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Stock Status and Escapement Goals for Chilkat Lake Sockeye Salmon in Southeast Alaska

by

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May 2010

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 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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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.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

Available information was assembled concerning estimated escapements, harvests, and age compositions of sockeye salmon, *Oncorhynchus nerka,* returning to the Chilkat Lake drainage in Southeast Alaska during the years 1976 to 2007. In addition, the estimates of hatchery and wild smolt outmigrations and age compositions were assembled. This information was used to reconstruct annual runs of Chilkat Lake sockeye salmon. Brood tables consisting of estimated escapements and resultant age-specific recruits for the 1979 to 2002 brood years and estimated age-specific smolts produced from the 1987, 1988, and 1994 to 2000 brood years were developed for this stock. These data were subsequently used to develop a hierarchy of Ricker-type stock-recruit, and stock-smolt relationships which examined the effect of spawner density, auto-correlation, and fry plants on recruits and smolts. These relationships were used to estimate the number of spawners that would, on average, provide for maximum sustained yield of this stock of sockeye salmon in fisheries that are believed to harvest this stock. Based upon the spawner-recruit relationship developed in this report, it is recommended that a biological escapement goal of 70,000 to 150,000 spawners per year be adopted.

Key words: Sockeye salmon, *Oncorhynchus nerka*, Chilkat Lake, stock-recruit analysis, escapement goals, Southeast Alaska

INTRODUCTION

The Chilkat River's estuary lies at the head of Chilkat Inlet, upper Lynn Canal, near the town of Haines, Alaska. The Chilkat River drainage is a large watershed that encompasses about 1,600 km^2. Volumetric flow measurements range from 24 to 6,181 m^3 (Bugliosi 1988). The Chilkat River receives input from several different glaciers, and varies from clear water in the late fall, winter, and early spring to high levels of turbidity during late spring, summer, and early fall. Principle tributaries include the Tahkin River, Tsirku River, Klehini River, Kelsall River and the Tahini River. Chilkat Lake, the primary destination of Chilkat River sockeye salmon (*Oncorhynchus nerka*), flows into the Tsirku River before eventually joining the Chilkat River.

The harvest of sockeye salmon was one of the principal reasons for prehistoric human settlement of the Chilkat Valley. As European-Americans colonized Southeast Alaska they built salmon canneries. Commercial fisheries were established, with first the reported catch occurring in 1878 (Rich and Ball 1932). The early fishery was first located in Lynn Canal and targeted sockeye salmon. The fishery was fully developed by 1900. Catches were very high relative to current levels, with sockeye salmon harvest during the period 1900–1920, averaging roughly 1.5 million fish. Because the fishery occurred in inside waters of Northern Southeast Alaska, the sockeye catches were dominated by Chilkat and Chilkoot river stocks (Rich and Ball 1932). A rough reconstruction of Chilkat and Chilkoot river catch is provided in Appendix A. In this reconstruction, the non-terminal area catch (i.e., Icy Strait and Northern Chatham Strait areas) was allocated to individual stocks based upon reasonable assumptions: (1) historical catch by District provided in Rich and Ball (1932), (2) relative magnitude of historical Lynn Canal and Stephens Passage District catches, and (3) average relative magnitude of the Lynn Canal sockeye salmon stock compositions (i.e., Chilkat, Chilkoot, and other stocks) determined by modern stock identification programs in place since 1975.

Chilkat sockeye salmon catches were sustained at a very high level during the period 1900 to 1925, with annual catch averaging about 480 thousand fish and ranging from about 325 to 780 thousand fish. Catches decreased in the early 1920s and remained at relatively low levels thereafter with annual catch, 1975 to 2007, averaging about 85 thousand fish and ranging from about 14 to 168 thousand fish (Geiger et al. 2004).

Historically Chilkat sockeye salmon were harvested in the large fish trap and purse seine fisheries in Icy Strait and northern Chatham Strait (c.f. Appendix B) as well as in more terminal gill net areas of Lynn Canal. The fish traps were eliminated with Alaska statehood in 1959 and Lynn Canal developed into a designated gillnet fishing area (ADF&G Fishing District 115; Figure 1). In the early 1970s, Icy Strait and the northern Chatham Strait purse seine fishing areas were closed to fishing, by regulation during the sockeye season, and now Chilkat sockeye salmon are harvested almost entirely in Lynn Canal (District 115).

After statehood in 1959, Alaska fishery managers began stock assessment investigations in Chilkat Lake and installed fish weirs beginning in 1967. The Chilkat Lake sockeye salmon run consists of a late and an early run largely based on bimodal timing of weir counts. The early run consists of mostly age-1. fish, which have spent one year in freshwater prior to migrating to sea, and the late run consists of mostly age-2. fish, which have remained in freshwater for 2 years after emergence prior to sea migration.

McPherson (1990) developed a scale pattern analysis (SPA) program that permitted stock-specific estimates of harvest for both Chilkat and Chilkoot lakes in the District 115 fishery. Using archival scale collections, the stock composition of the historical District 115 catches were estimated. Using the catch by stock and age and the Chilkat weir counts of escapements segregated by age, McPherson (1990) reconstructed total runs of Chilkat River and Chilkoot River sockeye salmon, developed brood tables, and developed escapement goals for both Chilkat and Chilkoot lakes using Ricker stock-recruitment analyses. The initial escapement goals (an overall escapement goal of 52,000 to 106,000 fish for Chilkat Lake based on the Chilkat Lake weir counts, with a separate goal for early and late runs) established for Chilkat Lake sockeye salmon were based on McPherson's (1990) analyses.

The assessment of Chilkat River escapement based on the Chilkat River weir counts were discontinued in 1996 and replaced by total escapements based on a Chilkat River mark-recapture experiment. Accordingly, the Chilkat escapement goal was later revised to 80,000 to 200,000 spawners and included combined early and late runs (Der Hovanisian and Geiger 2005) to be consistent with total escapement. The Alaska Department of Fish and Game (ADF&G) specified the goal as a *biological escapement goal* (BEG), meaning it was a scientifically defendable recommendation intended to produce maximum sustained catch for the stock (Geiger et al. 2004).

In the 1980s, using Koenings' Euphotic Volume model (Koenings and Burkett 1987), ADF&G limnologists concluded that the Chilkat Lake system was capable of rearing an additional 10 million sockeye fry, beyond what was naturally produced. They believed the lake was "spawning area limited" (from a series of unpublished memoranda and planning documents) and concluded "zooplankton densities were great enough to feed an additional 10 to 12 million fry annually over what the lake is capable of producing naturally, regardless of the number of adult sockeye getting into the lake." Consequently, they recommended that Chilkat Lake be used as a site for lake stocking. Eggs and milt were harvested from spawning sockeye salmon that had returned to the lake, and fry were stocked in the lake in the summer after hatching. On average, about 3 million fry were stocked annually in Chilkat Lake from 1994 to 1997 and again in 2001 (Table 1). The project initiators expected the lake stocking to almost double the gillnet fishery catch of sockeye salmon originating from Chilkat Lake (from unpublished letter dated April 9, 1994, from Steve Reifenstuhl, Northern Southeastern Regional Aquaculture Association, summarizing and explaining the work that led up to the lake stocking). Additional programs occurred to enhance sockeye production in Chilkat Lake; from 1989 to 1998 and again in 2003, incubation boxes alongside Chilkat Lake were seeded with sockeye salmon eggs. In the spring following incubation, an average of 300,000 fry emerged annually into Chilkat Lake (Table 1).

For this study, we describe: (1) the stock assessment information available for Chilkat River sockeye salmon, including reconstruction of the total Chilkat River sockeye salmon runs by age since 1976, (2) estimation of adult recruits and parental escapements for the 1979 to 2002 brood years, (3) the available information on lake-stocking and other enhancement activities in Chilkat Lake, (4) an assessment of smolt outmigrants by freshwater age and origin (wild or enhanced) for 1989 to 2004, and (5) the estimation of smolts from escapements at Chilkat Lake.

The current BEG for the Chilkat Lake sockeye salmon stock was evaluated based on updated stock-recruit and stock-smolt analyses using a hierarchal series of Ricker-type stock-recruit models. Trends in available stock assessment records were examined to evaluate the status of the Chilkat River sockeye salmon stock and the Chilkat Lake enhancement program including effects on the productivity of wild stocks.

STOCK ASSESSMENT INFORMATION

ESCAPEMENT

Sockeye salmon escapements were enumerated at Chilkat Lake from 1967 to 1995 and from 1999 to 2007 using a steel picket weir (Table 2).

ADF&G first carried out mark-recapture studies on fall chum salmon (*O. keta*) in the Chilkat River using fishwheels in 1990 (Leon Shaul, ADF&G Juneau, *personal communication*). The primary focus of the project at that time was to provide the District 15 fishery managers with an inseason assessment of chum salmon escapement to the Chilkat River drainage (Bachman and McGregor 2001, Bachman 2003).

From 1994 to 2004, ADF&G and the Northern Southeastern Regional Aquaculture Association (NSRAA) worked cooperatively to assess Chilkat River sockeye salmon stocks using the fishwheels in the lower river as the marking event (first event) in annual mark-recapture experiments. From 1994 to 1995 and from 1999 to 2007, the Chilkat Lake weir was operated in conjunction with the fishwheel project. In 2004, NSRAA ceased operating the Chilkat Lake weir; ADF&G took over weir operations. Currently, ADF&G operates a dual-frequency identification sonar (DIDSON) at Chilkat Lake to assess adult sockeye salmon escapement.

The Chilkat River fishwheel program began in 1994, and involved using mark-recapture techniques to assess escapement of sockeye, coho (*O. kisutch*), Chinook (*O. tshawytscha*), and fall chum salmon escapement. A 2 -event mark-recapture experiment was used to develop separate estimates of the spawning escapement of sockeye salmon to Chilkat Lake and the Chilkat River mainstem. The adult sockeye salmon marked at the fish wheels was the first event (marking). The sampling of adult sockeye salmon from the spawning grounds and as sockeye salmon passed through the Chilkat Lake weir was the second event of the mark-recapture experiment. The weekly estimates of Chilkat River mainstem and Chilkat Lake sockeye salmon were then determined by multiplying the weekly abundance estimate by the proportion of mainstem and Chilkat Lake fish as determined by scale pattern analysis from samples collected from the 2 fish wheels in the lower Chilkat River. Again, the population was stratified for both marking and recovery. Age composition of the Chilkat Lake sockeye salmon escapement was based on continuous sampling of scales at the Chilkat weir. Fishwheel catch data are also used as an indicator of inriver abundance of salmon during the commercial fishing season. This information is used by managers to modify fishing area boundaries and time allowed to exploit Chilkat River salmon stocks during the commercial fishing season.

An unknown number of sockeye salmon pass the weir undetected during periods of boat traffic and frequent flow reversals at the weir site and, as a result, the weir counts are thought to be biased low. This was verified in a radio-telemetry study conducted on Chilkat River drainage sockeye salmon in 2003 and 2004. Tagged fish were observed passing the weir into Chilkat Lake during flow reversal events at the lake outlet (Brian Elliott and Nicola Hillgruber, University of Alaska Fairbanks, *personal communication*).

The mark-recapture studies consistently yielded estimates of Chilkat sockeye salmon escapement that were higher than the weir counts and further demonstrated that the weir counts were not an accurate measure of the escapement (Table 2). As a result, the operation of the weir for determining escapement at Chilkat Lake was discontinued in 1996. From 1996 through 1998, second-event sampling of sockeye salmon was conducted by extensive beach seining at holding and spawning areas within Chilkat Lake. Analysis of these data revealed that recovery efforts targeted early run fish because later returning fish were not available at spawning beaches during seining operations (Kelley and Bachman 2000). Operation of the Chilkat Lake weir was re-established in 1999 to sample returning sockeye salmon for marks applied from the fishwheels, to determine age, sex and length composition of the stock, and to count sockeye salmon into Chilkat Lake. From 1994 to 2007, assessment of Chilkat River sockeye salmon escapements was based on mark-recapture studies (Table 2).

There has been a close relationship between the mark-recapture estimates of sockeye salmon escapement to Chilkat Lake and the Chilkat weir counts (Figure 2). We regressed the mark-recapture estimates against the weir counts for each year that we had paired estimates ($Y = 40.9 + 1.96X$, $R^2 = 0.77$). The regression was used to scale the weir counts to total escapement for years when mark-recapture experiments were not conducted, to give an uninterrupted time series of almost 30 years of escapement observations to use in developing escapement goals, and for examination of escapement trends. The estimated total escapements by age, based on the age composition at the Chilkat weir applied to the scaled Chilkat weir counts, prior to 1994, and to the mark-recapture estimates after 1994 are provided in Table 3.

HARVEST

The majority of the commercial sockeye salmon harvest in the Lynn Canal fishery is comprised of a mixture of stocks from Chilkat Lake, Chilkat River, Chilkoot Lake, and streams emptying into Berners Bay. SPA is used to estimate the contribution of these stocks of sockeye salmon in this fishery each season (Marshall et al. 1982; McPherson et al. 1983; McPherson et al. 1992; McPherson and Marshall 1986; McPherson 1987 and 1989; McPherson and Olsen 1992). SPA is used inseason to identify sockeye salmon stocks in the Lynn Canal fishery, as Chilkat Lake, Chilkoot Lake, and “other” (non Chilkoot Lake or Chilkat Lake) sockeye salmon. Scale samples from Chilkat Lake and mainstem area sockeye salmon stocks are collected for use as SPA standards.

Sockeye salmon originating in Chilkat Lake and Chilkat River contribute significantly to the Lynn Canal (District 115) commercial drift gillnet fishery (Kelley and Bachman. 1999). Chilkat Lake has produced annual commercial sockeye salmon harvests as high as 168,000 in 1986, with mean harvests of about 85,000 fish for the years 1976 to 2007 (Table 2). Annual harvests of "other" sockeye stocks, which include Chilkat River mainstem spawning fish, have been as high as 33,000 (1992), with a mean harvest of about 14,400 fish between 1976 and 2004 (Bachman 2005). In addition to the commercial harvest, sockeye salmon originating from Chilkat Lake and the Chilkat River are also taken in the Haines area subsistence fishery. Reported subsistence harvests in Chilkat Inlet and Chilkat River for the period 1990 to 2004 averaged approximately 6,700 sockeye salmon. The commercial catch by age, 1984 to 2007 is provided in Table 4. Total runs of Chilkat River sockeye salmon have ranged from a high in 1993 of about 403,000 to a low in 2007 of about 82,000 (Figure 3). Runs have been declining since 2000.

RECRUITS FROM PARENT ESCAPEMENT BY AGE

The recruits, by age, from parent escapements were estimated for the 1979 to 2002 brood years (Table 5). The recruits from brood year y and age a are the escapement and catch for age a in calendar year $y + a$,

$$\hat{R}_{a,y} = \hat{E}_{a,y+a} + \hat{C}_{a,y+a} \qquad (1)$$

where $R_{a,y}$ is the recruits for age a and brood year y, $E_{a,y+a}$ is the escapement by age a and calendar year $y+a$, and $C_{a,y+a}$ is catch by age a and calendar year $y+a$.

Production for year classes 1979 through 2002 was estimated for each cohort as the sum of production at age over ages of the cohort:

$$\hat{R}_y = \sum_{a=3}^{7} \hat{R}_{a,y} \qquad (2)$$

The 1979 to 1980, and 2001 and 2002 broods were incomplete, given the assessments of the 1981 to 2007 total runs. For these cohorts production was estimated by summing across older or younger ages, then prorating these sums for the younger production not assessed or the older ages yet to mature:

$$\hat{R}_{1979} = \frac{\sum_{a=5}^{7} \hat{R}_{a,1979}}{1-\hat{\bar{\tau}}_{4-}} \quad \hat{R}_{1980} = \frac{\sum_{a=4}^{7} \hat{R}_{a,1980}}{1-\hat{\bar{\tau}}_{3}} \quad \hat{R}_{2000} = \frac{\sum_{a=3}^{6} \hat{R}_{a,2000}}{1-\hat{\bar{\tau}}_{7}} \quad \hat{R}_{2001} = \frac{\sum_{a=4}^{5} \hat{R}_{a,2001}}{1-\hat{\bar{\tau}}_{6+}} \qquad (3)$$

where: $\hat{\bar{\tau}}_{4-}$ is the average fraction of production represented by 4-year-olds and younger; $\hat{\bar{\tau}}_{3}$ is the average fraction of 3 -year-olds, $\hat{\bar{\tau}}_{7}$ is the average fraction of 7-year-olds, and $\hat{\bar{\tau}}_{6+}$ is the average fraction of 6-year-olds and younger. The averages were taken over the complete 1981 to 2000 broods.

