2 - v(\hat{N})v(\hat{p}_a)$$

Statistics represented by $\hat{p}_a$ were calculated as weighted functions of samples taken at the carcass weir on the Nakina River:

$$\hat{p}_{1.2} = \frac{m_{1.2}\overline{w}_{1.2}^{-1}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

$$\hat{p}_{1.3} = \frac{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

$$\hat{p}_{1.4} = \frac{m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

$$\hat{p}_{1.5} = \frac{m_{F,1.5} + m_{M,1.5}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

$$\hat{p}_{LF} = \frac{m_{F,1.3} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{F,1.5}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

$$\hat{p}_{LM} = \frac{m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{M,1.5}}{m_{F,1.3} + m_{M,1.3}\overline{w}_{M,1.3}^{-1} + m_{F,1.4}\overline{w}_{F,1.4}^{-1} + m_{M,1.4}\overline{w}_{M,1.4}^{-1} + m_{F,1.5} + m_{M,1.5}}$$

where m_a is the number in the sample belonging to group a, *F* denotes female, *M* male, *LF* large females, *LM* large males, and the *w* are weights (see Appendix B). All age-1.2 fish are considered male. Note that because abundance estimated through mark–recapture experiments and aerial surveys is only for large fish (considered age-1.3 fish and older), $0 \leq \hat{p}_{1.3} \leq 1$, $0 \leq \hat{p}_{1.4} \leq 1$, $0 \leq \hat{p}_{1.5} \leq 1$, and $0 \leq \hat{p}_{LF} \leq 1$, while $0 \leq \hat{p}_{1.1}$ and $0 \leq \hat{p}_{1.2}$. Estimated variances were calculated with simulations described in Appendix A. Simulation also provided a means of estimating the statistical bias in the procedures used to estimate the multipliers (Table C1). Relative statistical bias was estimated by subtracting estimates $\hat{p}_{a,t}$ from the mean $\overline{p}'_{a,t}$ of simulated values, $\hat{p}'_{a,t(k)}$ and dividing the difference by $\hat{p}_{a,t}$ (from Efron and Tibshirani 1993:124-6). Table C2 contains estimated multipliers and estimates of their SEs. Estimated abundance by age and sex, the $\hat{N}_a$, are in Tables 2 and 3 in the text. Table C3 contains the SEs for the $\hat{N}_a$.

Table C1.–Estimated relative statistical bias in $\{\hat{\boldsymbol{p}}\}$ by age and large (≥660 mm MEF) female and male spawning Chinook salmon across years without mark–recapture experiments.

	1.2	1.3	1.4	1.5	Large females	Large males
Average	9%	-2%	5%	-3%	0%	0%
Minimum	2%	-5%	0%	-9%	-3%	-5%
Maximum	21%	0%	9%	5%	4%	4%

Table C2.–Simulated multipliers used to calculate numbers of spawning Chinook salmon in the Taku River by age and numbers of large (≥660 mm MEF) females from estimated abundance of large spawning Chinook salmon of both sexes for years without mark–recapture experiments.

Year		1.2	1.3	1.4	1.5	Large females	Large males
1973	$\hat{p}_a$	0.587	0.547	0.441	0.012	0.613	0.387
	SE	0.276	0.072	0.075	0.003	0.079	0.079
1974	$\hat{p}_a$	0.627	0.692	0.301	0.007	0.613	0.387
	SE	0.286	0.070	0.071	0.002	0.076	0.076
1975	$\hat{p}_a$	1.941	0.619	0.372	0.009	0.356	0.644
	SE	0.847	0.071	0.072	0.003	0.073	0.073
1976	$\hat{p}_a$	0.475	0.680	0.310	0.010	0.617	0.383
	SE	0.206	0.066	0.068	0.002	0.069	0.069
1977	$\hat{p}_a$	0.159	0.431	0.546	0.023	0.694	0.306
	SE	0.081	0.088	0.095	0.008	0.070	0.070
1978	$\hat{p}_a$	1.840	0.535	0.389	0.076	0.534	0.466
	SE	0.873	0.066	0.082	0.023	0.075	0.075
1979	$\hat{p}_a$	1.324	0.869	0.117	0.014	0.509	0.491
	SE	0.591	0.030	0.032	0.003	0.092	0.092
1980	$\hat{p}_a$	0.419	0.670	0.330	0.000	0.541	0.459
	SE	0.173	0.069	0.069	0.000	0.087	0.087
1981	$\hat{p}_a$	0.315	0.568	0.432	0.000	0.505	0.495
	SE	0.140	0.070	0.070	0.000	0.081	0.081
1982	$\hat{p}_a$	0.249	0.478	0.479	0.043	0.520	0.480
	SE	0.118	0.065	0.075	0.013	0.074	0.074
1983	$\hat{p}_a$	0.467	0.606	0.378	0.016	0.421	0.579
	SE	0.222	0.061	0.064	0.005	0.083	0.083
1984	$\hat{p}_a$	0.473	0.859	0.125	0.017	0.486	0.514
	SE	0.192	0.033	0.035	0.004	0.101	0.101
1985	$\hat{p}_a$	0.360	0.716	0.280	0.004	0.486	0.514
	SE	0.157	0.057	0.058	0.001	0.082	0.082
1986	$\hat{p}_a$	0.211	0.508	0.473	0.019	0.569	0.431
	SE	0.097	0.074	0.078	0.006	0.083	0.083
1987	$\hat{p}_a$	0.267	0.686	0.287	0.027	0.436	0.564
	SE	0.122	0.056	0.059	0.008	0.083	0.083
1988	$\hat{p}_a$	0.395	0.320	0.624	0.056	0.491	0.509
	SE	0.194	0.058	0.072	0.022	0.080	0.080
1991	$\hat{p}_a$	0.420	0.466	0.446	0.088	0.531	0.469
	SE	0.196	0.054	0.072	0.027	0.067	0.067
1992	$\hat{p}_a$	0.334	0.564	0.404	0.032	0.410	0.590
	SE	0.164	0.061	0.066	0.012	0.073	0.073
1993	$\hat{p}_a$	0.170	0.523	0.450	0.027	0.453	0.547
	SE	0.082	0.069	0.074	0.009	0.081	0.081
1994	$\hat{p}_a$	0.109	0.597	0.362	0.041	0.652	0.348
	SE	0.050	0.065	0.074	0.010	0.079	0.079

Table C3.–Estimated SEs for estimated numbers $\hat{N}_a$ of Chinook salmon by age and by large (≥660 mm MEF) females and males spawning in the Taku River from 1981 through 2007. Bold numbers came directly from mark–recapture experiments.

Calendar year	1.2	1.3	1.4	1.5	Large females	Large males
1981	7,956	7,973	6,469	0	7,536	7,430
1982	3,220	3,337	3,464	410	3,669	3,457
1983	2,905	1,928	1,341	74	1,571	1,965
1984	5,461	5,371	1,142	141	3,862	4,002
1985	8,746	9,262	4,441	67	7,177	7,473
1986	4,270	5,775	5,553	300	6,473	5,321
1987	4,177	5,533	2,820	317	4,165	4,995
1988	9,505	4,377	7,644	1,139	6,495	6,665
1989	**1,589**	**3,819**	**1,770**	**294**	**4,827**	**4,191**
1990	**1,338**	**3,779**	**5,434**	**264**	**5,831**	**3,218**
1991	10,699	6,294	6,474	1,684	7,280	6,599
1992	10,341	8,795	6,883	812	7,172	9,408
1993	6,561	10,691	9,713	800	10,036	11,472
1994	3,090	8,996	6,407	785	10,001	6,432
1995	**3,848**	**1,952**	**2,600**	**174**	**2,891**	**2,295**
1996	**1,097**	**7,692**	**1,287**	**84**	**4,595**	**4,588**
1997	**639**	**6,600**	**11,120**	**-**	**11,039**	**7,032**
1998	**2,005**	2,852	6,679	309	5,474	4,450
1999	**1,473**	**2,208**	**703**	**104**	**1,386**	**1,911**
2000	**1,766**	**3,745**	**1,482**	**61**	**3,025**	**2,513**
2001	**906**	**5,190**	**1,442**	**25**	**3,402**	**3,448**
2002	**1,134**	**6,525**	**4,245**	**71**	**8,395**	**7,242**
2003	**1,990**	**3,981**	**2,365**	**54**	**3,546**	**3,228**
2004	**2,316**	**7,393**	**1,966**	**108**	**7,265**	**7,273**
2005	**794**	**3,325**	**1,236**	**33**	**2,519**	**2,497**
2006	**505**	**2,667**	**2,753**	**80**	**2,875**	**2,783**
2007	**1,480**	**1,774**	**1,330**	**118**	**1,469**	**1,950**

APPENDIX D. ESTIMATES OF AGE COMPOSITION OF HARVESTED CHINOOK SALMON

Four age groups are represented in the age composition of harvests in commercial and recreational fisheries: age-1.2, -1.3, -1.4, and -1.5 Chinook salmon. The few sampled fish that were determined to be freshwater age 2. were considered anomalous and were lumped with those with age 1. Virtually no age-1.1 jacks have been harvested in these fisheries.

Marine Harvest

We estimated harvest by age of Taku-bound Chinook salmon in the U.S. marine gillnet fishery in District 111 during its first 3 or 4 weeks (statistical weeks 25–28) when these fish are still moving through the fishery (Table D1). The fishery starts on the third Sunday in June and judging from information from Canyon Island, over 95% of the Taku-bound Chinook salmon have passed through the fishery by July 9. Harvest by age and its estimated variance were estimated as:

$$\hat{H}_{a,t} = H_t \hat{p}_{a,t}$$

$$v(\hat{H}_{a,t}) = H_t^2 v(\hat{p}_{a,t})$$

where H_t is harvest in year t and $p_{a,t}$ the fraction of the harvest comprised of age group a that year. Harvests are reported on fish tickets and are considered known without error. Relative age composition in years when this fishery was not sampled (1977–1981 and 1993–1994) were predicted by adjusting estimates from spawning Chinook salmon with regressions on data from other years.

Regressions to predict missing data were dual in nature. Samples were first split into 2 groups: age-1.4 fish in 1 group and age-1.2 and -1.3 fish in the other (samples of fish age 1.1 and 1.5 were ignored). Fractions of samples represented by both groups were normalized, then the fraction of age-1.4 fish in samples from the fishery were regressed against the normalized fraction for spawning Chinook salmon. Estimated variances for predictions were estimated with eq. 1.4.11 in Draper and Smith (1981:30). The fraction predicted for the age-1.2/-1.3 group was the complement of the prediction for the age-1.4 fish; the estimated variance for both groups is the same. The second step involved splitting the age-1.2 and age-1.3 into 2 groups by normalizing their fractions against the prediction for both age groups combined. Fractions of samples represented in both groups were normalized, then the fraction of age-1.3 fish in samples from the fishery were regressed against the normalized fraction for spawning Chinook salmon. The predicted fraction for the age-1.2 fish was the complement of the fraction predicted for the age-1.3 fish. Variances of predictions were estimated as described before.

Harvests of Taku-bound Chinook salmon in the commercial troll fishery in Southeast Alaska (SEAK) were estimated from CWT recoveries as per Bernard and Clark (1996; Table D2). Some brood years were not tagged (1973–1974 and 1982–1990). Estimates were made for the 1973 and 1974 broods. Estimates were made for the 1988–1995 calendar years, from averages (about 2,000 fish per year) for 1996–2007 for age-1.3 and -1.4 fish. Given the major reductions in the spring troll fishery in SEAK in the years those fish returned, these harvests have a negligible effect in the analysis, whether left in or out.

Estimated age composition of Taku-bound Chinook salmon harvested by the recreational fishery in the Juneau area was calculated as the product of the estimated spring harvest and the estimated or predicted relative age composition of the catch (Table D3). This spring fishery runs from April through late June and covers the bulk of the Taku-bound migration. Age-0. fish (very rare) and contributions of other stocks, estimated from coded wire tag (CWT) recoveries, were first subtracted from estimated harvest. Relative age composition in years when this fishery was not sampled for age data (1977–1982) was predicted by adjusting estimates from spawning Chinook salmon with regressions on data from 1983–1997 when both the recreational fishery and escapements were sampled. Regressions were as described above with the exception that only age-1.3 and -1.4 salmon were involved.

