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Optimal Production of Coho Salmon from the Chilkat River

by

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and

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November 2006

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

Alaska 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

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ABSTRACT

An escapement goal range for adult coho salmon *Oncorhynchus kisutch* from the Chilkat River was developed with information from a stock assessment program (1998–2005) and catch sampling programs of the commercial and recreational fisheries in Southeast Alaska. Stock assessment was based on expanded annual peak escapement counts and mark-recapture estimates of abundance of spawning coho salmon. Relative age composition was estimated from samples collected in Chilkat River fish wheels (1998–2005). Optimal spawning abundance was recommended at 30,000 to 70,000 coho salmon based on two different models of available data. In 2006, the Alaska Department of Fish and Game adopted a biological escapement goal range expressed both in terms of total escapement, 30,000 to 70,000, and peak survey counts, 900–2,100, based on the information presented. We recommend continuation or implementation of several stock assessment components to improve estimation of population statistics and management of this stock.

Key words: Coho salmon, *Oncorhynchus kisutch*, Chilkat River, spawning abundance, mark-recapture, age, sex and length composition, escapement goal, stock-recruit analysis, freshwater production, Bayesian age-structured stock-recruit model, sustained yield.

INTRODUCTION

The Chilkat River produces 100,000 to 300,000 coho salmon *Oncorhynchus kisutch* per year, making it the second largest stock in Southeast Alaska (SEAK). This stock is comprised of a "fall run" of salmon; adults return to the Chilkat River from early August through October and spawn from late September into January. Juveniles rear for one to two years in freshwater after emergence. These fish emigrate from freshwater at age-1 or -2 smolt, and rear in the Gulf of Alaska (Ericksen 2001-2003, *In prep*; Ericksen and Chapell 2005, 2006). Almost all mature adults return after one year at sea with the exception of a few precocious males that return the same year they emigrate (age-1.0 and -2.0 fish). Age-1.1 fish dominate the annual spawning run, while age-2.1 fish typically represent less than 35% of the run.

The Chilkat River is a large glacial system that originates in British Columbia, Canada, flows through rugged dissected mountainous terrain, and terminates in Chilkat Inlet near Haines, Alaska (Figure 1). The mainstem and major tributaries comprise approximately 350 km of river channel in a watershed covering about 2,600 km² (Bugliosi 1988). However, only 1,667 km² are considered accessible to anadromous fish (Ericksen and McPherson 2004).

Coho salmon spawn throughout the Chilkat River drainage (Figure 2) over several months. A radiotelemetry study conducted in 2003 (Ericksen and Chapell 2005) identified nine major coho salmon spawning tributaries (with more than 5% of (13%); Tahini River (10%); Little Salmon River the Chilkat River spawners): Assignation Creek (10%); Clear Creek (adjacent to Chilkat Lake 10%); Chilkat River at Jacquot's Landing (9%); Chilkat River sites from river kilometer (RKM) 22 to 33 (8%); Chilkat Lake tributaries (7%); Bear Flats (7%); and, Kelsall River (6%). This study also documented that spawning timing varied widely between tributaries. While spawning was complete in some tributaries by the end of October (e.g., Tahini River), fish were actively spawning in other areas during January (e.g., Clear Creek near Chilkat Lake).

Exploitation rates on this stock have historically been very high, but have been more moderate in recent years. Research conducted during the 1970s and 1980s on coho salmon stocks in Lynn Canal (including the Chilkat River) concluded that these stocks have, at times, been subjected to very high (over 85%) exploitation rates (Elliott and Kuntz 1988; Gray et al. 1978; Shaul et al. 1986, Shaul et al. 1991). Exploitation rates have ranged from 40% to 65% since 2000 (Ericksen 2001-2003, *In prep*; Ericksen and Chapell 2005, 2006). Most of the harvest occurs in the commercial troll fisheries and Lynn Canal drift gillnet fishery. A history of management actions and regulations affecting this stock is contained in Appendix A.

The commercial troll fishery in northern Southeast Alaska harvests the majority of Chilkat coho salmon (Ericksen 2001-2003, *In prep;* Ericksen and Chapell 2005, 2006; Shaul et al. 1991). The timing of the harvest in this fishery is late relative to other stocks. About 90% of the troll harvest of Chilkat coho salmon occurs between statistical weeks 32

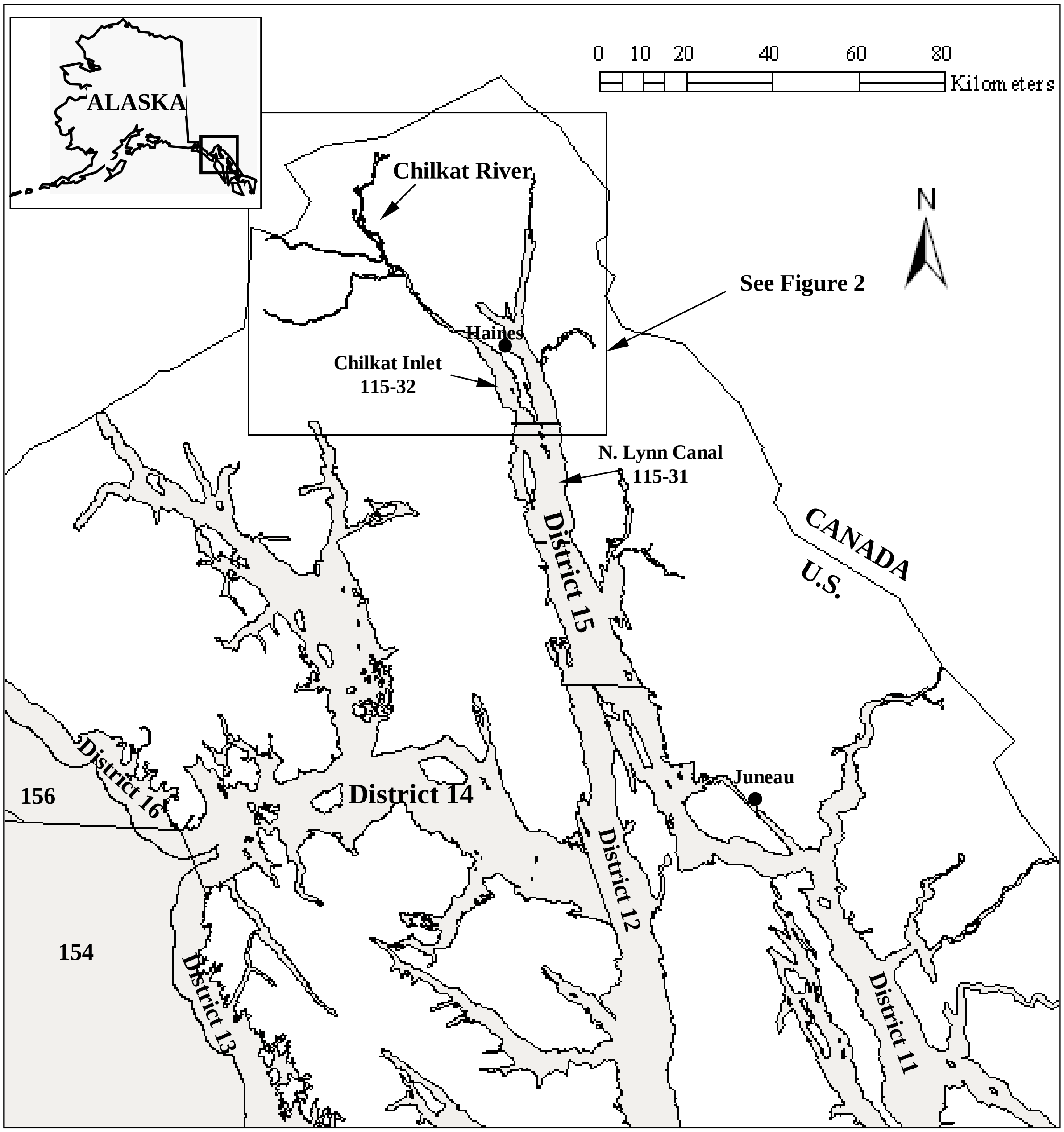

Figure 1.–The location of the Chilkat River and commercial fishing districts in northern Southeast Alaska.

through 40. Most of this harvest occurs in the northwest quadrant. District 14 (Figure 1) has had more Chilkat River coded wire tag recoveries than any other district (Table 1). The troll harvest of coho salmon in this district during statistical weeks 32 through 40 averaged less than 100,000 fish through 1980, then increased to a peak of nearly 300,000 in 1994 (Figure 3). Over the past decade, this harvest has averaged about 140,000 fish.

Commercial fisheries have operated in Chilkat Inlet since the late 1800s (Moser 1899). The largest commercial salmon fishery in Lynn Canal (including Chilkat Inlet) is the District 15 drift gillnet fishery. The summer fishery (through statistical week 31, roughly through July) was historically directed at sockeye salmon *O. nerka*, but in recent years has also targeted hatchery (summer) chum salmon *O. keta* returning to Boat

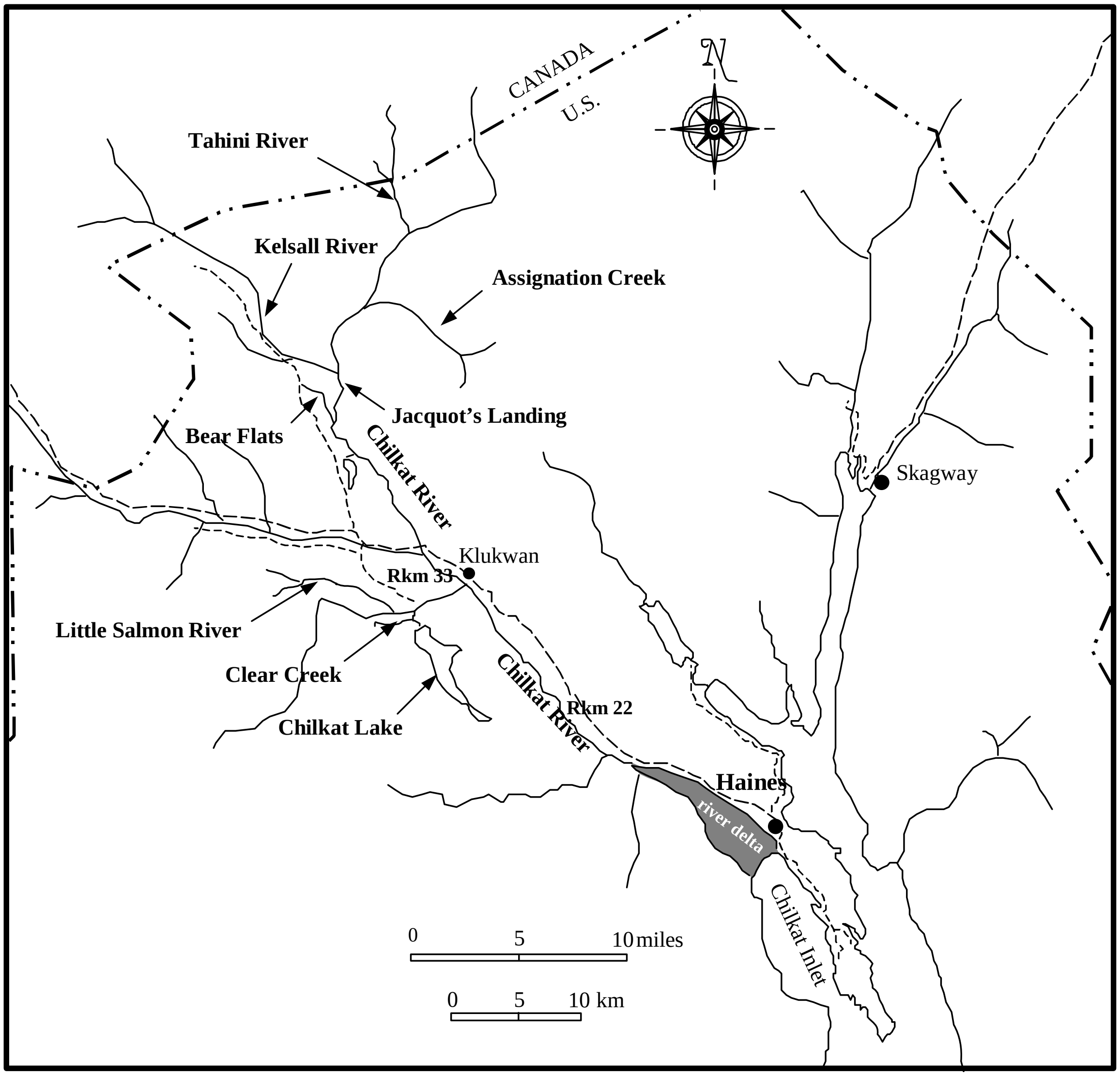

Figure 2.–The Chilkat River drainage showing the location of major coho salmon spawning areas.

Harbor in the southern end of Lynn Canal. The fall fishery (starting statistical week 32) in Lynn Canal historically targeted wild fall chum salmon returning to the Chilkat River. The harvest in this fishery peaked at over 600,000 fall chum salmon in 1985 (Figure 4). However by 1989, returns of wild fall chum salmon had declined dramatically. In recent years, the fall gillnet fishery in Lynn Canal has been directed more toward coho salmon, and effort has dropped to about a third of that observed during the 1980s.

The freshwater coho salmon fishery in Haines provides a small but important component of the local economy. In 1988, anglers fishing in Haines and Skagway for coho salmon spent an estimated $181,000 (Jones and Stokes 1991). This fishery operates late in the year when other fisheries have finished and is equally popular with local and non-local anglers; 58% of anglers who fished in fresh water areas of Haines during 2004 were nonresidents (Jennings et al. *In prep*). The Chilkat River produces most of the coho salmon harvested in Haines area recreational fisheries and supports one of the largest freshwater coho fisheries in the southeast region; annual harvests have averaged about 2,100 coho salmon over the past five years (Jennings et al. 2004, 2006a-b, *In prep*; Walker et al. 2003).

Table 1.–Number of Chilkat River coho salmon with coded wire tags recovered in the commercial troll fishery by year and reported district, 1978–2005.

District	1978	1979	1983	1984	1986	2000	2001	2002	2003	2004	2005	Total
02			1									1
04				1	1							2
09		1	2		1	1				1		6
11	3											3
12	4					2	4		8	5		23
13	1	5	5	6	10	37	28	34	41	18	6	191
14	46	3	12	14	2	37	58	82	163	102	42	561
15	3											3
16	2	1	19	4	1	10	7	3	4	11	7	69
54	1	3		1		2		1		2		10
56		2		1		4						7
57	2	1						1		1		5
81					4		1	1		2		8
83							1	1				2
89				1	5		2	21	7	1	11	48
subtotal	62	16	39	28	24	93	101	144	223	143	66	939
% in 13,14&16	79	56	92	86	54	90	92	83	93	92	83	87
No district reported	38	22	37	25	25	62	94	72	6	48	27	456
Grand total	100	38	76	53	49	155	195	216	229	191	93	1,395

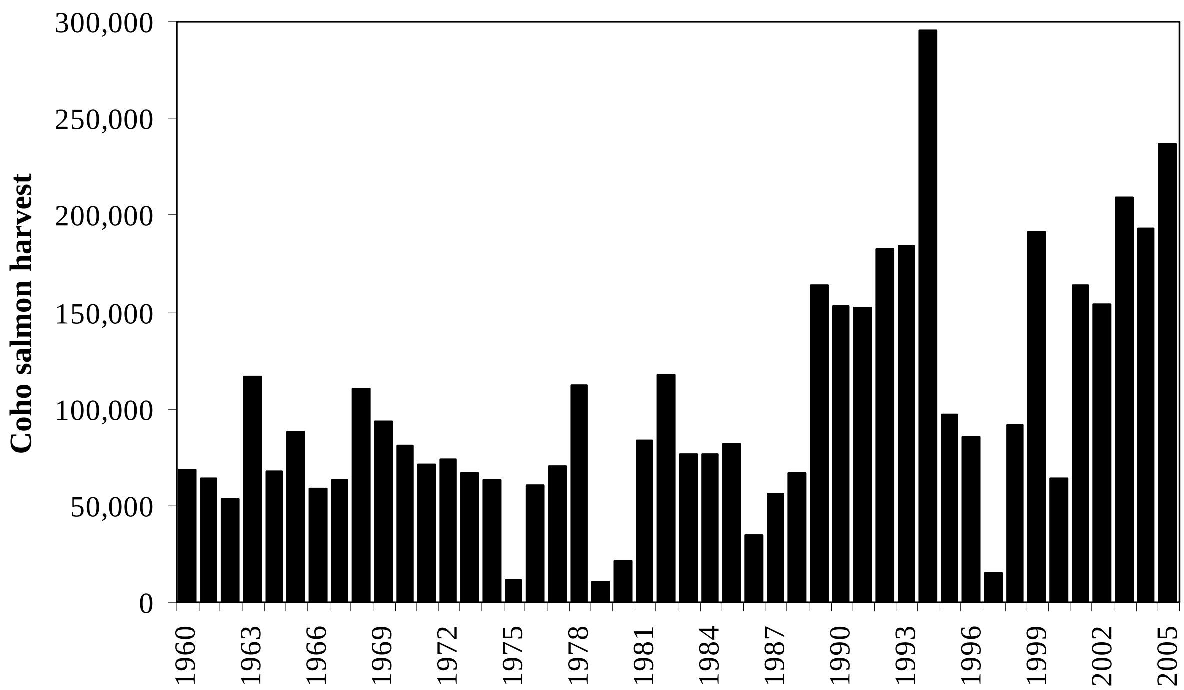

Figure 3.–Coho salmon harvest in the District 14 commercial troll fishery during statistical weeks 32–40, 1960–2005.

