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

by

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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

FISHERY DATA REPORT NO. 09-63

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ABSTRACT

Available information was assembled concerning estimated escapements, harvests, and age compositions of sockeye salmon *Oncorhynchus nerka*, returning to the Chilkoot Lake drainage in Alaska during the years 1976 to 2008. This information was used to reconstruct annual runs of Chilkoot Lake sockeye salmon. Brood tables consisting of estimated escapements and resultant age-specific recruits for the 1976 to 2003 brood years were developed for this stock. These data were subsequently used to develop a hierarchy of Ricker-type stock-recruit models that incorporate the effect of spawner density and autocorrelation on recruits. A Ricker stock-recruit model with an autoregressive term fit the data well and provided statistically meaningful reference points for the stock. The recommended escapement goal is the range of escapements that is expected to produce 90% or more of MSY. We recommend a sustainable escapement goal range of 38,000 to 86,000 spawners censused by weir count.

Key words: Sockeye salmon, *Oncorhynchus nerka*, Chilkoot Lake, stock-recruit analysis, escapement goals.

INTRODUCTION

The Chilkoot and Chilkat River watersheds (Figure 1) are the primary producers of sockeye salmon *Oncorhynchus nerka* caught in the Lynn Canal area of Southeast Alaska. Between 1900 and 1920, the average harvest of sockeye salmon in Northern Southeast Alaska was 1.5 million fish, and the majority of the harvest was believed to originate from Chilkat and Chilkoot rivers (Rich and Ball 1933). In comparison to the early years of the fishery, the average sockeye salmon harvest for Northern Southeast Alaska between 1980 and 2008 was 0.44 million fish, of which an average of 89 and 93 thousand fish originated from Chilkoot and Chilkat lakes, respectively (Eggers et al.*, in prep.*).

Chilkoot Lake (59°21′16” N, 135°35′42” W) is glacially turbid, has a surface area of 7.2 km^2 (1,734 acres), a mean depth of 54.5 meters, a maximum depth of 89 meters and a total volume of 382.4×10^6 m^3. The lake outlet is at the head of Lutak Inlet located approximately 16 kilometers northeast of the city of Haines, Alaska (Figure 1). Chilkoot Lake is located within the northern temperate rainforest that dominates the Pacific Northwest coast of North America. The climate of this area is characterized by cold winters and cool, wet summers. Average precipitation for the study area is ~165 cm/yr (Bugliosi 1988). Sitka spruce, western hemlock and Sitka alder dominate this forested watershed. The lake is set in a transitional zone, with warmer and drier summers, and cooler winters than the rest of Southeast Alaska.

Historically Chilkoot Lake sockeye salmon were harvested in the large fish trap and purse seine fisheries in Icy Strait and northern Chatham Strait 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 (Alaska Department of Fish and Game Fishing District 115; Figure 2). 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 Chilkoot Lake sockeye salmon are harvested commercially almost entirely in the Lynn Canal commercial drift gillnet fishery (District 115). Subsistence and sport fishing is an important secondary use of this stock, due to the lake’s proximity to the small city of Haines and easy road access. Subsistence and sport catch average about 2,500 fish. These catches were reduced to a few hundred fish from 1998 to 2000, during the years of low abundance in the Chilkoot Lake system when users were encouraged to target nearby Chilkat Lake sockeye salmon.

The sockeye salmon escapement goals for the Lynn Canal lake systems, including Chilkoot and Chilkat lakes, were first set in 1976 by measuring the surface area of each lake and back-calculating (using estimated sex ratios, fecundity, and mortality) to determine the number of spawners that would produce 5,000 rearing fry per surface acre. The escapement goals were set as a range of 80,000±10,000 for each individual lake (McPherson 1990). These numbers were revised to 80,000±10,000 for Chilkat Lake and 70,000±10,000 in 1983 based on a recalculation of surface area and analysis of a limited time series of spawner-recruit data. Neither of those analyses addressed the possible presence of multiple stocks in each lake nor how the overall escapement goals should be distributed. Alaska Department of Fish and Game (ADF&G) initiated the program in 1980 that identified Chilkoot and Chilkat Lake sockeye stocks in the fishery and allowed management biologists to regulate the fishery based on sockeye returns to the individual river systems. McPherson (1990) first developed a scale pattern analysis (SPA) system to identify local stocks of the Lynn Canal sockeye salmon, and Chilkoot and Chilkat lakes were thus treated separately in the analyses of escapement and return data.