Harvest by age was estimated along with its estimated variance as follows:

$$\hat{H}_{a,t} = \hat{H}_t \hat{p}_{a,t}$$

$$v(\hat{H}_{a,t}) = \hat{H}_t^2 v(\hat{p}_{a,t}) + v(\hat{H}_t)\hat{p}_{a,t}^2 - v(\hat{H}_t)v(\hat{p}_{a,t})$$

Harvests in this fishery were estimated from onsite creel surveys from 1977–2007.Appendix D1.–Page 2 of 5.Harvests occur outside of the recreational and commercial gillnet fisheries in the Juneau area. These harvests were estimated from CWT recoveries as per Bernard and Clark (1996; Table D5). These harvests are occasional, but have been documented to occur in the recreational fishery out of Sitka and in Icy Strait, and in the commercial gillnet fisheries in District 115 (Lynn Canal) and District 108 near Petersburg and Wrangell in the spring time frame.

INRIVER HARVEST

Relative age composition of Chinook salmon harvested in the Canadian inriver gillnet fishery was estimated from information gathered on the spawning grounds and sporadically from the fishery (Table D5). The fishery began in 1979 and was sampled in 1983–1987 and in 1997–2007 to estimate age composition. Fractions for relative age composition of harvests in other years were predicted with regressions following the same procedures described for the marine gillnet fishery. Because all harvest in this commercial and aboriginal fishery was reported, subsequent estimates of harvest by age were calculated with the same equations as were used for the marine gillnet fishery.

A test or assessment fishery has been conducted inriver since 1999, except in 2005 when the commercial fishery was run throughout the immigration. Almost all Chinook caught in the test fishery have been sampled for biological data, and harvest has been completely accounted for. Harvest by age was estimated in the test fishery conducted inriver from large sample sizes each year it was conducted (Table D6).

Table D1.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the commercial gillnet fishery in Taku Inlet. Standard errors are in parenthesis. Estimates in bold come from regressions of age composition.

Year	1.2		1.3		1.4		1.5		Total	
1973	239	(118)	1,255	(254)	6,634	(291)	299	(132)	8,427	(0)
1974	35	(35)	637	(132)	1,842	(140)	106	(61)	2,620	(0)
1975	69	(49)	1,039	(136)	970	(136)	35	(35)	2,113	(0)
1976	**834**	**(201)**	**500**	**(201)**	**209**	**(128)**			1,543	(0)
1977	**183**	**(90)**	**277**	**(90)**	**227**	**(58)**			686	(0)
1978	**1,403**	**(278)**	**0**	**(278)**	**128**	**(131)**			1,531	(0)
1979	**2,675**	**(478)**	**204**	**(478)**	**55**	**(266)**			2,934	(0)
1980	**771**	**(199)**	**544**	**(199)**	**233**	**(127)**			1,549	(0)
1981	**476**	**(146)**	**419**	**(146)**	**253**	**(93)**			1,148	(0)
1982	936	(51)	486	(45)	352	(41)	12	(8)	1,786	(16)
1983	368	(19)	61	(13)	61	(13)			489	(10)
1984	428	(38)	379	(38)	49	(17)			856	(13)
1985	697	(52)	572	(50)	220	(37)			1,489	(7)
1986	397	(82)	447	(85)	397	(82)			1,242	(24)
1987	349	(40)	323	(40)	108	(28)	18	(12)	797	(8)
1988	266	(42)	114	(34)	152	(38)			532	(13)
1989	327	(38)	709	(43)	209	(33)	18	(10)	1,263	(0)
1990	702	(168)	702	(168)	421	(145)			1,825	(0)
1991	765	(103)	659	(99)	659	(99)	64	(36)	2,147	(0)
1992	288	(33)	549	(37)	282	(33)			1,119	(0)
1993	**860**	**(400)**	**1,395**	**(400)**	**823**	**(252)**			3,078	(0)
1994	**302**	**(192)**	**807**	**(192)**	**326**	**(117)**			1,435	(0)
1995	1,823	(91)	344	(74)	203	(59)	41	(27)	2,411	(0)
1996	208	(31)	1,474	(42)	198	(31)	16	(9)	1,896	(0)
1997	120	(25)	808	(52)	1,185	(53)			2,114	(0)
1998	127	(38)	175	(41)	96	(35)			398	(16)
1999	447	(47)	583	(49)	204	(36)	8	(8)	1,241	(8)
2000	228	(25)	219	(25)	110	(20)	5	(5)	562	(0)
2001	175	(24)	647	(30)	142	(22)	8	(6)	972	(0)
2002	622	(64)	633	(64)	284	(51)			1,539	(19)
2003	414	(38)	335	(36)	272	(34)			1,021	(6)
2004	608	(49)	728	(50)	146	(29)			1,482	(21)
2005	2,921	(260)	13,992	(373)	5,177	(326)	106	(53)	22,196	(51)
2006	919	(166)	4,889	(295)	4,660	(294)	66	(46)	10,534	(65)
2007	512	(41)	295	(37)	197	(32)	20	(11)	1,023	(0)

Table D2.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the commercial troll fishery in Southeast Alaska. Standard errors are in parentheses.

Year	1.2		1.3		1.4		1.5		Total	
1978			2,272	(1,704)					2,272	(1,704)
1979	525	(525)	2,272	(1,704)	2,272	(1,704)			5,069	(2,466)
1980			1,540	(920)	2,272	(1,704)			3,813	(1,936)
1981			3,587	(1,882)	1,689	(988)			5,276	(2,126)
1982			552	(393)	2,157	(943)			2,709	(1,022)
1983					419	(316)			419	(316)
1984			2,754	(916)					2,754	(916)
1985					750	(401)			750	(401)
1986			808	(808)					808	(808)
1987					399	(399)			399	(399)
1988			1,169	(877)	865	(648)			2,034	(1,090)
1989			1,169	(877)	865	(648)			2,034	(1,090)
1990			1,169	(877)	865	(648)			2,034	(1,090)
1991			1,169	(877)	865	(648)			2,034	(1,090)
1992			1,169	(877)	865	(648)			2,034	(1,090)
1993			1,169	(877)	865	(648)			2,034	(1,090)
1994			1,169	(877)	865	(648)			2,034	(1,090)
1995			1,169	(877)	865	(648)			2,034	(1,090)
1996			1,605	(896)					1,605	(896)
1997					1,478	(1,045)			1,478	(1,045)
1998					656	(655)			656	(655)
1999	81	(81)	416	(318)	395	(394)			892	(513)
2000			387	(178)	1,003	(437)			1,390	(472)
2001			1,934	(554)	390	(177)			2,324	(582)
2002			1,386	(641)	1,271	(461)			2,658	(789)
2003			974	(445)	796	(476)	160	(159)	1,930	(671)
2004			2,249	(558)	1,666	(621)			3,916	(835)
2005			912	(413)	713	(273)			1,625	(495)
2006			967	(496)	1,054	(409)			2,021	(643)
2007	143	(143)	1,010	(431)	754	(441)			1,906	(633)
2008			1,017	(336)	199	(199)			1,216	(390)

Table D3.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the recreational (sport) fishery near Juneau. Standard errors are in parentheses. Estimates in bold come from regressions of age composition.

Year	1.2	1.3	1.4	1.5	Total
1977		**828 (318)**	**1,622 (355)**		2,450 (278)
1978		**781 (221)**	**892 (226)**		1,673 (190)
1979		**1,386 (292)**	**467 (252)**		1,853 (211)
1980		**1,598 (397)**	**1,302 (383)**		2,900 (329)
1981		**880 (254)**	**1,051 (262)**		1,931 (219)
1982		**616 (204)**	**955 (220)**		1,571 (178)
1983	61 (22)	514 (77)	514 (77)	0 0	1,089 (133)
1984	95 (29)	826 (121)	280 (56)	9 (9)	1,210 (166)
1985	60 (28)	1,162 (168)	627 (109)	15 (14)	1,863 (241)
1986	5 (5)	243 (45)	493 (76)	13 (8)	755 (107)
1987	26 (17)	545 (87)	372 (70)	77 (30)	1,019 (128)
1988	2 (3)	234 (56)	505 (102)	25 (14)	765 (144)
1989	109 (39)	1,183 (225)	462 (104)	97 (36)	1,852 (337)
1990	99 (34)	538 (115)	1,349 (257)	48 (22)	2,035 (377)
1991	333 (78)	1,275 (212)	2,356 (360)	235 (62)	4,199 (609)
1992	12 (12)	1,316 (260)	1,734 (333)	37 (21)	3,099 (574)
1993	55 (27)	1,449 (223)	4,185 (567)	170 (50)	5,860 (776)
1994	122 (35)	649 (106)	1,793 (243)	108 (33)	2,672 (347)
1995	357 (75)	1,614 (186)	1,414 (170)	100 (38)	3,486 (324)
1996	78 (34)	3,252 (362)	736 (122)	55 (29)	4,121 (441)
1997	0 0	1,861 (228)	4,130 (417)		5,991 (567)
1998	145 (37)	669 (96)	1,145 (144)	40 (18)	1,999 (234)
1999	529 (72)	1,074 (126)	779 (97)	25 (12)	2,408 (254)
2000	423 (74)	803 (129)	318 (59)	0 0	1,544 (237)
2001	153 (30)	1,057 (135)	211 (37)	8 (6)	1,429 (179)
2002	116 (34)	1,378 (203)	888 (140)	17 (12)	2,399 (332)
2003	360 (68)	757 (120)	870 (135)	0 0	1,987 (279)
2004	125 (44)	1,865 (273)	696 (128)	14 (14)	2,700 (373)
2005	253 (63)	1,605 (348)	1,090 (240)	20 (11)	2,967 (634)
2006	302 (62)	853 (149)	1,214 (205)	27 (12)	2,396 (390)
2007	107 (38)	859 (258)	429 (133)	15 (10)	1,411 (420)

Table D4.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the recreational and gillnet fisheries in Southeast Alaska, outside of the Juneau area. Standard errors are in parentheses.

Year	1.2	1.3	1.4	1.5	Total
2004		164 (116)		322 (321)	486 (342)
2005	222 (221)	133 (132)	299 (238)		654 (351)
2006		166 (165)	115 (115)		281 (201)
2007		440 (260)	193 (102)		632 (279)
2008		431 (168)	379 (295)	267 (267)	1,078 (432)

Table D5.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the commercial and aboriginal gillnet fisheries in Canada in the Taku River. Standard errors are in parentheses.

Year	1.2		1.3		1.4		1.5		Total	
1979	97	(24)							97	(0)
1980	165	(46)	87	(46)	58	(22)			310	(0)
1981	67	(23)	44	(23)	49	(11)			159	(0)
1982	19	(8)	14	(8)	21	(4)			54	(0)
1983	366	(23)	75	(16)	79	(17)			519	(13)
1984	273	(45)	212	(44)	15	(15)			500	(15)
1985			236	(35)	103	(34)	15	(15)	354	(0)
1986	56	(21)	139	(29)	158	(29)	9	(9)	362	(0)
1987	21	(21)	64	(33)	127	(37)	21	(21)	233	(0)
1988	403	(114)	0	(114)	365	(56)			768	(0)
1989	381	(147)	448	(147)	210	(74)			1,040	(0)
1990	247	(208)	391	(208)	749	(106)			1,386	(0)
1991	924	(246)	181	(246)	504	(111)			1,609	(0)
1992	778	(246)	450	(246)	486	(119)			1,713	(0)
1993	421	(265)	693	(265)	701	(127)			1,815	(0)
1994	332	(372)	1,318	(372)	770	(167)			2,419	(0)
1995	1,407	(392)	0	(392)	538	(135)			1,945	(0)
1996	393	(555)	3,011	(555)	134	(282)			3,538	(0)
1997	108	(43)	955	(108)	1,855	(111)			2,918	(0)
1998	396	(42)	521	(45)	402	(42)	44	(16)	1,363	(14)
1999	389	(34)	576	(36)	224	(28)	13	(7)	1,202	(7)
2000	387	(46)	939	(55)	380	(46)	7	(7)	1,713	(0)
2001	262	(37)	1,068	(49)	338	(41)	32	(14)	1,701	(0)
2002	310	(74)	1,190	(96)	315	(74)	76	(39)	1,891	(0)
2003	1,339	(97)	816	(87)	733	(85)	24	(17)	2,911	(25)
2004	732	(73)	1,694	(86)	435	(60)	52	(22)	2,913	(38)
2005	376	(74)	5,107	(176)	2,928	(172)	21	(18)	8,432	(0)
2006	268	(47)	3,102	(127)	4,286	(129)	142	(35)	7,797	(9)
2007	473	(28)	477	(28)	321	(25)	23	(8)	1,294	(3)

Table D6.–Estimated harvests by year and age of Chinook salmon bound for the Taku River caught in the inriver test fishery. Standard errors are in parentheses.