SMOLT ABUNDANCE

Estimates of sockeye salmon smolt outmigrations were made at the Chilkat weir site during the springs of 1989, 1990, and 1994 to 2004, by NSRAA. The estimates were made based on mark-recapture methods (Rawson 1984), where smolts were trapped at the adult weir site using an inclined plane trap. The smolts were marked with dye and then released approximately 200 m upstream. Estimates of trap efficiency are based on the fraction of marked smolts subsequently recovered in the trap. The proportion recovered provides the estimate of trap efficiencies used to expand the trap catches to abundance. Otolith-marked, hatchery-reared sockeye fry were released in Chilkat Lake in 1994 to 1997 and 2001 (Table 1). The smolt trap catches were sampled for scales and otoliths, enabling estimation of the freshwater age and hatchery versus wild compositions of the smolt outmigrations. Estimates of smolt outmigrations by age and by wild and hatchery fish for the years where smolt abundance was assessed is provided in Table 6.

Total wild smolts produced from brood year *y* parent escapement ($\hat{S}_y^T$) (Table 7) was estimated for wild smolt outmigrations by age ($\hat{S}_{a,y+a}$) as:

$$\hat{S}_y^T = \sum_{a=2}^{4} \hat{S}_{a,y+a} \tag{4}$$

Outmigrations are complete for the 1987, 1988, and 1992 to 2000 brood years; however estimated outmigrations are not complete for the 2001 brood year. Here the age-2. plus the age-3. smolts were expanded based on the average proportion of age-4 over the complete broods (Table 7).

Wild smolt abundance has ranged from a high of about 2.6 million in 1990 to a low of about 0.43 million in 2002 (Figure 4). In the 5 years where smolts were estimated, 1989 to 1994, wild smolts averaged 2.19 million. Wild smolt estimates declined in 1997 and since 1997, smolt abundance has been relatively stable and averaged about 1.23 million. Enhanced smolts were a significant component and averaged 26% of the total smolt outmigrations from 1995 to 1999.

LIMNOLOGICAL OBSERVATIONS

The decline in smolt abundance, beginning in 1997 (Figure 4), occurred following the initiation of fry stocking. The mean length and weight for age-1. and age-2. smolt dropped substantially after the stocking events; the mean length decreased by over 12 mm and the mean weight by over 3 g for age-1. and age-2. smolt (Table 8). In addition, the age composition of the smolt changed in Chilkat Lake following fry stocking. In the 3 years that smolt studies were performed before stocking began, no age-3. smolt were observed; however, after stocking an average of 2.3% of the smolt resided in the lake for 3 years (Table 8). In addition, the percent of sockeye fry that spent 2 years in the lake before smolting shifted from an annual average of 49% to 55%. Generally, in Southeast Alaska lakes, the majority of sockeye salmon remain in the lake for only a year before smolting, and sockeye salmon that reside in the lake for 3 years are considered a rare occurrence. Moreover, a decline in the number of outmigrating smolt, including those with both wild and enhanced origins, occurred from Chilkat Lake between 1997 to 2004 (Figure 4).

This decline in sockeye production (Figure 3) may be due to food limitation of the preferred zooplankton prey, *Daphnia*. After 1995, a trend occurred of declining densities of the zooplankton copepod *Cyclops* and the cladoceran *Daphnia* in Chilkat Lake. However, in 2000, *Daphnia* densities increased, which may be due to the population rebounding because stocking had not occurred since the spring of 1997. *Daphnia* densities declined again in 2001 and continued to decline after a spring stocking of about 2.7 million fry in 2001. The length of each zooplankton taxa did not vary much over the time series (Figure 5). After reevaluating the information in 2000, ADF&G linked future lake stockings in the system to zooplankton abundance and sockeye salmon smolt size (unpublished letter from Andy McGregor, fisheries scientist ADF&G Division of Commercial Fisheries, to Steve Reifenstuhl, Northern Southeast Regional Aquaculture Association).

STOCK-RECRUIT ANALYSIS

METHODS

The following hierarchal set of stock-recruitment models were fit to the Chilkat River stock-recruit data for the 1979 to 2003 brood years and to the Chilkat River stock-smolt data for the 1987, 1988, and 1992 to 2000 brood years. The stock-recruit models are Ricker type (Ricker 1975) and hierarchal terms included escapement density, fry plants and a first order autoregressive term. Hilborn and Eggers (2000) used the term fry plants as was done herein to evaluate the effect of hatchery releases of pink salmon on wild stock productivity. Five models were constructed: (1) linear, no density dependence escapement; (2) straight Ricker, escapement density dependence; (3) Ricker with fry plants, density dependence-fry plants (this model used in Hilborn and Eggers 2000); (4) autoregressive Ricker, density dependence with first order autoregressive term; and (5) autoregressive Ricker with fry plants, and the highest order model escapement density dependence-fry plants, and autoregressive term. The significance of the relative fit of the alternative models was evaluated using the likelihood ratio test (Hilborn and Mangel 1997).

Model 1—Linear;

$$R_i = S_i \exp(\alpha)\exp(\varepsilon_i) \qquad (5)$$

Model 2— Straight Ricker;

$$R_i = S_i \exp\left(\alpha\left(1 - {S_i}/{\beta}\right)\right)\exp(\varepsilon_i) \qquad (6)$$

Model 3—Ricker with fry plants;

$$R_i = S_i \exp\left(\alpha\left(1 - {S_i}/{\beta} - \gamma F_{i+1}\right)\right)\exp(\varepsilon_i) \qquad (7)$$

Model 4—Autoregressive Ricker;

$$R_i = S_i \exp\left(\alpha\left(1 - {S_i}/{\beta}\right)\right)\exp(\phi\varepsilon_{i-1}) \qquad (8)$$

Model 5—Autoregressive Ricker with fry plants;

$$R_i = S_i \exp\left(\alpha\left(1 - {S_i}/{\beta} - \gamma F_{i+1}\right)\right)\exp(\phi\varepsilon_{i-1}) \qquad (9)$$

Where α, β, γ, ϕ are model parameters, and the data are total recruits or total smolts from brood year *i* escapement (R_i), escapement in brood year *i* (S_i), fry plants from brood year *i* in year *i + 1* (F_{i+1}). ε_i is the process error, $ln(\varepsilon_i) \sim$ normal$(0,\sigma)$.

Each of these models was fit to Chilkat stock-recruit and stock-smolt data using the method of maximum likelihood. Parameters were selected to maximize likelihood *(L)*. The log normal error structure was used to derive the likelihood function (*L*; equation 10).

$$L(\alpha,\beta,\gamma,\delta | data) = \prod \left[\left(\frac{1}{\sigma\sqrt{2\pi}} \right) \exp - \left(\frac{\ln\left(\frac{R_i}{\hat{R}_i} \right)}{2\sigma^2} \right) \right] \quad (10)$$

The parameters *(α, β, γ, ϕ,* and σ) of the respective models were estimated using EXCEL. The models were fit to the data using the solver routine to search over the parameter space to minimize the -ln*(L)* which is equivalent to maximizing *L*. The (α, β) parameters of the stock-recruit models were bias corrected using procedures in Hilborn and Walters (1992). Appropriate reference points were calculated using the bias corrected parameters (α' and β'**),**

$$\alpha' = \alpha + \sigma^2 / 2 \quad (11)$$

$$\beta' = \frac{\alpha'}{\alpha} \beta \quad (12)$$

$$\sigma^2 = \frac{\sum \ln\left(\frac{\hat{R}_i}{S_i} \right)^2}{n - p} \quad (13)$$

For the autoregressive model the bias correction is,

$$\alpha' = \alpha + \sigma^2 / 2(1 - \phi^2) \quad (14)$$

For each model applied to stock-recruit data, the maximum sustained yield (MSY) escapement goal, and the range of escapement that produce 90% of MSY, and MSY harvest rate were calculated. In addition the likelihood profile for the MSY escapement goal and the MSY harvest rate were calculated. The likelihood profiles were estimated using a numerical method described in Hilborn and Mangel (1997) and subsequently used to evaluate the uncertainty in these reference points.

RESULTS OF STOCK-RECRUIT ANALYSIS

The hierarchal set of stock-recruit models was fit to the Chilkat River recruits from parental escapements of the 1979 to 2002 brood years (Table 9). There was significant density dependence in the stock-recruit data with the escapement term (Model 2 to Model 5) having a significant fit improvement (likelihood ratio test $p < 0.001$) over the linear model (Model 1). There was also significant autocorrelation in the Model 2 residuals with Model 4 (i.e, with the autoregressive term, $\phi = 0.50$, which corrects for time series bias) providing a significant improvement in fit (likelihood ratio test, p = 0.035). The models with the fry plant terms (Model 3, Model 5) showed improved fit relative to lower order models (Model 2 and Model 4, respectively, Table 9); however, the fit improvements were not significant (likelihood ratio tests, p = 0.215, 0.515).

Each of the models fit to the 1979 to 2002 brood year stock-recruit data provided good resolution of the MSY escapement level and associated 90% MSY escapement ranges (Figure 6, Table 9). The reference points were generally consistent among the models with the time series bias corrected model (Model 4, Model 5) having slightly higher point values and the models correcting for fry plants (Model 2 and Model 5) having slightly lower point values (Figure 6, Table 9).

The predicted Model 5 recruits for brood years where fry were planted the year following the brood year return were higher (Figure 7) than predicted from the base (i.e., Model 5 assuming no fry plants) stock-recruit model. This is consistent with the expected higher adult production from the fry plant enhancement activity. The effect of the fry plant term ($\gamma = 0.069$) is to correct the increased production due to the fry plants and to provide an unbiased estimate of wild stock MSY escapement goal and 90% MSY escapement goal range. It is clear that the productivity under the base stock-recruit model (Model 5 with no fry plants) is lower than the biased stock-recruit model fit to the raw stock-recruit data (Figure 8).

The best model in terms of fit criteria (i.e., minimum AIC) is Model 4. Since Model 5 is consistent with increased recruits independent of wild stock production, and therefore provides a correction for effect of fry plants, Model 5 should be used to estimate BEGs for Chilkat Lake sockeye salmon. Observed recruits and predicted recruits under Model 5 as well as the base level Model 5 (i.e., without fry plant effects and autoregressive effects) from which escapement goals were determined is shown in Figure 8. The residuals for Model 5 showed no autocorrelation, although production was generally low after the 1992 brood year (Figure 9). The MSY escapement level under Model 5 is about 105,000 spawners and the 90% MSY escapement goal range is about 69,000 to 147,000 sockeye salmon.

The hierarchal set of smolt from parental escapement models was fit to the Chilkat River data for the 1987, 1988, and 1994 to 2001 brood years (Table 10). There was significant density dependence in the smolt recruit data, with the models with the escapement term (Model 2, Model 3) having a significant fit improvement (likelihood ratio test, p = 0.003) over the linear model (Model 1). Note that the autoregressive models (Model 4, Model 5) did not result in a significant improvement in fit to the smolt data and were not considered further. The smolt model with the fry plant terms (Model 3) showed improved fit relative to lower order models (Model 2 Table 10); however, the fit improvement was not significant (likelihood ratio test, p =0.498).

The predicted Model 3 smolts for brood years where fry were coincident with wild smolt residence were lower than that predicted from the base (i.e., Model 3 assuming no fry plants) (Figure 10). This result is consistent with the hypothesis that competition with planted fry reduced the abundance and condition of wild smolts. The estimated average reduction (taken over 1994 to 2001 brood years) in wild smolts (i.e, the difference in Model 3 predicted smolts with fry plants explicit and the base level Model 3 predictions) was 343,000 fish and the estimated average smolts produced from the respective brood year fry plants was 507,000 fish. There were positive net smolts produced from the enhancement fry plants but the increase was buffered by a corresponding decrease in wild smolts.

The hierarchal set of stock-recruit models was also fit to the 1987 to 2001 stock-recruit data (Table 10) to provide a consistent temporal comparison with the results from the fits to the smolt data. The results were very similar to the models fit to the entire stock-recruit data set (Table 11), except that the Model 4 (with the autoregressive term (ϕ = 0.535)) fit improvement was not significant (likelihood ration test p = 0.083) and reference points were slightly higher for the models fit to the reduced stock-recruit data set. The Model 2 and Model 3 fit to 1987 to 2001 brood year stock-recruit data and 1987 to 1988, 1994 to 2001 brood year smolt data, provided good resolution of the MSY escapement level and associated 90% MSY escapement ranges (Figure 11; Tables 10 and 11). These reference points were almost identical for Model 2 fit to stock-recruit and to smolt data (Figure 10). The MSY escapement level for Model 3 (with the fry plant correction) fit to the stock-recruit data was lower than Model 2 (Figure 11); however, the MSY escapement levels for Model 3 (with the fry plant correction) fit to the smolt data was higher than Model 2 (Figure 11).

Observed smolts, predicted smolts under Model 3, and the base level (i.e., without the fry plant effect) are shown in Figure 12. The maximum smolts escapement level under the base level Model 3 is 115,000 fish.

STOCK STATUS AND ESCAPEMENT GOAL RECOMMENDATION

A biological escapement goal range of 70,000 to150,000 spawners per year as assessed with the Didson sonar counter at the Chilkat River weir site is recommended. This goal range is the escapement range that produces 90% of MSY as determined by Model 5 (Autoregressive Ricker with fry plants) fit to the 1979 to 2002 stock-recruit data.

While this model was not the most parsimonious (i.e., minimum AIC) it was selected because it accounted for the bias in assessing wild stock production due to the added production due to the enhancement stocking of fry that occurred from 1989 to 2003 and is, therefore, the most meaningful biological model.

Escapements for the stock have been generally within or above the recommended biological escapement goal (Figure 13). The 5-year moving average of escapement, which is the indicator of stock concern as specified in the Sustainable Salmon Fisheries Policy, was within or above the BEG range for the period of available stock assessments. There were a few years in the mid- to late-1990s when the trend in escapement was above the BEG range. This indicates that the stock is healthy and somewhat underutilized in some years.

Our recommendation is to establish a biological escapement goal range of 70,000 to 150,000 spawners per year for Chilkat Lake sockeye salmon as assessed with the Didson sonar counts made at the Chilkat Lake weir site.

DISCUSSION

The recommended BEG (70,000 to 150,000 spawners) is very close to the prior weir count escapement goals based on the prior stock-recruit analysis (McPherson 1990) once converted to total escapement based on the regression (Figure 8) reported here. The weir count escapement goal of 52,000 to 106,000 converts to 75,000 to 153,000 total escapement using mark-recapture experiments to correct weir counts.

MSY escapement level and associated 90% MSY escapement goal ranges were very consistent among models fit to the stock-recruit data and to the smolt data. The reference points were slightly higher reference points based on model fits to the smolt data. This is likely due to the difference between the time periods as the reference points based on the reduced stock-recruit data were more consistent with those based on smolt data. The effect of the fry plants is increased recruits for years of fry plants

It is clear that the fry plants depressed the wild smolt production, and further the fry plants generally occurred in the face of relatively high wild stock escapements. The uncorrected Model 2 fit to the wild smolts from parent escapement data set reflects the smolt production in the face of consistent fry plants. The estimated wild spawner carrying capacity based on Model 3 reflects the smolt production expected absent fry plants as the reference points are calculated based upon the assumption that the fry plants are zero. This suggests that production is rearing limited, and that fry plants in conjunction with moderate to high wild stock escapement resulted in decreased wild smolt production; however, the significant production of enhanced smolts (503,000 fish per year, on average) from the fry plants more than compensated for the reduced wild smolt production (343,000 fish).

The MSY escapement level based upon models with the fry plant term explicitly fit to the smolt data and to the stock-recruit data appear to be inconsistent. Here, the MSY escapement level based upon Model 5 fit to the stock-recruit data decreased while the maximum smolt production level based upon the Model 3 fit to the smolt data increased. In addition, the effect of the fry plant term in Model 5, once fit to the stock-recruit data set, was to increase adult recruits with increasing fry plants, while the effect of fry plants in Model 3, once fit to the smolt data, was to decrease wild smolts. The uncorrected Model 4 fit to the stock-recruit data set reflects the total adult production in the face of some level of fry plants. The corrected Model 5 fit to the spawner-recruit data reflects the adult production expected absent fry plants. Because of a significant level of adult production resulting from the fry plants, the estimates of biological reference points based on Model 4 is biased high. The estimated reference points using the models correcting for fry plants fit to stock-recruit data and smolt data are consistent.