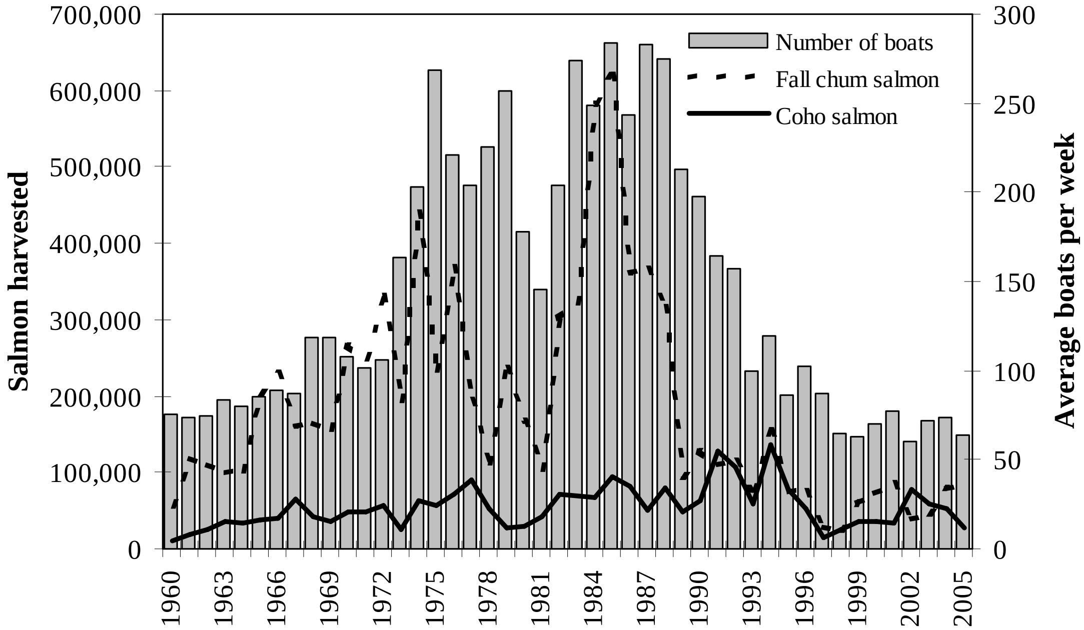

Figure 4.–Effort and harvest of chum and coho salmon in the fall (statistical week 32 until end of season) Lynn Canal (District 15) commercial drift gillnet fishery, 1960–2005

Natural habitat changes have likely influenced coho salmon production in the area. The Chilkat River Valley is uplifting at a rate greater than 1.9 cm per year due to isostatic rebound (Hicks and Shofnos 1965). This phenomenon, combined with rapid river sediment deposition, has accelerated natural succession of aquatic and riparian habitats in the drainage. In addition, beaver activity has increased dramatically over the past two decades. Beavers were virtually non-existent in the Chilkat River drainage prior to 1990 (personal observation). Since that time, beavers have colonized the area. In some areas of the drainage, beaver dams and ponds are extensive. This activity can be detrimental to adult salmon when upstream migration (to spawning areas) is blocked. However, accessible beaver ponds provide excellent rearing habitat for juvenile coho salmon.

Human development activities in the drainage have also likely affected coho salmon production over the past century. Activities such as timber harvest, mining, road construction, and residential development, have likely impacted fish habitat in the area. In recent years, fish habitat mitigation has been required for larger projects. When the Haines Airport was reconstructed in 1991, a series of rearing ponds and groundwater stream channels were created to provide rearing habitat for juvenile coho salmon. The mitigation projects were monitored over three years and coho smolt production increased by an estimated two to four times pre-project levels (Josephson et al. 1997). Similarly, fisheries mitigation measures were required during the first two phases of Haines Highway realignment project constructed between 1991 and 2001. The most significant in terms of coho salmon production was the two-mile extension of 37 Mile Creek with adjacent wetland creations. The monitoring of the mitigation projects is still ongoing, but preliminary results indicate that success was mixed (Kirkpatrick *Unpublished*).

There was one habitat enhancement project specifically designed to increase rearing habitat for juvenile coho salmon in the Chilkat River drainage. Between 1980 and 1982, the Alaska Department of Fish and Game (ADF&G), Fisheries Research, Enhancement and Development (FRED) Division connected 7 isolated ponds to the river to allow juvenile coho salmon access to potential rearing habitat. This project had some success in increasing available coho salmon rearing habitat (Appendix B).

ADF&G adopted a biological escapement goal range (BEG) of 30,000 to 70,000 spawners for this stock in 2006 based on an analysis of the best available information. This report describes the analysis used to develop the escapement goal range for the population of coho salmon in the Chilkat River. We provide an overview of the stock assessment programs used to gather information on this population since 1987. Sources of information are cited and analyses described.

AVAILABLE DATA

SMOLT ABUNDANCE

Juvenile coho salmon have been coded wire tagged in the Chilkat River drainage periodically since 1976 (Appendix C). However, coho smolt have been tagged on an annual basis since 1999. This program has allowed us to estimate annual smolt production using mark-recapture techniques. Smolt were captured each spring in the Chilkat River and marked with an adipose fin clip and a coded wire tag (CWT). In addition, smolt were systematically sampled for scales to estimate age composition. Returning adults were sampled the following year for missing adipose fins as the second sampling event.

Smolt abundance (number emigrating) of coho salmon smolt during year *t* was estimated using Chapman's modified Petersen estimator for a closed population (Seber 1982).

The proportion of age *a* smolt and its variance were estimated as:

$$\hat{p}_{t,a} = \frac{n_{t,a}}{n_t} \tag{1a}$$

$$\hat{\mathbf{v}}[\hat{p}_{ta}] = \frac{\hat{p}_{t,a}(1-\hat{p}_{t,a})}{n_t - 1} \tag{1b}$$

where n_t is the number of successfully aged smolt and $n_{t,a}$ is the subset of n_t determined to be age *a*.

The abundance of age *a* smolt in the emigration was estimated as:

$$\hat{M}_{t,a} = \hat{M}_t \, \hat{p}_{t,a} \tag{2a}$$

$$\hat{v}[\hat{M}_{t,a}] = \hat{v}[\hat{p}_{t,a}]\hat{M}_t^2 + \hat{v}[\hat{M}_t]\,\hat{p}_{t,a}^2 - \hat{v}[\hat{p}_{t,a}]\hat{v}[\hat{M}_t] \tag{2b}$$

where $\hat{M}_t$ is the estimated number of smolt emigrating in year *t*.

The resulting six years of smolt production (Table 2) represents five complete brood years (1997–2001). Annual smolt production over this time averaged about 1.6 million smolt comprised primarily of age-1 fish.

SPAWNING ESCAPEMENT

Escapements have been assessed annually using peak coho survey counts on tributaries of the Chilkat River. The peak survey count program has been standardized in time and area since 1987. The surveys were done multiple times during the peak spawning period of October 1 to October 31. One surveyor conducted essentially all surveys since inception to ensure that the peak survey counts capture trends in relative spawning abundance. Independent mark-recapture studies were conducted five times between 1990 and 2005 (Dangel et al. *Unpublished*; Ericksen 1999; 2003; *In prep;* Ericksen and Chapell 2005, 2006). These studies

Table 2.–Estimated numbers of Chilkat River coho salmon smolt, by age and emigration year, 1999–2004.

Year	Age-1	Age-2	All ages
1999	1,010,262 (182,856)	226,794 (53,499)	1,237,056 (219,715)
2000	1,059,165 (148,766)	126,639 (30,806)	1,185,805 (164,121)
2001	2,576,209 (331,046)	394,248 (69,316)	2,970,458 (377,695)
2002	1,379,793 (159,039)	316,419 (50,823)	1,696,212 (190,330)
2003	1,811,785 (376,083)	126,537 (36,603)	1,938,322 (401,419)
2004	723,476 (138,195)	53,459 (16,587)	776,934 (147,738)
Average	1,426,782	207,349	1,634,131

Note: Standard errors are in parentheses.

validated that the peak survey counts were a good relative measure of coho escapement to the Chilkat River (Ericksen *In prep*). The results of these studies were used to expand the peak survey counts. For years in which mark-recapture experiments were conducted (i=1990, 1998, 2002, 2003, 2005), the ratio ($\hat{Q}_i$) of abundance to peak survey counts for spawning Chilkat coho salmon in year *i* was:

$$\hat{Q}_i = \hat{S}_i / C_i \tag{3a}$$

$$\mathrm{v}(\hat{Q}_i) = \hat{\mathrm{v}}\left(\hat{S}_i\right) / C_i^2 \tag{3b}$$

where $\hat{S}_i$ was the mark-recapture escapement estimate of coho salmon (inriver abundance minus inriver harvest) and C_i was the total of peak survey counts for that year.

The mean of the five $\hat{Q}_i$ estimates was used to expand peak survey counts in years *j* without such estimates:

$$\hat{S}_j = \overline{\hat{Q}} C_j \tag{4a}$$

$$\hat{\mathrm{v}}(\hat{S}_j) = C_j^2 \ \hat{\mathrm{v}}(Q) \tag{4b}$$

where

$$\overline{\hat{Q}} = \frac{1}{5} \sum_{i=1}^{5} \hat{Q}_i \tag{5a}$$

$$\hat{\mathrm{v}}(Q) = \frac{\sum_{i=1}^{5}\left(\hat{Q}_i - \overline{\hat{Q}}\right)^2}{5-1} - \frac{\sum_{i=1}^{5}\hat{\mathrm{v}}\left(\hat{Q}_i\right)}{5} \tag{5b}$$

Note that $\hat{v}(Q)$ instead of $\hat{v}\left(\overline{\hat{Q}}\right)$ was used in equation 4b to capture the expected year-to-year variability in the expansion factor. The variability in the expansion factor. The escapement estimates ranged from 29,341 to 205,429 fish (Table 3).

ADF&G sampled adult coho salmon from fish wheels operating in the Chilkat River annually since 1998. Data from this sampling program were used to estimate numbers of coho salmon in the escapement by age and sex. Abundance of adults by age-sex group *a* and its variance were estimated with equations 2a and 2b above. Table 4 contains the estimates of overall and female spawning abundance for 1998–2005.

HARVEST AND EXPLOITATION RATE

The harvest of Chilkat River coho salmon has been estimated using three methods (Appendix D). First, for year classes with tagged fish, CWTs recovered during harvest sampling in the marine fisheries were expanded for the fraction inspected and the estimated fraction of each year class marked, per procedures described in Bernard and Clark (1996). Second, coho salmon harvests in the Chilkat Inlet and River subsistence fisheries were enumerated from catch reports returned to ADF&G for permits issued to fishery participants. Finally, the estimated harvest of Chilkat River coho salmon in the Haines marine and Chilkat River sport fisheries came from the Sport Fish Division's postal Statewide Harvest Survey (SWHS; e.g. Jennings et al. *In prep*). Harvests within the Chilkat River drainage were identified in the SWHS and summed to estimate the total inriver coho salmon harvest. The marine sport fishery estimates were restricted to locations in the SWHS near the terminus of the Chilkat River and all coho salmon harvested within these locations were assumed to be of Chilkat River origin.

Run size (harvest plus escapement) of coho salmon returning to the Chilkat River in year *t* was estimated as:

$$\hat{T}_t = \hat{H}_t + \hat{S}_t \tag{6a}$$

$$\hat{\mathrm{v}}\left[\hat{T}_t\right] = \hat{\mathrm{v}}\left[\hat{H}_t\right] + \hat{\mathrm{v}}\left[\hat{S}_t\right] \tag{6b}$$

where $\hat{H}_t$ was the estimated total harvest of Chilkat River coho salmon and $\hat{v}\left[\hat{H}_t\right]$ its estimated variance.

The fraction of the run harvested (the exploitation rate) was estimated as:

$$\hat{\mu}_t = \frac{\hat{H}_t}{\hat{T}_t} \tag{7a}$$

$$\hat{\mathrm{v}}[\hat{\mu}_t] \approx \frac{\hat{\mathrm{v}}[\hat{H}_t] S_t^2}{\hat{T}_t^4} + \frac{\mathrm{v}[\hat{S}_t] \hat{H}_t^2}{\hat{T}_t^4} \tag{7b}$$

Table 3.–Peak survey counts, estimated total spawning abundance ($\hat{N}_t$, inriver run minus inriver fishery harvests), associated SEs, and approximate 95% confidence intervals for (all aged) Chilkat River coho salmon, 1987–2005.

Year	Survey counts	$\hat{N}_t$	SE($\hat{N}_t$)	95% confidence interval Lower	95% confidence interval Upper
1987	1,113	37,237	3,101	31,160	43,314
1988	877	29,341	2,443	24,553	34,130
1989	1,452	48,578	4,045	40,651	56,506
1990	3,383	**79,807**	**9,980**	**60,247**	**99,367**
1991	2,513	84,076	7,001	70,355	97,797
1992	2,307	77,184	6,427	64,587	89,780
1993	1,731	57,913	4,822	48,461	67,364
1994	5,781	193,411	16,104	161,846	224,975
1995	1,687	56,441	4,700	47,230	65,652
1996	1,110	37,136	3,092	31,076	43,197
1997	1,294	43,292	3,605	36,227	50,358
1998	1,460	**50,758**	**10,698**	**29,789**	**71,727**
1999	1,699	56,842	4,733	47,566	66,119
2000	2,635	88,157	7,340	73,770	102,544
2001	3,232	108,131	9,003	90,484	125,777
2002	5,660	**205,429**	**31,165**	**144,345**	**266,513**
2003	3,950	**134,340**	**15,070**	**104,803**	**163,877**
2004	2,006	67,113	5,588	56,160	78,066
2005	997	**38,504**	**4,625**	**29,439**	**47,569**
Average	2,362	78,615			
Minimum	877	29,341			
Maximum	5,781	205,429			
Mean Expansion Factor ($\bar{\hat{Q}}$)		33.5			
SE ($\bar{\hat{Q}}$)		2.79			
CV ($\bar{\hat{Q}}$)		0.08			

Note: Statistics in bold come from M-R estimates.

Table 4.–Estimated abundance of spawning coho salmon (both sexes) by age, of spawning female coho salmon, and number of fish sampled (n) in the Chilkat River, 1998–2005.