Using a Ricker stock-recruit analysis on the catches and weir counts of Chilkoot River sockeye salmon from the 1976 to 1984 brood years, McPherson (1990) established an escapement goal range in 1990. He recommended an overall escapement goal of 50,500 to 91,500 sockeye salmon, divided into separate goals for early and late stocks. For early stocks, the current escapement goal range is 16,500 to 31,500 spawners; for late run stocks, the escapement goal range is 34,000 to 60,000 (Geiger and McPherson 2004). The escapement goals have not been updated since established by McPherson (1990).

For this study, we describe: (1) the stock assessment information available for Chilkoot Lake sockeye salmon, including reconstruction of the total Chilkoot Lake sockeye salmon runs by age since 1976, and (2) estimation of adult recruits and parental escapements for the 1976–2002 brood years. The current biological escapement goal (BEG) for the Chilkoot Lake sockeye salmon stock was evaluated based on an updated stock-recruit analysis using a hierarchal series of Ricker-type stock-recruit models. Trends in available stock assessment records were examined to evaluate the status of the Chilkoot Lake sockeye salmon stock.

STOCK ASSESSMENT INFORMATION

ESCAPEMENT

Sockeye salmon entering into Chilkoot Lake have been counted through a weir on the Chilkoot River, located downstream of the lake outlet, from 1976 through 2008 (Bergander 1989, 1990; Kelley and Bachman 1999; Bachman 2003; Bachman and Sogge 2006; Bachman and Eisenman, *in prep*.; Bachman, et. al., *in prep*.). The run has two components, an early and a late run, and these two components are currently managed as separate units. The sockeye salmon weir counts have varied dramatically during these years, from 7,200 (1995) to 103,000 (1982) fish (Table 1, Figure 3). Weir counts have averaged 66,273 sockeye salmon between 1976 and 2008. Weir counts were low during the period, 1994 to 2000, and averaged a little over 30 thousand during this period. Escapement age compositions are based on annual scale samples taken at the weir and used to estimate escapement by age (Table 2).

The extremely low weir count in 1995 prompted ADF&G to verify the weir counts by conducting mark-recapture experiments on Chilkoot Lake sockeye salmon. The mark-recapture project has been conducted annually from 1996 to 2004 and again in 2007, (Kelley and Bachman 1999, Bachman and Sogge 2006, Bachman and Eisenman *in prep*.). The mark recapture estimates were consistently higher than weir counts averaging 1.84 times the weir count (Table 1). Because spawning in Chilkat Lake occurs primarily in beach spawning areas and in the remote upper reaches of the Chilkoot watershed, the second-event recovery is difficult and low tag recoveries have contributed to imprecise mark recapture estimates. Differences between mark recapture were not consistent enough for a calibration of the weir counts (Figure 4). Assessments of Chilkoot sockeye salmon escapements are based on weir counts, recognizing that they are likely conservative.

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, 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 as well as estimating the age structure of the Chilkoot Lake sockeye salmon escapement.

Chilkoot Lake has produced annual commercial sockeye salmon harvests as high as 338,000 in 1987, with mean harvests of about 100,000 fish for the years 1976 to 2008 (Table 1, Figure 3). In addition to the commercial harvest, sockeye salmon originating from Chilkoot Lake are also taken in the Haines area sport and subsistence fisheries. The commercial catch by age, 1984–2008 is provided in Table 3. Total runs of Chilkoot Lake sockeye salmon, based on weir counts, have ranged from a high in 1987 of about 432,000 to a low in 1998 of about 14,700 (Table 1, Figure 3). Chilkoot Lake sockeye salmon runs were very low from 1994 through 2004, but have generally increased in recent years (Figure 3).