Year	1.2		1.3		1.4		1.5		Total	
1999	249	(12)	238	(12)	85	(9)	4	(2)	576	(2)
2000	288	(17)	693	(21)	409	(19)	6	(3)	1,397	(2)
2001	254	(22)	866	(28)	277	(23)	7	(4)	1,404	(0)
2002	466	(29)	662	(31)	521	(29)	15	(6)	1,664	(2)
2003	372	(30)	681	(36)	739	(36)	2	(2)	1,795	(4)
2004	295	(27)	1,003	(35)	391	(30)	3	(3)	1,692	(0)
2005										
2006			237	(20)	393	(20)	13	(6)	643	(0)
2007[a]	307	(20)	655	(26)	711	(26)	24	(6)	1,697	(1)

[a] The fishery in 2007 was a limited assessment fishery.

APPENDIX E.
ESTIMATES OF SMOLT ABUNDANCE

Appendix E1.–Estimates of smolt abundance.

Smolt abundance was estimated for 16 year classes, using a 2-sample, mark–recapture experiment with Petersen's estimator as modified by Chapman (1951):

$$\hat{N}_{s,y} = \frac{(n_{c,y}+1)(n_{e,y}+1)}{m_{e,y}+1} - 1$$

$$v[\hat{N}_{s,y}] = \frac{\hat{N}_{s,y}(n_{c,y}-m_{e,y})(n_{e,y}-m_{e,y})}{(m_{e,y}+1)(m_{e,y}+2)}$$

where $\hat{N}_{s,y}$ is the number of smolt leaving the Taku River from year class y, $n_{c,y}$ is the number of smolt tagged from year class y, $n_{e,y}$ is the number of adults sampled in the escapement in subsequent years from year class y, and $m_{e,y}$ is the number of adults in that sample with missing adipose fins.

Young Chinook salmon were captured and implanted with coded wire tags (CWTs) in the Taku River from the 1975–1981 and 1991–present year classes (Table E1). Too few smolt from year classes 1977, 1978, 1980 and 1981 were tagged to produce estimates of smolt abundance. The 2002 and 2003 year classes are incomplete. The 2002 year class contains information for age-1.1 to age-1.3 fish, and the 2003 year class has information for age-1.1 to age-1.2 fish. Thus, smolt estimates for these year classes will improve over time as information from older age classes is accumulated. We estimated smolt abundance for the 1975, 1976, 1979 and 1991–2003 year classes. Young fish were captured in the mainstem of the Taku River with baited minnow traps for the 1975–1981 year classes (Kissner and Hubartt 1986) and with rotary screw traps and minnow traps in some later years. Numbers of smolt marked by CWT ranged from approximately 9,000 to 11,000 for the 1975, 1976, 1979 and 1991–1993 year classes to about 42,000 for the 1999 year class.

Adults were inspected on the spawning grounds or in fish wheels at Canyon Island (near the international border) to estimate the fraction of year class y tagged in year y+2 as smolt. Adults were inspected in years y+3 (age 1.1), y+4 (age 1.2), y+5 (age 1.3), y+6 (age 1.4) and y+7 (age 1.5).

Table E1.–Numbers of smolt marked by CWT, adults inspected and marked, and estimated smolt abundance and associated SEs for Taku River Chinook salmon.

Year class[a]	$n_{c,y}$	$n_{e,y}$	$m_{e,y}$	$\hat{N}_{s,y}$	SE
1975	9,912	5,397	44	1,189,118	174,197
1976	9,550	2,594	15	1,549,052	374,227
1979	8,961	3,245	43	661,150	97,648
1991	10,015	10,267	48	2,098,862	295,390
1992	9,858	3,792	18	1,968,167	438,569
1993	11,121	699	6	1,112,199	391,128
1994	21,588	2,058	30	1,433,926	251,389
1995	37,869	3,279	99	1,242,135	121,538
1996	32,723	5,740	97	1,917,024	190,730
1997	19,531	3,840	38	1,923,651	302,306
1998	17,298	4,486	64	1,194,260	145,660
1999	41,836	7,853	188	1,738,624	124,324
2000	37,776	5,566	105	1,984,004	189,699
2001	27,995	2,494	32	2,116,807	360,408
2002	23,078	1,456	22	1,462,461	296,011
2003	27,335	839	21	1,043,352	214,599

[a] The 2002 year class contains information for age-1.1 through age-1.3 fish; the 2003 year class contains information for age-1.1 to age-1.2 fish.

Details

Escapement sampling for the returning adults from the 1975–1981 year classes was limited to the Nakina River (Figure 1). The Nakina River produces more Chinook than any other tributary in the Taku River drainage (Pahlke and Bernard 1996) and it also has the longest standing stock assessment program. A carcass weir has been operated on this tributary each year since 1973 and an average of 1,000 fish have been sampled annually for age, sex, and length.

Additionally, all other Chinook caught at the weir (up to 4,500) have been sampled for sex and length. In order to estimate smolt abundance (for the 1975, 1976 and 1979 year classes) from recoveries in the Nakina River, samples from this subpopulation must be representative of the entire drainage. Sampling for the 1991–1995 year classes indicate that tagged smolt represented all subpopulations in the Taku River in near equal proportions (Table E2). For example, the marked fraction of fish sampled from the 1991 year class at Canyon Island (0.0056) was not different than the marked fraction of fish sampled at Nakina River (0.0043, $P = 0.40$, $\chi^2 = 0.70$). Similarly, the marked fraction of fish sampled from the 1992 year class at Canyon Island (0.0052) was not different than the marked fraction of fish sampled at Nakina River (0.0044, $P = 0.77$, $\chi^2 = 0.08$). The benchmark for the entire run is Canyon Island. At this location, fish are sampled from fish wheel catches throughout the duration of the adult migration. Canyon Island is located in the lower river below all known Chinook spawning areas and catches are composed of all subpopulations.

Our analysis included smolt estimates from the 2002–2003 year classes, for which adult returns are incomplete (Table E2). Results from earlier brood years indicate that estimates of smolt abundance are relatively stable as the results accumulate across a given brood. For example, the estimated smolt abundance varied from 1.2 to 1.4 million across the 5 age classes for the 1975 year class, from 1.4 to 1.6 million for the 1976 year class and from 0.6 to 0.7 million for the 1979 year class.

Smolt estimates seldom varied after 2 age classes or 5 marked adults were recovered. The narrow range of estimated smolt abundance through the course of accumulated data over each year class is a strong indicator that the marked fraction is consistent across age classes. Marked fractions across age classes for all year classes were not significantly different with the exception of the 1999 year class (Table E3). The 1999 year class had marked fractions for age-1.1 fish (0.0208), age-1.2 fish (0.0173), age-1.3 fish (0.0297) and age-1.4 fish (0.0119) that were significantly different ($P < 0.001$, $\chi^2 = 17.14$). The marked fraction for age-1.3 fish was substantially higher than that seen in the age-1.1, age-1.2 and age-1.4 fish. Marked fractions excluding the age-1.3 component were not significantly different ($P = 0.32$, $\chi^2 = 2.28$). All other year classes had consistent marked fractions across age classes within year class sampled with P-values ranging between 0.09 and 0.96 (Table E3).

Table E2.–Smolt tagged, adults subsequently sampled for marks, marked fraction, estimated smolt abundance with standard errors for year classes 1975, 1976, 1979 and 1991–2003 for Taku River Chinook salmon.

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
1975		1978	1.1	Nakina River	2,192	15	0.0068	1,358,700	328,064
		1979	1.2	Nakina River	1,352	12	0.0089	1,255,056	231,808
		1980	1.3	Nakina River	646	5	0.0077	1,258,950	214,698
		1981	1.4	Nakina River	1,184	12	0.0101	1,184,052	173,452
		1982	1.5	Nakina River	23	0	0.0000	1,189,118	174,197
1975	9,912	1978–1982	1.1-1.5	Cumulative total	5,397	44	0.0082	1,189,118	174,197
1976		1979	1.1	Nakina River	675	3	0.0044	1,614,118	719,566
		1980	1.2	Nakina River	542	3	0.0055	1,454,139	585,655
		1981	1.3	Nakina River	563	3	0.0053	1,417,527	511,171
		1982	1.4	Nakina River	811	6	0.0074	1,375,343	373,793
		1983	1.5	Nakina River	3	0	0.0000	1,376,935	374,227
1976	9,550	1979–1983	1.1-1.5	Cumulative total	2,594	15	0.0058	1,549,052	374,227
1979		1982	1.1	Nakina River	856	11	0.0129	640,035	176,149
		1983	1.2	Nakina River	1,134	17	0.0150	615,287	111,334
		1984	1.3	Nakina River	490	3	0.0061	694,834	119,958
		1985	1.4	Nakina River	757	12	0.0159	659,521	97,405
		1986	1.5	Nakina River	8	0	0.0000	661,150	97,648
1979	8,961	1982–1986	1.1-1.5	Cumulative total	3,245	43	0.0133	661,150	97,648
1991		1994	1.1	Canyon Island	400	2	0.0050	1,338,804	666,794
		1995	1.2	Canyon Island	980	6	0.0061		
				Nakina River	1,230	4	0.0033		
				Nahlin River	1,172	3	0.0026		
				Tats/Kowatua	180	2	0.0111		
				Subtotal	3,562	15	0.0042	2,230,437	539,313
		1996	1.3	Canyon Island	1,330	6	0.0045		
				Nakina River	1,801	9	0.0050		
				Subtotal	3,131	15	0.0048	1,960,631	473,928
		1997	1.4	Canyon Island	674	5	0.0074		
				Nakina River	2,500	11	0.0044		
				Subtotal	3,174	16	0.0050	1,870,634	439,358
1991	10,015	1994–1997	1.1-1.4	Cumulative total	10,267	48	0.0047	2,098,862	295,390
1992		1995	1.1	Canyon Island	162	2	0.0123		
				Nakina River	122	0	0.0000		
				Nahlin River	14	0	0.0000		
				Tats/Kowatua	7	0	0.0000		
				Subtotal	305	2	0.0066	1,005,617	500,262
		1996	1.2	Canyon Island	390	1	0.0026		
				Nakina River	487	2	0.0041		
				Tatsamenie River	70	1	0.0143		
				Subtotal	947	4	0.0042	1,869,265	760,916
		1997	1.3	Canyon Island	376	1	0.0027		
				Nakina River	1,212	5	0.0041		
				Tatsamenie River	234	1	0.0043		
				Subtotal	1,822	7	0.0038	2,246,619	746,925

-continued-

Table E2.–Page 2 of 7.