Year	Age 1.0	Age 2.0	Age 1.1	Age 2.1	All ages	All ages, females only	*n*
1998	915 (353)	6,307 (1,518)	31,635 (6,754)	11,901 (2,679)	**50,758 (10,698)**	23,334 (4,938)	546
1999		2,062 (172)	36,520 (3,041)	18,260 (1,520)	56,842 (4,733)	22,872 (1,951)	671
2000	671 (63)	3,086 (265)	59,442 (4,957)	24,958 (2,086)	88,157 (7,340)	38,627 (3,288)	760
2001		996 (89)	82,442 (6,870)	24,693 (2,062)	108,131 (9,003)	53,515 (4,517)	1,277
2002		681 (402)	163,435 (24,944)	41,313 (6,827)	**205,429 (31,165)**	85,335 (13,002)	1,052
2003		1,897 (528)	115,871 (13,074)	16,571 (2,296)	**134,340 (15,070)**	53,872 (6,336)	1,187
2004	216 (18)	216 (18)	53,474 (4,453)	13,206 (1,100)	67,113 (5,588)	31,752 (3,162)	372
2005	334 (153)	4,805 (781)	28,428 (3,486)	4,938 (797)	**38,504 (4,625)**	14,946 (1,930)	693

Note: Bold numbers came directly from mark-recapture experiments after subtracting inriver fishery harvests. All others are based on expansion of survey counts from 1998–2005. Age composition estimated from Chilkat fish wheel samples 1998–2005. Standard errors are in parentheses.

where the variance was approximated by the delta method (Seber 1982).

Harvest and exploitation rates for 1998 to 2005 are summarized in Table 5. The average exploitation rate for 2000–2005 was used to estimate returns for years without CWT-based harvest estimates (1998 and 1999). It is reasonable to expect that these rates are near current exploitation rates as harvest regimes have not changed significantly over the past decade.

MARINE SURVIVAL

The estimated marine survival rate of smolt leaving freshwater during year t and returning as adults at age a and the delta method approximation of its variance were calculated as:

$$\hat{V}_{t,a} = \frac{\hat{T}_{t+a}}{\hat{M}_t} \tag{8a}$$

$$\hat{v}[\hat{V}_{t,a}] \approx \hat{V}_{t,a}^2 \left[\frac{\hat{v}[\hat{T}_{t+a}]}{\hat{T}_{t+a}^2} + \frac{\hat{v}[\hat{M}_t]}{\hat{M}_t^2} \right] \tag{8b}$$

The results of five complete return years of the stock assessment program are found in Table 6. During this time, annual smolt production has averaged 1.6 million (range = 0.8–3.0 million, average CV = 15.9%) and adult marine harvest has averaged 73,000 (range = 30,000–120,000, average CV = 11.1%). Marine survival has averaged 11% (range 8–13%), and marine exploitation averaged 41% (range 30–66%).

Table 5.–Estimated total harvest of Chilkat River coho salmon, by age and return year, 1998–2005.

	Age-			Exploitation
Return year	1.1	2.1	All ages	rate
1998	***25,416 (2,557)***	***9,562 (1,187)***	***34,977 (3,364)***	***0.408 (0.096)***
1999	***26,113 (2,630)***	***13,057 (1,478)***	***39,170 (3,768)***	***0.408 (0.096)***
2000	28,572 (2,743)	11,997 (1,331)	40,569 (3,752)	0.320 (0.029)
2001	36,966 (3,567)	11,072 (1,219)	48,038 (4,566)	0.299 (0.031)
2002	90,992 (8,425)	23,001 (2,587)	113,993 (10,382)	0.345 (0.040)
2003	75,444 (6,150)	10,790 (877)	86,234 (6,974)	0.377 (0.033)
2004	105,564 (16,126)	26,071 (3,958)	131,635 (19,893)	0.656 (0.038)
2005	26,479 (4,047)	4,600 (852)	31,079 (4,716)	0.450 (0.049)
			2000–2005 average =	0.408 (0.096)

Note: Standard errors are in parentheses. Estimates in bold italics were derived using the average exploitation rate.

Table 6.–Estimated numbers of smolt, marine harvest, inriver run, marine exploitation and survival rates of Chilkat River coho salmon by return year, 2000–2005.[a]

		Adult return (t)			Marine	
Return year (t)	Number smolt (t-1)	Marine harvest	Inriver	Total	Exploitation	Survival
2000	1,237,056 (219,715)	39,716 (3,746)	84,402 (8,831)	124,117 (9,592)	0.320 (0.03)	0.100 (0.02)
2001	1,185,805 (164,121)	45,867 (4,543)	107,136 (11,939)	153,003 (12,774)	0.300 (0.03)	0.129 (0.02)
2002	2,970,458 (377,695)	110,105 (10,355)	208,720 (31,172)	318,825 (32,847)	0.345 (0.04)	0.107 (0.02)
2003	1,696,212 (190,330)	82,384 (6,909)	135,989 (15,067)	218,373 (16,576)	0.377 (0.03)	0.129 (0.02)
2004	1,938,322 (401,419)	128,466 (19,882)	67,299 (5,257)	195,765 (20,565)	0.656 (0.04)	0.101 (0.02)
2005	776,934 (147,738)	29,518 (4,719)	36,028 (4,570)	65,546 (6,569)	0.450 (0.05)	0.084 (0.02)
Ave.	1,634,131	72,676	106,596	179,272	0.408	0.108

Note: Standard errors are in parentheses.

[a] Inriver run includes both escapement and inriver fishery harvests (excluding jacks).

PRODUCTION

Estimated freshwater production of smolt F from brood year y and its estimated variance were calculated as:

$$\hat{F}_y = \sum_{a=1}^{2} \hat{M}_{y+a+1,a} \quad (9a)$$

$$v(\hat{F}_y) = \sum_{a=1}^{2} \hat{v}(\hat{M}_{y+a+1,a}) \quad (9b)$$

where $\hat{M}_{y+a+1,t}$ is the estimated number of age-a coho salmon smolt leaving the Chilkat River in year y+a+1.

The estimated production of adults R from brood year y and its estimated variance were calculated as:

$$\hat{R}_y = \sum_{f=1}^{2} \sum_{m=0}^{1} \hat{S}_{f.m,y+f+2} + \sum_{f=1}^{2} \hat{H}_{f.1,y+f+2} \quad (10a)$$

$$\hat{v}(\hat{R}_y) = \sum_{f=1}^{2} \sum_{m=0}^{1} \hat{v}(\hat{S}_{f.m,y+f+2}) + \sum_{f=1}^{2} \hat{v}(\hat{H}_{f.1,y+f+2}) \quad (10b)$$

where $\hat{S}_{f.m,y+f+2}$ is the estimated spawning escapement and $\hat{H}_{f.1,y+f+2}$ the estimated harvest of coho salmon age-f.m in year y+f+2.

Estimated smolt and adult production by age and estimates of their SEs are in Table 7 for brood years 1994 through 2002.

ANALYSIS

We fitted a smolt production model (Bradford et al. 1999) and a Ricker spawner-recruit model (Ricker 1975) to assess optimal escapement levels for Chilkat River coho salmon. In the case of the spawner-recruit model, Bayesian methods were used to quantify uncertainty about optimal escapement levels.

FRESHWATER PRODUCTION MODEL

We used a piecewise linear "hockey stick" model (Bradford, 1999) to evaluate the minimum number of spawners needed to maximize smolt production. This model uses life history information of coho salmon that indicates that the production of smolt is strongly limited by the availability of rearing habitat. Thus, streams can become fully "seeded" with juveniles at relatively low spawner densities (Bradford et al. 1997; Chapman 1965). The production of smolt from the Chilkat River was modeled as:

$$F_y = \min(\delta N_f, \kappa) \quad (11)$$

where δ is the productivity parameter (smolt per female) for low spawner abundance, N_f is the number of female spawners, and K is the carrying capacity of the Chilkat River drainage for coho salmon smolt. This "hockey stick" model assumes that survival is independent of density up to a critical spawner level N^* (= K/δ) at which point the habitat becomes fully seeded.

The model as fit to the data is shown in Figure 5. The parameter estimates were δ = 84.2 and K = 1,850,543. The model indicates that at low spawner abundance, about 84 smolt were produced per female spawner until 21,990 females spawned (N^*) at which point production stabilized at 1,850,543 smolt. Using an average ratio of 0.44 females in the escapement (Table 4), this equated to a critical spawning abundance of 49,977 of both males and females.

SPAWNER-RECRUIT MODEL

The Ricker spawner-recruit model (Ricker 1975) is widely used in fisheries population dynamics. The total return R is:

$$R_y = S_y \, \alpha \, e^{-\beta S_y} \, e^{\varepsilon_y} \quad (12)$$

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 rate 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}) for the stock of interest.

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

$$S_{EQ} = \frac{\ln(\alpha)'}{\beta} \quad (13)$$

where $\ln\alpha$ is corrected for asymmetric lognormal process error as follows:

Table 7.–Estimated smolt production and adult returns of Chilkat River coho salmon, by age and brood year, 1994-2002. Standard errors are in parentheses. Estimates in bold include harvests derived using the average exploitation rate, and estimates in bold italics were derived using sibling relationships.

			Number of smolt			Adult return				
Brood year	All Spawners	Females	Age-1	Age-2	Total	Age-1.0	Age-2.0	Age-1.1	Age-2.1	All ages
1994	193,411							***41,198 (8,260)***	**21,463 (2,931)**	62,660 (8,764)
1995	56,441						6,307 (1,518)	**57,051 (7,222)**	**31,317 (2,120)**	94,674 (7,679)
1996	37,136	16,340	**1,273,926 (166,077)**	226,794 (53,499)	1,500,720 (174,481)	915 (353)	2,062 (172)	**62,634 (4,020)**	36,954 (2,475)	102,565 (4,737)
1997	43,292	19,049	1,010,262 (182,856)	126,639 (30,806)	1,136,902 (185,432)		3,086 (265)	88,015 (5,666)	35,765 (2,395)	126,866 (6,157)
1998	50,758	23,334	1,059,165 (148,766)	394,248 (69,316)	1,453,414 (164,122)	671 (63)	996 (89)	119,408 (7,741)	64,314 (7,301)	185,388 (10,641)
1999	56,842	22,872	2,576,209 (331,046)	316,419 (50,823)	2,892,628 (334,925)		681 (402)	254,427 (26,328)	27,361 (2,458)	282,469 (26,445)
2000	88,157	38,627	1,379,793 (159,039)	126,537 (36,603)	1,506,331 (163,196)		1,897 (528)	191,316 (14,448)	39,277 (4,108)	232,490 (15,031)
2001	108,131	53,515	1,811,785 (376,083)	53,459 (16,587)	1,865,243 (376,449)		216 (18)	159,039 (16,730)	9,538 (1,167)	168,793 (16,770)
2002	205,429	85,335	723,476 (138,195)			216 (18)	3,753 (757)	54,907 (5,341)	***19,270 (4,307)***	78,147 (6,903)

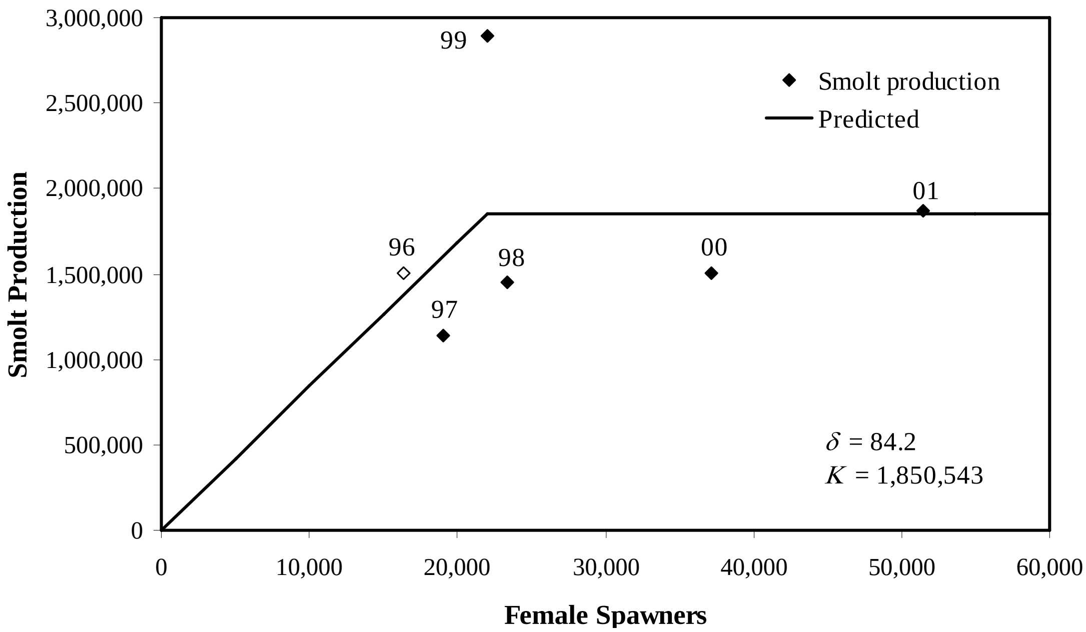

Figure 5.–Freshwater smolt production data against estimated female spawning abundance for Chilkat River coho salmon brood years, 1996–2001. Production off the 1996 escapement was partially estimated using a sibling regression.

$$\ln(\alpha)' = \ln(\alpha) + \frac{\sigma_{SR}^2}{2} \tag{14}$$

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

$$S_{MSY} \approx S_{EQ}\left(0.5 - 0.07\ln(\alpha)'\right) \tag{15}$$

Classical Analysis

Traditionally, Ricker parameters are estimated by dividing both sides of equation 12 by S and taking the natural logarithm, yielding:

$$\ln\frac{R}{S} = \ln\alpha - \beta S + \varepsilon \tag{16}$$

Viewed as a simple linear regression of ln(R/S) on S, the intercept is an estimate of lnα, the negative slope an estimate of β, and the mean squared error an estimate of the process error variance σ^2_{SR}. Escapements and returns for brood years 1994–2002 are listed in Table 7 and the resulting model fit is shown in Figure 6. The parameter estimates were lnα = 1.85, α = 6.33, β = 0.0000140, and σ_{SR} = 0.37.

Replacement escapement (S_{EQ}), or the point in the spawner-recruit relationship where harvestable surplus fell to zero, was 136,409 coho salmon, and maximum stock size S_{MAX} occurred at 71,264 coho salmon in the escapement. The point estimate of S_{MSY} is 50,051 fish. The number of spawners estimated to produce 90% of maximum sustained yield ranged from 31,850 to 71,488.

Bayesian Analysis

The above approach has been used in Alaska to establish an escapement goal range when stock-specific production parameters can be estimated for individual stocks (e.g., Clark et al. 2002). However, for the Chilkat River coho salmon dataset, several factors were identified that could compromise the validity of such an approach.

1) The time series of spawner-recruit data is short. Although foot surveys have been conducted since 1987 to index escapement, paired spawner-recruit data were available for only nine brood years (1994–2002).

2) Escapements expanded from foot survey counts were probably subject to substantial measurement error. Even though the foot surveys show good agreement with mark-recapture (MR) abundance estimates and MR estimates have encompassed a wide range of

abundances, there were only five such estimates and only four degrees of freedom to describe variability. A very small proportion (~3%) of estimated escapement was observed in the foot surveys. The foot surveys probably did not index escapement as precisely as the small dataset seemed to indicate.

3) The estimated escapement for one of the brood years that carried the most influence (1994-large escapement and low return) was expanded from foot surveys. Furthermore, estimated return from the 1994 and 2002 brood years depended partially on imputed values of harvest (1998) and returns at age (age-1.1 fish in 1997 and age-2.1 fish in 2006).

4) The residuals from the fitted Ricker model exhibit very high autocorrelation (Figure 7). Auto-correlated residuals can affect the accuracy of estimates of spawner-recruit parameters.

It is important to assess how much uncertainty was introduced into the estimate of S_{MSY} as a result of the above factors. This can be difficult to accomplish with classical statistical methods. Thus, we used Bayesian methods to quantify uncertainty about optimal escapement levels for this stock.

The Bayesian age-structured spawner-recruit (BASSR) analysis considered all the data simultaneously in the context of the following statistical model: returns of coho salmon originating from spawning escapement in brood year y (y=1994-2002) were modeled with a Ricker stock-recruit function with autoregressive lognormal errors

$$\ln(R_y) = \ln(S_y) + \ln(\alpha) - \beta S_y + \phi \nu_{y-1} + \varepsilon_y \quad (17)$$

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

$$\nu_y = \ln(R_y) - \ln(S_y) - \ln(\alpha) + \beta S_y \quad (18)$$

and the ε_y were independently and normally distributed process errors with variance σ^2_{SR}.