Barto (2005) reconstructed the escapement into Chilkat Lake from 1700 to 2000 by examining δN^{15} levels in the lake sediment cores. Barto scaled his reconstructed δN^{15} time series to total escapement by comparing the lag-1 year (from the estimated date of the δN^{15} sample) 5-year moving average of Chilkat weir counts to δN^{15} levels for 6 discrete time periods between 1976 and 1995. Barto estimated that the trend in Chilkat Lake escapement fluctuated between 50,000 and 150,000 during the period, 1700 to 2000. Since the weir counts are substantially lower than the actual total escapement, Barto's historical estimates of escapement are undoubtedly low. To account for this bias we re-estimated Barto's reconstruction of Chilkat Lake sockeye salmon escapements using the time series of Chilkat River total escapement based on the weir count to mark-recapture calibration. Details are in Appendix B.

Note that, the range of sediment δN^{15} levels (4.9–5.9) during the calibration period (i.e., years with available escapement data) was relatively narrow compared to the range of δN^{15} levels found in the sediment core (3.25–6.94). There would be considerable uncertainty in escapement projections for δN^{15} values outside the narrow range of calibration data.

Nevertheless, the general trends in δN^{15} levels since 1700 as well as the escapement magnitudes relative to the recent Chilkat escapement levels can be ascertained from sediment core data (Barto 2005). The trend (expressed as a 5 to 7 year moving average) of re-estimated escapement fluctuated between 50,000 and 230,000 during the period 1700–2000 (Appendices B.1 to B.4).

Escapement levels during the 18th century were similar to those during the calibration period (i.e., 1976–1995). Escapements during most of the 19th century and from the mid 1920s to early 1970s were lower than those of the calibration period. However escapements from the onset of commercial fishing in the late 1870s to the early 1920s were higher and potentially substantially higher than escapement levels during the calibration period. Note that the period of high escapement from about 1900 to 1920 corresponded to a period of very high commercial catches of Chilkat sockeye salmon (c.f. Appendix A).

The average escapement level of Chilkat Lake sockeye salmon in the few decades prior to the outset of commercial fishing were below the estimated pristine abundance level or carrying capacity from the stock-recruit analysis (roughly 250,000 based on the Model 5 stock-recruit analysis, i.e. β parameter in Table 9). A substantial increase in escapement levels and total runs occurred with the onset of commercial fishing on the Chilkat stock. This is consistent with the prediction of the stocks response to fishing based on a compensatory stock-recruitment relationship. Production was very high and persisted for about 30 years and resulted from average escapements consistent with the recommended escapement goals for the stock. Based on the reconstructed catch (Appendix A) and escapements (Appendix B), there have been 3 productivity regimes for the Chilkat stock: a high productivity regime, 1890 to 1920; an intermediate productivity regime, 1920 to 1950; and a lower production regime from 1950 to the present. Note that average escapements through the entire period have been relatively stable, presumably because of compensatory fishing mortality, generally within the proposed escapement goal range.

It is also clear that the pristine abundance level for Chilkat Lake sockeye has not been consistent over the period of the sediment core data but instead fluctuated, presumably with decadal scale oscillations in climate (Beamish and Bouillon 1993, Beamish et al 1999, Hare and Mantua 2000, Finney et al. 2000).

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TABLES AND FIGURES

Table 1.–Number of enhanced sockeye salmon fry in Chilkat Lake for 1989 to 2003. No enhancement action was performed in years not listed in the table. The stocked fry were incubated as eggs in the hatchery and released as fry into Chilkat Lake in the spring. The number of fry that emerged in the spring each year from incubation boxes was estimated from the number of eggs seeded in incubation boxes minus the dead eggs counted in the spring.

Year	Stocked fry	Incubation box fry	Total enhanced fry
1989	0	15,094	15,094
1990	0	300,127	300,127
1991	0	388,000	388,000
1992	0	201,753	201753
1993	0	594,000	594,000
1994	4,400,000	550,700	4,950,700
1995	2,394,000	289,500	2,683,500
1996	2,691,000	572,350	3,263,350
1997	2,807,000	96,500	2,903,500
1998	0	437,950[a]	437,950
2001	2,699,000	0	2,699,000
2003	0	49,500[b]	47,500

[a] The number of fry from the incubation box was estimated from a 95% survival rate.

[b] The number of fry from the incubation box was estimated from a 99% survival rate.

Table 2.–Weir counts, escapement estimates, and harvest (in thousands of fish), for Chilkat Lake sockeye salmon from 1976 to 2007, together with total return and harvest rate estimates.

Year	Weir Counts	Mark-Recapture Estimates	Catch	Total Return	Estimated Exploitation Rate
1976	70	n/a	59	n/a	n/a
1977	41	n/a	41	n/a	n/a
1978	68	n/a	90	n/a	n/a
1979	81	n/a	116	n/a	n/a
1980	95	n/a	31	n/a	n/a
1981	84	n/a	48	n/a	n/a
1982	80	n/a	127	n/a	n/a
1983	134	n/a	124	n/a	n/a
1984	115	n/a	98	n/a	n/a
1985	58	n/a	136	n/a	n/a
1986	24	n/a	168	n/a	n/a
1987	49	n/a	70	n/a	n/a
1988	28	n/a	76	n/a	n/a
1989	140	n/a	159	n/a	n/a
1990	60	n/a	147	n/a	n/a
1991	53	n/a	60	n/a	n/a
1992	98	n/a	112	n/a	n/a
1993	210	n/a	101	n/a	n/a
1994	81	154	122	276	44.30%
1995	60	185[a]	63	248	25.60%
1996	*no weir*	263	96	359	26.80%
1997	*no weir*	239	70	309	22.70%
1998	*no weir*	211	121	332	36.40%
1999	130	236	150	386	38.80%
2000	47	131	79	210	37.50%
2001	76	132	59	191	30.90%
2002	65	128	47	185	25.60%
2003	52	113	50	167	30.10%
2004	76	119	51	170	30.00%
2005	30	84	23	107	21.40%
2006	37	73	16	89	18.10%
2007	21	68	14	82	17.30%

[a] Estimate derived from marking experiment at the weir.

Table 3.–Chilkat Lake total estimated escapement by numbers of fish for 1976 to 2007, and numbers of fish by age for 1982 to 2007. Escapement prior to 1994 was estimated by expansion of weir counts. Ages are listed in total age and European ages (years in freshwater, years in marine).

Return Year	Escapement	Age in Years												Total
		3		4			5		6			7		
		0.2	1.1	0.3	1.2	2.1	2.2	1.3	1.4	3.2	2.3	2.4	3.3	
1975	100,883	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1976	59,106	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1977	98,002	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1978	116,730	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1979	136,898	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1980	121,052	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1981	115,608	142	426	71	2,695	3,050	52,414	14,894	0	1,489	40,285	0	142	115,608
1982	193,380	0	1,426	0	6,247	5,296	53,981	73,536	68	272	52,419	68	68	193,380
1983	166,098	0	122	61	2,496	2,557	89,077	37,810	61	304	33,488	61	61	166,098
1984	83,198	0	500	0	563	2,750	33,067	7,689	188	375	38,067	0	0	83,198
1985	34,539	0	0	0	588	184	7,128	551	0	661	25,243	0	184	34,539
1986	70,044	0	623	0	1,294	1,918	23,923	17,163	0	384	24,547	48	144	70,044
1987	39,792	0	0	41	332	0	3,133	18,838	83	41	17,282	21	21	39,792
1988	202,410	0	0	0	1,463	0	58,481	86,755	209	52	55,345	0	105	202,410
1989	86,810	0	0	66	1,548	0	21,513	12,124	428	659	50,373	66	33	86,810
1990	76,233	0	0	0	1,618	0	16,655	27,505	48	0	30,074	190	143	76,233
1991	140,846	56	0	169	1,519	0	23,849	57,429	281	56	57,317	56	112	140,846
1992	302,179	0	0	256	19,293	0	109,372	45,487	0	10,861	116,911	0	0	302,179
1993	154,000	0	0	0	4,014	0	17,534	90,203	141	211	40,912	0	986	154,000
1994	165,000	0	0	61	9,075	0	29,186	44,760	1,410	184	80,201	61	61	165,000
1995	184,541	0	0	69	10,149	0	32,643	50,061	1,577	206	89,699	69	69	184,541
1996	262,852	0	0	0	27,309	0	23,042	177,510	0	0	34,990	0	0	262,852
1997	238,803	0	955	0	92,656	3,184	33,432	47,442	0	0	61,134	0	0	238,803
1998	211,114	0	176	0	10,397	705	40,179	146,617	0	0	12,688	352	0	211,114
1999	236,374	0	0	0	3,989	0	33,860	74,771	278	93	122,918	464	0	236,374
2000	131,322	0	0	57	3,175	0	10,206	6,748	340	3,686	106,940	113	57	131,322
2001	131,687	0	0	0	3,838	0	15,623	72,168	162	108	34,111	216	5,460	131,687
2002	128,111	0	51	51	3,172	153	25,735	33,921	512	0	64,414	51	51	128,111
2003	112,619	0	208	156	5,711	415	16,719	23,676	208	363	64,799	363	0	112,619
2004	119,280	0	159	79	4,209	238	20,529	59,322	40	159	33,870	199	476	119,280
2005	84,039	0	74	111	3,304	223	7,981	28,174	557	37	43,504	37	37	84,039
2006	73,064	0	71	142	3,471	460	5,135	37,860	35	35	25,535	0	319	73,064

Table 4.–Catch of Chilkat Lake sockeye salmon by age, 1984 to 2007 in numbers of fish. Ages are listed in total age and European ages (years in freshwater, years in marine).

Return	Age 3		4			5		6			7		Total
Year	0.2	1.1	0.3	1.2	2.1	2.2	1.3	1.4	3.2	2.3	2.4	3.3	
1984	98	0	0	295	0	24,165	37,131	0	98	36,345	0	98	98,231
1985	136	0	0	678	0	19,919	28,591	678	271	84,960	136	0	233,598
1986	337	0	0	3,367	0	49,161	16,331	0	2,862	95,797	168	337	303,728
1987	420	0	0	631	0	17,657	20,040	0	420	30,410	70	420	238,430
1988	153	0	0	1,377	0	13,077	18,124	76	306	42,978	76	229	146,466
1989	0	159	0	478	0	52,617	48,312	0	0	57,560	0	159	235,683
1990	0	0	0	1,765	0	50,146	16,911	147	882	76,910	147	0	306,195
1991	179	0	0	1,077	0	8,433	13,935	60	0	35,764	179	239	206,775
1992	112	0	0	783	0	22,489	28,867	112	112	59,300	112	112	171,865
1993	101	0	0	1,813	0	20,043	15,007	201	2,316	61,035	101	201	212,817
1994	0	122	0	1,711	0	14,177	53,651	0	122	50,351	122	1,955	223,030
1995	0	0	0	3,297	0	10,460	18,765	254	0	30,430	63	127	185,608
1996	0	0	0	2,795	0	19,854	34,119	96	96	39,323	96	96	159,872
1997	0	0	70	2,872	0	10,789	17,584	70	0	38,671	0	70	166,603
1998	0	0	0	1,503	0	21,760	51,035	99	99	43,747	33	99	188,503
1999	0	0	0	1,150	0	17,133	47,037	40	0	86,777	79	119	270,712
2000	0	0	0	2,760	0	6,900	11,187	493	49	130,898	0	49	304,672
2001	0	0	0	1,323	0	4,669	31,902	81	0	18,596	27	2,348	211,283
2002	0	0	0	928	0	11,516	8,003	649	0	26,156	40	0	106,239
2003	0	0	0	1,151	0	8,597	6,179	13	129	34,115	0	26	97,501
2004	0	0	0	2,254	0	5,492	20,133	0	19	22,993	38	208	101,346
2005	0	0	0	512	0	1,332	7,000	113	0	13,948	0	0	74,042
2006	0	0	0	1,310	0	778	7,838	61	20	5,956	0	123	38,991
2007	0	0	0	546	0	1,414	8,040	50	0	4,144	25	0	30,305

Table 5.–Total recruits of Chilkat Lake sockeye salmon by age class, for brood years 1977 to 2000. Quantities in bold italics are age classes from incomplete broods and are estimated from returns of older or younger age classes for that respective brood year.

Brood	Age													
	2		3			4		5			6			
Year	0.2	1.1	0.3	1.2	2.1	2.2	1.3	1.4	3.2	2.3	2.4	3.3	Escapement	Recruits
1977	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	84	182	n/a	n/a
1978	n/a	n/a	n/a	n/a	n/a	n/a	n/a	84	518	82,548	136	0	n/a	n/a
1979	***129***	***426***	***51***	***17,085***	***1,070***	147,064	89,299	936	788	137,469	168	590	161,036	395,076
1980	***81***	***267***	84	3,739	3,528	65,530	39,196	0	3,774	130,592	136	619	188,869	247,546
1981	98	266	0	1,454	3,794	58,987	17,091	0	949	64,266	105	258	167,000	147,268
1982	136	825	0	4,178	253	50,653	43,712	191	363	66,803	0	304	159,487	167,418
1983	337	337	0	2,416	2,645	17,396	44,094	288	72	133,923	238	45	266,817	201,792
1984	420	1,280	57	1,834	0	133,307	168,013	738	1,791	146,394	442	436	229,166	454,713
1985	153	153	0	2,497	0	79,821	33,635	125	0	77,246	189	267	114,761	194,087
1986	0	0	91	3,901	0	31,405	51,872	500	189	138,377	101	201	47,609	226,637
1987	0	0	0	3,308	0	55,393	108,099	201	17,303	222,355	122	2,941	96,608	409,722
1988	179	179	233	2,878	0	170,961	77,772	141	333	91,263	125	188	54,858	344,253
1989	189	112	353	28,435	0	31,710	143,854	1,664	184	110,631	96	96	279,278	317,325
1990	101	101	0	5,725	0	39,646	63,525	96	96	74,333	0	70	119,745	183,694
1991	0	0	61	12,371	0	42,909	211,729	70	0	99,536	385	99	105,148	367,162
1992	0	0	0	30,120	0	44,249	65,066	99	99	54,667	542	119	194,317	194,961
1993	0	0	70	95,604	3,505	64,207	197,572	318	93	209,501	107	103	416,964	571,080
1994	0	956	0	11,894	176	50,940	121,598	762	3,703	238,255	143	6,567	154,000	434,994
1995	0	176	0	5,226	0	16,948	17,689	312	116	49,631	40	51	165,000	90,189
1996	0	0	0	5,769	0	20,505	107,785	1,162	0	90,310	126	26	263,000	225,683
1997	0	0	0	5,888	0	37,301	41,955	265	570	103,779	196	684	239,000	190,639
1998	0	0	0	4,215	205	25,981	25,516	40	178	56,817	41	0	211,000	112,994
1999	0	51	0	6,190	441	25,993	79,375	687	0	54,329	0	446	236,000	167,511
2000	0	315	0	6,457	238	9,654	37,500	97	56	31,186	365	0	131,000	85,869
2001	0	159	0	4,325	246	5,838	46,133	438	194	30,645	***72***	***170***	132,000	88,219
2002	0	123	0	4,791	467	14,859	28,668	***140***	***319***	***36,980***	***70***	***167***	128,000	86,584
2003	0	72	0	4,963	1,650	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2004	0	437	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2005	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2006	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 6.–Sockeye salmon smolt outmigration from Chilkat Lake, 1989 to 2004, by wild and enhanced and by freshwater age.

Year[a]	Fry Stocked	Total Outmigration	Total Wild	Total Enhanced	Percent Enhanced	Age 1.0		Age 2.0		Age 3.0	
						Wild	Enhanced	Wild	Enhanced	Wild	Enhanced
1989	0	2,000,000	2,000,000	0	0.00%	1,520,000	0	480,000	0	0	0
1990	0	2,600,000	2,600,000	0	0.00%	702,000	0	1,898,000	0	0	0
1994	4,400,000	2,367,891	2,367,891	0	0.00%	1,207,624	0	1,160,267	0	0	0
1995	2,393,558	1,897,413	1,210,977	686,436	36.00%	403,217	686,436	801,223	n/a	6,537	0
1996	2,691,311	2,869,160	2,269,741	599,419	21.00%	939,393	269,365	1,325,183	330,054	5,165	0
1997	2,806,858	1,515,859	1,039,634	476,225	31.00%	113,201	98,786	918,711	377,439	7,722	0
1998	0	1,386,118	1,115,700	270,418	19.50%	666,224	220,892	340,569	33,683	108,907	15,843
1999	0	1,809,273	1,362,342	446,931	24.70%	620,377	0	716,718	446,931	25,247	0
2000	0	1,629,883	1,629,883	0	0.00%	115,214	0	1,509,020	0	5,649	0
2001	2,698,874	1,398,802	1,398,802	0	0.00%	657,269	0	694,397	0	47,136	0
2002	0	434,411	432,608	1,803	0.40%	114,619	1,803	316,686	0	1,303	0
2003	0	1,458,025	1,401,462	56,563	3.90%	840,998	0	549,390	56,563	11,075	0
2004	0	1,457,990	1,457,990	0	0.00%	831,210	0	624,685	0	2,096	0

[a] Project operated by ADF&G in 1989 to 1990. Northern Southeastern Regional Aquaculture Association operated project from 1994 to 2005.