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE\left(\hat{N}_{s,y}\right)$ SE smolt estimate
1992		1998	1.4	Canyon Island	237	2	0.0084		
				Nakina River	214	2	0.0093		
				Tatsamenie River	267	1	0.0037		
				Subtotal	718	5	0.0070	1,181,436	444,539
1992	9,858	1995–1998	1.1-1.4	Cumulative total	3,792	18	0.0047	1,968,167	438,569
1993		1996	1.1	Canyon Island	25	1	0.0400		
				Nakina River	18	0	0.0000		
				Subtotal	43	1	0.0233	244,683	138,008
		1997	1.2	Canyon Island	73	1	0.0137		
				Nakina River	110	0	0.0000		
				Subtotal	183	1	0.0055	1,023,223	587,486
		1998	1.3	Canyon Island	129	1	0.0078		
				Nakina River	100	0	0.0000		
				Subtotal	229	1	0.0044	1,279,029	735,164
		1999	1.4	Canyon Island	205	3	0.0146		
				Tatsamenie River	39	0	0.0000		
				Subtotal	244	3	0.0123	681,222	302,100
1993	11,121	1996–1999	1.1-1.4	Cumulative total	699	6	0.0086	1,112,199	391,128
1994		1997	1.1	Canyon Island	151	2	0.0132		
				Nakina River	108	2	0.0185		
				Subtotal	259	4	0.0154	1,122,627	453,830
		1998	1.2	Canyon Island	251	4	0.0159		
				Nakina River	200	3	0.0150		
				Tats/Kowatua	89	1	0.0112		
				Subtotal	540	8	0.0148	1,297,738	406,868
		1999	1.3	Canyon Island	248	1	0.0040		
				Test fishery	352	7	0.0199		
				Tatsamenie River	213	1	0.0047		
				Subtotal	813	9	0.0111	1,757,344	526,472
		2000	1.4	Canyon Island	193	4	0.0207		
				Test fishery	253	5	0.0198		
				Subtotal	446	9	0.0202	965,027	287,627
1994	21,588	1997–2000	1.1-1.4	Cumulative total	2,058	30	0.0146	1,433,926	251,389
1995		1998	1.1	Canyon Island	263	5	0.0190		
				Nakina River	137	2	0.0146		
		1999	1.2	Canyon Island	417	14	0.0336		
				Tats/Kowatua	176	4	0.0227		260,402
				Subtotal	593	18	0.0304	1,183,935	
		2000	1.3	Canyon Island	546	20	0.0366		
				Tatsamenie River	436	13	0.0298		181,759
				Subtotal	982	33	0.0336	1,094,888	
		2001	1.4	Canyon Island	224	5	0.0223		
				Nakina River	436	11	0.0252		
				Little Tatsamenie	84	3	0.0357		
				Nahlin River	43	1	0.0233		
				Test fishery	517	21	0.0406		
				Subtotal	1,304	41	0.0314	1,176,674	176,432
1995	37,869	1998–2001	1.1-1.4	Cumulative total	3,279	99	0.0302	1,242,135	121,538

-continued-

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
1996		1999	1.1	Canyon Island & TF	50	2	0.0400		
				Tats/Kowatua	10	0	0.0000		
				Subtotal	60	2	0.0333	665,387	324,395
		2000	1.2	Canyon Island	393	7	0.0178		
				Test Fishery	266	4	0.0150		
				Subtotal	659	11	0.0167	1,799,819	494,531
		2001	1.3	Canyon Island	718	13	0.0181		
				Nakina River	911	15	0.0165		
				Little Tatsamenie	473	6	0.0127		
				Nahlin River	356	3	0.0084		
				Test fishery	1,505	26	0.0173		
				Subtotal	3,963	63	0.0159	2,026,842	249,117
		2002	1.4	Canyon Island	322	9	0.0280		
				Nakina River	461	9	0.0195		
				Little Tatsamenie	38	0	0.0000		
				Nahlin River	133	2	0.0150		
				Dudidontu River	41	0	0.0000		
				Kowatua River	62	1	0.0161		
				Subtotal	1,057	21	0.0199	1,573,726	324,606
		2003	1.5	Little Tatsamenie	1				
1996	32,723	1999–2003	1.1-1.5	Cumulative total	5,724	97	0.0169	1,917,024	190,730
1997		2000	1.1	Canyon Island	54	0	0.0000		
				Test Fishery	2	0	0.0000		
				Subtotal	56	0	0.0000	665,387	324,395
		2001	1.2	Canyon Island	243	3	0.0123		
				Nahlin River	14	0	0.0000		
				Little Tatsamenie	71	1	0.0141		
				Test Fishery	115	1	0.0087		
				Nakina River	299	4	0.0134		
				Subtotal	742	9	0.0121	1,799,819	494,531
		2002	1.3	Canyon Island	613	4	0.0065		
				Nakina River	369	6	0.0163		
				Little Tatsamenie	159	1	0.0063		
				Nahlin River	296	1	0.0034		
				Dudidontu River	139	1	0.0072		
				Kowatua River	87	2	0.0230		
				Subtotal	1,663	15	0.0090	2,026,842	249,117
		2003	1.4	Canyon Island	228	2	0.0088		
				Little Tatsamenie	129	2	0.0155		
				Nahlin River	67	0	0.0000		
				Dudidontu River	106	1	0.0094		
				Tseta Creek	16	1	0.0625		
				Test Fishery	739	6	0.0081		
				Kowatua River	62	1	0.0161		
				Subtotal	1,347	13	0.0097	1,573,726	324,606

-continued-

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
1997		2004	1.5	Canyon Island	6		0.0000		
				Little Tatsamenie	2		0.0000		
				Nakina River	11		0.0000		
				Nahlin River	1		0.0000		
				Test Fishery	12	1	0.0833		
				Subtotal	32	1	0.0313	322,277	180,331
1997	19,531	2000–2004	1.1-1.5	Cumulative total	3,840	38	0.0099	1,923,651	302,306
1998		2001	1.1	Canyon Island	49	1	0.0204		
				Test fishery	1	0	0.0000		
				Nakina River	259	4	0.0154		
				L Tats/Kowatua	41		0.0000		
				Subtotal	350	5	0.0143	1,011,991	379,148
		2002	1.2	Canyon Island	357	4	0.0112		
				Little Tatsamenie	33	0	0.0000		
				Nahlin River	37	0	0.0000		
				Dudidontu River	7	0	0.0000		
				Kowatua River	3	0	0.0000		
				Nakina River	359	8	0.0223		
				Subtotal	796	12	0.0151	1,060,561	281,020
		2003	1.3	Canyon Island	402	3	0.0075		
				Little Tatsamenie	254	3	0.0118		
				Nahlin River	178	0	0.0000		
				Dudidontu River	129	2	0.0155		
				Tseta Creek	32	0	0.0000		
				Test fishery	681	13	0.0191		
				Kowatua River	78		0.0000		
				Subtotal	1,754	21	0.0120	1,380,275	285,816
		2004	1.4	Canyon Island	216	4	0.0185		
				Dudidontu River	15	1	0.0667		
				Little Tatsamenie	73		0.0000		
				Nakina River	920	12	0.0130		
				Nahlin River	27	1	0.0370		
				Test Fishery	332	8	0.0241		
				Subtotal	1,583	26	0.0164	1,014,874	190,003
		2005	1.5	Canyon Island	1		0.0000		
				Little Tatsamenie	2		0.0000		
				Subtotal	3		0.0000		
1998	17,298	2001–2005	1.1-1.5	Cumulative total	4,486	64	0.0143	1,194,260	145,660
1999		2002	1.1	Canyon Island	288	9	0.0395		
				Nakina River	281	2	0.0071		
				L Tats/Kowatua	21	0	0.0000		
				Subtotal	530	11	0.0208	1,851,286	507,547
		2003	1.2	Canyon Island	625	17	0.0272		
				Little Tatsamenie	267	1	0.0037		
				Nahlin River	38	1	0.0263		
				Dudidontu River	25	0	0.0000		
				Kowatua River	46		0.0000		
				Tseta Creek	12	0	0.0000		
				Test fishery	372	5	0.0134		
				Subtotal	1,385	24	0.0173	2,319,932	450,720

-continued-

Table E2.–Page 5 of 7.

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
1999		2004	1.3	Canyon Island	861	27	0.0314		
				Dudidontu River	202	2	0.0099		
				Little Tatsamenie	306	17	0.0556		
				Nakina River	2,000	58	0.0290		
				Nahlin River	236	6	0.0254		
				Test fishery	1,043	28	0.0268		
				Subtotal	4,648	138	0.0297	1,399,281	116,286
		2005	1.4	Canyon Island	111	1	0.0090		
				Dudidontu River	41		0.0000		
				Little Tatsamenie	78	1	0.0128		
				Nakina River	1,030	13	0.0126		
				Subtotal	1,260	15	0.0119	3,297,278	794,466
		2006	1.5	Canyon Island	2		0.0000		
				Dudidontu River	1		0.0000		
				Little Tatsamenie	5		0.0000		
				Nahlin River	2		0.0000		
				Test fishery	5		0.0000		
				Commercial fishery	15		0.0000		
				Subtotal	30		0.0000		
1999	41,836	2002–2006	1.1-1.5	Cumulative total	7,853	188	0.0239	1,738,624	124,324
2000		2003	1.1	Canyon Island	78	1	0.0128		
				Little Tatsamenie	161	2	0.0124		
				Kowatua River	1	1	1.0000		
				Test fishery	5		0.0000		
				Subtotal	245	4	0.0163	1,858,627	750,981
		2004	1.2	Canyon Island	805	14	0.0174		
				Dudidontu River	111	1	0.0090		
				Little Tatsamenie	169	3	0.0178		
				Nakina River	1,120	30	0.0268		
				Nahlin River	98	2	0.0204		
				Test fishery	306	4	0.0131		
				Subtotal	2,609	54	0.0207	1,792,689	236,848
		2005	1.3	Canyon Island	327	1	0.0031		
				Dudidontu River	158	3	0.0190		
				Little Tatsamenie	403	1	0.0025		
				Nakina River	704	18	0.0256		
				Subtotal	1,592	23	0.0144	2,507,447	497,539
		2006	1.4	Canyon Island	183	5	0.0273		
				Dudidontu River	69	1	0.0145		
				Little Tatsamenie	185	4	0.0216		
				Nahlin River	59	1	0.0169		
				Nakina River	436	11	0.0252		
				Test fishery	188	2	0.0106		
				Subtotal	1,120	24	0.0214	1,693,920	328,371
2000	37,776	2003–2006	1.1-1.4	Cumulative total	5,566	105	0.0189	1,984,004	189,699

-continued-

Table E2.–Page 6 of 7.

y Year class	$n_{c,y}$ Smolt CWTd	Year adult sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
2001		2004	1.1	Canyon Island	107	1	0.0093		
				Dudidontu River	1		0.0000		
				Little Tatsamenie	39		0.0000		
				Nakina River	63	1	0.0159		
				Nahlin River	1		0.0000		
				Subtotal	211	2	0.0095	1,978,383	982,115
		2005	1.2	Canyon Island	87	1	0.0115		
				Dudidontu River	22		0.0000		
				Little Tatsamenie	104	3	0.0288		
				Nakina River	227	7	0.0308		
				Subtotal	440	11	0.0250	1,028,852	281,383
		2006	1.3	Canyon Island	186	2	0.0250		
				Dudidontu River	130		0.0108		
				Little Tatsamenie	221	1	0.0000		
				Nahlin River	93	2	0.0045		
				Nakina River	298	6	0.0215		
				Test fishery	117	1	0.0201		
				Subtotal	1,045	12	0.0115	2,252,600	598,141
		2007	1.4	Canyon Island	81		0.0000		
				Inriver assessment	662	6	0.0091		
				Little Tatsamenie	48	1	0.0209		
				Nahlin River	7	0	0.0000		
				Subtotal	798	7	0.0088	2,796,678	927,416
2001	27,995	2004–2007	1.1-1.4	Cumulative total	2,494	32	0.0128	2,116,807	360,408
2002		2005	1.1	Canyon Island	23	2	0.0870		
				Dudidontu River	1		0.0000		
				Little Tatsamenie	45	2	0.0444		
				Nakina River	300	4	0.0133		
				Subtotal	369	8	0.0217	948,802	296,308
		2006	1.2	Canyon Island	75	1	0.0133		
				Dudidontu River	16		0.0000		
				Little Tatsamenie	46		0.0000		
				Nahlin River	13		0.0000		
				Nakina River	96	1	0.0104		
				Test fishery	2		0.0000		
				Commercial fishery	32		0.0000		
				Subtotal	280	2	0.0071	2,164,113	1,076,202
		2007	1.3	Canyon Island	104	2	0.0192		
				Little Tatsamenie	76	2	0.0263		
				Nahlin River	15	0	0.0000		
				Inriver Assessment	612	8	0.0131		
				Subtotal	807	12	0.0149	1,434,707	380,238
2002	23,078	2005–2007	1.1-1.3	Cumulative total	1,456	22	0.0151	1,462,461	296,011

-continued-

y Year class	$n_{c,y}$ Smolt CWTd	Year adults sampled	Age	Location sampled	$n_{e,y}$ Adults examined	$m_{e,y}$ Marked adults	Marked fraction	$\hat{N}_{s,y}$ Estimated smolt	$SE(\hat{N}_{s,y})$ SE smolt estimate
2003		2006	1.1	Canyon Island	69	2	0.0290		
				Dudidontu River	1		0.0000		
				Little Tatsamenie	51	1	0.0196		
				Nahlin River	1		0.0000		
				Nakina River	127	2	0.0157		
				Commercial fishery	1		0.0000		
				Subtotal	250	5	0.0200	1,143,831	427,084
		2007	1.2	Canyon Island	192	2	0.0104		
				Little Tatsamenie	94	1	0.0106		
				Nahlin River	11	1	0.0909		
				Inriver Assessment	292	12	0.0411		
				Subtotal	589	16	0.0272	948,123	220,161
2003	27,335	2006–2007	1.1-1.3	Cumulative total	839	21	0.0250	1,043,352	214,599

Table E3.–Numbers of unmarked and marked adult Chinook salmon gathered by year and age class during CWT sampling in the Taku River from 1994 to 2007 and the resulting χ^2 test statistic and p-value obtained from tests for differences in marked rates between age classes by year class.