RECRUITS FROM PARENT ESCAPEMENT BY AGE

The recruits, by age, from parent escapements were estimated for the 1976 to 2003 brood years (Table 4). The recruits from brood year y and age a is the escapement and catch for age a in calendar year $y + a$.

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

$R_{a,y}$ 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 1976 through 2003 was estimated for each cohort as the sum of production at age over ages of the cohort:

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

The 2002 and 2003 broods were incomplete, given the assessments of the 1976 to 2008 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:

$$\hat{R}_{2002} = \frac{\sum_{a=3}^{6} \hat{R}_{a,2002}}{1-\hat{\bar{\tau}}_7}; \qquad \hat{R}_{2003} = \frac{\sum_{a=4}^{5} \hat{R}_{a,2003}}{1-\hat{\bar{\tau}}_{6+}} \quad (3)$$

Where: $\hat{\bar{\tau}}_7$ is the average fraction of seven-year-olds, and $\hat{\bar{\tau}}_{6+}$ is the average fraction of six-year-olds and younger. The averages were taken over the complete 1976 to 2001 broods.

LIMNOLOGICAL OBSERVATIONS

Zooplankton densities in Chilkoot Lake have been monitored from 1986 to 1991, and annually since 1995 (Figure 5). Chilkoot Lake is glacially influenced by the Chilkoot River that flows directly through the lake. Warm conditions during the summer (as indexed by Haines average air during June and July) affects glacial melt, which in turn, affects the euphotic zone depth (EZD; Figure 5) of the lake. The EZD is the average depth in the lake to which 1% of the light penetrates (i.e. 1% of the subsurface photosynthetically active radiation). Lloyd et al. (1988) showed that the EZD is related to zooplankton density in clear and glacially turbid Alaskan lakes. This measurement has been used to characterize a lake's potential for sockeye salmon production. Very limited information exists on the euphotic depth in this lake, with measurements from 1987 to 1991 and then again from 2001 to 2004. For years where EZD's were determined, EZD decreases with mean air temperatures during June and July (Figure 5). Average summer temperatures (NOAA National Climate Data Center) fluctuated from 1976 to 1986, but then the remained high from 1988 to 1998. Summer air temperatures again were generally lower, except for 2003 through 2005, since 1998. During the period of high summer air temperatures, 1988 to 1998, the standing crop of zooplankton dropped and remained low (Figure 5).

STOCK-RECRUIT ANALYSIS

METHODS

The following hierarchal set of stock-recruitment models were fit to the Chilkoot Lake stock-recruit data for the 1976 to 2002 brood years. The stock-recruit models are Ricker type (Ricker 1975) and hierarchal terms included escapement density and a first order autoregressive term. Three models were constructed: (1) linear, no density dependence due to escapement; (2) straight Ricker, density dependence due to escapement; and (3) autoregressive Ricker with the density dependence due to escapement and autoregressive terms included. The significance of the relative fit of the alternative models was evaluated using the likelihood ratio test (Hilborn and Mangel 1997).

Model 1, Linear;

$$R_i = S_i \exp(\alpha)\exp(\varepsilon_i) \tag{4}$$

Model 2, Straight Ricker;

$$R_i = S_i \exp\left(\alpha\left(1 - S_i/\beta\right)\right)\exp(\varepsilon_i) \tag{5}$$

Model 3, Autoregressive Ricker. The autoregressive Ricker model is the result of a first order (mean = 0, parameter ϕ) autoregressive process where observations are linearly related to the prior year observation (c.f. Noakes et al 1987).

$$R_i = S_i \exp\left(\alpha\left(1 - S_i/\beta\right)\right)\exp(\phi)\left(R_{i-1} \Big/ S_{i-1}\exp\left(\alpha\left(1 - S_{i-1}/\beta\right)\right)\right)\exp(\varepsilon_i) \tag{6}$$

Where α, β, ϕ are model parameters, and the data are total recruits from brood year i escapement (R_i), escapement in brood year i (S_i), ε_i is the process error, and $\ln(\varepsilon_i) \sim \text{normal}(0,\sigma)$.