Table 7.–Wild and enhanced smolt outmigrations for 1987, 1988, and 1992 to 2002 brood years, by freshwater age. Wild smolts per spawner and survival of enhanced cohorts are shown for complete broods and for brood years of fry plants. Note: Italic numbers are extrapolated from mean proportions; n/a denotes 'not applicable.'

Brood Year	Wild Escapement (thousands)	Stocked Fry	Wild Smolt age 1.0	Wild Smolt age2.0	Wild Smolt age 3.0	Wild Smolt Total	Wild Smolts/ Spawner	Enhanced Smolt age 1.0	Enhanced Smolt age2.0	Enhanced Smolt age 3.0	Enhanced Smolt Total	Enhanced Survival[a]
1987	97	0	1,520,000	1,898,000	0	3,418,000	35.38	0	0	0	0	n/a
1988	55	0	702,000	1,160,267	0	1,862,267	33.95	0	0	0	0	n/a
1989	279	0	n/a	n/a	n/a	n/a	n/a	0	0	0	0	n/a
1990	120	0	n/a	n/a	n/a	n/a	n/a	0	0	0	0	n/a
1991	105	0	n/a	n/a	n/a	n/a	n/a	0	0	0	0	n/a
1992	194	0	1,207,624	801,223	5,165	2,014,012	10.36	0	0	0	0	n/a
1993	417	4,400,000	403,217	1,325,183	7,722	1,736,122	4.16	686,436	330,054	0	1,016,490	0.23
1994	154	2,393,558	939,393	918,711	108,907	1,967,011	12.77	269,365	377,439	15,843	662,647	0.28
1995	165	2,691,311	113,201	340,569	25,247	479,017	2.9	98,786	33,683	0	132,469	0.05
1996	263	2,806,858	666,224	716,718	5,649	1,388,591	5.28	220,892	446,931	0	667,823	0.24
1997	239	0	620,377	1,509,020	47,136	2,176,533	9.11	0	0	0	0	n/a
1998	211	0	115,214	694,397	1,303	810,914	3.84	0	0	0	0	n/a
1999	236	0	657,269	316,686	11,075	985,030	4.17	0	0	0	0	n/a
2000	131	2,698,874	114,619	549,390	2,096	666,105	5.08	1,803	56,563	0	58,366	0.02
2001	132	0	840,998	624,685	*25,989*	1,491,672	11.3	0	0	0	0	n/a
2002	128	0	831,210	n/a	n/a	n/a	n/a	0	0	0	0	n/a

[a] Percent fry to smolt survival

Table 8.–Age composition and average length and weight of sockeye smolt by year and averages for all years (1989 to 2004), as well as before (1989 to 1994), and after (1995 to 2004), stocking events.

	Percent age			Average length (mm)			Average weight (g)		
Year	**age-1.0**	**age-2.0**	**age-3.0**	**age-1.0**	**age-2.0**	**age-3.0**	**age-1.0**	**age-2.0**	**age-3.0**
1989	76.00%	24.00%	0.00%	100.2	121	n/a	8.9	14.6	n/a
1990	27.00%	73.00%	0.00%	103.9	118.9	n/a	10	14.8	n/a
1994	51.00%	49.00%	0.00%	102.3	119.5	n/a	9.9	14.8	n/a
1995	62.00%	37.00%	4.00%	92.5	115.4	147.4	7.1	13.2	27.2
1996	42.00%	58.00%	2.00%	86.3	107.2	185.0	5.7	10.3	56.0
1997	13.00%	86.00%	1.00%	95.2	101.2	154.5	7	8.8	34.4
1998	64.00%	27.00%	9.00%	92.7	109.4	138.3	7.3	11.2	22.7
1999	34.00%	64.00%	2.00%	88.1	107.6	155.8	5.3	9.5	37.7
2000	7.10%	92.60%	0.30%	93.8	104.8	120.4	7.1	9.4	14.3
2001	47.00%	49.60%	3.40%	92.5	113.4	131.5	6.8	11.8	19.0
2002	26.80%	72.90%	0.20%	85.5	92.7	175.0	5.2	6.3	38.7
2003	75.30%	24.10%	0.60%	88.9	111.4	136.9	5.9	11.4	21.1
2004	57.00%	42.80%	0.10%	87.2	93.8	115	5.6	6.8	12.5
Average all years	44.80%	53.90%	2.30%	93	108.9	146	7.1	11	28.4
Average before stocking	51.30%	48.70%	0.00%	102.1	119.8	n/a	9.6	14.7	n/a
Average after stocking	42.80%	55.40%	2.30%	90.3	105.7	146	6.3	9.9	28.4

Table 9.–Results of model fits to the escapement-recruit data for brood years 1979 to 2002. Estimated parameters, reference points (MSY escapements, 90% MSY escapement goal ranges, and MSY harvest rates), measures fit (-log L, AIC), and p-values for likelihood ratio tests for significance of straight Ricker relative to linear, Ricker with fry plants relative to straight Ricker, autoregressive Ricker relative to straight Ricker , and autoregressive Ricker with fry plants relative to autoregressive Ricker, respectively.

Model	Parameters				MSY Escapement	MSY Escapement Goal Range		MSY Harvest Rate	Fit Criteria		Number of Parameters	p-value
	α	β	ϕ	γ		Lower	Upper		-log L	AIC		
1: Linear	0.39								28.41	30.41	1	
2: Straight Ricker	1.61	240			93,000	60,000	132,000	0.626	21.38	25.38	2	0.0004
3: Ricker with fry plant	1.64	213		-0.079	82,000	53,000	117,000	0.636	20.82	26.82	3	0.291
4: Autoregressive Ricker	0.91	282	0.496		118,000	77,000	166,000	0.402	19.13	25.13	3	0.035
5: Autoregressive Ricker with fry plants	0.87	253	0.483	-0.069	105,000	69,000	147,000	0.387	18.92	26.92	4	0.515

Table 10.–Results of model fits to the escapement-recruit data, for brood years 1987 to 2001. Estimated parameters, and reference points (MSY escapements, 90% MSY escapement goal ranges, and MSY harvest rates), measures fit (-log L, AIC), and p-values for likelihood ratio tests for significance of straight Ricker relative to linear, Ricker with fry plants relative to straight Ricker, autoregressive Ricker relative to straight Ricker , and autoregressive Ricker with fry plants relative to autoregressive Ricker, respectively.

Model	Parameters				MSY Escapement	90% MSY Escapement Goal Range		MSY Harvest Rate	Fit Criteria		Number of Parameters	p-value
	α	β	ϕ	γ		Lower	Upper		-log L	AIC		
1: Linear	0.42								20.4	22.4	1	
2: Straight Ricker	1.70	258			98,000	63,000	139,000	0.68	15.2	19.2	2	0.001
3: Ricker with fry plant	1.74	230		-0.063	87,000	56,000	124,000	0.68	15.0	21.0	3	0.471
4: Autoregressive Ricker	1.07	321	0.535		137,000	90,000	189,000	0.52	13.7	19.7	3	0.083
5: Autoregressive Ricker with fry plants	1.12	277	0.600	-0.070	117,000	77,000	162,000	0.50	13.6	21.6	4	0.647

Table 11.–Predicted additional recruits due to fry plants in BY +1 based on the autoregressive Ricker with fry plants model and depression of wild stock smolts due to fry plants in BY+1 based on the straight Ricker with fry plant model.

Brood Year	**Fry Plants in BY+1 (in thousands)**	**Additional Recruits (in thousands)**	**Additional Smolts (in thousands)**
1994	4,400	78	-354
1995	2,394	40	-334
1996	2,691	45	-366
1997	2,807	45	-284
2001	2,699	39	-378

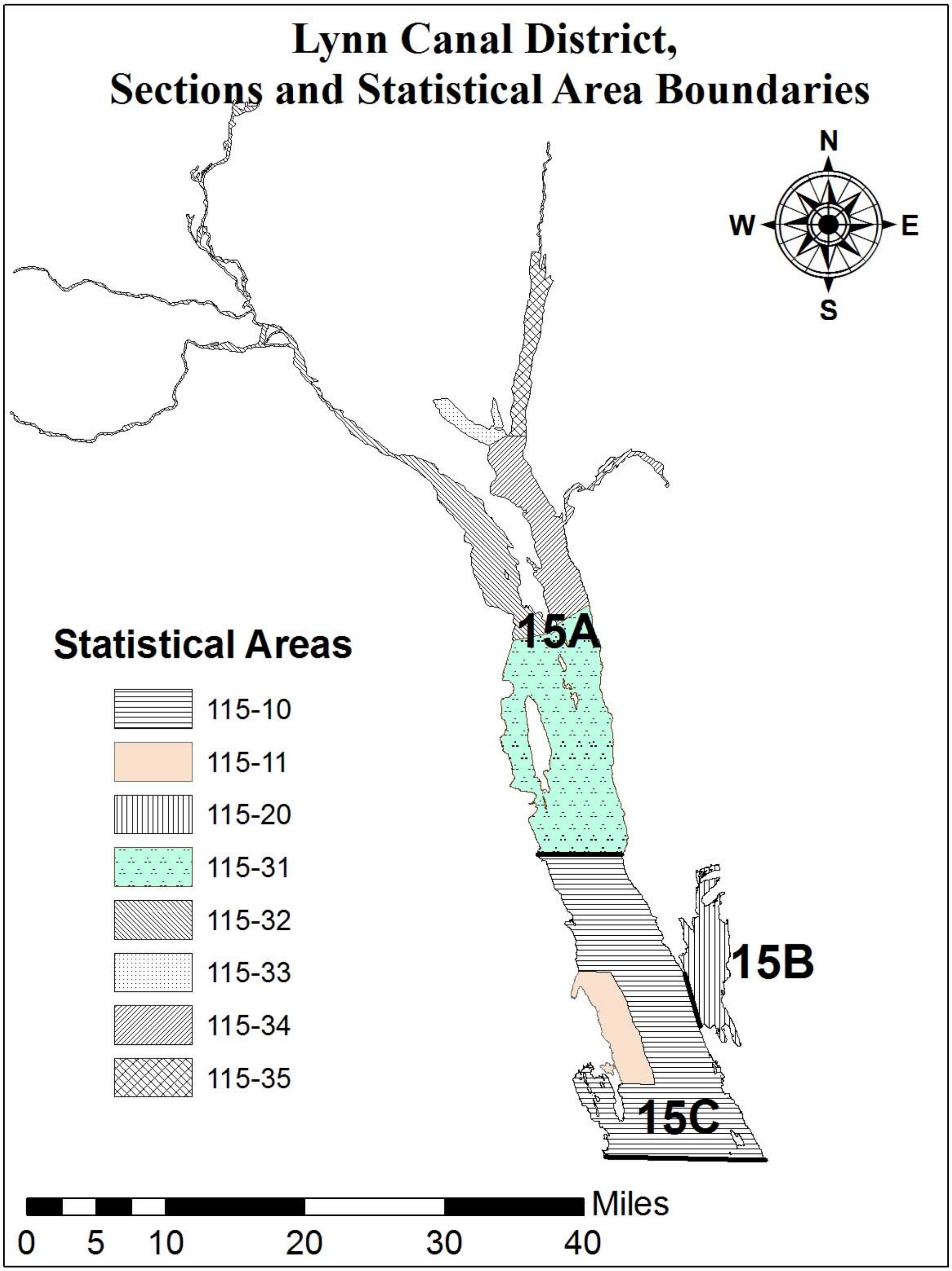


Figure 1.–Map of the Lynn Canal district and statistical area boundaries.

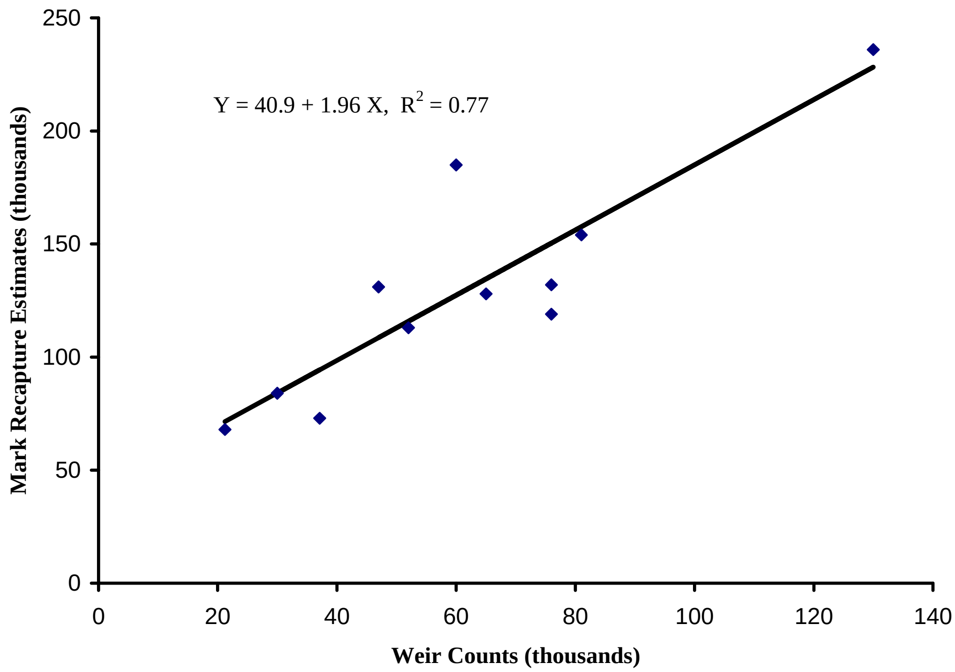


Figure 2.–Relationship between mark-recapture estimates of sockeye salmon escapement and Chilkat River weir counts.

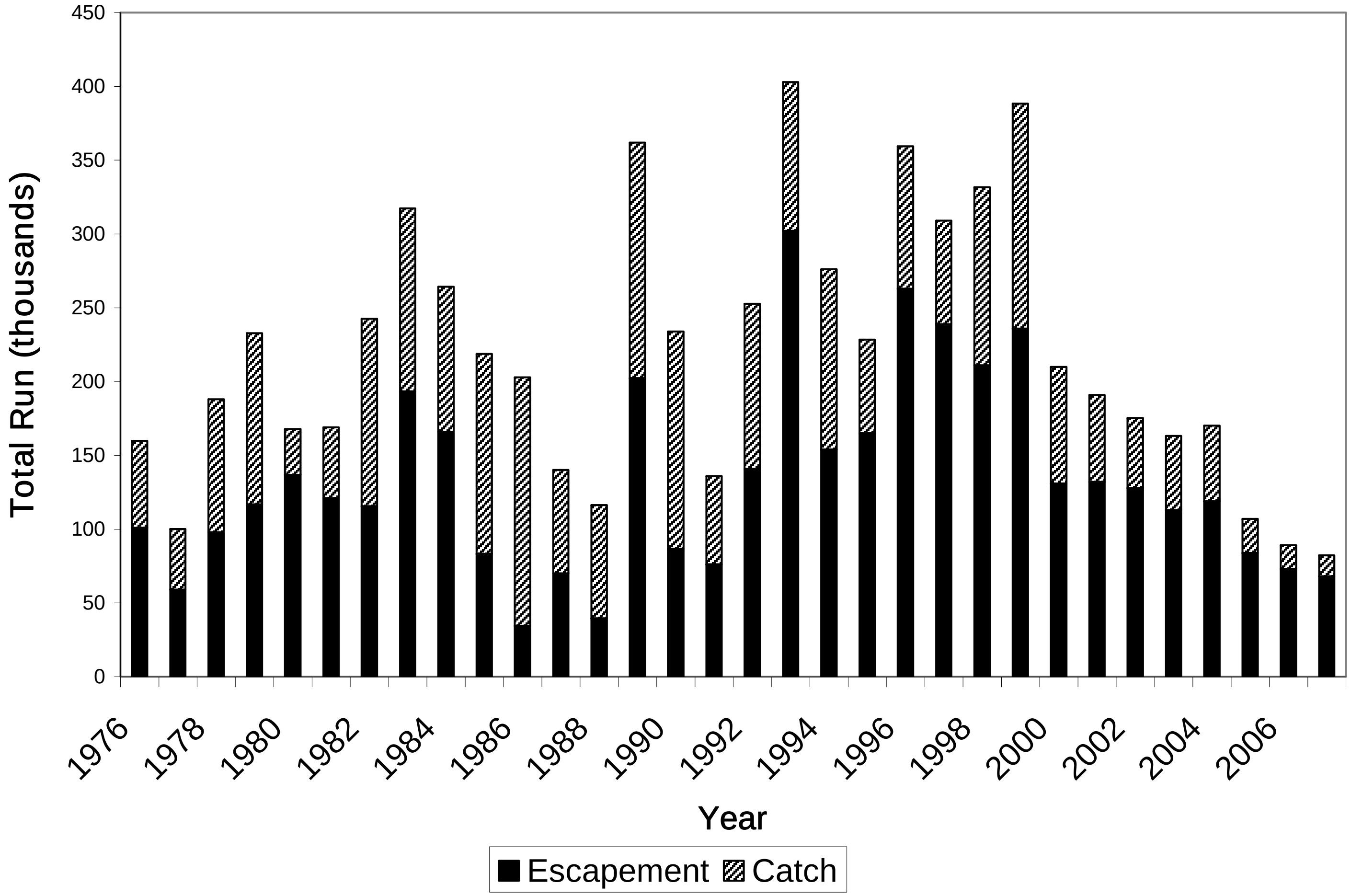


Figure 3.–Chilkat Lake sockeye salmon catch and escapement (total return), 1978 to 2007.