Proportions of fish p_{ya} from brood year y returning at age a were modeled as Dirichlet distributed (multivariate analogue of the beta distribution) with parameters:

$$\eta_a = D\pi_a \quad (19)$$

where π_a were the overall age proportions and D reflected the inverse dispersion of the $p_{y,a}$ age proportion vectors among brood years (small values of D signify greater variability of age proportions, and vice-versa).

The abundance N of age-a coho salmon in calendar year t (t = 1994-2005) was the product of the age proportion q and the total return R from brood year $y = t\text{-}a$:

$$N_{t,a} = R_{t-a}\, q_{t-a,a} \quad (20)$$

Total abundance during year t was the sum of abundance at age across ages:

$$N_{Rt} = \sum_a N_{Rt,a} \quad (21)$$

Spawning abundance during year t was:

$$S_t = N_{Rt} - N_{Ht} \quad (22)$$

where N_H is the combined sport and commercial harvest, i.e., the product of the total exploitation rate μ_t and total abundance N_{Rt}

$$N_{Ht} = \mu_t N_{Rt} \quad (23)$$

Exploitation rates were drawn from a common beta distribution with parameters B_1 and B_2.

Spawning abundance yielding peak return S_{MAX} was calculated as the inverse of the Ricker β parameter. Equilibrium spawning abundance, S_{EQ}, and spawning abundance leading to maximum sustained yield S_{MSY} were obtained using equations 14 and 15, except that ln(α) was corrected for AR1 serial correlation as well as lognormal process error:

$$\ln(\alpha)' = \ln(\alpha) + \frac{\sigma^2_{SR}}{2(1-\phi^2)} \quad (24)$$

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

$$SY = R - S = Se^{\ln(\alpha)' - \beta S} - S \quad (25)$$

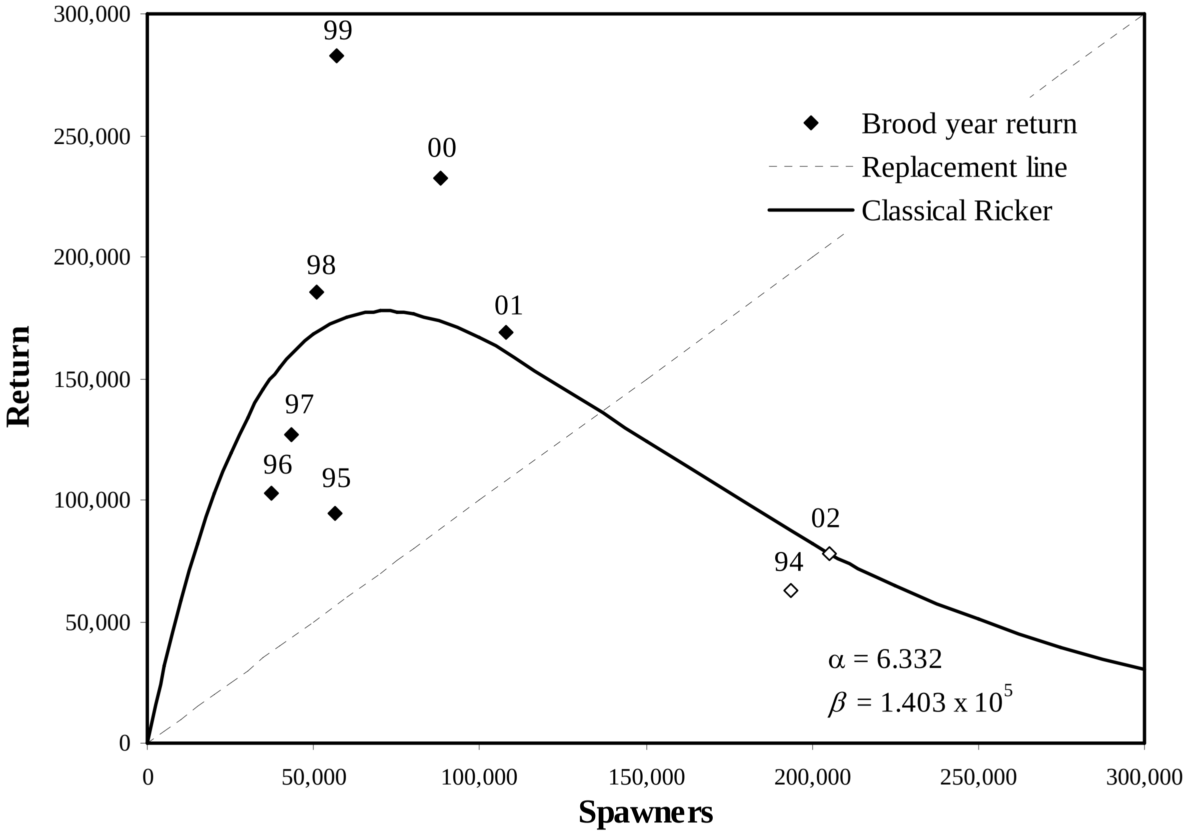

Figure 6.–Estimated Chilkat River coho salmon adult return for brood years 1994–2002 against the estimated spawning abundance of their parents. The 1994 and 2002 returns were partially estimated using sibling regressions.

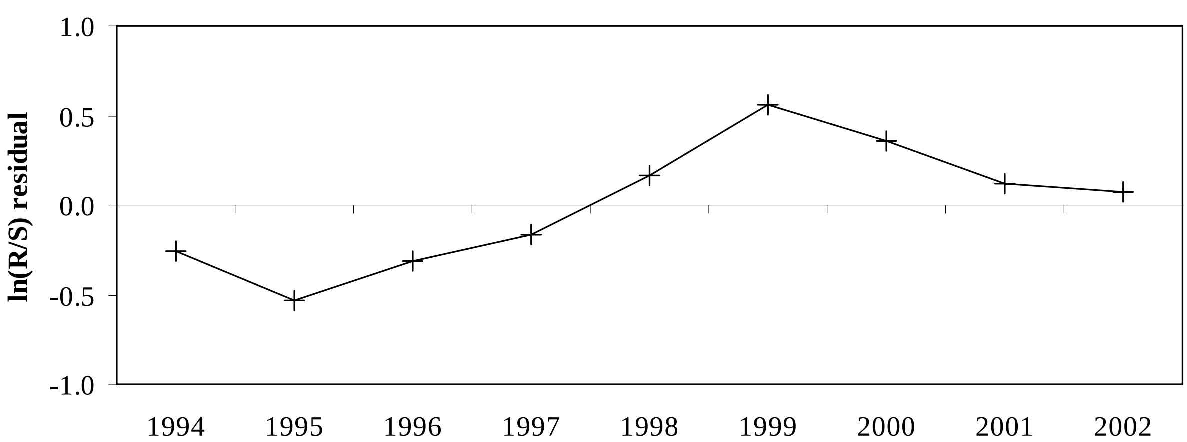

Figure 7.–Residuals ((ln(R/S) - fitted ln(R/S)) from conventional Ricker spawner-recruit analysis of Chilkat River coho salmon, 1994-2002 brood years. The residuals exhibit high autocorrelation.

Observed data included estimates of spawning abundance, foot survey counts, estimates of harvest, and scale age counts. Likelihood functions for the data follow.

Estimated spawning abundance was modeled as:

$$\hat{S}_t = S_t e^{\varepsilon_{MRt}} \tag{26}$$

where ε_{MRt} was normal $(0,\sigma^2_{MRt})$ with individual variances σ^2_{MRt} assumed known from mark-recapture experiment coefficients of variation.

Foot survey counts were modeled as linearly related to true spawning abundance:

$$c_t = \lambda S_t e^{\varepsilon_{FSt}} \tag{27}$$

where λ was the fraction of spawning salmon observed in the foot surveys, ε_{FSt} was normal $(0,\sigma^2_{FS})$, and the common error variance σ^2_{FS} was informed by the relationship between $\hat{S}$ and C for years 1990, 1998, 2002, 2003, and 2005.

Estimated harvest (2000–2005) was modeled as

$$\hat{H}_t = \hat{H}_t e^{\varepsilon_{Ht}} \tag{28}$$

where ε_{Ht} was normal $(0,\sigma^2_{Ht})$ with individual variances σ^2_{Ht} assumed known from CWT/SWHS coefficients of variation.

Numbers of fish sampled for scales x_{ta} that were classified as age-a in calendar year t were multinomial $(r_{ta},n/4)$ distributed, with proportion parameters as follows:

$$r_{t,a} = \frac{N_{Rt,a}}{\sum_a N_{Rt,a}} \tag{29}$$

The order parameter of the multinomial distribution was set equal to the number of valid scale ages divided by 4. This arbitrarily reduced the effective sample size (and thus the precision) of the scale sampling program to account for possible aging error, which is not uncommon for coho salmon.

Bayesian analyses require that prior probability distributions be specified for all unknowns in the model. With one exception described below, non-informative priors were used. Initial returns R_{1990}-R_{1993} (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 zero, very large variances, and constrained to be positive, were used for $\ln(\alpha)$ and β (Millar 2002), as well as for B_1, B_2, and μ_{LOGR}. The initial model residual ν_0 was given a normal prior with mean zero and variance $\sigma^2/(1-\phi^2)$. Diffuse conjugate inverse gamma priors were used for σ^2_{SR}, σ^2_{FS}, σ^2_H, and σ^2_{LOGR}.

The model was run a second time to introduce informed skepticism about the precision of the foot surveys into the model. A subjective, informative, prior distribution for σ_{FS} was elicited from one reviewer. The prior reflected the reviewer's professional opinion regarding how much precision we could expect from foot surveys similar to those conducted on the Chilkat River, and counting only 3% of spawning coho salmon. The skeptical prior (σ^2_{FS}~inverse gamma(4,1)) was centered at approximately $\sigma_{FS} = 0.5$, which generated a positive relationship between true spawning abundance and foot survey counts, but a very inconsistent and imprecise one. The data themselves indicated an error standard deviation of $\hat{\sigma}_{FS}$ (CV) = 0.08 (Table 3).

The Markov-chain Monte Carlo method drew samples from the joint posterior probability distribution of all unknowns in the model. Three Markov chains were initiated, a 4,000-sample burn-in period was discarded, and >50,000 updates generated to estimate the marginal posterior means, standard deviations, and percentiles. The diagnostic tools of WinBUGS (Gilks et al. 1994) assessed mixing and convergence. No convergence problems were experienced. Interval estimates were obtained from the percentiles of the posterior distribution.

The posterior distribution from an age-structured model is multivariate with many dozens of free dimensions. Additionally, any quantity that can be calculated from model parameters can also be monitored by WinBUGS and its posterior density estimated. A summary of posterior percentiles from key model quantities is in Table 8.

Posterior medians of R_t are plotted versus posterior medians of S_t in Figure 8. Uncertainty (plotted as 80% intervals) is substantial in both R (vertical) and S (horizontal) dimensions. As expected, the true escapement was very uncertain for brood year 1994 due to the issues discussed earlier. The escapement for 1998 was known with the most certainty because it was the only completed brood year for which *S* was estimated directly with relatively precise MR experiments.

The uncertainty in *R* (vertical error bars) was primarily due to measurement error in the escapement estimates because escapement usually comprises a large fraction of the total return. Multinomial sampling error for age composition and harvest estimate sampling error also contributed to this uncertainty.

The *SR* data pairs all have different levels of uncertainty. The effect of the BASSR analysis was to simultaneously consider all data *and* their relative uncertainty when sampling from most probable values of the model parameters. Thus each data point was weighted differently in the analysis, and subject to different levels of "shrinkage" away from the original data-based point estimates and toward values which fit the model (Figure 9).

For Chilkat River coho salmon, the Ricker model described by the posterior median of $\ln(\alpha)$ and β was similar to the model estimated by the conventional analysis (Table 8, Figure 9). The uncertainty in $\ln(\alpha)$ and β, plus the very strong autocorrelation, translated into extremely wide interval estimates of the fitted Ricker values of *R* (Figure 10).

On the other hand, the posterior distribution of S_{MSY} was reasonably narrow (Figure 11). We can be 80% certain that maximum sustained yield occurs when spawning abundance is between 34,000 and 58,000 fish. The width of the 80% interval divided by the posterior median of S_{MSY} is an index of the relative uncertainty (RU) of our knowledge about S_{MSY}. For Chilkat coho this ratio was $RU_{80} = 0.51$, which is near the lower end of the range of values from other salmon stocks analyzed in a similar manner (Table 9).

Expected sustained yield *SY* was a fairly flat function of *S* between 30,000 and 70,000 spawners, and it is maximal (*SY* posterior median = 132,000) at about *S* = 46,000 (Figure 12). The probability that a given spawning escapement will result in a *SY* exceeding 90% of maximum sustained yield is plotted in Figure 13. That probability is maximized (to ~92%) at *S* = 45,000. The probability that (*SY* > 0.9 MSY) exceeds 50% between spawning abundances of 30,000 and 67,000 fish.

DISCUSSION

The two modeling approaches resulted in similar point estimates for the optimal number of spawners for the Chilkat River stock (50,000 smolt production model vs. 46,000 Ricker spawner-recruit model). Despite numerous opportunities for differences due to differing treatment of measurement error, autocorrelation, and missing data, Bayesian posterior medians differed little from the conventional point estimates. The posterior distribution for S_{MSY} was reasonably narrow (compared to similar analyses on other salmon species).

There was general agreement among reviewers that the precise correlation between foot surveys and mark recapture estimates may be misleading and "too good to be true," because of the small fraction surveyed. Bayesian statistics provided a coherent framework for quantifying the impact of such skepticism, by formulating it in terms of prior knowledge about the log measurement error standard deviation σ_{FS}. The resulting posterior distribution reflected a re-weighting of the data given the new prior information, i.e., it reflected increased uncertainty about model parameters and other quantities in the context of skepticism about foot surveys with small fractions of spawning coho salmon. Inference about optimal spawning abundance remained relatively strong in the context of skepticism about the foot survey data. The effect of the new prior on the posterior was a modest increase in the uncertainty about model parameters (Table 8). Our analyses support a biological escapement goal range of 30,000 to 70,000 spawners for the Chilkat River coho salmon stock. This is equivalent to peak survey counts of between 900 and 2,100 spawners. We can improve the chances of achieving near optimal production of Chilkat River coho salmon by managing for escapements near 50,000 spawning adults (1,500 survey count).

Table 8.–Parameter estimates and related quantities from Ricker spawner-recruit analyses of Chilkat River coho salmon, 1994–2002 brood years. Medians (p50) of the BASSR posterior serve as a point estimate for comparison to the classical equivalent. The p10 and p90 values represent the lower and upper bounds of an 80% Bayesian interval estimate.

		Bayesian age-structured spawner-recruit (BASSR) analysis					
		Non-informative priors[a]			Informative priors[b]		
Parameter	Classical Ricker	p_{10}	p_{50}	p_{90}	p_{10}	p_{50}	p_{90}
$\ln(\alpha)$	1.85	1.28	1.90	2.55	1.33	1.95	2.68
α	6.3	3.6	6.8	13.1	3.8	7.0	14.6
$\beta \times 10^5$	1.4	1.1	1.5	2.0	1.1	1.6	2.1
σ_{SR}	0.35	0.21	0.31	0.49	0.21	0.31	0.50
ϕ		0.23	0.69	0.94	0.23	0.71	0.94
S_{MAX}	71,264	49,020	64,810	90,400	47,090	62,870	88,280
S_{EQ}	136,409	90,280	124,200	161,600	90,850	123,400	162,200
S_{MSY}[c]	50,051	36,410	46,290	60,030	35,690	45,590	59,450
D		8	14	25	8	16	28
π_1		0.71	0.77	0.81	0.71	0.77	0.81
π_2		0.19	0.23	0.29	0.19	0.23	0.29
λ	0.028	0.025	0.030	0.036	0.024	0.030	0.037
$1/\lambda$	33.5	27.6	33.4	40.5	26.9	33.3	41.1
σ_{FS}	0.08	0.25	0.37	0.55	0.35	0.43	0.56

[a] Posterior percentiles from BASSR analysis with non-informative priors on foot surveys ($\sigma^{-2}_{FS} \sim \Gamma(0.1,0.1)$).