Each of these models was fit to Chilkoot Lake stock-recruit 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).

$$L(\alpha,\beta,\gamma,\delta|data) = \prod\left[\left(\frac{1}{\sigma\sqrt{2\pi}}\right)\exp-\left(\frac{\ln\left(\frac{R_i}{\hat{R}_i}\right)}{2\sigma^2}\right)\right] \tag{7}$$

The parameters (α, β, 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'**),**

$$\alpha' = \alpha + \sigma^2/2 \tag{8}$$

$$\beta' = \frac{\alpha'}{\alpha}\beta \tag{9}$$

$$\sigma^2 = \frac{\sum \ln\left(\frac{\hat{R}_i}{S_i}\right)^2}{n-p} \tag{10}$$

For the autoregressive model the bias correction is:

$$\alpha' = \alpha + \sigma^2/2(1-\phi^2) \tag{11}$$

For each model applied to stock-recruit data, the maximum sustained yield (S_{MSY}) escapement goal, and the range of escapement that produce 90% of MSY, and MSY harvest rate were calculated. The likelihood profile for the MSY escapement goal and the MSY harvest rate were also 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 Chilkoot Lake recruits from parental escapements from the 1976 to 2002 brood years (Table 5). There was significant density dependence in the stock-recruit data with the escapement term (Model 2 and Model 3) having a significant fit improvement (likelihood ratio test $p < 0.018$) over the linear model (Model 1). There was also significant autocorrelation in the Model 2 residuals with the Model 3 (i.e, with the autoregressive term, ϕ= 0.64, which corrects for time series bias) providing a significant improvement in fit (likelihood ratio test, p = 0.002). The autoregressive Ricker (Model 3) was the best model (Figure 6) in terms of fit criteria (i.e., minimum AIC). The Ricker model (Model 2) fit to the 1976 to 2002 brood year stock-recruit data showed significant density dependence. The resolution of the MSY escapement level and associated 90% MSY escapement ranges are provided in Figure 7. Model 3 showed good resolution of the MSY escapement level and associated 90% MSY escapement ranges (Figure 7). The residuals for Model 3 showed no autocorrelation and indicated improved fit over Model 2 (Figure 8). The MSY escapement level under Model 3 is approximately 58,000 spawners and the 90% MSY escapement goal range is approximately 38,000 to 86,000 sockeye salmon (Table 5).

In the Ricker model the parameter, exp(α), reflects the potential productivity of the stock and is considered constant over time. In the autoregressive Ricker the time series factor, $\exp(\phi)(R_{i-1}/\hat{R}_{i-1})$, corrects for the serial correlation in the Ricker model (Model 2) residuals fit to the data. The potential productivity reflected in the autoregressive Ricker model is the product of the base Ricker potential productivity and the autocorrelation correction, (i.e., $\exp(\alpha\phi)(R_{i-1}/\hat{R}_{i-1})$), and varies over time.

The time series of potential productivity based on Model 3, over the 1976 to 2002 brood years is shown in Figure 9 together with observed recruits per spawner, and the air temperature index during June and July of the first years of lacustrine residence. It is clear that estimated potential productivities and observed production (recruits per spawner) for Chilkoot River sockeye salmon were low over an extended period during the 1988 to 1996 brood years. This was also an extended period of generally warm summertime conditions, high turbidly, and low zooplankton abundance during the lacustrine residence of the respective low production broods.