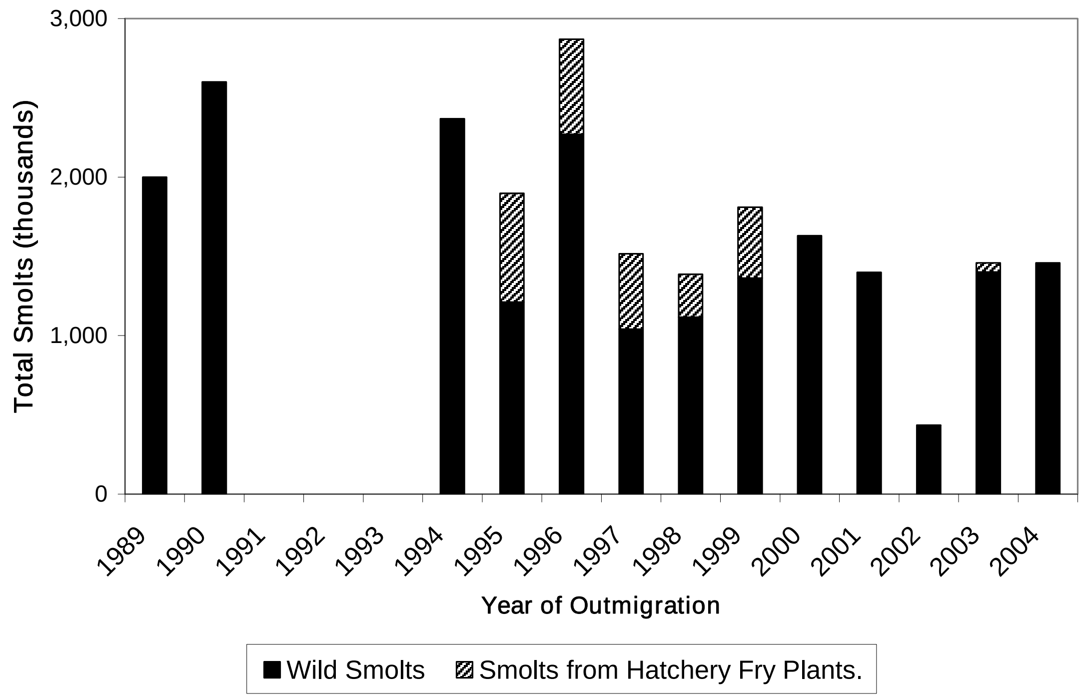


Figure 4.–Estimated number of wild sockeye salmon smolts and sockeye salmon smolts resulting from hatchery fry plants, Chilkat Lake, 1989 to 1990 and 1994 to 2004.

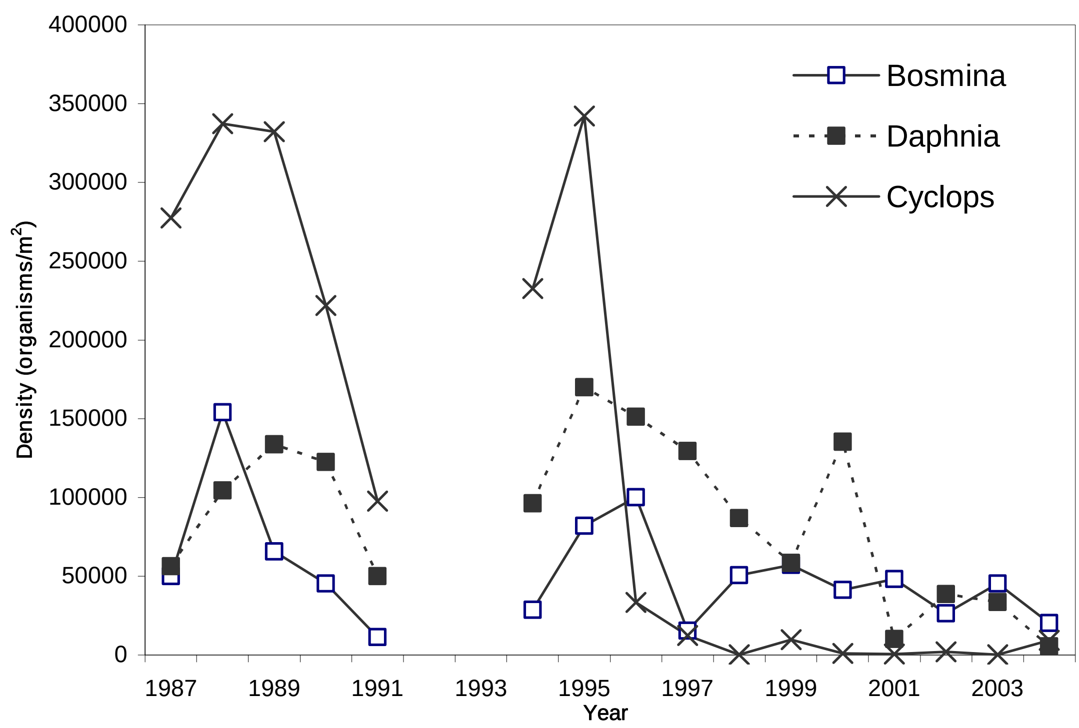


Figure 5.–The densities of cladocerans, *Daphnia* and *Bosmina*, and the copepod Cyclops averaged for July to October of each year, 1987 to 2004. The length of each zooplankton taxa (*Bosmina*, 0.34–0.4 mm; *Cyclops*, 0.7–1.08 mm; *Daphnia*, 0.66–0.94 mm) did not vary much over the time series, consequently, biomass was not graphed.

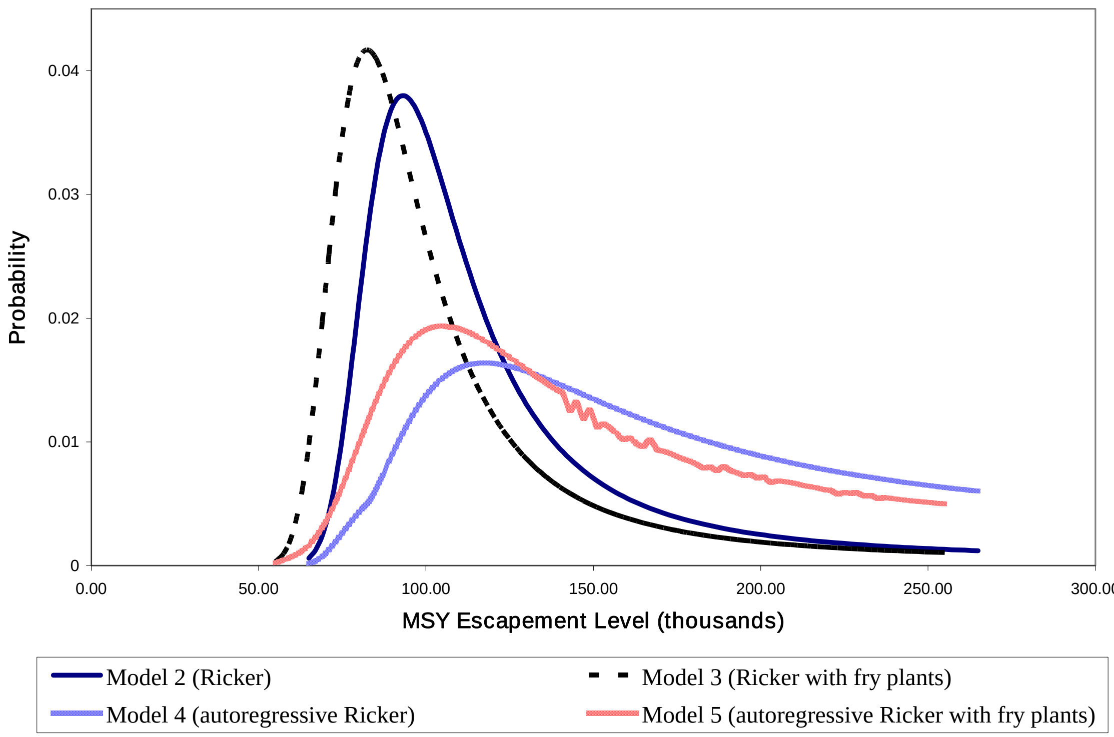


Figure 6.–Likelihood profiles for MSY escapement levels, for alternative models fit to escapement-recruit data for brood years 1979 to 2002.

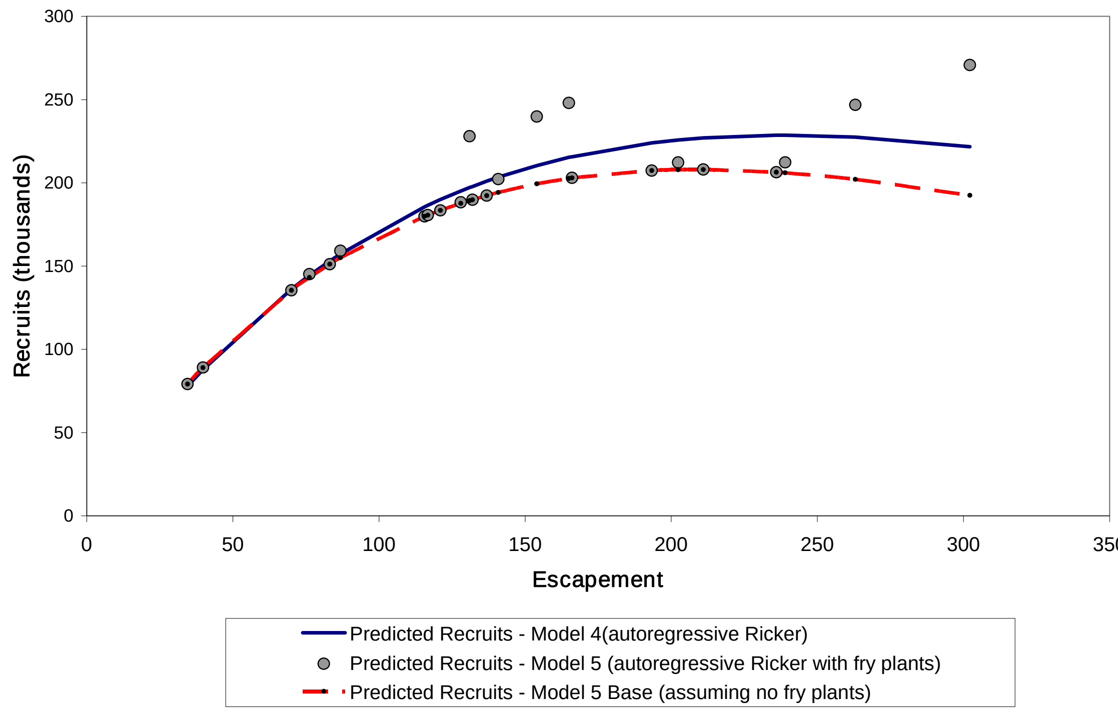


Figure 7.–Comparison of predicted recruits from Model 4 (ignore fry plant effect), predicted recruits from Model 5 (corrected for fry plant effect), and predicted recruits from the Model 5 base (assuming no fry plants).

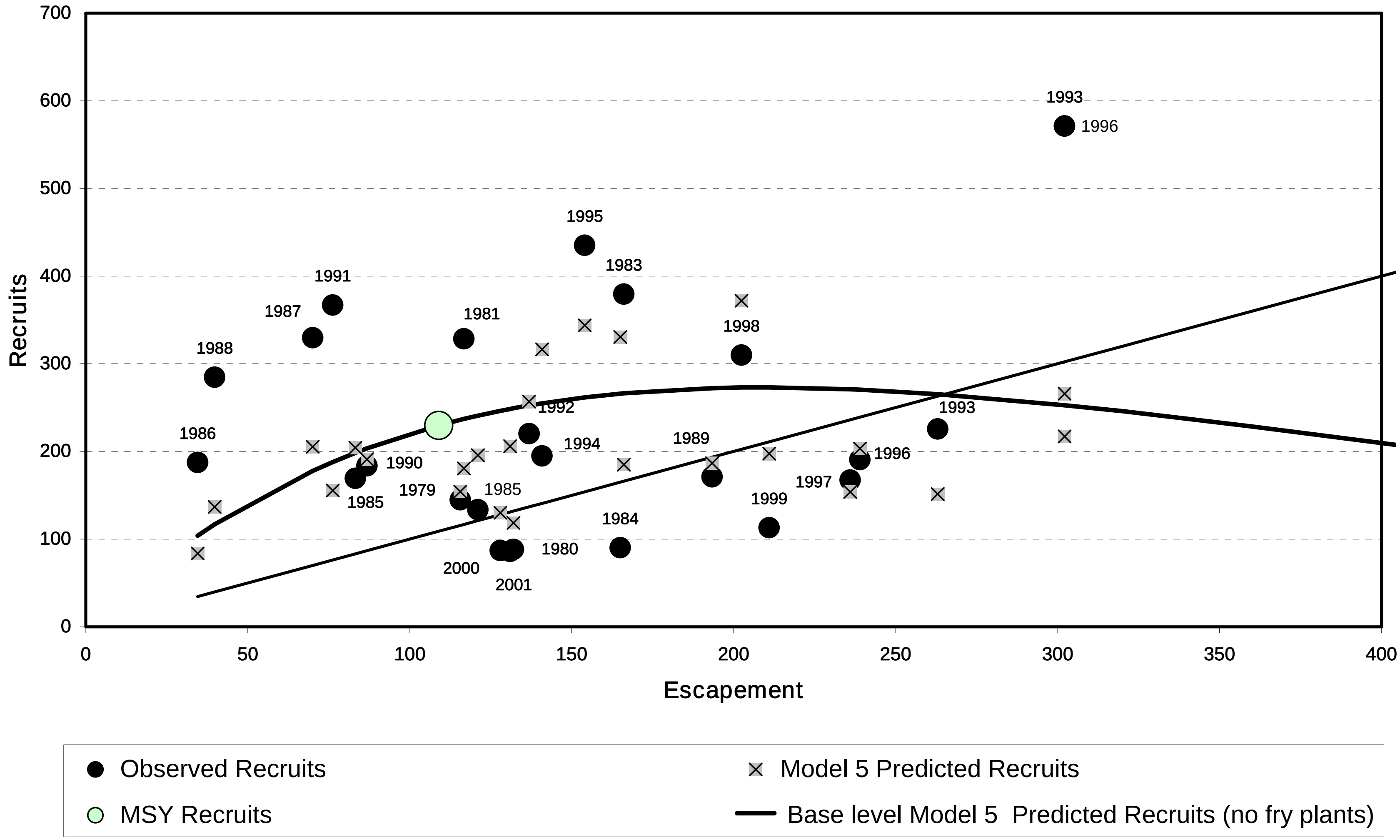


Figure 8.–Stock-recruitment relationship for Chilkat Lake sockeye salmon, 1979 to 2002. Brood years (solid circles) are observed recruits from parental escapements, curved line is the Model 5 base level predicted recruits, x marks are Model 5 predicted recruits, and the straight line is replacement. The large circle is the estimated recruits at MSY escapement.