Year	Class	Age-1.1	Age-1.2	Age-1.3	Age-1.4	Total	χ^2 test statistic	P-value
1975	Unmarked	2,177	1,340	641	1,172	5,330		
	Marked	15	12	5	12	44		
	Marked-fraction	0 .0069	0 .0090	0 .0078	0 .0102	0 .0083	1.14	0.77
1976	Unmarked	672	539	560	805	2,576		
	Marked	3	3	3	6	15		
	Marked-fraction	0 .0045	0 .0056	0 .0054	0 .0075	0 .0058	0.60	0.90
1979	Unmarked	845	1,117	487	745	3,194		
	Marked	11	17	3	12	43		
	Marked-fraction	0 .0130	0 .0152	0 .0062	0 .0161	0 .0135	2.56	0.46
1991	Unmarked	398	3,547	3,116	3,158	10,219		
	Marked	2	15	15	16	48		
	Marked-fraction	0 .0050	0 .0042	0 .0048	0 .0051	0 .0047	0.27	0.96
1992	Unmarked	303	943	1,815	713	3,774		
	Marked	2	4	7	5	18		
	Marked-fraction	0 .0066	0 .0042	0 .0039	0 .0070	0 .0048	1.33	0.72
1993	Unmarked	42	182	228	241	693		
	Marked	1	1	1	3	6		
	Marked-fraction	0 .0238	0 .0055	0 .0044	0 .0124	0 .0087	2.17	0.54
1994	Unmarked	255	532	804	437	2,028		
	Marked	4	8	9	9	30		
	Marked-fraction	0 .0157	0 .0150	0 .0112	0 .0206	0 .0148	1.69	0.64
1995	Unmarked	393	575	949	1,263	3,180		
	Marked	7	18	33	41	99		
	Marked-fraction	0 .0178	0 .0313	0 .0348	0 .0325	0 .0311	2.66	0.45
1996	Unmarked	58	648	3,900	1,036	5,642		
	Marked	2	11	63	21	97		
	Marked-fraction	0 .0345	0 .0170	0 .0162	0 .0203	0 .0172	1.78	0.62
1997	Unmarked	56	733	1,648	1,334	3,771		
	Marked		9	15	13	37		
	Marked-fraction		0 .0123	0 .0091	0 .0097	0 .0098	1.08	0.78
1998	Unmarked	345	784	1,733	1,557	4,419		
	Marked	5	12	21	26	64		
	Marked-fraction	0 .0145	0 .0153	0 .0121	0 .0167	0 .0145	1.22	0.75
1999[a]	Unmarked	519	1,361	4,510	1,245	7,635		
	Marked	11	24	138	15	188		
	Marked-fraction	0 .0212	0 .0176	0 .0306	0 .0120	0 .0246	17.14	0.0007
2000	Unmarked	241	2,555	1,569	1,096	5,461		
	Marked	4	54	23	24	105		
	Marked-fraction	0 .0166	0 .0211	0 .0147	0 .0219	0 .0192	2.64	0.45
2001	Unmarked	209	429	1,033	791	2,462		
	Marked	2	11	12	7	32		
	Marked-fraction	06 .009	0 .0256	0 .0116	0 .0088	0 .0130	6.52	0.09
2002	Unmarked	361	278	795		1,434		
	Marked	8	2	12		22		
	Marked-fraction	02 .022	0 .0072	01 .015		0 .0153	2.27	0.32
2003	Unmarked	5	573			818		
	Marked	04 .020	16			21		
	Marked-fraction		0 .0279			0 .0257	0.37	0.54

[a] Marked fractions were significantly different between age classes for the 1999 year class.

APPENDIX F.
AGE-STRUCTURED BAYESIAN STATISTICAL ANALYSIS OF TAKU RIVER CHINOOK SALMON STOCK-RECRUIT DATA

Appendix F1.–Bayesian age-structured spawner recruit mode[1] and MCMC methods.

A Ricker spawner recruit function (Ricker 1975) was chosen to model the relationship between escapement and recruitment. Under the Ricker model, the total recruitment R from brood year y is:

$$R = S\,\alpha\,e^{-\beta S}\,e^{\varepsilon} \quad \text{(F1.1)}$$

where S is the number of spawners, α and β are parameters, and the $\{\varepsilon_y\}$ are normally distributed process errors with variance σ^2_{SR}. Parameter α is the number of recruits per spawner in the absence of density dependence and is a measure of the productivity of a stock. Parameter β is a measure of density dependence; the inverse of β is the number of spawners that produces the theoretical maximum return (S_{MAX}).

Equilibrium spawning abundance, in which the expected return $R = S$, is

$$S_{EQ} = \frac{\ln(\alpha')}{\beta} \quad \text{(F1.2)}$$

where $\ln(\alpha)$ is corrected for asymmetric lognormal process error (Hilborn and Walters 1992) as follows:

$$\ln(\alpha') = \ln(\alpha) + \frac{\sigma^2_{SR}}{2} \quad \text{(F1.3)}$$

Number of spawners leading to maximum sustained yield S_{MSY} is approximately (Hilborn 1985)

$$S_{MSY} \approx S_{EQ}\left(0.5 - 0.07\ln(\alpha')\right). \quad \text{(F1.4)}$$

The classical way to estimate the Ricker parameters is to linearize the Ricker relationship by dividing both sides of equation F1.1 by S and taking the natural logarithm, yielding:

$$\ln\frac{R}{S} = \ln(\alpha) - \beta S + \varepsilon \quad \text{(F1.5)}$$

This streamlines parameter estimation because the relationship can now be viewed as a simple linear regression (SLR) of $\ln(R/S)$ on S, in which the intercept is an estimate of $\ln(\alpha)$, the negative slope an estimate of β, and the mean squared error an estimate of the process error variance σ^2_{SR}.

The SLR approach requires that the usual assumptions of linear regression analysis be met, including that the independent variable (S) be measured without error. Small amounts of measurement error in S have little effect; however measurement error with coefficients of variation exceeding 20% can cause substantial bias in SLR estimates of S_{MSY}, as well as increased uncertainty that is not reflected in the classical estimates. We estimate that the measurement error (expressed as CV%) associated with annual spawning escapement estimates ranges from 12% to 25% (Table 1). Other shortcomings of the SLR approach are that it cannot account for serially correlated process error or incomplete brood years.

For these reasons we employed Markov Chain Monte Carlo (MCMC) methods, which are especially well-suited for modeling complex population and sampling processes. This enabled us to analyze the escapement and return data in the context of an age-structured Ricker spawner recruit model in which measurement error, serially correlated process errors, and incomplete brood years are explicitly considered. We implemented the MCMC algorithms in WinBUGS (Gilks et al. 1994), which is a Bayesian software program. This methodology allows for inclusion of the effects of measurement error, serially correlated process errors, and missing data in the analysis; it provides a more realistic assessment of uncertainty than is possible with classical statistical methods. Bayesian statistical methods employ probability as a language to quantify uncertainty about model parameters. Knowledge existing about the parameters outside the framework of the experimental design is the "prior" probability distribution. The output of the Bayesian analysis is called the "posterior" probability distribution, which is a synthesis of the prior information and the information in the data. For similar analyses see Ericksen and Fleischman 2006 and Szarzi et al. (2007).

[1] Statistical notation in Appendix F differs from that in the main body of the report. Correspondences between key quantities are summarized in Table F4.1.

The Bayesian MCMC analysis considers all the data simultaneously in the context of the following "full-probability" statistical model. Returns of Chinook salmon originating from spawning escapement in brood years y = 1983–2001 are modeled as a Ricker stock-recruit function with autoregressive lognormal errors:

$$\ln(R_y) = \ln(S_y) + \ln(\alpha) - \beta S_y + \phi \nu_{y-1} + \varepsilon_y \quad \text{(F1.6)}$$

where α and β are Ricker parameters, ϕ is the autoregressive coefficient, $\{\nu_y\}$ are the model residuals:

$$\nu_y = \ln(R_y) - \ln(S_y) - \ln(\alpha) + \beta S_y , \quad \text{(F1.7)}$$

and the $\{\varepsilon_y\}$ are independently and normally distributed process errors with variance σ^2_{SR}.

Age proportion vectors $\underline{\boldsymbol{p}}_y$ = (p_{y5}, p_{y6}, p_{y7}) from brood year y returning at ages 5-7 are drawn from a common Dirichlet distribution (multivariate analogue of the beta). The Dirichlet is re-parameterized such that the usual parameters:

$$D_a = \pi_a D \quad \text{(F1.8)}$$

are written in terms of location (overall age proportions π_a) and inverse scale (D, which governs the inverse dispersion of the $\underline{\boldsymbol{p}}_y$ age proportion vectors among brood years).

The abundance N of age-a Chinook salmon in calendar year t (t = 1983–2007) is the product of the age proportion scalar p and the total return R from brood year $y = t\text{-}a$:

$$N_{ta} = R_{t-a}\, p_{t-a,a} \quad \text{(F1.9)}$$

Total run during calendar year t is the sum of abundance at age across ages:

$$N_{t\cdot} = \sum_a N_{ta} \quad \text{(F1.10)}$$

Spawning abundance is total abundance minus harvest:

$$S_t = N_{t\cdot} - H_t \quad \text{(F1.11)}$$

where H_t is in turn the product of the annual exploitation rate and total run:

$$H_t = \mu_t N_t \, . \quad \text{(F1.12)}$$

Spawning abundance yielding peak return S_{MAX} is the inverse of the Ricker β parameter. Equilibrium spawning abundance S_{EQ} and spawning abundance leading to maximum sustained yield S_{MSY} are obtained using equations F1.2 – F1.4, except that ln(α) is corrected for AR1 serial correlation as well as lognormal process error:

$$\ln(\alpha') = \ln(\alpha) + \frac{\sigma^2_{SR}}{2(1-\phi^2)} \, . \quad \text{(F1.13)}$$

Expected sustained yield at a specified escapement S is calculated by subtracting spawning escapement from the expected return, again incorporating corrections for lognormal process error and AR1 serial correlation:

$$SY = E[R] - S = Se^{\ln(\alpha')-\beta S} - S \, . \quad \text{(F1.14)}$$

Probability that a given level of escapement would produce average yields exceeding 90% of *MSY* was obtained by calculating the expected sustained yield (*SY*; Equation F1.14) at multiple incremental values of S (0 to 10,000) for each Monte Carlo sample, then comparing *SY* with 90% of the value of *MSY* for that sample. The proportion of samples in which *SY* exceeded 0.9 *MSY* is the desired probability.

Observed data include estimates of spawning abundance, aerial survey counts of spawning fish, estimates of harvest, and scale age counts. Likelihood functions for the data follow.

Estimated inriver abundance is modeled as:

$$\hat{S}_t = S_t e^{\varepsilon_{St}} \quad \text{(F1.15)}$$

where the $\{\varepsilon_{St}\}$ are normal $(0,\sigma^2_{St})$ with measurement error variance σ^2_{St}. Estimates were obtained from mark–recapture methods (Table 1).

Aerial survey counts (1983–2007) are modeled as:

$$\hat{A}_t = qS_t e^{\varepsilon_{At}} \quad \text{(F1.16)}$$

where ε_{At} are normal $(0,\sigma^2_A)$ with variance σ^2_A.

Estimated harvest (1983–2007) is modeled as:

$$\hat{H}_t = H_t e^{\varepsilon_{Ht}} \quad \text{(F1.17)}$$

where ε_{Ht} are normal $(0,\sigma^2_{Ht})$ with individual variances σ^2_{Ht} assumed known from creel survey and Statewide Harvest Survey (SWHS) coefficients of variation.

Numbers of fish sampled for scales (n) that were classified as age-a in calendar year t (x_{ta}) are assumed multinomially (r_{ta},n) distributed[2], with proportion parameters as follows:

$$r_{ta} = \frac{N_{ta}}{N_{t\cdot}} \quad \text{(F1.18)}$$

Bayesian analyses require that prior probability distributions be specified for all unknowns in the model. Non-informative priors (chosen to have a minimal effect on the posterior) were used almost exclusively. Initial returns R_{1976}-R_{1982} (those with no linked spawner abundance) were modeled as drawn from a common lognormal distribution with median μ_{LOGR} and variance σ^2_{LOGR}. Normal priors with mean 0, very large variances, and constrained to be positive, were used for ln(α) and β (Millar 2002), as well as for μ_{LOGR}. The initial model residual ν_0 was given a normal prior with mean 0 and variance $\sigma^2_{SR}/(1-\phi^2)$. Diffuse conjugate inverse gamma priors were used for σ^2_{SR}, σ^2_A, and σ^2_{LOGR}. Annual exploitation rates $\{\mu_t\}$ were given beta (0.1,0.1) prior distributions.