[b] Posterior percentiles from BASSR analysis with skeptical, informative prior on foot survey ($\sigma^{-2}_{FS} \sim \Gamma(4,1)$).

[c] Values exceeding 200,000 excluded.

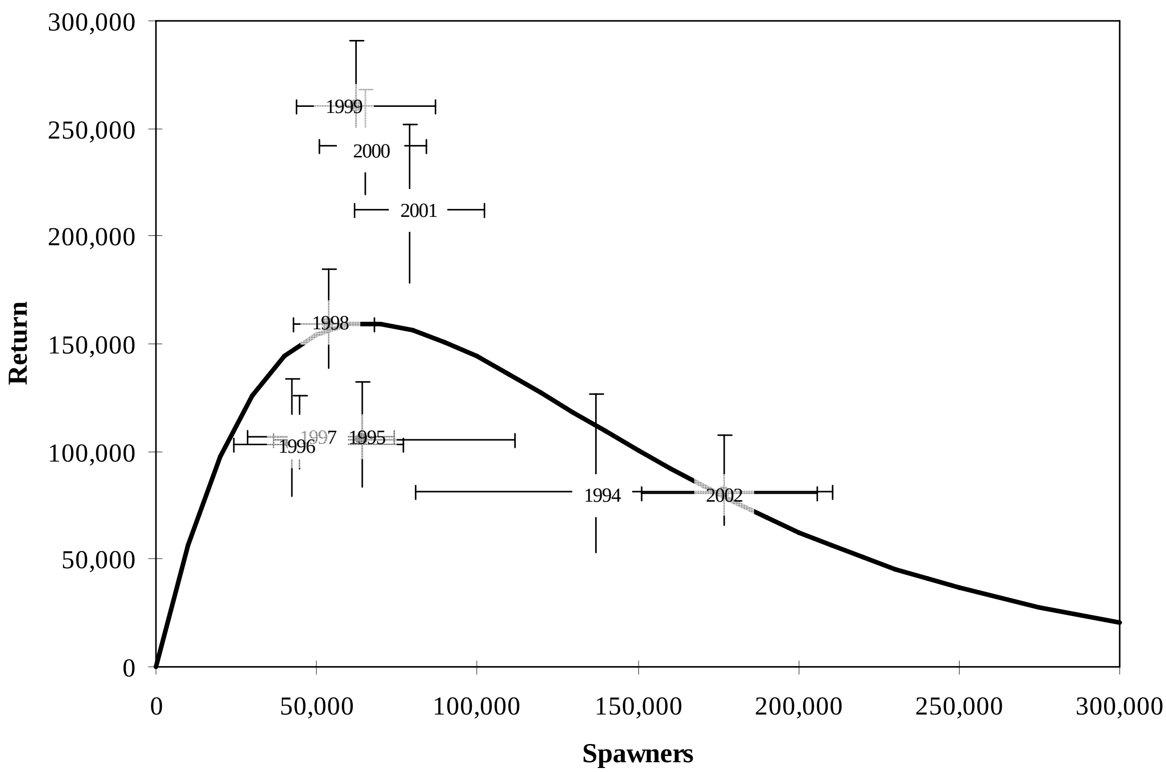

Figure 8.–Posterior medians of return versus spawning escapement and resulting Ricker function from the (informed) Bayesian age-structured spawner-recruit analysis of Chilkat River coho salmon data, brood years 1994–2002. Error bars connect the 10th and 90th posterior distribution percentiles and constitute 80% credibility intervals for each quantity.

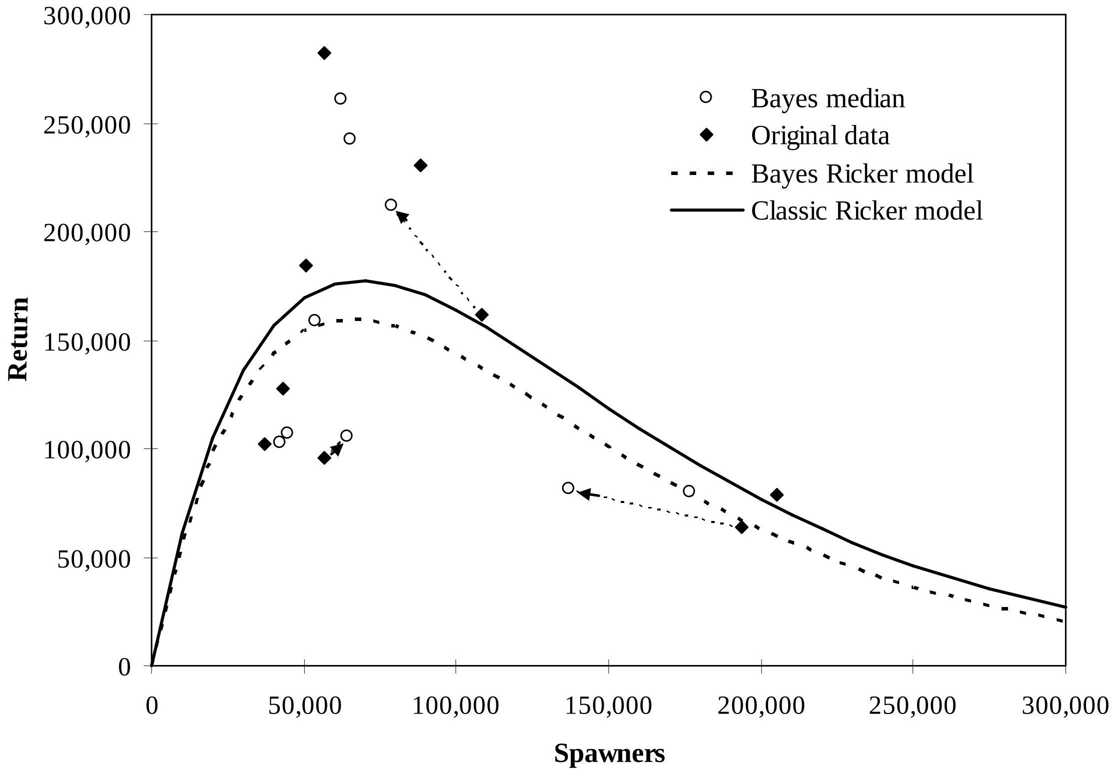

Figure 9.–Estimates of spawning escapement and return, and fitted Ricker models from Bayesian and classical analyses of Chilkat River coho salmon data, brood years 1994–2002. Bayesian spawner-recruit point estimates are posterior medians, which differ from classic data-based point estimates because of substantial measurement error, and because all data are considered simultaneously in the context of the full statistical model. The correspondence between some Bayesian/classical spawner-recruit points with common brood years is shown by arrows.

Table 9.–Relative uncertainty (RU80) of Ricker spawner-recruit (SR) parameter estimates for Pacific salmon populations analyzed with Bayesian age-structured stock recruit methods. RU80 is defined as the width of 80% credibility intervals (90th posterior percentile – 10th posterior percentile) divided by the posterior median.

							RU_{80}		
Species	River	Years[a]	*S* contrast[b]	*S* uncertainty	$\hat{\phi}$	$\hat{\sigma}_{SR}$	$\ln(\alpha)$	β	S_{MSY}
Coho	Chilkat	7/9	5.5	high	0.69	0.31	0.67	0.60	0.51
Chinook	Karluk[c]	12/29	3.2	low	0.16	0.49	1.46	1.63	1.39
Chinook	Ayakulik[c]	12/28	22.2	low	-0.17	0.51	1.44	0.59	0.38
Chinook	Kenai, early run[c]	17	2.5	mod	0.35	0.26	0.67	0.86	0.55
Chinook	Kenai, late run[c]	17	2.6	mod	0.58	0.25	0.87	1.52	1.70
Chinook	Deshka[c]	10/31	10.1	low	0.67	0.44	0.77	0.69	0.57
Sockeye	Buskin[c]	8	1.7	low	0.43	0.57	1.21	1.63	2.11

[a] Years of complete data/any data.

[b] *S* contrast = max(*S*) / min(*S*).

[c] Unpublished data.

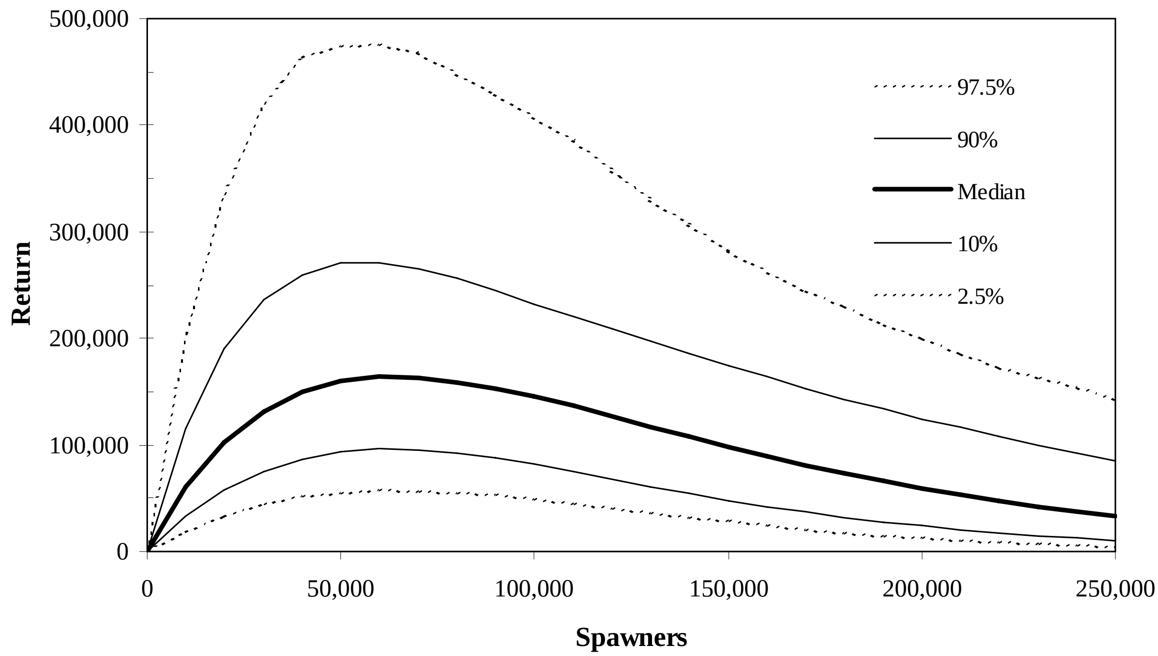

Figure 10.–Bayesian posterior percentiles of fitted Ricker returns at specified spawning abundance. There is an 80% probability that the true Ricker function lies between the two solid lines, and a 95% probability that it lies between the two dotted lines.

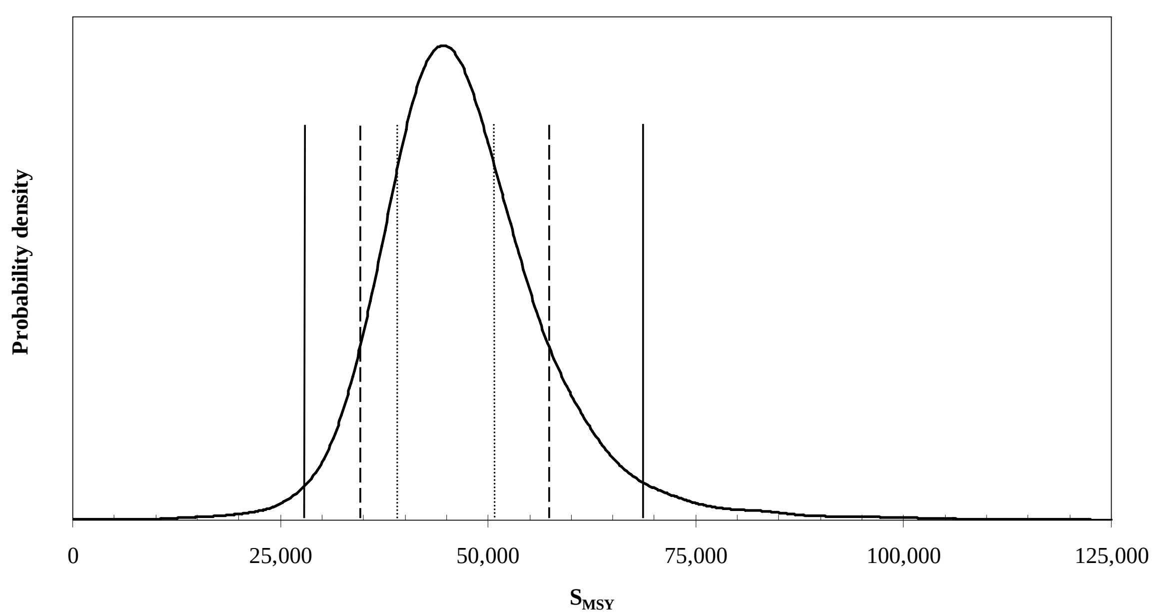

Figure 11.–Bayesian posterior probability distribution of optimal spawning escapement SMSY. There is 95% probability that the true S_{MSY} is between 28K and 69K (solid bars), 80% probability that SMSY is between 34K and 58K (dashed bars), and 50% probability that S_{MSY} is between 39K and 51K (dotted bars). These are highest posterior density (shortest possible) intervals and thus are not equivalent to percentiles in Table 8.

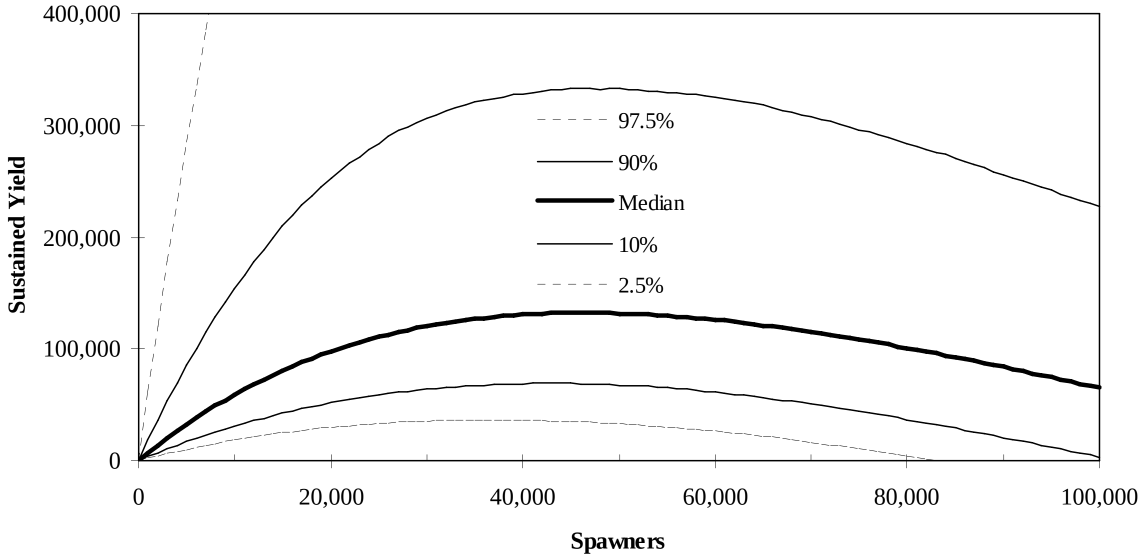

Figure 12.–Bayesian posterior percentiles of expected sustained yield at specified spawning abundances.