31

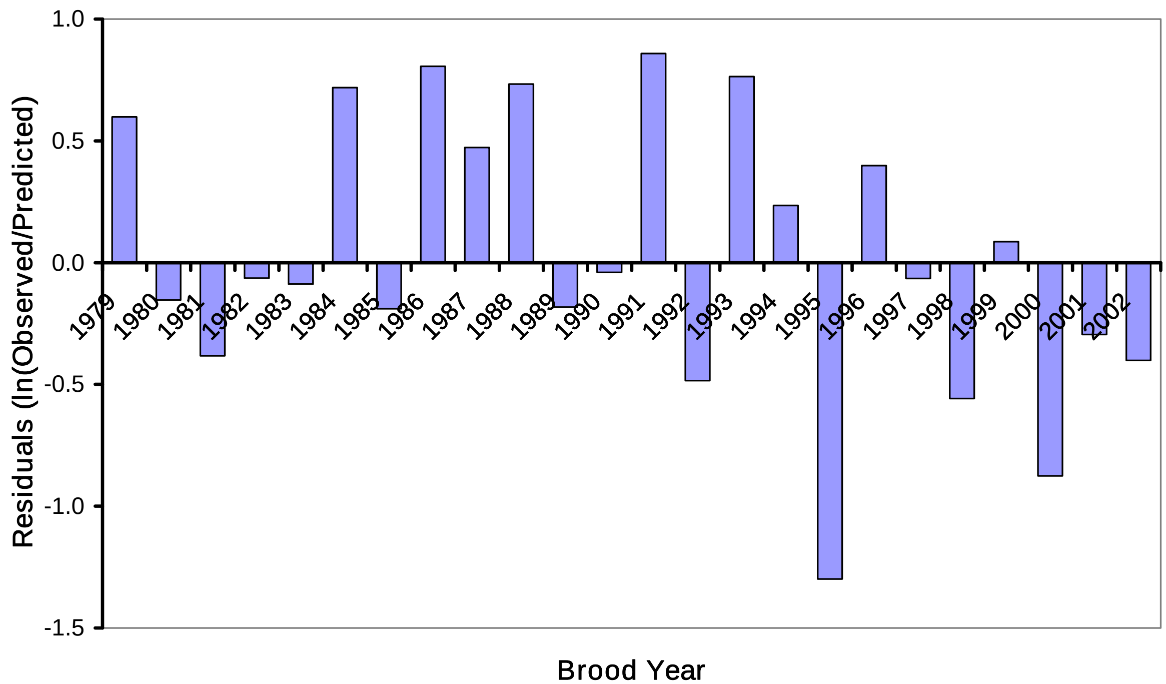


Figure 9.–Residual plots for the Model 5 stock-recruit relationship fit to the 1979 to 2002 brood years for Chilkat Lake sockeye salmon.

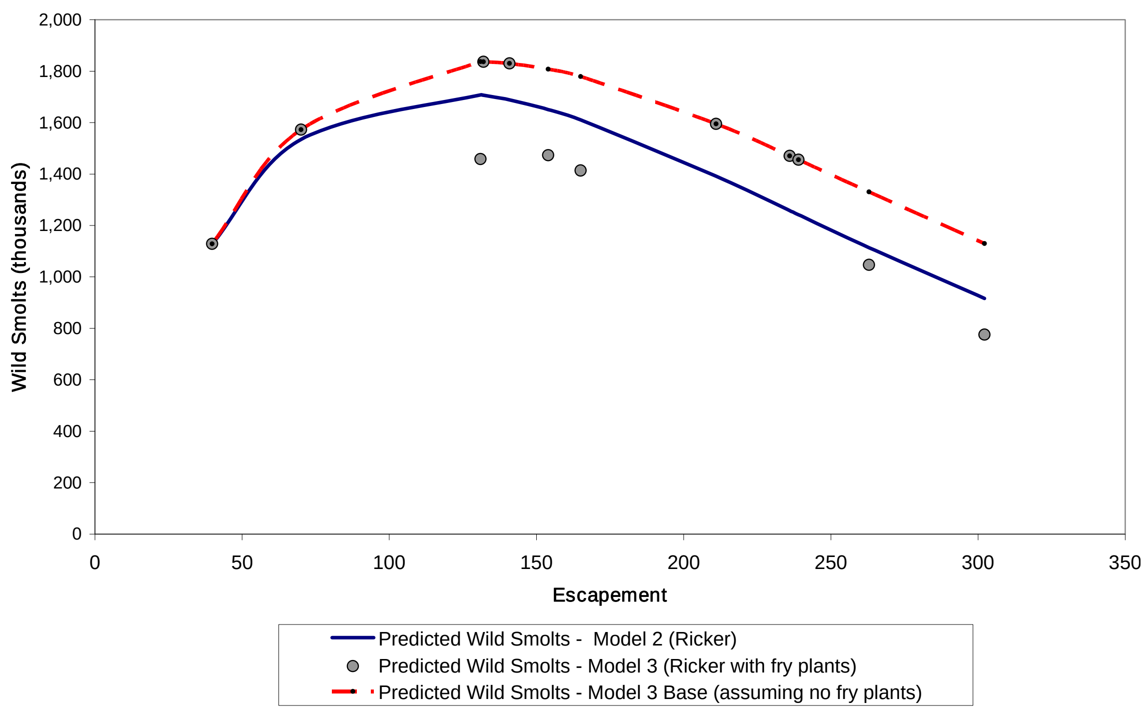
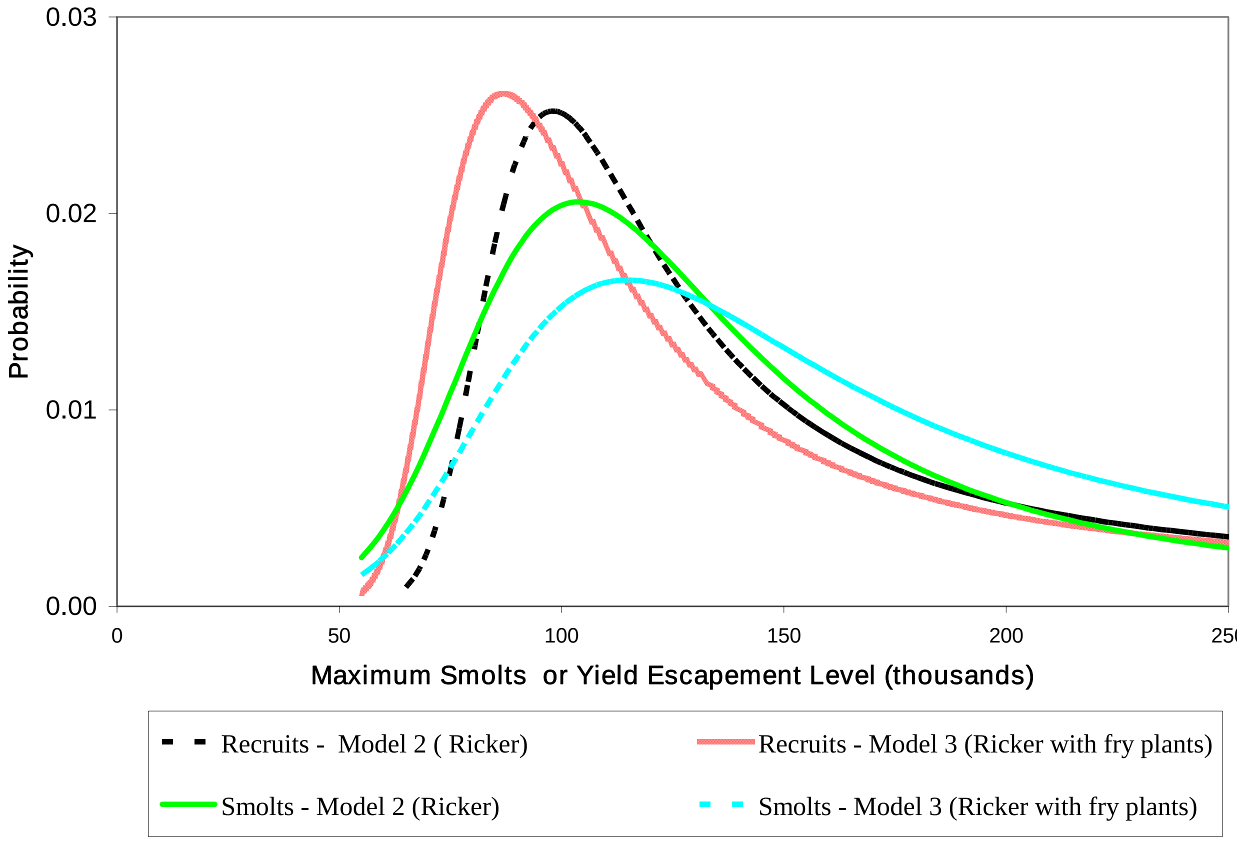


Figure 10.–Comparison of predicted smolts from Model 2 (ignore fry plant effect), predicted smolts from Model 3 (corrected for fry plant effect), and predicted smolts from Model 3 base (assuming no fry plants).



32

Figure 11.–Likelihood profiles for maximum wild smolts produced for alternative models fit to wild smolts-escapement data for brood years 1987, 1988, and 1994 to 2001 brood years, and to recruits-escapement data for brood years 1987 to 2001.

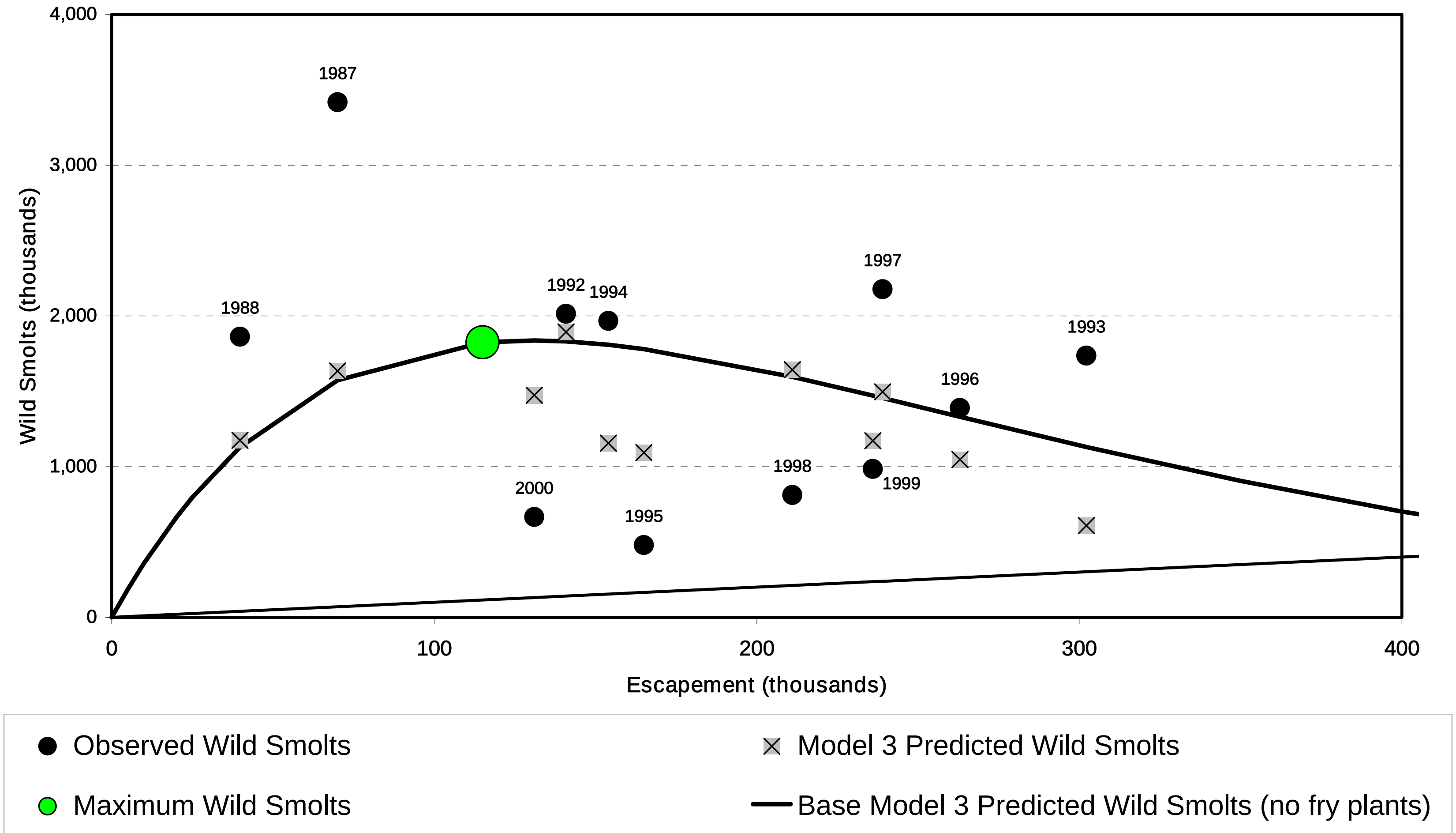


Figure 12.–Smolts from parent escapement relationship for Chilkat Lake sockeye salmon for brood years 1987, 1988, and 1994 to 2000.

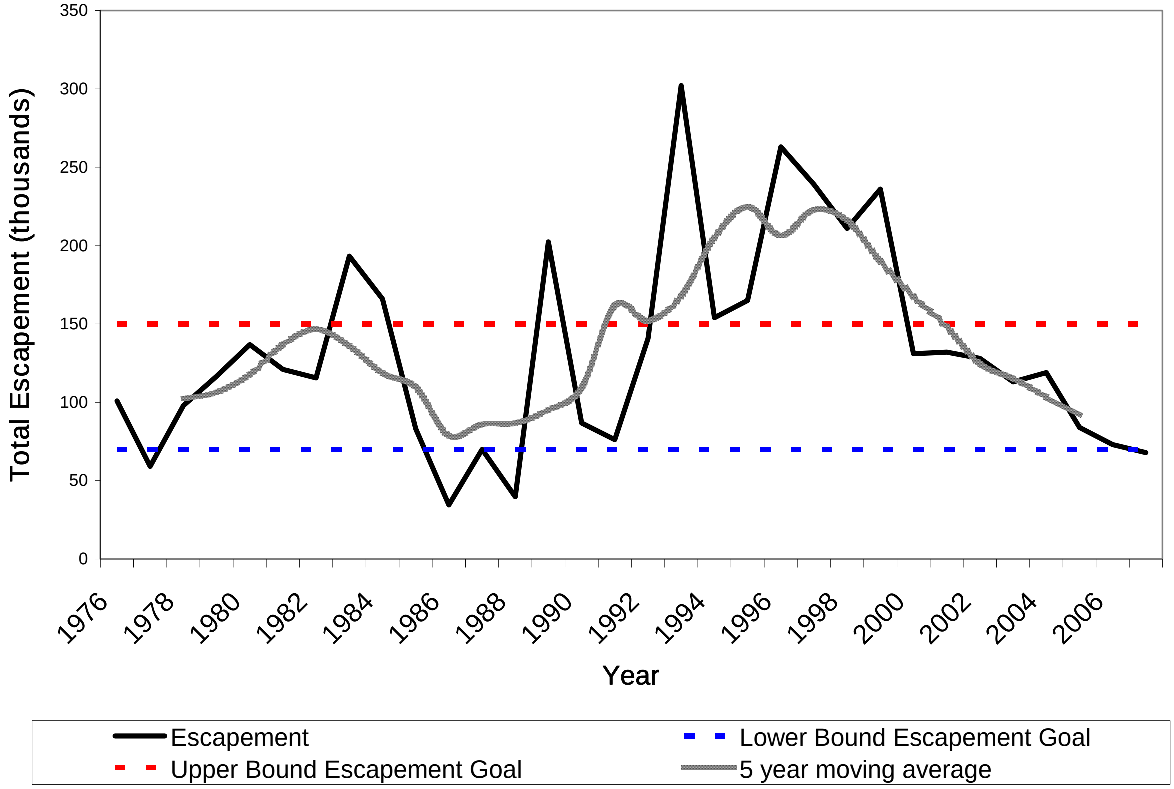


Figure 13.–Chilkat Lake sockeye salmon escapements from 1976 to 2007 plotted along with the escapement trend (5-year moving average) and the recommended biological escapement goal.

APPENDIX A

Appendix A1.–Description of historical catch reconstruction for Chilkat Lake sockeye salmon, 1878 to 2007.