Markov-chain Monte Carlo samples were drawn from the joint posterior probability distribution of all unknowns in the model. For each of 2 Markov chains initialized, a 4,000-sample burn-in period was discarded, thinning by a factor of 10 was initiated, and 25,000 additional updates were generated. The resulting total of 50,000 samples was used to estimate the marginal posterior means, standard deviations, and percentiles. The diagnostic tools of WinBUGS assessed mixing and convergence, and no major problems were encountered. Interval estimates were obtained from the percentiles of the posterior distribution.

[2] This multinomial structure is an oversimplification of the age data, which were collected independently from multiple projects targeting specific components of the run. Rather than program all the complexity of the age composition sampling programs, we assumed a simple multinomial structure and ran the model with two divergent values for the multinomial n (100 and 1,000), meaning that we assumed alternately that the age composition of the total run was estimated with the equivalent of 100 or 1,000 independently sampled ages. The posterior distributions for the two runs were negligibly different.

Appendix F2.–WinBUGS code for Bayesian age-structured spawner-recruit analysis of Taku River Chinook salmon data, 1983–2007. Prior distributions are in italics; sampling distributions of the data are in bold.

```
model {
#  RICKER STOCK-RECRUIT RELATIONSHIP WITH AR1 ERRORS;
#  R[y] IS THE TOTAL RETURN FROM BROOD YEAR y
#  THERE ARE A TOTAL OF Y+A-1 = 25 + 3 - 1 = 27 BROOD YRS REPRESENTED IN DATA+FORECAST
#  THE FIRST A+a.min-1 = 7 DO NOT HAVE CORRESPONDING SPAWNING ABUNDANCES
#  THE REMAINING Y-a.min = 20 DO (BROOD YEARS A+a.min=8 - 27)

  for (y in A+a.min:Y+A-1) {
    log.R[y] ~ dt(log.R.mean2[y],tau.white,500)
    R[y] <- exp(log.R[y])
    log.R.mean1[y] <- log(S[y-a.max]) + lnalpha - beta * S[y-a.max]
    log.resid[y] <- log(R[y]) - log.R.mean1[y]
    }
  log.R.mean2[A+a.min] <- log.R.mean1[A+a.min] + phi * log.resid.0
  for (y in A+a.min+1:Y+A-1) {
    log.R.mean2[y] <- log.R.mean1[y] + phi * log.resid[y-1]
    }
  lnalpha ~ dnorm(0,1.0E-6)I(0,)
  beta ~ dnorm(0,1.0E-1)I(0,)
  phi ~ dnorm(0,1.0E-4)I(-1,1)
  tau.white ~ dgamma(0.01,0.01)
  log.resid.0 ~ dnorm(0,tau.red)I(-3,3)
  alpha <- exp(lnalpha)
  tau.red <- tau.white * (1-phi*phi)
  sigma.white <- 1 / sqrt(tau.white)
  sigma.red <- 1 / sqrt(tau.red)
  lnalpha.c <- lnalpha + (sigma.white * sigma.white / 2 / (1-phi*phi) )
  S.max <- 1 / beta
  S.eq <- lnalpha.c * S.max
  S.msy <- S.eq * (0.5 - 0.07*lnalpha.c)

#  BROOD YEAR RETURNS W/O SR LINK DRAWN FROM COMMON LOGNORMAL DISTN
  mean.log.R ~ dnorm(0,1.0E-4)I(0,)
  tau.R ~ dgamma(0.1,0.1)
  for (y in 1:a.max) {
    log.R.lag[y] ~ dt(mean.log.R,tau.R,500)
    R.lag[y] <- exp(log.R.lag[y])
    }

# GENERATE Y+A-1 = 27 MATURITY SCHEDULES, ONE PER BROOD YEAR
  D.scale ~ dunif(0,1)
  D.sum <- 1 / (D.scale * D.scale)
  pi[1] ~ dbeta(1,1)
  pi.2p ~ dbeta(1,1)
  pi[2] <- pi.2p * (1 - pi[1])
  pi[3] <- 1 - pi[1] - pi[2]
for (a in 1:A) {
  gamma[a] <- D.sum * pi[a]
  for (y in 1:Y+A-1) {
      g[y,a] ~ dgamma(gamma[a],1)
      p[y,a] <- g[y,a]/sum(g[y,])
    }
  }
for (a in 2:A) {
  sibratio[a] <- pi[a] / pi[a-1]
  }

# ASSIGN PRODUCT OF P AND R TO ALL CELLS IN N MATRIX
# y SUBSCRIPT INDEXES BROOD YEAR
# y=1 IS THE BROOD YEAR OF THE OLDEST FISH IN YEAR 1 (upper right cell)
# y=27 IS THE BROOD YEAR OF THE YOUNGEST FISH IN YEAR Y (lower left cell)

# FIRST DO INITIAL CELLS WITHOUT SR LINK (o's and x's INMATRIX ABOVE)
for (y in 3:a.max)  {  N.ta[y-2,1] <- p[y,1] * R.lag[y]  }    # COLUMN 1
for (y in 2:a.max)  {  N.ta[y-1,2] <- p[y,2] * R.lag[y]  }    # COLUMN A=2
for (y in 1:a.max)  {  N.ta[y   ,3] <- p[y,3] * R.lag[y]  }    # COLUMN A=3
```

-continued-

```
# THEN DO CELLS DESCENDING WITH SR LINK (y's IN MATRIX)
for (y in a.max+1:Y+2)   {  N.ta[y-2,1] <- p[y,1] * R[y]  }
for (y in a.max+1:Y+1)   {  N.ta[y-1,2] <- p[y,2] * R[y]  }
for (y in a.max+1:Y)       {  N.ta[y  ,3] <- p[y,3] * R[y]  }

# MULTINOMIAL SCALE SAMPLING ON TOTAL ANNUAL RETURN N
# INDEX t IS CALENDAR YEAR
for (t in 1:Y) {
  N[t] <- sum(N.ta[t,1:A])
  for (a in 1:A) {
    q[t,a] <- N.ta[t,a] / N[t]
    }
  n[t] <- sum(x[t,1:A])
  x[t,1:A] ~ dmulti(q[t,],n[t])
  }

# HARVEST BELOW LOCATION OF STOCK ASSESSMENT PROJECT IS ESTIMATED
# NO HARVEST ABOVE
# AERIAL SURVEY DETECT CONSTANT FRACTION OF SPAWNERS, SUBJECT TO LOGNORMAL ERROR
for (y in 1:Y) {
  mu.Hbelow[y] ~ dbeta(0.1,0.1)
  H.below[y] <- mu.Hbelow[y] * N[y]
  log.Hb[y] <- log(H.below[y])
  tau.log.Hb[y] <- 1 / Hb.cv[y] / Hb.cv[y]
  Hhat.below[y] ~ dlnorm(log.Hb[y],tau.log.Hb[y])
  S[y] <- max(N[y] - H.below[y],1)
  log.S[y] <- log(S[y])
  tau.log.S[y] <- 1 / S.cv[y] / S.cv[y]
  S.hat[y] ~ dlnorm(log.S[y],tau.log.S[y])
  log.qS[y] <- log(q.AS * S[y])
  Air.Survey[y] ~ dlnorm(log.qS[y],tau.AS)
  }
  q.AS ~ dunif(0,1)
  tau.AS ~ dgamma(0.1,0.1)
  sigma.AS <- 1 / sqrt(tau.AS)


# GENERATE FITTED VALUES OF R EVERY 1000 SPAWNING FISH FOR GRAPHICS;
for (i in 1:25) {
  S.star.1[i] <- 8000*i
  R.fit[i] <- S.star.1[i] * exp(lnalpha - beta * S.star.1[i])
  }
# CALCULATE SUSTAINED YIELD AT REGULAR INTERVALS OF S;
# FIND THE PROBABILITY THAT EACH VALUE OF S WILL RESULT IN YIELDS WITHIN X% OF MSC;
R.msy <- S.msy * exp(lnalpha - beta * S.msy)*exp(sigma.red*sigma.red/2)
MSY <- R.msy - S.msy
for (i in 1:100) {
  S.star.2[i] <- 1000*i
  R.fit2[i] <- S.star.2[i] * exp(lnalpha - beta * S.star.2[i])*exp(sigma.red*sigma.red/2)
  SY[i] <- R.fit2[i] - S.star.2[i]
  I90[i] <- step(SY[i] - 0.9 * MSY)
  I80[i] <- step(SY[i] - 0.8 * MSY)
  I70[i] <- step(SY[i] - 0.7 * MSY)
  }
}
```

Appendix F3.–Data for Bayesian age-structured spawner-recruit analysis, Taku River Chinook salmon 1983-2007.

```
list( Y=25, A=3, a.min=5, a.max=7,
x = structure(.Data =c(
577,409,14,
868,117,14,
703,293,4,
514,467,19,
672,299,29,
329,619,52,
661,302,37,
405,574,21,
459,460,81,
558,413,29,
508,467,25,
586,376,38,
428,554,18,
878,119,2,
373,627,0,
294,681,25,
737,250,13,
709,288,3,
790,209,2,
605,391,4,
613,380,7,
783,209,8,
713,284,3,
481,512,7,
587,400,14
),.Dim = c(25, 3))
)

Hhat.below[] Hb.cv[]  S.hat[]  S.cv[] Air.Survey[]
17210.20NA0.991094
45240.21NA0.992284
36990.13NA0.994561
27080.30NA0.993652
20510.21NA0.992837
34280.32NA0.994126
53710.21403290.144339
62320.19521420.184332
79660.16NA0.994543
68870.18NA0.995308
114500.12NA0.996714
78040.16NA0.995121
62880.19338050.154814
104800.11790190.1112057
122730.101149380.167754
37480.19NA0.993609
46240.13167860.192272
52800.10349970.153025
69870.09465440.153690
86370.10550440.204215
71590.10364350.183791
114290.09750320.145953
321030.03387250.132983
221830.04422960.133637
64210.13148540.22933
END
```

Appendix F4.–Results of Bayesian age-structured spawner-recruit analysis, Taku River Chinook salmon, 1983–2001 brood years.

The amount of measurement error in the paired spawner recruit statistics *S* and *R* differed by brood year (Figure F4.1). Precision of individual spawning escapement estimates depended primarily upon whether or not direct estimates, as opposed to aerial survey expansions, were available. Brood year return estimates *R* were also imprecise, because escapement generally comprised a large fraction of the total return. Measurement error in harvest estimates, and to a smaller extent age composition, also contribute to uncertainty in *R*. Posterior medians of *S* and *R* differ from the original data-based point estimates because of measurement error and because all the data are considered simultaneously in the context of the full statistical model.

Because *S* and *R* measurement error was explicitly included in the age-structured spawner recruit model, the results automatically take the effect of such measurement error into account when estimating the Ricker parameters and reference points. Thus the Bayesian MCMC "point estimate" of the Ricker relationship Figure F4.1, constructed from the posterior medians of ln(α) and β, differs from the classical estimate calculated by simple linear regression. In this case the differences are small: the Bayesian analysis indicates slightly lower productivity α, the density dependence parameter β is virtually unchanged, and the estimate of optimal escapement S_{MSY} is slightly (6%) lower (Table F4.1).

Figure F4.2 graphically displays the degree of uncertainty about the true Ricker relationship for Taku River Chinook salmon. Ricker relationships that could have generated the observed {*S*,*R*} data are diverse. The slope at the origin (α) varies substantially among the individual curves; as does the point of maximum recruitment S_{MAX}, which is the inverse of the density-dependent parameter β. On the other hand, most of the possible curves pass through the replacement line within a fairly narrow window, indicating that carrying capacity S_{EQ} is well-estimated. This is a common result for stocks that have experienced relatively low harvest rates with escapements hovering near or slightly below carrying capacity.

The graphical evidence is confirmed by wide 90% interval estimates for ln(α) (0.60 – 1.94), β (1.17 – 3.73 x 10^{-5}), S_{MAX} (26,850 – 85,370), and a narrower interval for S_{EQ} (47,420 – 91,460; Table F4.1). Similarly, S_{MSY} is also reasonably well estimated (90% interval 18,470 – 36,530). S_{MSY} is equally likely to be above or below 23,600. (Table F4.1).