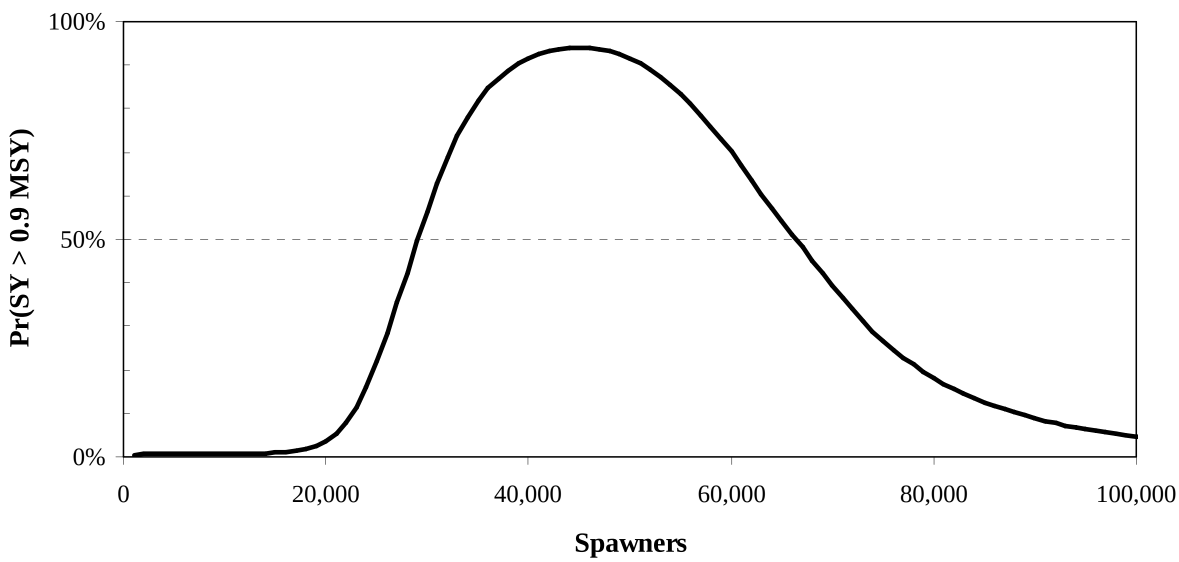

Figure 13.–Probability that a specified spawning abundance will result in sustained yield exceeding 90% of maximum sustained yield.

The escapement goal range for the Chilkat River coho salmon stock represents a great improvement for managing this stock. It provides benchmarks for judging management performance and ensures the sustainability of this stock. This range will allow for a conservative level of harvest in the near future, pending new information.

All ongoing scientific investigations improve with the addition of new information. This will be especially true for future investigations of the coho salmon of the Chilkat River. We have initiated an annual smolt coded wire tag program for Chilkat River coho salmon at higher tagging levels than were done historically. These efforts have and will provide reasonably precise estimates of smolt production, marine harvest, total return and exploitation rates for the 1999–2005 brood years. This will add important information including total return estimates for some of the two highest levels of spawning abundance in the time series.

Managing to stay above the lower end of the escapement goal range of 30,000 to 70,000 spawners should not be beyond the capability of ADF&G, given refinement of our stock assessment program. We have developed preseason forecasts and will continue to refine the precision of the preseason forecasts as stock assessment improves. However, managing to stay below the upper end of the range could be more difficult in years of high returns when the price of gillnet-caught coho salmon is low.

We conclude that the Chilkat River coho salmon stock is not currently being overharvested and has been fished at moderate rates for the past 10 years or more.

RECOMMENDATIONS

Because this analysis may set the stage for future actions, we recommend some strategies to improve analyses and management. We recommend continued measurement of population parameters, especially periodic direct estimation of escapement.

We believe that preserving long-term stock assessment programs should continue to be one of the highest priorities for ADF&G. These types of programs provide information on the population dynamics of the resource, which is often poorly understood due to the lack of long-term programs. For the Chilkat River coho salmon stock we recommend:

- Continuation of the annual foot survey program in the Chilkat River drainage. If possible, expand the program to include additional streams to increase the proportion of escapement counted. Total spawning abundance from mark-recapture studies should be conducted every three to five years to refine the estimate of the expansion factor and its variance.
- Continue annual biological sampling in the Chilkat River escapement for age, sex and size structure as well as recovery of CWTs and other tags.
- Annually CWT coho salmon smolt at high rates (20,000 to 25,000), to estimate smolt production and adult harvest of this stock.
- Develop reliable preseason and/or inseason estimates of run size and escapement.
- Review this escapement goal in 2008, incorporating additional data available at that time.

ACKNOWLEDGMENTS

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APPENDIX A: SUMMARY OF REGULATIONS IN SOUTHEAST ALASKA FOR SUBSISTENCE, RECREATIONAL, COMMERCIAL GILLNET AND COMMERCIAL TROLL FISHERIES, WHICH PERTAIN TO THE HARVEST OF CHILKAT-BOUND COHO SALMON

Appendix A1.–Major regulatory actions taken in the management of the Chilkat River and Inlet subsistence fisheries since 1955.

Year	Action
1955–1959	Personal use fishery.
1960	Title of regulation changed to "subsistence fishery."
1961	Subsistence permit required in all areas (5AAC 115.91).
1969	Subsistence permits for taking king and coho salmon no longer issued (5AAC 33.990) Subsistence salmon fishing in saltwater in District 15A prohibited during the closed periods of commercial net fishery (5AAC 33.990(4)).
1972	Subsistence permits for taking coho salmon issued for the Chilkat River adjacent to the Klukwan Reservation (5AAC 33.990(5)).
1975	Subsistence set gillnet fishing closed in all of Southeast Alaska (5AAC01.720(2)).
1976	The use of set gillnet gear allowed in the mainstream of the Chilkat River north of the latitude of Zimovia Point (5AAC 33.990).
1981	Subsistence drift gill netting in all of District 15A allowed by policy during commercial openings.
1989	A positive Customary & Traditional use (C&T) finding for Alaska residents domiciled in Klukwan (that area west of the Haines Highway between Mile 20 and Mile 24 and east of the Chilkat River) for salmon and smelt. Subsistence permits will not be issued for taking king or coho salmon, but king and coho may be taken incidentally under terms of a subsistence permit (5AAC 01.730(b)).
1993	Customary and traditional findings by community were repealed in spring 1993 because of constitutional considerations. The Alaska Board of Fisheries (BOF) delineated geographic areas where subsistence C&T uses took place for each community within which subsistence fishing will be permitted. 5 AAC 01.716. Customary and traditional uses of fish stocks. (2) salmon and smelt in all waters of the Chilkat River and Chilkat Inlet north of the latitude of Glacier Point. Subsistence fishing permits. c) In the Chilkat River, the subsistence fishing permit holder shall be physically present at the net while it is fishing.
2003	The BOF amended regulations to allow subsistence permits to be issued for taking coho salmon except for the Taku and Stikine River drainages (5AAC 01.730(b)).

Appendix A2.–Sport fishing regulations in Southeast Alaska affecting the Chilkat River coho salmon stock, 1963–2005.

Year(s)	Saltwater regulations	Freshwater regulations: Regional bag, possession, and size limits	Freshwater regulations: Chilkat River exceptions
1963	Salmon may not be taken by means of treble hook(s). No bag or possession limits for coho salmon.	Bag and possession limits: immature salmon 15 per day and possession; mature coho salmon over 20 inches 5/day; under 20 inches no limit.	none
1964–1968	No bag or possession limit for coho salmon.	Bag and possession limits: immature salmon 15 per day and possession; mature coho salmon over 20 inches 5/day; under 20 inches no limit.	none
1969–1974	6 coho salmon per day, 12 in possession, no size limit.	Coho salmon over 20 inches: 6 per day 12 in possession. Under 20 inches: no limits.	none
1975	6 salmon per day, 12 in possession, no size limit.	6 salmon per day, 12 in possession, no size limit.	none
1976	Salmon over 16 inches: 6 per day, 12 in possession. Under 16 inches: 10 per day and in possession.	Salmon over 16 inches: 6 per day, 12 in possession. Under 16 inches: 10 per day and in possession.	none
1977–1979	Salmon over 16 inches: 6 per day, 12 in possession. Salmon 16 inches or less: 10 per day and in possession.	Salmon over 16 inches: 6 per day, 12 in possession. Salmon 16 inches or less: 10 per day and in possession.	none
1980–1990	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	none
1991–1996	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Coho salmon 16 inches or more: 3 per day, 6 in possession. Less than 16 inches: 10 per day and in possession.
1997	Through 8/31: Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession. By emergency order in northern inside waters of Southeast Alaska effective 9/1: Salmon 16 inches or more: 3 per day, 6 in possession.	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Coho salmon 16 inches or more: 3 per day, 6 in possession. Less than 16 inches: 10 per day and in possession.
1998–2005	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Salmon 16 inches or more: 6 per day, 12 in possession. Less than 16 inches: 10 per day and in possession.	Coho salmon 16 inches or more: 3 per day, 6 in possession. Less than 16 inches: 10 per day and in possession.

Appendix A3.–Commercial fishing regulations for drift gillnets in District 15 likely affecting the Chilkat River coho salmon stock, 1960–2005.

	Last statistical week fished				
Year	N. Lynn Canal 115-31	Chilkat Inlet 115-32	District 15	Fall mesh restrictions	Comments
1960	43	43	43	records missing	Fall season (8/16 to E.O. closure) weekly fishing set noon Mon. to noon Friday.
1961	41	41	41	records missing	Same as 1960.
1962	41	41	41	records missing	Same as 1960.
1963	37	42	42	records missing	Same as 1960.
1964	41	41	41	records missing	Fall season (early August to E.O. closure) weekly fishing set at 48 hrs.
1965	37	43	43	records missing	Same as 1964.
1966	41	42	42	records missing	Same as 1964.
1967	41	41	41	records missing	Same as 1964.
1968	40	40	40	records missing	Weekly fishing set at 36 hrs.
1969	40	40	40	records missing	Same as 1968.
1970	41	41	41	records missing	Same as 1968.
1971	42	42	42	records missing	Same as 1968.
1972	40	40	40	records missing	Same as 1968.
1973	40	40	40	records missing	Same as 1968.
1974	41	41	41	records missing	Same as 1968.
1975	43	43	43	records missing	Same as 1968. Drift gillnet fishery goes limited entry.
1976	43	43	43	records missing	Same as 1968.
1977	39	39	39	records missing	Same as 1968.
1978	38	38	38	records missing	Same as 1968.
1979	38	38	38	records missing	Same as 1968.
1980	39	39	39	records missing	Same as 1968.
1981	39	37	39	min. 6.25" mesh starting sw36	Same as 1968.
1982	44	44	44	none	Same as 1968.
1983	42	42	42	min. 6.25" mesh in 15A in sw36	Same as 1968.
1984	42	42	42	min. 6.25" mesh in 15A in sw35	Same as 1968.
1985	42	42	42	none	Same as 1968.
1986	41	41	41	none	Weekly fishing time set by E.O.
1987	42	41	42	none	
1988	41	41	41	none	
1989	38	38	38	none	Fall chum returns start to decline.
1990	38	38	38	none	District 15 closed sw34 due to sockeye and chum conservation.
1991	39	closed	41	none	Chilkat Inlet closed entire season.

-continued-

Appendix A3.-Page 2 of 2.

	Last statistical week fished				
Year	N. Lynn Canal 115-31	Chilkat Inlet 115-32	District 15	Fall mesh restrictions	Comments
1992	38	36	40	none	
1993	38	35	41	none	
1994	41	37	41	none	
1995	39	36	39	none	
1996	39	36	39	none	
1997	36	36	37	none	District 15 closed early due to coho and chum conservation.
1998	38	38	39	none	
1999	40	37	42	none	
2000	39	36	40	none	
2001	39	38	41	none	
2002	38	36	41	none	
2003	40	37	42	none	
2004	42	39	42	none	
2005	41	41	41	none	

Appendix A4.–Major regulatory actions taken in the management of the summer troll fishery in northern Southeast Alaska for coho salmon.

Year	Summer coho closure	Major Regulatory Actions Associated with Management of Southeast Alaska Troll Fishery
Prior to 1924		Congressional Act in 1906 provided for 36 hour per week closure in all waters of Alaska, but very little enforcement was conducted.
Prior to 1950		Troll fishery was unlimited by area restrictions and continued year round. Trollers were limited to four lines in Territorial waters.
1950		"Outside" waters were closed from 10/31 to 3/15.
1974		All State waters north and west of Cape Suckling were closed to troll fishing.
1975	15 days, August 15–31	Power trolling was placed under limited entry with 940 permits allowed.
1979	13 days, September 8–20	A 8-day "on" and 6-day "off" fishing period was implemented for the troll fishery in Districts 12 north of Point Hepburn and in Districts 14, 15A and 15C. "Outside" waters were closed to hand trolling.
1980	10 days, July 15– 24	Limited entry for hand trolling was implemented; 2,150 permits were issued, 1,300 of them as non-transferable permits. The number of lines allowed to be fished in the Federal Conservation Zone was limited to 4 lines per vessel south of Cape Spencer and 6 lines per vessel between Cape Spencer and Cape Suckling with a limit of 6 operational gurdies. A 9/21 to 9/30 closure of the troll fishery was implemented.
1981	10 days, August 10–19	A summer troll fishing season was established from 4/15 to 9/20.
1982	10 days, July 29–August 7	
1983	10 days, August 5–14	
1984	10 days, August 15–24	
1985	10 days, August 15–24	By regulation, the summer season definition was extended to 9/30. However, the season closed 9/21.
1986	10 days, August 11–20	Summer season closed 9/21
1987	10 days, August 3–12	Summer season closed 9/21
1988	10 days, August 15–24	Summer season closed 9/21
1989	10 days, August 14–23	Summer season closed 9/21
1990	10 days, August 13–22	Summer season closed 9/21
1991	10 days, August 16–24	Summer season closed 9/21
1992	10 days, August 13–22	Summer season closed 9/21
1993	8 days, August 13–20	Summer season closed 9/21
1994	2 days, August 27–28	
1995	10 days, August 13–22	
1996	5 days, August 14–18	Summer season closed 9/21
1997	10 days, August 8–17	Summer season closed 9/21
1998	8 days, August 12–19	
1999	5 days, August 13–17	
2000	10 days, August 13–22	Summer season closed 9/21
2001	5 days, August 13–17	
2002	2 days, August 10–11	
2003	none	
2004	2 days, August 10–11	
2005	4 days, August 10–13	

APPENDIX B: A HISTORY OF THE CHILKAT PONDS PROJECT CONDUCTED BY THE ALASKA DEPARTMENT OF FISH AND GAME, FISHERIES REHABILITATION, ENHANCEMENT, AND DEVELOPMENT DIVISION

Appendix B1.–The 1986 project update written by Ron Josephson.

Chilkat Ponds Project Update
January, 1986

By Ron Josephson

The Chilkat River is a large glacial river originating in Canada and flowing down a glacier-formed valley to Haines where it dumps into Lynn Canal. The river valley has a great number of ponds and channels with flows highly variable in location and volume. Many of the ponds are connected to the river by naturally occurring channels, however, there are a number of ponds similar in morphology but lacking a connecting channel. Connected ponds are heavily utilized by coho salmon fry for rearing. Commercial Fisheries staff first suggested that certain ponds could be easily connected to the river channel allowing access for salmon. The coho research staff felt that rearing area was limiting coho production on the river and that accessing ponds could result in increased adult production.

Capital Improvement Funds were granted in 1980 for the Chilkat Ponds project and enabled us to survey the valley and provide access to 7 ponds.

An initial survey was conducted in 1979 with the aid of topographic maps, aerial photos and local knowledge of the valley. This survey revealed a number of candidate ponds, one of which was connected through a combined Fish and Game, and community effort in July 1980.

In March of 1981, a winter trip to pond #1 revealed an anoxic condition unable to support salmon. However the pond was flowing, and presumably coho fry had left as conditions deteriorated; an adjacent natural pond known to support coho populations also was anoxic. Research in the Taku River indicated that the natural winter movement of coho is out of the ponds to hold in pools in the main river channel.

An extensive ground survey was conducted in 1981 (Table 1) of all the ponds identified from aerial photos and topographic maps. Each pond was surveyed to reveal the presence of an outlet channel, pond depth, logical channel choice, distance to the river, acreage, and the presence or absence of fish. Another more complete winter survey in 1982 revealed that many ponds along the river were anoxic although some did hold some rearing coho. Oxygen levels were low even when coho were present. Outlets of all ponds were frozen during this winter survey.

Based on the previous surveys, we selected ponds for channel access in 1982. These ponds were selected to represent a spectrum of the candidate ponds and also to allow for comparison to natural ponds. In May 1982 we connected the ponds by hand dug channels (Table 2). As the river rose that spring, coho started using these ponds.