Note that the parameters and associated biological reference points (i.e., the maximum sustained yield escapement level, the range of escapement that produce 90% of MSY, and MSY harvest rate) in Model 3 represent the long term average of the time varying potential productivity.. These reference points are not specific to any individual time period and are reflective of the stocks productivity integrated over the term of the available data. It is not possible to condition escapement goals and associated management decisions to achieve maximum sustained yield expected for a given regime of productivity because of inability to forecast or monitor rearing conditions that affect the productivity expected for the escapement.

ESCAPEMENT GOAL RECOMMENDATION

Our recommendation is to establish a sustainable escapement goal range of 38,000 to 86,000 spawners per year for Chilkoot Lake sockeye salmon as assessed by the Chilkoot River weir count. This goal range is the escapement range that produces 90% of MSY as determined by Model 3 (Autoregressive Ricker) fit to the 1976 to 2002 stock-recruit data. The proposed goal is a sustainable escapement goal because of the uncertainty in escapement levels based on weir counts.

McPherson (1990) established a separate set of goals by stock for the early and late portions of the total escapement. Because there is no biological reason (i.e., obvious modality in run-timing or identifiable time segregated spawning populations within the Chilkoot Lake drainage) to manage this stock with two sets of goals, we recommend management of the new *sustainable escapement goal* to encompass the historical (1976–2004) run timing observed at the Chilkoot River weir (Table 6).

STOCK STATUS AND DISCUSSION

Escapements for the Chilkoot Lake sockeye salmon have been generally within or above the recommended biological escapement goal (Figure 10), except for 3 years during the mid- to late-1990s when runs were reduced due to the extended period of low production.

Management of sockeye salmon runs to Chilkoot Lake has presented a major challenge following the collapse of sockeye recruitment to this system in the mid-1990s. The very low recruitment in 1995 appeared after a slow erosion of the stock's productivity, and after at least a decade of very large returns and large escapements. The stock crash was concurrent with a severe crash in zooplankton populations in the lake (Bachman 2003). Currently, Chilkoot Lake appears to be recovering from this downturn in productivity.

Our operating hypothesis is that the amount of glacial silt in the lake periodically increases due to glacial melt during periods of very warm summertime conditions. During times of increased silt in the lake, the euphotic volume of the lake is reduced. The euphotic volume determines the level of primary and secondary production, and amount of the sockeye food base (Koenings and Burkett 1987). The environmental conditions that drive these variations in lake conditions are typically highly autocorrelated and can be modeled as a first order autoregressive process. This explains the high serial correlation observed in the time series of recruits per spawner for Chilkoot Lake sockeye salmon. In view of the significant density dependence in the stock recruit model, it is likely that several large escapements of sockeye salmon into the system, which occurred during the period of reduced zooplankton abundance, further reduced the production of sockeye salmon.

Note that the biological reference points estimated for Chilkoot Lake sockeye salmon and the proposed sustainable escapement goal for the stocks are not specific to any individual time period or production regime. These are integrated over the variation in productivity observed for the stock and are reflective of the stock over the long term. It is not possible to condition escapement goals and associated management decisions to achieve maximum sustained yield (which varies in concert with the varying lake productivity) because of the inability to forecast or monitor rearing conditions that affect the productivity expected for the escapement.

Management actions designed to reduce the harvest rate on Chilkoot Lake sockeye salmon while harvesting other salmon stocks and species have been successful during years of low abundance. In recent years, management has directed harvests on Chilkoot Lake sockeye salmon to reduce the potential of exceeding the carrying capacity of Chilkoot Lake during years of low zooplankton abundance. Summer conditions have generally been cooler since 1999, and Chilkoot Lake sockeye salmon runs have increased. During the period, 2001–2007, the total weir count has been within or above the proposed escapement goals for this system. Note the 2008 escapement was slightly below the goal; due to extremely weak return from the 2003 brood which reared in Chilkoot Lake during very warm summer conditions of 2004 (Figure 10, Bachman and Eisenman *in prep.*).