The SY probability profiles in Figure 16 above display the probability of achieving near maximal SY (>70%, 80%, and 90% of *MSY*) for specified levels of escapement. For this stock, the limbs of the profiles are quite steep, indicating that we have good information about the range of escapements that would produce near-maximal yield. For example, there is near 100% certainty that spawning escapements between (approximately) 20,000 and 28,000 fish would result in expected *SY* exceeding 90% of *MSY*. The classical (non-Bayesian) version of the 90% profile is also plotted for comparison. The proposed escapement goal is 90% certain to achieve >90% of *MSY* at the lower end, and better than 25% certain to exceed 90% of *MSY* at the upper end of the escapement goal range.

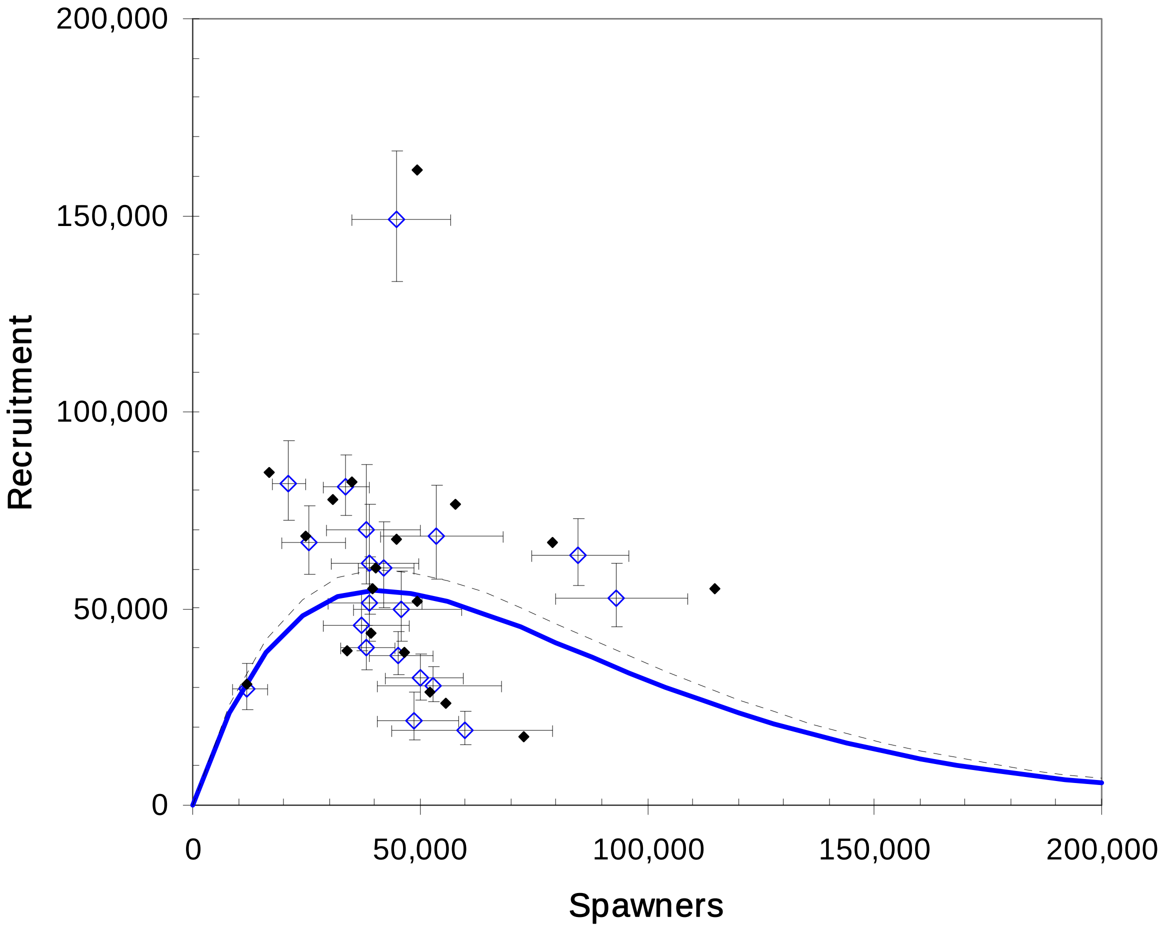


Figure F4.1.–Scatter plot of recruitment versus escapement estimates, Taku River Chinook salmon, 1983–2001 brood years. Posterior medians are plotted as open symbols, 10th and 90th posterior percentiles are bracketed by error bars. Original data-based estimates of S and R are plotted as solid black symbols. Ricker relationships are Bayesian posterior median (solid line) and classical estimate (Table 9; dashed line).

Table F4.1.–Posterior percentiles from a Bayesian age-structured Ricker spawner-recruit analysis of 1983–2007 Taku River Chinook salmon escapement and harvest data, with corresponding quantities from classical analysis in Table 11.

Notation		Point estimates		Lower and upper 90% intervals			
Bayes	Classical	Bayes[a]	Classical	Bayes		Classical	
$ln(\alpha)$	$ln(\alpha)$	1.28	1.35	0.60	1.94		
α	α	3.59	4.48	1.8	7.0		
β	β	2.42E-05	2.37E-05	1.17E-05	3.73E-05		
σ_{SR}		0.55		0.41	0.77		
ϕ		0.20		(0.27)	0.68		
$\sigma_{SR}(1-\phi^2)$		0.58		0.42	0.93		
S_{MSY}	N_{MSY}	23,600	25,075	18,470	36,530	20,655	30,669
S_{MAX}	N_{MAX}	41,250	42,142	26,850	85,370		
S_{EQ}	N_{EQ}	60,020	63,185	47,420	91,460		
D		40		23	76		
p_5		0.596		0.564	0.626		
p_6		0.382		0.351	0.413		
p_7		0.022		0.015	0.032		

[a] Bayesian posterior median.

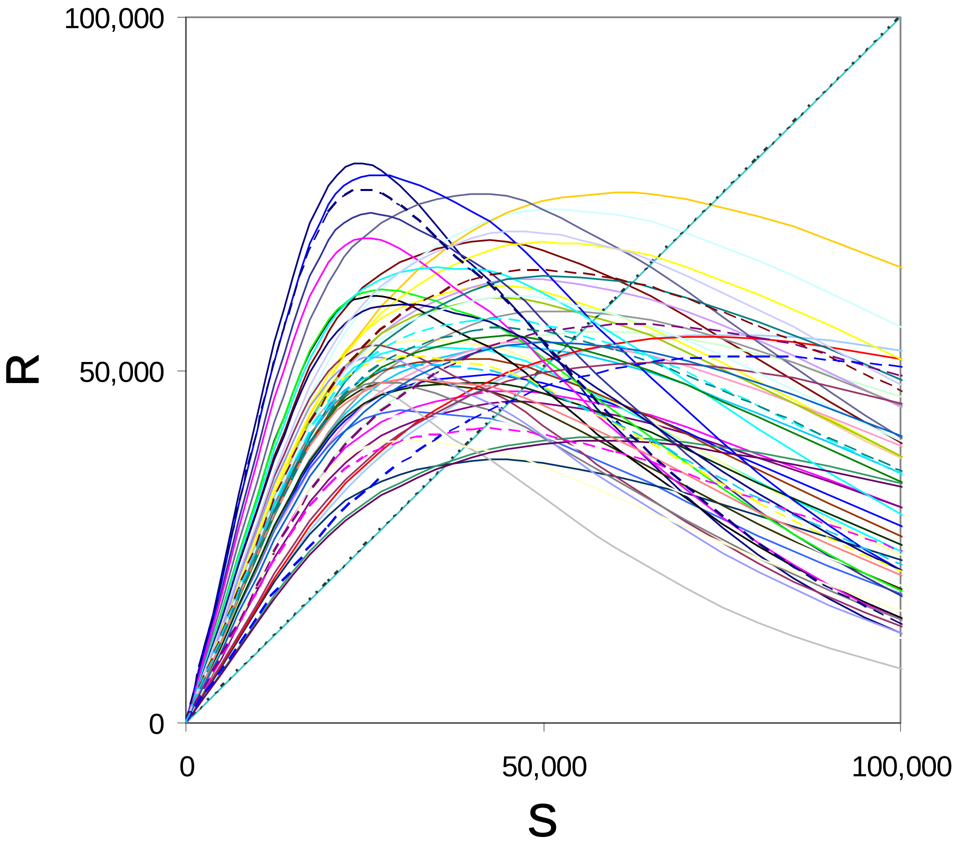


Figure F4.2.–Ricker relationships represented by approximately 50 paired values of ln(a) and b sampled from the posterior probability distribution of stock-recruitment statistics, Taku River Chinook salmon. Symbols are posterior medians of R (recruits) and S (spawners). Curves can be interpreted as a sampling of Ricker relationships that could have generated the observed data.

APPENDIX G.
MANAGEMENT OF TAKU RIVER CHINOOK SALMON

The terminal run of the Chinook salmon stock returning to the Taku River is jointly managed by Canada and the U.S. under the auspices of the Pacific Salmon Treaty (PST), which was renegotiated in May 2008 for 10 years, from 2009–2018. Sections of Annex IV, Chapter 1, of the PST relevant to Taku River Chinook salmon are included in Appendix H. Those sections of the PST define the boundaries of the terminal run, the management approach and provisions for periodic evaluation of the escapement goal.

Management of this stock is an abundance-based approach for "large" Chinook salmon, members of the population that are $\geq$660 mm MEF, where annual allowable harvest is limited to the surplus identified (if any) above spawning requirements. Preseason forecasts of large fish are developed by December 1. These are in effect until inseason forecasts become available in the 2nd or 3rd week in May. Postseason estimates of the escapement and harvest statistics are compiled to assess fishery performance and develop the preseason forecast for the next season. All statistics are developed through a jointly implemented stock assessment program.

Harvests are shared according to a prescribed allocation scheme, shown in Appendix H. These are developed for harvests in excess of base harvests associated with directed sockeye and sport fisheries. The PST directs the parties to manage for diversity and conservation units:

"The Parties agree to share in the burden of conservation. Fishing arrangements must take biodiversity and eco-system [sic] requirements into account."

(v) "Management of Taku River Chinook salmon will take into account the conservation of specific stocks or conservation units when planning and prosecuting their respective fisheries. To avoid over-harvesting [sic] of specific components of the run, weekly guideline harvests, or other agreed management measures, will be developed by the Committee by apportioning the allowable harvest of each Party over the total Chinook season based on historical weekly run timing."

In prosecution of these fisheries to achieve provisions of the PST, past data brings into play important aspects of harvest by age and sex and run timing.

The sex composition of Chinook salmon from the Taku River is variable by individual age class, similar to trends observed in other spring Chinook stocks that produce yearling smolt. Age-1.1 fish are 100% males and the percentage of males decreases as age increases as follows:

Sex	1.1	1.2	1.3	1.4	1.5
Male	100%	94%	53%	36%	21%
Female	0%	6%	47%	64%	79%

Age classes 1.3, 1.4 and 1.5 contain almost all of the females in the spawning population. While age-1.3 fish exhibit a slight majority of males (53%), age-1.4 fish are clearly composed of a majority of females (64%). It would be disadvantageous to selectively harvest age-1.4 fish.

Amongst large age-.3 to -.5 fish, the average (1973-2007) age composition for sexes combined is dominated by age-1.3 fish, composing an average of 60% of the large escapements:

Age class	1.3	1.4	1.5
Percent	60%	38%	2%

It is the combination of majority abundance of age-1.3 fish and other factors that has led to an almost 1:1 ratio of large females to large males on the spawning grounds since 1973, averaging 51% females and 49% males. Management of this stock should be structured to not selectively harvest large females and to maintain the historical proportion of about 1:1 sex ratio amongst large fish. During the 2 years of directed commercial fishing to date (2005 and 2006), the sex composition of large spawners was 50% and 51% females, while exploitation rates were 45% and 34%, respectively.

The Chinook salmon run into the Taku River is composed of early, middle and late run segments. These have been identified as conservation units by Canada. Figure 2 depicts surrogates for these components and shows that, past the tagging station at Canyon Island in the lower river, the early run is composed of fish from the Nahlin, Nakina-bound fish dominate the middle portion, and fish from the Kowatua and Tatsamenie are mostly late run fish. Note that there is overlap of all 4 substocks. Spawning timing follows the same trend, with Nahlin fish spawning in late July to early August, Nakina in August, and Tatasamenie/Kowatua in late August and September. Fish from the Dudidontu, Tseta, Hackett and Yeth rivers run through the middle portion of the migration.