In July of 1982, we captured and coded wire tagged coho in seven ponds representing both natural and artificially connected ponds. The adults from this tagging returned in 1984 (Table 3). Although our analysis was limited to fisheries contribution, as opposed to total survival, the percent survival was very good and demonstrated the immediate success of connected ponds.

A second tagging operation was undertaken in 1984 to provide us with additional information to be used in evaluating the ponds.

The tagging work in 1982 has revealed a considerable amount of movement in and out of the ponds during July and presumably all summer. In addition, the winter surveys has raised the question of winter survival in the ponds. The anoxic conditions and frozen outlets suggested that coho could be trapped in a pond. Of course, the Chilkat system is a major producer of coho salmon and we can certainly expect the fish in it long ago adapted to the particular characteristics of its morphology. The next tagging would be designed to address this winter condition.

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In October of 1984, we tagged coho salmon juveniles in seven ponds and surveyed a number of others, (Table 4). The work was immediately prior to freeze up and populations tagged were representative of the respective ponds. The freeze up conditions lowered river water levels considerably, however in most cases the ponds flowed freely at this time. Presumably the coho are keyed by these fall conditions to leave the ponds. We were not able to observe this movement, however marked fish from this operations were recovered later that winter in the spawning channel.

The adult returns expected back in 1986 will complete the Chilkat Ponds Project; we will then examine the whole project with that new information. Additional survey work and possible channel access will probably be proposed to increase production of coho for this system and further our understanding of the population dynamics of coho salmon in the Chilkat River.

Appendix Table B1.1.–Candidate Ponds after June 1981 Survey.

		Distance to River (ft)		Highpoint
Pond	Open Water Acres	Above Water	Below Water	Elevation (ft) Above River
B	1.3	47	25	5.0
C*	2.5	275 mixed		1.5
D*	1.3	25	60	3.1
2	3.1	63	20	2.9
3	2.6	41	15	2.0
E	0.6	19	16	2.3
6	3.1	67	61	1.4
5	6.6	30	15	1.4
F	2.5	56	70	2.1
G	3.8	56	10	2.0
37*	3.8	63	-	1.0
H*	1.3	26	30	0.7
I	1.9	32	44	1.6
J	1.3	75	142	1.8
34	0.6	20	110	1.0
L	23.4	712	160	3.1
32	6.9	27	33	0.6
30*	42.5	20	125	2.3
25	5.0	20	80	0.4
21	1.9	40	95	1.0
P	8.1	405	165	N/A
T	6.9	250	80	N/A
U	1.3	60	95	0.8
V*	2.5	29	-	1.5

* Channel provided in 1982

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Appendix Table B1.2.–Access Channels Provided

Date	Pond	Acres	Channel Length (ft)	Channel Depth (in)	First Access
July, 1980	1	49	60	36	July
May 20, 1982	37	3.8	33	36	May 27
May 21, 1982	H	1.3	33	40	May 26
May 23, 1982	C	2.5	275	18	May 24
May 24, 1982	D	1.3	19	48	June 15
May 26, 1982	30	42.5	171	60	May 28
June, 1982	V	2.5	25	24	June
	“swimming hole”	(culvert)			

Appendix Table B1.3.–Preliminary Results of 1982 Tagging on the Chilkat River Ponds Project.

Pond	Status	Number Tagged	Commercial Catch	% Catch
15	Natural	1,362	67	4.9
M	Natural	950	29	3.0*
M (outlet)	Natural	758	78	10.7
30	Artificial	764	56	7.3
H	Artificial	889	31	3.5
1&37	Artificial	807	23	2.8
V	Artificial	2,985	30	1.0
		8,515		

* Average Catch for pond M is 6.3.

Appendix Table B1.4.–Tagging Operations in October 1984.

Pond	Status	Number Tagged	Population Estimate	Comments
15	Natural	4,262	23,354	Smolt size
1	Artificial	1,345	5,109	
37	Artificial	1,701	2,400	
H	Artificial	811	2,300	Young fish
M	Natural	2,840	39,388	Young fish improved access
30	Artificial	2,034	5,765	Smolt size
V	Artificial	1,633	7,500	Young fish
		14,626		

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A Brief History of 1982 Channel Excavation

The last two weeks of May were spent on the Chilkat River doing survey and channel construction work. The creation of access channels is outlined below.

May 20 -Pond "37"

The channel through the river berm is 23 feet long with a maximum depth of 3 feet and width of 4 feet. There is an additional 15 feet of channel in the sedges at the pond edge.

The Chilkat River was f1owing into this pond on May 28.

May 21 -Pond "H"

The channel through the river berm is 29 feet long with a maximum depth of 4 ½ feet, the average width is 4 feet. There is an additional 15 feet of channel in the sedges at the pond edge.

On May 26, water was flowing out of the pond and a fingerling could negotiate the channel.

May 22 & 23 -Pond "C"

This pond should primarily benefit fish on the Assignation River. Channel excavation took 2 days and this was the most difficult one.

The channel is 275 feet long with an average depth and width of 1 ½ feet. There was an outf1ow of 1 cfs after excavation. On May 24, coho and stickleback were observed in this channel.

May 24 -Pond "D"

The channel through the river berm is 19 feet long, 4 feet wide, and has a maximum depth of 4 feet.

The river channel here was still dry but normal high water will provide access for coho.

May 26 -Pond "30"

The channel through the river berm is 36 feet long with a maximum depth of 5 feet and is 2 ½ feet wide. There is an additional 135 feet of channel in the sedges at the pond edge.

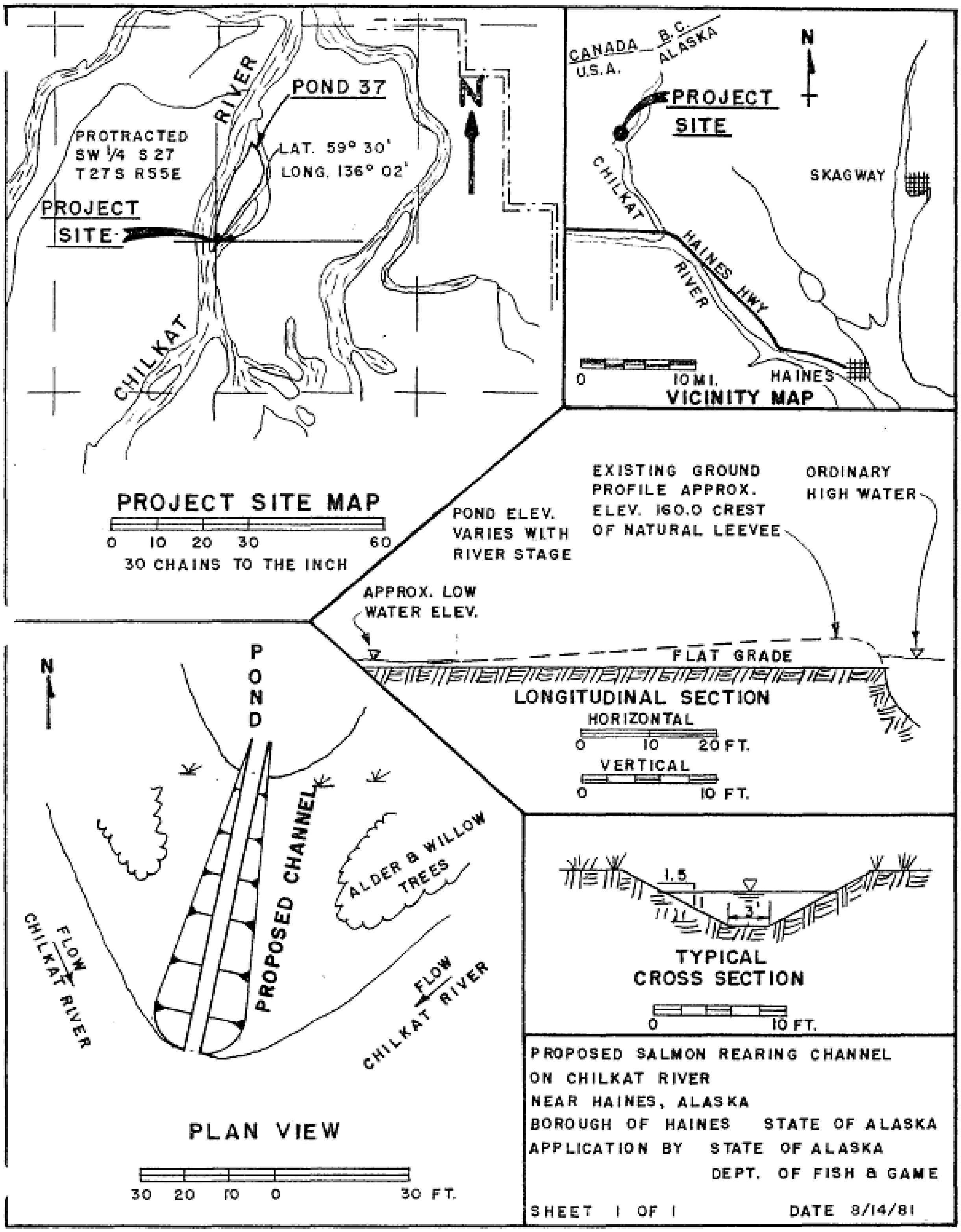
When this channel was completed, there was about 1 cfs of outflow and a drop from pond level to river level of 2 feet. Coho will be able to move upstream into the pond with a slight river rise.

June -Pond "V" Swimming Hole (11 mile)

Highways installed a culvert allowing access of coho to pond “V”. Ray Staska assisted on this and reported coho using the culvert the day after installation.

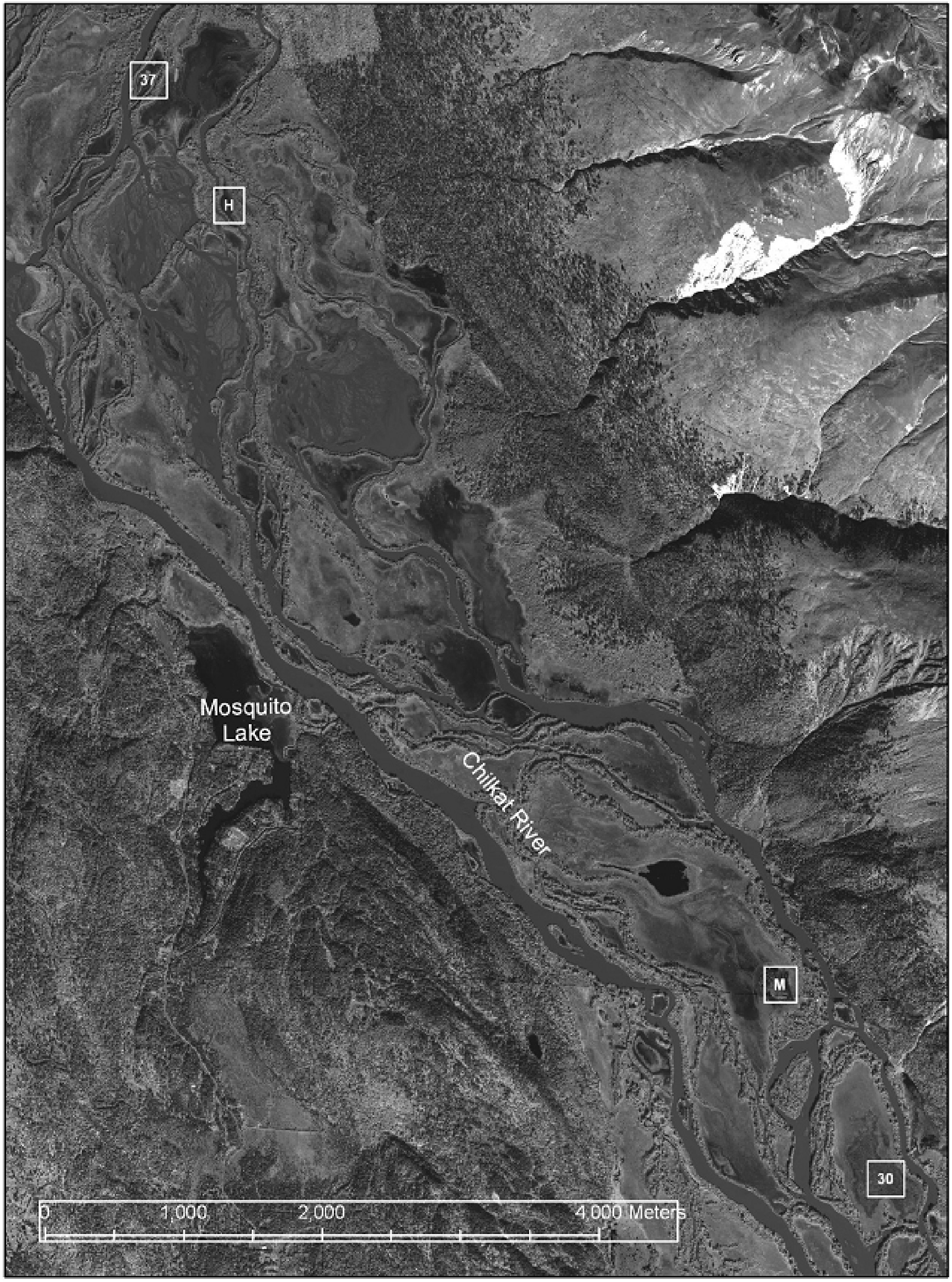
Ron Josephson

Appendix B2.–A figure submitted with the original Chilkat Ponds Project proposal packet. Courtesy of Ron Josephson.

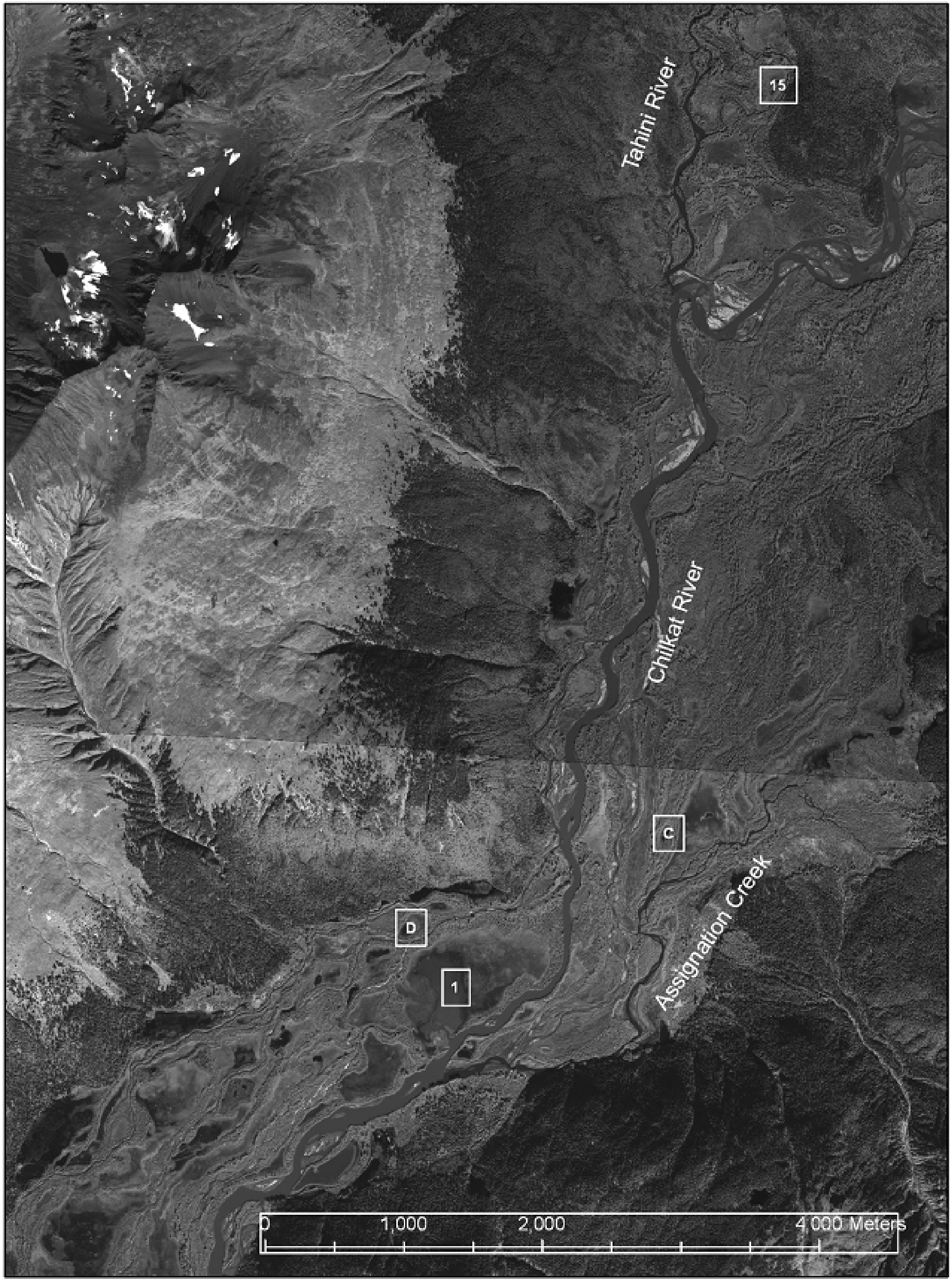


Appendix B3.–A satellite image of the Chilkat River from approximately Haines Highway mile 10 to 12, showing the location of pond V.