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Table 1.–Chilkoot sockeye salmon annual escapements (weir counts for 1976–2008, and mark-recapture estimates for 1996–2004, 2007); harvests (commercial, sport, and subsistence); total runs; and, estimated exploitation rates. Escapement, harvest, and return numbers are in thousands of fish. The escapement component of total runs and exploitation rates are shown, based on the weir counts for 1976 to 2008, and on the mark-recapture estimates for 1996 to 2004.

	Escapement		Harvest[b,c]	Total Run		Exploitation Rate (%)	
Year	**Weir count**	**Estimate[a]**	**All sources**	**Based on weir count**	**Based on estimate[1]**	**Based on weir count**	**Based on estimate[1]**
1976	71.3		62.5	133.7		46.7%	
1977	97.4		113.7	211		53.9%	
1978	35.5		14.8	50.2		29.4%	
1979	95.9		70.2	166.1		42.2%	
1980	96.5		21.5	118.1		18.3%	
1981	84		45	129		34.9%	
1982	103		145.4	248.4		58.5%	
1983	80.1		242.1	322.3		75.1%	
1984	100.8		232.8	333.6		69.8%	
1985	69.1		154.5	223.7		69.1%	
1986	88		115	203.1		56.7%	
1987	94.2		337.9	432.1		78.2%	
1988	81.3		255.3	336.6		75.9%	
1989	54.9		294.9	349.7		84.3%	
1990	76.1		183.9	260		70.7%	
1991	87.3		229.1	316.5		72.4%	
1992	65		145.3	210.3		69.1%	
1993	52.1		54.4	106.5		51.1%	
1994	37		27.4	64.4		42.5%	
1995	7.2		8.5	15.7		54.2%	
1996	50.7	**65**	21.6	72.3	**86.5**	29.8%	**24.9%**
1997	44.3	**79**	31.2	75.4	**110.2**	41.3%	**28.3%**
1998	12.3	**28**	2.4	14.7	**30.4**	16.1%	**7.8%**
1999	19.3	**62**	4.4	23.7	**66.4**	18.6%	**6.6%**
2000	43.6	**60**	14.8	58.3	**74.7**	25.3%	**19.7%**
2001	76.3	**100**	71.3	147.5	**171.3**	48.3%	**41.6%**
2002	58.4	**61**	27.1	85.4	**88**	31.6%	**30.7%**
2003	74.5	**177**	35.9	110.3	**212.9**	32.5%	**16.9%**
2004	75.6	**150**	69.2	144.8	**219.2**	47.8%	**31.6%**
2005	51.2		30.7	81.9		37.5%	
2006	96.2		119	215.2		55.3%	
2007	72.6	**79.7**	125.3	197.9	**205.0**	63.31%	**61.1%**
2008	33.0		7.5	40.5		18.52%	

[a] Official escapement estimates, total runs, and exploitation rates for years 1996 through 2004 were based on mark-recapture estimates (bold numbers).

[b] Harvest from all sources (commercial, subsistence, sport). Commercial harvest comprised 96% of total harvest on average, and over 90% in all but two years.

[c] Harvest total did not include subsistence in 1976–1984, and did not include sport in 1976, 2005, or 2006. Sport fishing was closed in 1998 and 1999.

Table 2.–Chilkoot Lake total estimated escapement for 1982 to 2008, by numbers of fish, and numbers of fish by age class. Escapement estimated by weir counts. Age classes are listed in European ages (years in freshwater, years in marine).