Rich and Ball (1932) reported catches of sockeye salmon in Southeastern Alaska by fishing districts for the period 1878–1927. Simpson (1960) reported catches for the period 1951–1959. Federal documents which reported catches by district for the period 1929–1950 have been lost. Edfelt (1973) reported catches for combined districts in Northern Southeast Alaska. The federal fishing districts were not completely consistent between the 2 reports; however, it is possible to construct consistent catches by the districts used in Rich and Ball (1932). The fishing districts reported in Rich and Ball (1932) conform to current ADF&G District/SubDistrict designations as follows: Lynn Canal District included ADF&G District 115 and northern areas of District 112 (Subdistricts 15, 61, and 63); Icy Strait District included ADF&G Districts 116 and 114; Stephens Passage District included ADF&G District 111 and portions of District 110 (Subdistricts 21, 31, 24, 33, 34, and 22); Upper Chatham District included ADF&G District 112 except the subdistricts above included in the Lynn Canal District; the remainder of the northern southeast Alaska federal districts (i.e., lower Chatham Strait District and Fredrick Sound District) included ADF&G District 113 subdistricts in Hoonah Sound (Subdistricts 51–59), ADF&G District 109, and ADF&G District 110 except subdistricts above included in the Stephens Passage District. Sockeye salmon catches for these federal districts from 1878 to 2007 are provided in Appendices A.2 to A.4.

Most of the sockeye catches in northern southeast Alaska during the outset of the fishery, until the trap fishery was established in the first decade of the twentieth century, occurred in the Lynn Canal District (Appendix A5). The fish traps were fully established in the entry corridors of southeast Alaska by 1915. After the establishment of fish traps, most of the Northern Southeast Alaska sockeye salmon catches occurred in the Icy Strait and Northern Chatham Strait Districts and this pattern persisted until the early 1970s. At that time, the Icy Strait and Northern Chatham areas were closed to seine fishing by the Board of Fisheries; since then, most of the sockeye catch in Northern Southeast Alaska has occurred in the Lynn Canal and the Stephens Passage areas (Appendix A4). Note that the catch in the Stephens Passage areas were much lower than in the Lynn Canal areas until the late 1980s and, since then, the annual catches in the Stephens Passage areas have been much larger than in the Lynn Canal areas. This suggests that Lynn Canal sockeye stocks (Chilkat and Chilkoot river sockeye salmon) were more abundant than the Stephens Passage sockeye stocks (i.e., Taku River and Snettisham River) until the late 1980s.

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Given a few assumptions based on the current stock assessments and stock identification programs that have been implemented by ADF&G since the late 1970s, it is possible to roughly reconstruct the historical catches of the northern Southeast Alaska stock groups (Lynn Canal, Stephens Passage and other Northern Southeast Alaska stocks). These assumptions are as follows:

1. The Lynn Canal District catch is entirely composed of Lynn Canal stocks.
2. The Stephen Passage District catches are entirely Stephens Passage stocks.
3. The migratory area catches (Icy Strait District and Northern Chatham Strait District) are composed of 10% minor small system sockeye stocks (i.e., lake systems of Eastern Chichagof and western Admiralty Island).
4. The remainder of the migratory area catches are mixtures of Lynn Canal and Stephens Passage stocks, with stock composition equal to the relative magnitude of the Lynn Canal District and Stephens Passage District catch in the respective year.
5. The composition of the Lynn Canal catch is 47% Chilkat Lake, 42% Chilkoot River, and 12% other Lynn Canal stocks. Note this assumption is based upon the average stock composition of the Lynn Canals sockeye catches, 1984 to 2007.

Based upon these assumptions, the Rich and Ball (1932) district catches (Appendices A.2 to A.4) for the period 1878 until 2007 were apportioned into Chilkat Lake, Chilkoot River, Stephens Passage, and other northern Southeast sockeye stocks (Appendix A6). The Chilkat sockeye catches during the period 1890–1927 ranged from about 150,000 to 780,000 fish, and averaged about 360,000 fish. These catches were substantially larger than recent catches of Chilkat River sockeye which ranged from about 10,000 to 170,000 fish and averaged about 90,000 fish during the period 1960 to 2007.

Appendix A2.–Historical catches of sockeye salmon by federal fishing districts, 1878 to 1921.

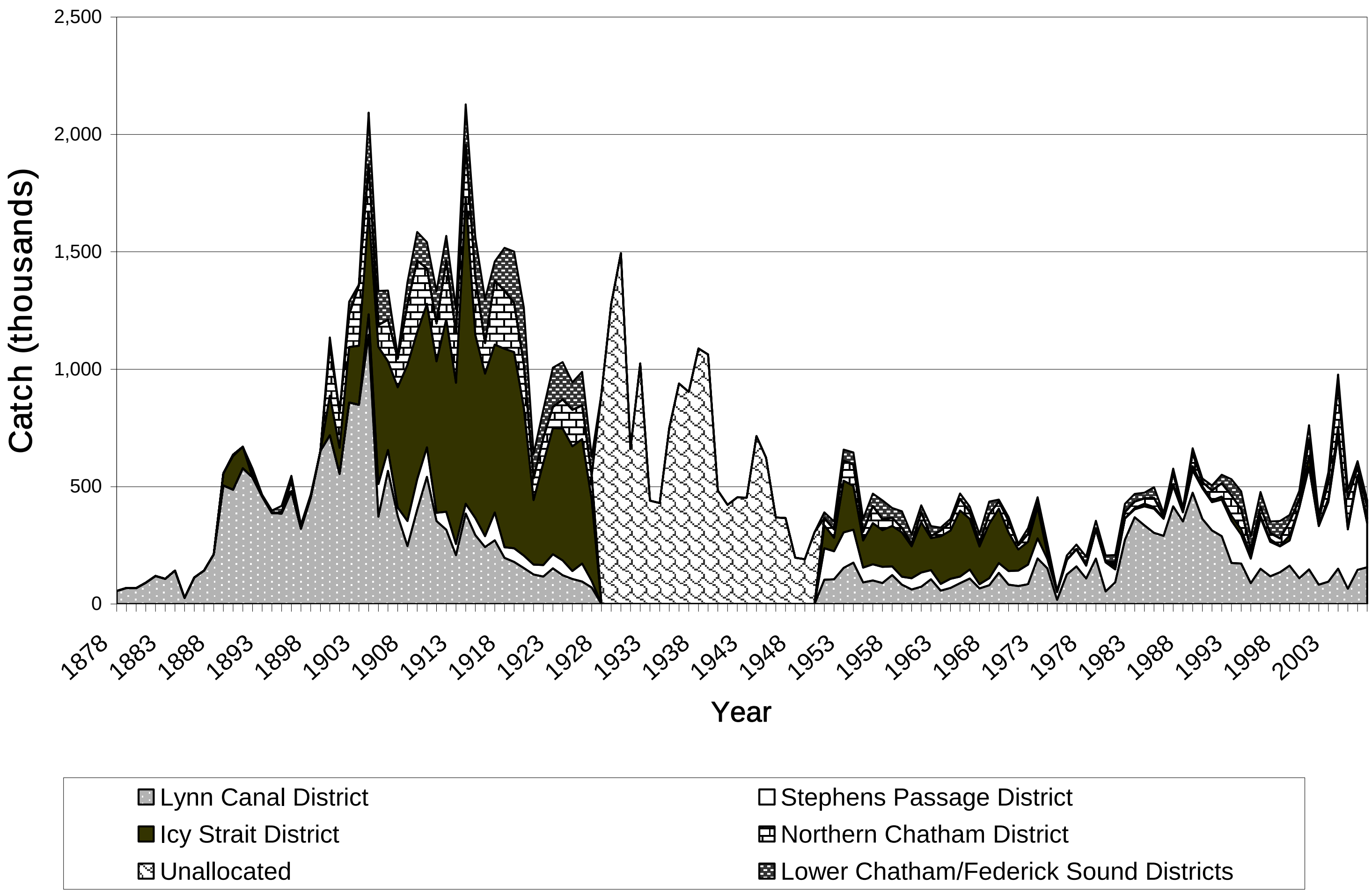
Year	Lynn Canal District	Icy Strait District	Northern Chatham District	Stephens Passage District	Lower Chatham/Federick Sound Districts	Northern Southeast
1878	56,000	0	0	0	0	56,000
1879	69,000	0	0	0	0	69,000
1880	68,000	0	0	0	0	68,000
1881	91,000	0	0	0	0	91,000
1882	119,000	0	0	0	0	119,000
1883	107,800	0	0	0	0	107,800
1884	143,000	0	0	0	0	143,000
1885	26,400	0	0	0	0	26,400
1886	113,300	0	0	0	0	113,300
1887	143,000	0	0	0	0	143,000
1888	212,300	0	0	0	0	212,300
1889	504,900	51,600	0	0	0	556,500
1890	487,300	144,000	4,902	0	0	636,202
1891	578,413	91,200	0	0	0	669,613
1892	538,604	0	21,875	0	16,521	577,000
1893	457,177	0	0	0	8,789	465,966
1894	387,903	0	0	0	10,268	398,171
1895	385,500	0	5,285	0	27,268	418,052
1896	480,536	0	43,064	0	22,729	546,329
1897	321,517	0	566	0	15,917	338,000
1898	453,196	0	0	0	13,209	466,405
1899	651,692	0	0	0	0	651,692
1900	719,012	168,432	215,334	0	32,662	1,135,440
1901	554,807	110,770	150,362	0	0	815,939
1902	857,748	237,112	139,255	0	54,279	1,288,395
1903	848,736	251,718	257,056	0	3,578	1,361,088
1904	1,147,088	436,638	201,217	86,540	221,493	2,092,976
1905	371,492	584,275	93,200	140,226	144,807	1,334,000
1906	567,678	376,897	177,879	88,303	124,337	1,335,094
1907	374,645	512,254	121,643	36,812	12,812	1,058,167
1908	247,384	664,182	257,799	106,982	93,929	1,370,275
1909	401,283	626,511	304,351	130,389	122,466	1,585,000
1910	542,222	610,109	150,968	125,847	112,630	1,541,776
1911	353,500	644,883	161,246	35,388	136,897	1,331,913
1912	317,031	819,050	248,233	76,526	106,860	1,567,700
1913	208,120	687,441	209,294	47,410	103,878	1,256,143
1914	385,589	1,305,220	223,797	41,263	172,690	2,128,559
1915	294,229	780,177	245,575	72,325	169,943	1,562,248
1916	243,434	692,467	130,106	45,840	186,348	1,298,195
1917	271,336	715,513	271,755	118,195	82,796	1,459,596
1918	196,890	845,561	247,259	44,801	182,409	1,516,921
1919	179,988	835,109	208,658	58,052	219,540	1,501,346
1920	152,863	629,575	184,932	53,415	241,563	1,262,348
1921	125,626	274,829	92,650	42,559	102,912	638,577

Appendix A3.–Historical catches of sockeye salmon by federal fishing districts, 1922 to 1964. Note: Northern Southeast Alaska salmon catches were not reported by district for years 1928 to 1950.

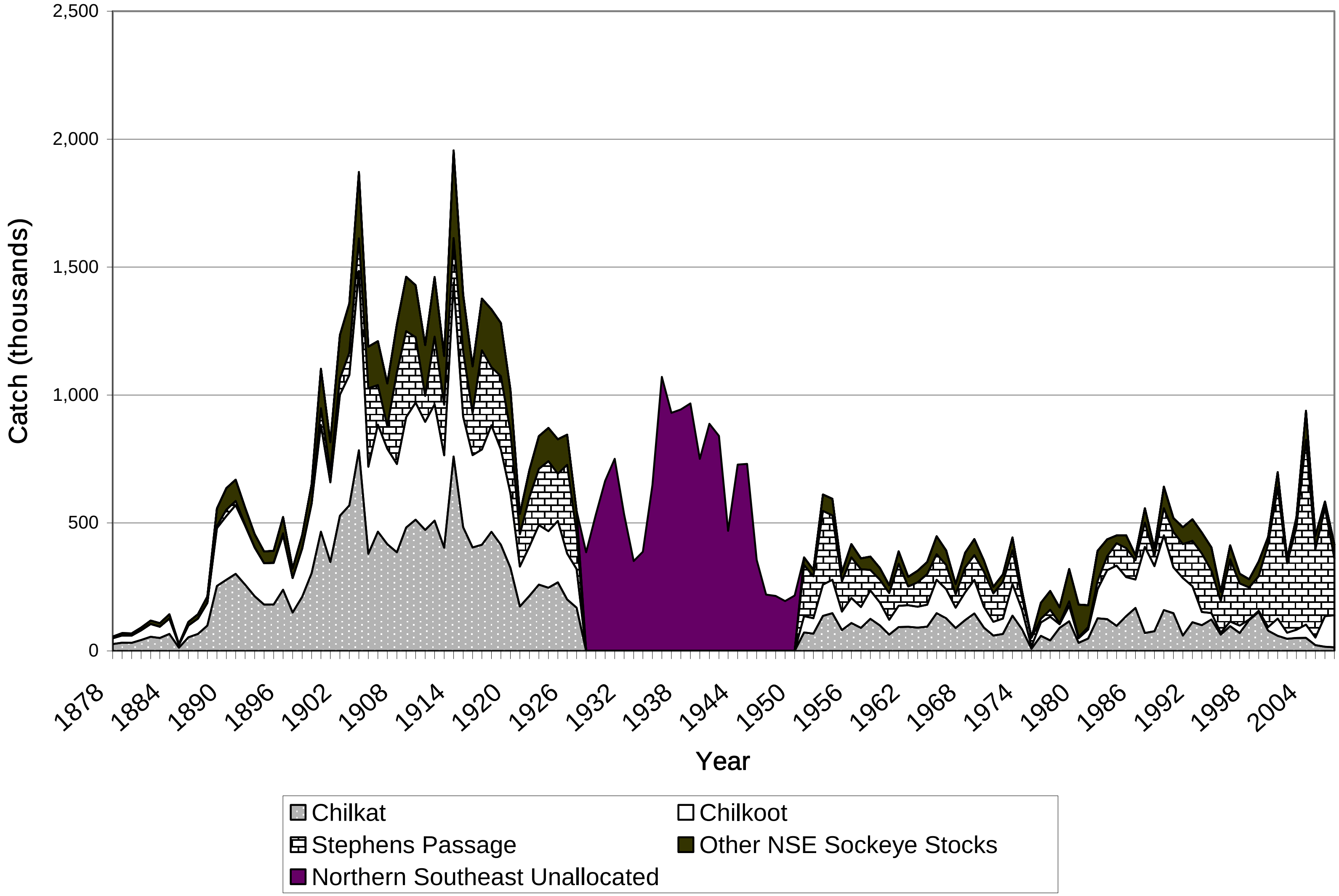
Year	Lynn Canal District	Icy Strait District	Northern Chatham District	Stephens Passage District	Lower Chatham/Federick Sound Districts	Northern Southeast
1922	117,424	435,284	106,331	48,660	119,466	827,165
1923	152,102	537,280	89,508	60,038	168,201	1,007,128
1924	123,036	561,442	123,492	63,366	158,536	1,029,873
1925	106,699	531,279	155,214	34,196	117,584	944,973
1926	95,674	529,759	142,468	77,030	144,487	989,418
1927	70,751	346,693	102,680	27,339	79,449	626,913
1928	n/a	n/a	n/a	n/a	n/a	896,000
1929	n/a	n/a	n/a	n/a	n/a	1,277,000
1930	n/a	n/a	n/a	n/a	n/a	1,494,000
1931	n/a	n/a	n/a	n/a	n/a	660,000
1932	n/a	n/a	n/a	n/a	n/a	1,025,000
1933	n/a	n/a	n/a	n/a	n/a	441,000
1934	n/a	n/a	n/a	n/a	n/a	430,000
1935	n/a	n/a	n/a	n/a	n/a	750,000
1936	n/a	n/a	n/a	n/a	n/a	939,000
1937	n/a	n/a	n/a	n/a	n/a	903,000
1938	n/a	n/a	n/a	n/a	n/a	1,088,000
1939	n/a	n/a	n/a	n/a	n/a	1,063,000
1940	n/a	n/a	n/a	n/a	n/a	484,000
1941	n/a	n/a	n/a	n/a	n/a	423,000
1942	n/a	n/a	n/a	n/a	n/a	454,000
1943	n/a	n/a	n/a	n/a	n/a	453,000
1944	n/a	n/a	n/a	n/a	n/a	715,000
1945	n/a	n/a	n/a	n/a	n/a	623,000
1946	n/a	n/a	n/a	n/a	n/a	369,000
1947	n/a	n/a	n/a	n/a	n/a	367,000
1948	n/a	n/a	n/a	n/a	n/a	198,000
1949	n/a	n/a	n/a	n/a	n/a	191,000
1950	n/a	n/a	n/a	n/a	n/a	306,000
1951	103,979	96,341	31,138	134,108	24,907	390,473
1952	105,688	57,435	35,433	119,010	34,389	351,955
1953	154,264	219,905	86,451	150,636	47,460	658,716
1954	176,185	186,439	91,242	140,373	51,793	646,032
1955	92,447	115,948	36,462	62,392	55,709	362,957
1956	100,557	175,560	73,581	68,104	51,970	469,772
1957	90,191	155,824	47,120	68,591	79,767	441,493
1958	123,408	172,996	34,893	36,701	41,271	409,269
1959	82,232	189,005	18,245	34,489	70,937	394,907
1960	62,325	136,895	9,855	47,406	39,282	295,763
1961	74,055	213,802	40,974	60,554	31,391	420,776
1962	106,116	136,726	8,855	38,321	41,659	331,677
1963	57,528	202,499	25,178	27,967	11,752	324,924
1964	68,201	204,793	34,254	40,011	15,487	362,746

Appendix A4.–Historical catches of sockeye salmon by federal fishing districts, 1965 to 2007.