Appendix B4.–A satellite image of the upper Chilkat River near Mosquito Lake, showing the location of ponds 30, M, H, and 37.



Appendix B5.–A satellite image of the upper Chilkat River between Assignation Creek and the Tahini River, showing the location of ponds 1, D, C, and 15.



Appendix B6.–Results of coded wire tag analysis of the Chilkat Ponds Project written by Ron Josephson.

CHILKAT PONDS SUMMARY

by Ron Josephson

Attached is a summary of data pertinent to the returns of coho salmon tagged on the Chilkat River in 1982 and 1984. The tables compare contribution and survival for the two years of tagging. The coded-wire tag report shows all known recoveries of adult coho salmon from this tagging without expansions.

The 1982 tagging was conducted in June and July and fish were moving in and out of ponds. After our experiences in 1982 and a winter survey we felt the critical aspect of pond productivity was over winter survival. Accordingly, in 1984 tagging was conducted during October to better address how the ponds performed at the onset of winter. It is my feeling that the differences in survival observed in the 1984 tagging are due to the channel morphology. Fish are better able to emigrate from enhanced ponds at the onset of winter due to the more defined channels.

Appendix Table B6.1.–Comparison of contribution and survival rates of coho salmon tagged in artificially and naturally connected ponds in October 1984.[a]

ARTIFICIALLY CONNECTED PONDS							
Pond	Tag code	# Tagged	Population	%Contribution	#Contribution	%Survival[b]	#Survived[b]
1	04-24-21	1,345	5,109	5.82%	297	7.28%	372
37	04-24-16	1,701	2,400	2.02%	48	2.53%	61
H	04-24-20	811	2,300	1.20%	28	1.50%	35
30	04-24-19	2,034	5,765	3.62%	209	4.53%	261
V	04-23-62	1,633	7,500	5.57%	418	6.96%	522
All		7,524	23,074	4.33%	1,000	5.42%	1,250
						(Ave. 4.56%)	

NATURALLY CONNECTED PONDS							
Pond	Tag code	# Tagged	Population	%Contribution	#Contribution	%Survival[b]	#Survived[b]
	04-23-10	4,262	23,354	0.16%	37	0.20%	46
	04-24-17	2,840	39,388	1.71%	674	2.14%	842
	04-24-18						
All		7,102	62,742	1.13%	711	1.42%	888
						(Ave. 1.17%)	

[a] Based on 1986 returns, more fish are expected in 1987.

[b] Extrapolation based on an assumed 80% harvest rate.

Appendix Table B6.2.–Comparison of contribution and survival rates of coho salmon tagged in artificially and naturally connected ponds in October 1982.

ARTIFICIALLY CONNECTED PONDS							
Pond	Tag code	# Tagged	Population	%Contribution	#Contribution	%Survival[a]	#Survived[a]
1&37	04-21-37	807	1,382	2.87%	40	3.59%	50
H	04-21-39	889	1,151	3.79%	44	4.74%	55
30	04-21-38	764	1,105	7.18%	79	8.97%	99
V	04-22-07	2,985	7,150	1.05%	75	1.31%	94
All		5,445	10,788	2.20%	238	2.75%	297
						(Ave. 4.65%)	

NATURALLY CONNECTED PONDS							
Pond	Tag code	# Tagged	Population	%Contribution	#Contribution	%Survival[a]	#Survived[a]
15	04-22-09	1,362	2,211	4.57%	101	5.72%	126
M	04-21-40 04-22-10	1,708	2,124	6.36%	135	7.95%	169
All		3,070	4,335	5.45%	236	6.81%	295
						(Ave. 3.42%)	

[a] Extrapolation based on an assumed 80% harvest rate.

APPENDIX C: A COMPLETE HISTORY OF COHO SALMON CODED WIRE TAG RELEASES IN THE CHILKAT RIVER DRAINAGE

Appendix C1.–Number of live coded wire tagged coho salmon released into the Chilkat River by year of release and life stage through 2005.

Release year	Capture site	Stage	Total marked	Shed tags	Valid tags
1976	Airport ponds	Fry	5,070	0	5,070
1976	Chilkat Lake	Fry	2,985	0	2,985
1976	Upper Chilkat ponds[a]	Fry	1,019	0	1,019
1976	Mosquito Lake	Fry	3,347	0	3,347
1976 total			**12,421**	**0**	**12,421**
1977	Airport ponds	Fry	4,060	0	4,060
1977	Chilkat Lake	Fry	2,284	0	2,284
1977	Upper Chilkat ponds[a]	Fry	2,729	0	2,729
1977	Mosquito Lake	Fry	6,005	0	6,005
1977 total			**15,078**	**0**	**15,078**
1981 total	Chilkat Lake	Fry	**2,603**	**0**	**2,603**
1982 total	Chilkat ponds[b]	Fry	**8,608**	**93**	**8,515**
1984 total	Chilkat ponds[b]	Fry	**14,644**	**102**	**14,542**
1999	Lower Chilkat River	Smolt	12,037	10	12,027
1999	Chilkat Lake	Smolt	4,078	0	4,078
1999	Chilkat tributaries[c]	Smolt	9,800	29	9,771
1999 total			**25,915**	**39**	**25,876**
2000	Chilkat tributaries[c]	Smolt	9,980	20	9,960
2000	Lower Chilkat River	Smolt	11,953	4	11,949
2000	Upper Chilkat River	Smolt	3,083	0	3,083
2000 Total			**25,016**	**24**	**24,992**
2001 Total	Lower Chilkat River	Smolt	**36,114**	**117**	**35,997**
2002 Total	Lower Chilkat River	Smolt	**25,296**	**7**	**25,289**
2003 Total	Lower Chilkat River	Smolt	**24,563**	**4**	**24,559**
2004 Total	Lower Chilkat River	Smolt	**17,279**	**0**	**17,279**
2005 Total	Lower Chilkat River	Smolt	**26,342**	**16**	**26,326**

[a] Unidentified ponds in the upper Chilkat River drainage.

[b] Chilkat ponds were several ponds throughout the drainage where fish access was improved (see Appendix B).

[c] Tributaries of the lower Chilkat River including airport ponds.

APPENDIX D: ESTIMATED HARVEST OF COHO SALMON BOUND FOR THE CHILKAT RIVER

Appendix D1.–Estimated commercial harvest and percent by gear type, escapement and total returns of coho salmon returning to Chilkat Lake, 1978–1979.[a]

	1978		1979	
Gear Type/Escapement	Harvest	Percent	Harvest	Percent
Troll	2,035	60.5	669	26.3
Drift Gill Net	891	26.5	907	35.7
Total Catch	2,926	87.0	1,576	62.0
Escapement[a]	438	13.0	966	38.0
Total Run	3,364	100	2,542	100
Fishery Sample Size	34		22	

Source: Shaul et al. 1986.

[a] The escapement counted through the weir on the outlet of Chilkat Lake.

Appendix D2.–Estimated commercial harvest and percent by gear type, escapement and total returns of coho salmon returning to Chilkat Lake, 1983. [a]

Gear Type/Escapement	Harvest	Percent
Troll	29,503	46.4
Purse Seine	693	1.1
Drift Gill Net	20,845	32.7
Total Catch	51,041	80.2
Escapement[a]	12,601	19.8
Total Run	63,642	100.0
Fishery Sample Size	114	

Source: Shaul et al. 1991.

[a] The escapement estimate is for Chilkat Lake only. The escapement was estimated under the assumption that the combined troll and purse seine harvest rate for Chilkat Lake was the same as the average estimate for the Berners River and Chilkoot Lake stocks.

Appendix D3.–Total coho salmon harvest and estimated Chilkat River coho salmon harvest in Alaska fisheries, by fishery and area, 2000.

		Coho salmon harvest			Percent of harvest	
Fishery	Area	Total	Chilkat	SE	Fishery[a]	Chilkat[b]
Drift gillnet	District 115	34,940	15,744	2,238	45.1	38.8
U.S. troll fishery	NW Quadrant	813,695	21,765	2,887	2.7	53.6
	NE Quadrant	95,421	265	155	0.3	0.7
	Subtotal	909,116	22,030	2,891	2.4	54.3
Seine fishery	District 112	28,992	256	183	0.9	0.7
	District 114	4,038	577	577	14.3	1.4
	Subtotal	33,030	833	605	2.5	2.1
Recreational	Juneau marine	11,960	938	545	7.8	2.3
	Haines marine	233	136	69	58.4	0.3
	Chilkat River	688	688	221	100.0	1.7
	Subtotal	12,881	1,762	592	13.7	4.3
Subsistence	Chilkat Inlet	34	34	0	100.0	0.1
	Chilkat River	165	165	0	100.0	0.4
	Subtotal	199	199	0	100.0	0.5
Total		990,166	40,569	3,752	4.1	100.0

Source: Ericksen 2001.

[a] Percent of Chilkat River coho salmon in the fishery harvest.

[b] Percent of the Chilkat River coho salmon harvest by the fishery.

Appendix D4.–Total coho salmon harvest and estimated Chilkat River coho salmon harvest in Alaska fisheries, by fishery and area, 2001.

		Coho salmon harvest			Percent of harvest	
Fishery	Area	Total	Chilkat	SE	Fishery[a]	Chilkat[b]
Drift gillnet	District 115	34,039	13,709	2,213	40.3	28.5
U.S. troll fishery	NW Quadrant	1,260,898	30,021	3,929	2.4	62.5
	NE Quadrant	218,221	603	310	0.3	1.2
	Subtotal	1,479,119	30,624	3,941	2.1	63.7
Seine fishery	District 109	59,753	220	220	0.4	0.5
	District 112	35,273	453	248	1.3	0.9
	Subtotal	95,026	673	331	0.7	1.4
Recreational	Sitka marine	78,218	154	154	0.2	0.3
	Juneau marine	16,036	498	258	3.1	1.0
	Haines marine	176	165	108	93.8	0.4
	Chilkat River	2,094	2,094	451	100.0	4.4
	Subtotal	96,524	2,911	552	3.0	6.1
Subsistence	Chilkat Inlet	44	44	0	100.0	0.1
	Chilkat River	82	82	0	100.0	0.2
	Subtotal	126	126	0	100.0	0.3
Total		1,704,834	48,038	4,566	2.8	100.0

Source: Ericksen 2002.

[a] Percent of Chilkat River coho salmon in the fishery harvest.

[b] Percent of the Chilkat River coho salmon harvest by the fishery.

Appendix D5.–Total coho salmon harvest and estimated Chilkat River coho salmon harvest in Alaska fisheries, by fishery and area, 2002.

		Coho salmon harvest			Percent of harvest	
Fishery	Area	Total	Chilkat	SE	Fishery[a]	Chilkat[b]
Drift gillnet	District 115	77,521	43,296	5,848	55.9	38.0
U.S. troll fishery	NW Quadrant	802,569	63,056	8,452	7.9	55.3
Seine fishery	District 109	104,609	654	653	0.6	0.6
	District 114	19,739	159	158	0.8	0.1
	Subtotal	124,348	812	672	0.7	0.7
Recreational	Sitka marine	46,154	340	339	0.7	0.3
	Gustavus marine	29,636	845	845	2.9	0.7
	Juneau marine	26,273	1,059	521	4.0	0.9
	Haines marine	642	532	213	82.9	0.5
	Chilkat River	3,480	3,480	742	100.0	3.1
	Subtotal	106,185	6,255	1,302	5.9	5.5
Subsistence	Chilkat Inlet	166	166	0	100.0	0.1
	Chilkat River	408	408	0	100.0	0.4
	Subtotal	574	574	0	100.0	0.5
Total		1,111,197	113,993	10,382	10.3	100.0

Source: Ericksen 2003.

[a] Percent of Chilkat River coho salmon in the fishery harvest.

[b] Percent of the Chilkat River coho salmon harvest by the fishery.

Appendix D6.–Total coho salmon harvest and estimated Chilkat River coho salmon harvest in Alaska fisheries, by fishery and area, 2003.

		Coho salmon harvest			Percent of harvest	
Fishery	Area	Total	Chilkat	SE	Fishery[a]	Chilkat[b]
Drift gillnet	District 115	59,621	26,305	2,510	44.1	30.5
U.S. troll fishery	NW Quadrant	699,833	50,105	6,338	7.2	58.1
	NE Quadrant	131,894	1,689	622	1.3	2.0
	Subtotal	831,727	51,794	6,369	6.2	60.1
Seine fishery	District 112	34,996	1,268	643	3.6	1.5
	Subtotal	34,996	1,268	643	3.6	1.5
Recreational	Yakutat marine	8,494	239	171	2.8	0.3
	Sitka marine	73,759	242	242	0.3	0.3
	Icy Strait marine	19,611	2,070	968	10.6	2.4
	Juneau marine	18,682	1,230	689	6.6	1.4
	Haines marine	377	101	51	26.8	0.1
	Chilkat River	2,489	2,489	497	100.0	2.9
	Subtotal	123,412	6,372	1,323	5.2	7.4
Subsistence	Chilkat Inlet	51	51	0	100.0	0.1
	Chilkat River	443	443	0	100.0	0.5
	Subtotal	494	494	0	100.0	0.6
Total		918,356	86,234	6,974	9.4	100.0

Source: Ericksen and Chapell 2005.

[a] Percent of Chilkat River coho salmon in the fishery harvest.

[b] Percent of the Chilkat River coho salmon harvest by the fishery.

Appendix D7.–Total coho salmon harvest and estimated Chilkat River coho salmon harvest in Alaska fisheries, by fishery and area, 2004.

		Coho salmon harvest			Percent of harvest	
Fishery	Area	Total	Chilkat	SE	Fishery[a]	Chilkat[b]
Drift gillnet	District 111	45,289	727	727	1.6	0.6
	District 115	51,887	34,427	6,228	66.4	26.2
	Subtotal	97,176	35,155	6,271	36.2	26.8
U.S. troll fishery	NW Quadrant	1,237,623	81,444	18,636	6.6	61.9
	NE Quadrant	228,725	2,842	1,309	1.2	2.1
	Subtotal	1,466,348	84,286	18,681	5.7	64.0
Seine fishery	District 112	83,284	636	636	0.8	0.5
	District 114	10,097	301	301	3.0	0.2
	Subtotal	83,284	937	703	1.1	0.7
Recreational	Yakutat marine	7,425	365	267	4.9	0.3
	Icy Strait marine	26,114	5,496	2,753	21.0	4.2
	Juneau marine	20,543	1,750	1,023	8.5	1.3
	Haines marine	727	371	124	51.0	0.3
	Chilkat River	2,822	2,822	661	100.0	2.1
	Subtotal	57,631	10,804	3,025	18.7	8.2
Subsistence[b]	Chilkat Inlet	107	107	0	100.0	0.1
	Chilkat River	347	347	0	100.0	0.2
	Subtotal	454	454	0	100.0	0.3
Total		1,430,879	131,635	19,893	9.2	100.0

Source: Ericksen and Chapell 2006.

[a] Percent of Chilkat River coho salmon in the fishery harvest.

[b] Percent of the Chilkat River coho salmon harvest by the fishery.