The PST specifically directs the parties to avoid overharvesting of specific components of the run. Management must therefore be structured to spread harvest over the run components. To date, temporal (weekly) harvest guidelines have been deployed in order to accomplish this. We also have no evidence that any 1 run component is more productive than another, based on aerial survey count trends and radio telemetry studies conducted in 1989 and 1990. Additionally, regardless of the substock, fry emerge from the spawning tributaries and rear in a common environment, the mainstem of the Taku River. Regardless, the Transboundary Technical Committee (TTC) must ensure that management regimes accomplish the objectives of this PST directive.Females contain the eggs to produce progeny. There are 11 year classes with estimated escapements of less than 15,200 large females, of the 29 year classes from 1973 to 2001 (Table G1). Of these 11, estimated escapements of large females averaged 9,904 fish and ranged from a low of 4,593 (1975) to 15,165 (1976); the return/large female ratio averaged 5.5:1, and total returns averaged about 48,300 fish. Of the 18 year classes with higher escapements, escapements averaged about 27,500 large females, return/large females averaged 2.2:1 (just over replacement of 2.0), and returns averaged 54,600 large fish.

Returns of over 25,000 large females tended to not replace themselves (Figure G1). Of the 18 escapements with more than 17,500 large females, returns in 10 of them fell below replacement, compared to 2 of 11 year classes with escapements below 15,200 large females. The empirical data show that the best average total return (about 59,200) occurred between spawning escapements of 9,824 and 19,199 large females, which translates to 19,263 to 37,645 large spawners.

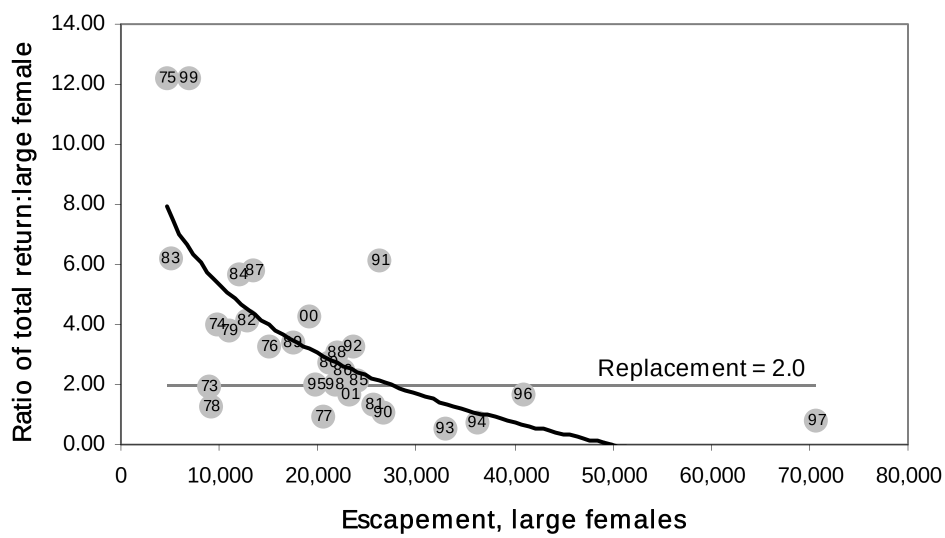


Figure G1.–Estimated escapements of large females against the return per spawner ratio.

Table G1.–Estimated large female (LF) and large parents, total returns (R), returns per large female and exploitation rates for the 1973–2001 year classes.

Year class	Parent large females	Total return of large fish age-.3-.5	R/LF	Parent large spawners	Exploitation rate
1975	4,593	56,126	12.22	12,920	0.122
1983	4,998	30,892	6.18	11,881	0.107
1999	**6,948**	84,703	12.19	**16,786**	0.214
1973	8,929	17,539	1.96	14,564	0.333
1978	9,143	11,503	1.26	17,123	0.089
1974	9,824	39,475	4.02	16,015	0.196
1979	10,997	41,834	3.80	21,617	0.141
1984	12,047	68,371	5.68	24,805	0.105
1982	12,871	53,600	4.16	24,762	0.055
1987	13,424	77,779	5.79	30,811	0.131
1976	15,165	49,300	3.25	24,582	0.171
1989	**17,580**	60,343	3.43	**40,329**	0.117
2000	**19,199**	82,253	4.28	**34,997**	0.408
1995	**19,705**	39,208	1.99	**33,805**	0.115
1977	20,466	19,485	0.95	29,497	0.141
1980	21,228	58,187	2.74	39,239	0.054
1998	21,732	43,785	2.01	39,196	0.161
1988	22,005	67,470	3.07	44,810	0.127
1986	22,583	55,087	2.44	39,663	0.124
2001	**23,110**	39,049	1.69	**46,544**	0.335
1992	23,657	76,549	3.24	57,647	0.078
1985	24,063	51,894	2.16	49,535	0.139
1981	25,642	34,137	1.33	50,784	0.078
1991	26,210	161,498	6.16	49,339	0.112
1990	**26,749**	28,697	1.07	**52,142**	0.146
1993	33,055	17,503	0.53	72,917	0.175
1994	36,282	25,938	0.71	55,617	0.199
1996	**40,897**	66,971	1.64	**79,019**	0.135
1997	**70,691**	55,050	0.78	**114,938**	0.164
Averages					
<16,000 LF	9,904	48,284	5.5	19,624	0.151
>16,000 LF	27,492	54,617	2.2	51,668	0.156
9,800 to 19,200	13,888	59,119	4.3	27,240	

APPENDIX H.
SECTIONS OF THE 2009–2018 PACIFIC SALMON TREATY RELEVANT TO TAKU RIVER CHINOOK SALMON

Appendix H1.– Sections of the 2009–2018 Pacific Salmon Treaty relevant to Taku River Chinook Salmon.

Annex IV

Chapter 1. Transboundary Rivers

The provisions of this Chapter shall apply for the period 2009 through 2018.

1) Recognizing the desirability of accurately determining exploitation rates and spawning escapement requirements of salmon originating in the Transboundary Rivers, the Parties shall maintain a joint Transboundary Technical Committee (the "Committee") reporting, unless otherwise agreed, to the Transboundary Panel and to the Commission. The Committee shall, *inter alia,*:
   - (a) assemble and refine available information on migratory patterns, extent of exploitation and spawning escapement requirements of the stocks;
   - (b) examine past and current management regimes and recommend how they may be better suited to achieving escapement goals;
2) The Parties shall improve procedures for coordinated or cooperative management of the fisheries on transboundary river stocks. To this end, the Parties affirm their intent to continue to implement and refine abundance-based management regimes for Transboundary Chinook in the Taku and Stikine Rivers, sockeye in the Taku and Stikine Rivers, and coho salmon in the Taku River. Further, the Parties affirm their intent to continue to fully develop and implement abundance-based management regimes for Chinook and sockeye in the Alsek River and coho in the Stikine River during the Chapter period.
3) Recognizing the objectives of each Party to have viable fisheries, the Parties agree that the following arrangements shall apply to the United States and Canadian fisheries harvesting salmon stocks originating in the Canadian portion of:
   - (a) the Stikine River: ……
   - (b) the Taku River: ……

   (3) Chinook salmon:
   - (i) This agreement shall apply to large (greater than 659 mm mid-eye to fork length) Chinook salmon originating in the Taku River.
   - (ii) Both Parties shall take the appropriate management action to ensure that the necessary escapement goals for Chinook salmon bound for the Canadian portions of the Taku River are achieved. The Parties agree to share in the burden of conservation. Fishing arrangements must take biodiversity and eco-system requirements into account.
   - (iii) Consistent with paragraph 2 above, management of directed fisheries will be abundance-based through an approach developed by the Committee. The Parties agree to implement assessment programs in support of the abundance-based management regime.
   - (iv) Unless otherwise agreed, directed fisheries on Taku River Chinook salmon will occur only in the Taku River drainage in Canada, and in District 111 in the U.S.
   - (v) Management of Taku River Chinook salmon will take into account the conservation of specific stocks or conservation units when planning and prosecuting their respective fisheries. To avoid over-harvesting [sic] of specific components of the run, weekly guideline harvests, or other agreed management measures, will be developed by the Committee by apportioning the allowable harvest of each Party over the total Chinook season based on historical weekly run timing.

(vi) Commencing 2009, the Parties agree to implement through the Committee an agreed Chinook genetic stock identification (GSI) program to assist the management of Taku Chinook salmon. The Parties agree to continue the development of joint (GSI) baselines.

(vii) The Parties agree to periodically review the above-border Taku River Chinook spawning escapement goal which will be expressed in terms of large Chinook fish (greater than 659 mm mid-eye to fork length).

a. By January 15, 2009, the Parties agree to jointly review the currently agreed escapement goal and pass a jointly prepared technical report through accelerated domestic review processes in time for a revised goal to be applied in the 2009 season. Formal review processes will proceed as required.

(viii) A preseason forecast of the Taku River Chinook salmon terminal run[1] size will be made by the Committee by December 1 of each year.

(ix) Directed fisheries may be implemented based on preseason forecasts only if the preseason forecast terminal run size equals or exceeds the midpoint of the MSY escapement goal range plus the combined Canada, U.S. and test fishery base level catches (BLCs) of Taku River Chinook salmon. The preseason forecast will only be used for management until inseason projections become available.

(x) For the purposes of determining whether to allow directed fisheries using inseason information, such fisheries will not be implemented unless the projected terminal run size exceeds the bilaterally agreed escapement goal point estimate (N_{MSY}) plus the combined Canada, U.S. and test fishery BLCs of Taku River Chinook salmon. The Committee shall determine when inseason projections can be used for management purposes and shall establish the methodology for inseason projections and update them weekly or at other agreed intervals.

(xi) The allowable catch (AC) is calculated as follows:

Base terminal run (BTR) = escapement target + test fishery BLC + U.S. BLC + Cdn BLC

Terminal run – (BTR) = AC

(xii) The BLCs include the following:

a. U.S. Taku BLC: 3,500 large Chinook[2]

b. Canadian Taku BLC: 1,500 large Chinook[3]

c. Test fishery: 1,400 large Chinook;

(xiii) Harvest sharing and accounting of the AC shall be as follows:

Allowable Catch Range		Allowable Catch Share			
		U.S.		Canada	
Lower	Upper	Lower	Upper	Lower	Upper
0	5,000	0	0	0	5,000
5,001	20,000	1	11,000	5,000	9,000
20,001	30,000	11,001	17,500	9,000	12,500
30,001	50,000	17,501	30,500	12,500	19,500
50,001	100,000	30,501	63,000	19,500	37,000

[1] Terminal run = total Taku Chinook run size minus the US troll catch of Taku Chinook salmon outside District 111.

[2] Includes average combined US gillnet and sport catches of Taku Chinook salmon in District 111.

[3] Includes average combined Canadian Aboriginal, commercial and estimated sport catch of Taku Chinook salmon.

Within each Allowable Catch Range, each Party's Allowable Catch Share will be calculated proportional to where the AC occurs within the range.

(xiv) The U.S. catch of the Taku Chinook salmon AC will not count towards the SEAK AABM allocation. In particular:

a. non-Taku Treaty Chinook salmon harvested in District 111 will continue to count toward the SEAK AABM harvest limit;

b. the U.S. BLC of Taku Chinook salmon in District 111 will count toward the SEAK AABM harvest limit;

c. the U.S. catch of Taku Chinook salmon in District 111 above the U.S. BLC will not count towards the SEAK AABM allocation.

Accounting for the SEAK AABM Chinook salmon catches as pertains to transboundary rivers harvests will continue to be the responsibility of the Chinook Technical Committee as modified by (a) through (c) above.

(xv) The Parties shall determine the domestic allocation of their respective harvest shares.

(xvi) When the terminal run is insufficient to provide for the Party's Taku Chinook BLC and the lower end of the escapement goal range, the reductions in each Party's base level fisheries, i.e. the fisheries that contributed to the BLCs, will be proportionate to the Taku Chinook BLC shares, excluding the test fishery.

(xvii) When the escapement of Taku River Chinook salmon is below the lower bound of the agreed escapement range for three consecutive years, the Parties will examine the management of base level fisheries and any other fishery which harvests Taku River Chinook salmon stocks, with a view to rebuilding the escapement.