Year	Lynn Canal District	Icy Strait District	Northern Chatham District	Stephens Passage District	Lower Chatham/Federick Sound Districts	Northern Southeast
1965	89,197	281,058	49,351	28,219	23,344	471,169
1966	108,871	217,152	28,204	37,532	23,893	415,652
1967	66,732	160,053	15,929	18,155	37,158	298,027
1968	80,005	230,899	42,183	30,073	53,080	436,240
1969	133,486	231,952	29,563	41,296	8,929	445,226
1970	82,937	163,300	49,601	57,621	17,389	370,848
1971	76,844	89,021	18,391	66,315	6,128	256,699
1972	84,070	97,160	33,766	83,987	24,835	323,818
1973	194,044	131,207	31,911	86,489	11,305	454,956
1974	152,195	21,012	23,647	40,036	21,961	258,851
1975	18,491	2,506	1	32,563	3,038	56,599
1976	125,422	290	20	62,261	19,203	207,196
1977	160,442	2,270	57	72,044	19,250	254,063
1978	108,514	930	5,309	55,554	31,891	202,198
1979	193,241	1,197	1,929	124,048	34,870	355,285
1980	54,101	2,514	1,397	123,451	25,332	206,795
1981	93,247	13,227	17,389	54,757	30,351	208,971
1982	273,837	766	26,567	90,460	35,132	426,762
1983	370,350	5,431	27,056	33,220	33,284	469,341
1984	334,914	10,676	23,632	81,338	24,192	474,752
1985	303,451	7,305	38,584	102,821	45,085	497,246
1986	290,296	2,161	8,464	73,093	13,473	387,487
1987	416,142	8,194	46,330	86,561	19,969	577,196
1988	351,877	5,526	4,085	38,968	9,631	410,087
1989	474,902	17,907	54,385	94,834	22,006	664,034
1990	362,137	8,346	18,419	130,932	14,543	534,377
1991	313,681	7,890	41,588	120,522	21,625	505,306
1992	289,371	12,631	57,099	155,297	36,600	550,998
1993	175,224	21,240	86,161	179,853	68,898	531,376
1994	171,796	21,433	86,277	124,514	75,673	479,693
1995	88,676	16,420	21,346	104,715	55,805	286,962
1996	149,578	6,964	39,162	217,796	63,607	477,107
1997	118,830	10,612	26,630	146,201	49,457	351,730
1998	134,937	2,239	32,021	111,004	74,062	354,263
1999	163,560	20,620	57,828	107,365	29,765	379,138
2000	109,560	2,701	32,068	301,373	36,154	481,856
2001	147,811	48,706	66,748	435,303	63,566	762,134
2002	82,014	5,028	26,005	249,722	17,755	380,524
2003	95,133	14,235	70,933	340,588	40,007	560,896
2004	151,247	36,348	183,839	566,345	40,018	977,797
2005	65,479	14,602	117,702	252,103	36,031	485,917
2006	145,591	10,216	33,948	394,018	24,391	608,164
2007	156,800	18,382	53,228	187,188	27,011	442,609



Appendix A5.–Northern Southeast Alaska sockeye salmon catch, by fishing district designations, 1878 to 2007.



Appendix A6.–Northern Southeast Alaska sockeye salmon catches, by stock (Chilkat, Chilkoot, Stephens Passage, and other northern Southeast Alaska stocks) from 1878 to 2007.

APPENDIX B

Appendix B1.–Re-estimation of Barto (2005) reconstruction of Chilkat Lake sockeye salmon escapement 1700 to 2007.

Barto (2005) reconstructed the escapement into Chilkat Lake from 1700 to 2000 by examining δN^{15} levels in the lake sediment cores. Barto scaled his reconstructed δN^{15} time series to total escapement by comparing the lag-1 yr (from the estimated date of the δN^{15} sample) 5-year moving average of Chilkat weir counts to δN^{15} levels for 6 discrete time periods between 1976 and 1995. Barto estimated that the trend in Chilkat Lake escapement fluctuated between 50,000 and 150,000 fish during the period 1700–2000.

Since the weir counts are substantially lower than the actual total escapement, we re-estimated Barto's (2005) reconstruction of Chilkat Lake sockeye salmon escapement. This was done by fitting the δN^{15} levels for the 6 discrete time periods (in the period 1976–1995) to estimated total escapement based on the weir count-to-mark-recapture calibrated total escapement time series relationship discussed earlier in this report. We used the same model (linear regression of the lag-1, 5-year moving average escapement and δN^{15} levels for 6 recent discrete time periods) (Appendices B.2 and B.3). The linear regression calibration of the δN^{15} levels predicts negative escapement for δN^{15} below 4.72. Because there is a positive base level δN^{15} in the sediments of lakes without anadromous salmon runs, the liner regression calibration is unreliable for small δN^{15} levels that lie outside the range of values in the calibration. To correct for this, an empirical cumulative probability distribution function (CPDF, c.f. Quinn and Deriso 1999) with a double asymptote (low side *p*) and high side ($^{15}N_{max}$) was used to calibrate the δN^{15} levels. The model is:

$$N = \frac{p + r(^{15}N_{\max})S}{1 + rS}$$

Where N=δN^{15} level, S=appropriate average escapement, p, r, $^{15}N_{\max}$ are estimated parameters. Note that the model is fit to the δN^{15} levels rather than to the escapement since there is no algebraic inverse to the CPDF model an iterative procedure was used to hind cast historical escapements from observed δN^{15}. Base levels (i.e., those for zero escapements) were taken from Sweetheart Lake sediment cores. Sweetheart Lake has no anadromous salmon present. The CPDF model was fit to the 5 recent data points using maximum likelihood assuming normal probabilities. Several possible lags and moving average periods were examined, and the lag-1, 7-year moving average provided the best fit (i.e., minimum -Log L).

The range of δN^{15} levels (4.9–5.9) for which escapement data were available for calibration was relatively narrow compared to the range of δN^{15} levels found in the sediment core (3.25–6.94). There would be considerable uncertainty in escapement projections based upon the narrow range of calibration data from the entire core's δN^{15} data.

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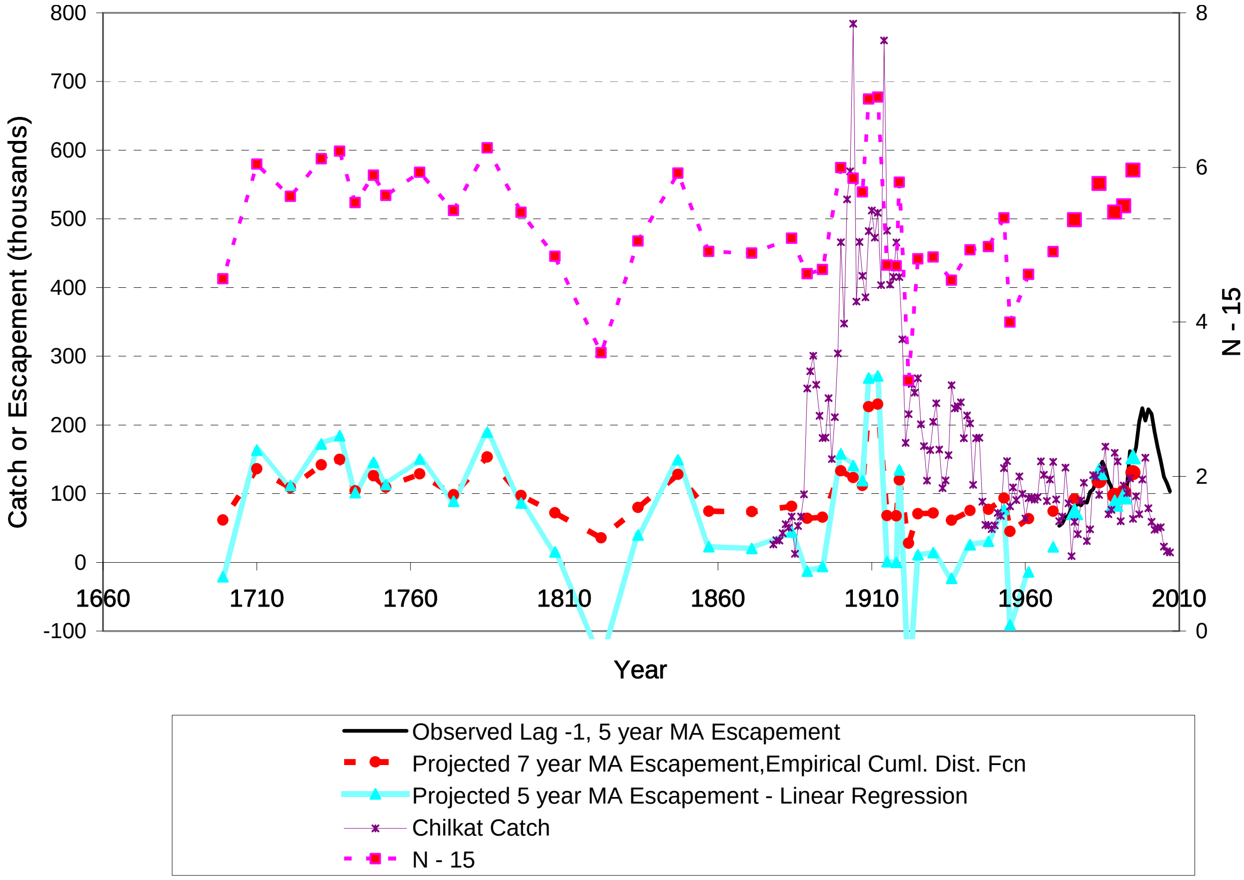
The estimates of escapements for lower values based on the linear regression calibration are almost certainly biased low; whereas the estimates of escapements for higher values of δN^{15} based on the CPDF are probably biased low. The actual values are probably above the trend based on the CPDF calibrations. Note there is considerable uncertainty in assigning exact escapements to historical δN^{15} that exceed those observed during the calibration period (i.e., 1976–1995). The trend (i.e., as 5- to 7-year moving average) of escapement fluctuated between 50,000 and 230,000 during the period 1700–2000 (Appendices B.2 to B.4). Escapement levels during the 18th century were similar to those during the calibration period. Escapements during most of the 19th century and from the mid 1920s to early 1970s were lower than the calibration period. However escapements from the onset of commercial fishing in the late 1870s to the early 1920s were higher, and potentially substantially higher, than escapement during the calibration period. Note that the period of high escapement from about 1900 to 1920 corresponded to period of very high commercial catches of Chilkat River drainage sockeye salmon (Appendix A).

Appendix B2.–Historical reconstruction of Chilkat Lake sockeye salmon escapement between 2007 and 1967, based on linear regression and empirical cumulative distribution function δN^{15} calibration models with data from Barto (2005).

Year	Observed Escapement (thousands)	Escapement Estimates (thousands)		Catch (thousands)	dN^{15}	Predicted Escapement Empirical Cumulative Distribution Function	Linear Regression
		Lag-1, 5 Year MA	Lag-1, 7 Year MA				
2007	68	103	111	14	n/a	n/a	n/a
2006	73	115	135	16	n/a	n/a	n/a
2005	84	125	153	23	n/a	n/a	n/a
2004	119	148	170	51	n/a	n/a	n/a
2003	113	168	191	50	n/a	n/a	n/a
2002	128	190	197	47	n/a	n/a	n/a
2001	132	216	200	59	n/a	n/a	n/a
2000	131	223	224	79	n/a	n/a	n/a
1999	236	206	211	152	n/a	n/a	n/a
1998	211	225	191	121	n/a	n/a	n/a
1997	239	205	170	70	n/a	n/a	n/a
1996	263	168	161	96	n/a	n/a	n/a
1995	165	152	143	63	5.96	130	154
1994	154	162	131	122			
1993	302	109	93	101			
1992	141	95	85	112	5.5	102	97
1991	76	87	98	60			
1990	87	86	113	147			
1989	202	79	100	159	5.42	97	86
1988	40	109	112	76			
1987	70	119	122	70			
1986	35	136	133	168			
1985	83	147	135	136			
1984	166	137	120	98	5.79	119	132
1983	193	118	107	124			
1982	116	106	99	127			
1981	121	102	99	48			
1980	137	87	90	31			
1979	117	88	84	116			
1978	98	83	80	90			
1977	59	86	80	41			
1976	101	80	75	59	5.32	92	74
1975	60	80	75	n/a			
1974	122	68	62	n/a			
1973	73	66	n/a	n/a			
1972	75	57	n/a	n/a			
1971	71	53	n/a	n/a			
1970	59	n/a	n/a	n/a			
1969	64	n/a	n/a	n/a	4.91	74	22
1968	59	n/a	n/a	n/a			
1967	29	n/a	n/a	n/a			

Appendix B3.–Historical reconstruction of Chilkat Lake sockeye salmon escapement between 1961 and 1699, based on linear regression and empirical cumulative distribution function δ N^{15} calibration models with data from Barto (2005).

		Escapement Estimates (thousands)				Predicted Escapement	
Year	**Observed Escapement (thousands)**	**Lag-1, 5 Year MA**	**Lag-1, 7 Year MA**	**Catch (thousands)**	**dN^{15}**	**Empirical Cumulative Distribution Function**	**Linear Regression**
1961	n/a	n/a	n/a	n/a	4.61	64	-14
1955	n/a	n/a	n/a	n/a	4	45	-91
1953	n/a	n/a	n/a	n/a	5.35	94	77
1948	n/a	n/a	n/a	n/a	4.97	77	31
1942	n/a	n/a	n/a	n/a	4.93	75	26
1936	n/a	n/a	n/a	n/a	4.54	61	-23
1930	n/a	n/a	n/a	n/a	4.84	72	14
1925	n/a	n/a	n/a	n/a	4.81	71	11
1922	n/a	n/a	n/a	n/a	3.24	28	-185
1919	n/a	n/a	n/a	n/a	5.81	120	135
1918	n/a	n/a	n/a	n/a	4.73	67	0
1915	n/a	n/a	n/a	n/a	4.73	68	1
1912	n/a	n/a	n/a	n/a	6.91	230	271
1909	n/a	n/a	n/a	n/a	6.89	227	268
1907	n/a	n/a	n/a	n/a	5.68	112	119
1904	n/a	n/a	n/a	n/a	5.86	123	141
1900	n/a	n/a	n/a	n/a	6	133	158
1894	n/a	n/a	n/a	n/a	4.68	66	-6
1889	n/a	n/a	n/a	n/a	4.62	64	-13
1884	n/a	n/a	n/a	n/a	5.08	81	44
1871	n/a	n/a	n/a	n/a	4.89	74	20
1857	n/a	n/a	n/a	n/a	4.91	75	23
1847	n/a	n/a	n/a	n/a	5.93	128	149
1834	n/a	n/a	n/a	n/a	5.05	80	39
1822	n/a	n/a	n/a	n/a	3.6	36	-140
1807	n/a	n/a	n/a	n/a	4.85	72	15
1796	n/a	n/a	n/a	n/a	5.42	97	86
1785	n/a	n/a	n/a	n/a	6.25	153	190
1774	n/a	n/a	n/a	n/a	5.44	98	89
1763	n/a	n/a	n/a	n/a	5.94	129	150
1752	n/a	n/a	n/a	n/a	5.64	109	113
1748	n/a	n/a	n/a	n/a	5.9	126	146
1742	n/a	n/a	n/a	n/a	5.54	104	101
1737	n/a	n/a	n/a	n/a	6.21	150	184
1731	n/a	n/a	n/a	n/a	6.11	142	172
1721	n/a	n/a	n/a	n/a	5.63	109	112
1710	n/a	n/a	n/a	n/a	6.04	136	163
1699	n/a	n/a	n/a	n/a	4.56	62	-21



Appendix B4.–Historical reconstructions of Chilkat River sockeye salmon escapement using the linear regression and CPDF calibrations of recent escapements to δN^{15} levels and moving average escapement. Note that the period of δN^{15} levels used for calibration was from 1976 to 1995 and are shown in the larger squares in the figure. Also shown are the reconstructed Chilkat Lake sockeye catches detailed in Appendices A2 to A4.