Return Year	Escapement	Age in Years										
		3		4		5		6			7	
		1.1	0.2	0.3	1.2	1.3	2.2	2.3	1.4	3.2	3.3	2.4
1982	103,076	0	0	124	19,534	80,916	546	978	978	0	0	0
1983	80,423	88	0	88	9,609	48,648	1,125	20,688	177	0	0	0
1984	100,417	0	0	0	4,539	87,062	372	7,652	793	0	0	0
1985	69,026	41	0	0	8,421	45,847	1,829	10,975	1,657	41	0	214
1986	88,033	44	0	0	11,646	58,958	1,928	14,797	493	0	44	123
1987	95,195	0	0	0	7,977	65,859	2,113	18,847	219	0	48	133
1988	81,282	0	0	0	3,576	63,345	2,203	10,688	1,162	0	33	276
1989	54,905	0	0	0	2,465	30,124	2,761	18,386	659	0	296	214
1990	73,324	0	0	0	1,430	33,260	1,071	35,995	704	29	81	755
1991	90,638	0	0	0	11,321	50,630	4,423	23,521	353	0	118	272
1992	67,078	0	0	34	1,187	42,000	3,883	18,981	463	101	101	329
1993	51,853	0	0	0	1,348	18,513	923	30,573	150	0	124	223
1994	37,416	0	0	37	659	25,005	602	10,776	224	19	19	75
1995	7,210	0	0	0	3,176	2,212	274	1,440	60	0	0	48
1996	50,739	0	0	25	3,146	42,722	396	4,328	96	25	0	0
1997	44,258	0	0	22	987	39,873	168	3,146	40	0	22	0
1998	12,323	0	0	0	616	7,471	263	3,776	170	0	14	14
1999	19,286	0	0	0	5,550	8,963	1,556	3,139	39	0	0	39
2000	43,555	0	17	0	5,767	25,532	823	11,359	39	0	0	17
2001	76,283	0	0	229	3,677	68,510	130	3,707	31	0	0	0
2002	58,361	0	0	0	3,747	52,268	619	1,459	268	0	0	0
2003	74,459	0	0	0	30,744	33,477	3,135	6,791	283	0	0	30
2004	75,596	0	0	0	11,128	53,787	4,490	6,138	53	0	0	0
2005	51,178	0	0	0	10,159	34,550	1,986	4,406	77	0	0	0
2006	96,203	0	0	38	7,869	77,376	818	10,024	38	0	0	38
2007	72,561	0	0	0	5,145	57,352	457	9,201	406	0	0	0
2008	32,954	0	0	92	3,210	26,534	188	1,371	1,467	0	0	92

Table 3.–Catch of Chilkoot Lake sockeye salmon by age, 1982 to 2008, in numbers of fish. Ages are listed in total age and European ages (years in freshwater, years in marine).

Return Year	Catch	Age in Years										
		3		4		5		6			7	
		1.1	0.2	0.3	1.2	1.3	2.2	2.3	1.4	3.2	3.3	2.4
1982	144,505	0	0	0	10,516	119,946	1,478	442	12,119	4	0	0
1983	241,432	1	0	0	7,257	174,413	856	803	58,056	0	0	46
1984	231,792	0	232	0	5,331	209,076	232	695	15,762	0	0	464
1985	152,325	152	305	0	6,550	119,575	1,219	3,047	21,173	0	152	152
1986	110,430	0	552	0	8,282	84,810	1,325	663	14,356	0	110	331
1987	334,995	0	0	0	17,755	230,142	2,345	335	84,084	0	0	335
1988	253,968	0	0	0	17,016	198,857	8,381	1,270	27,936	0	0	508
1989	291,863	0	0	0	9,923	155,271	12,258	876	111,200	0	2,043	292
1990	178,864	0	0	0	7,155	84,066	3,577	82,099	715	0	179	1,073
1991	224,265	0	0	0	13,891	147,195	2,913	59,147	672	0	224	224
1992	88,653	0	0	0	2,674	37,009	3,940	43,764	985	0	141	141
1993	52,504	0	0	0	1,028	24,889	1,697	24,529	154	0	51	154
1994	25,414	0	0	0	525	18,651	189	5,902	147	0	0	0
1995	7,946	0	0	0	2,524	3,443	216	1,632	122	0	0	9
1996	18,861	0	0	0	1,711	15,469	395	1,272	15	0	0	0
1997	28,913	0	0	0	1,051	25,245	144	2,411	62	0	0	0
1998	2,206	0	0	0	135	1,576	92	404	0	0	0	0
1999	4,268	0	0	0	704	2,155	373	994	41	0	0	0
2000	14,136	0	0	0	943	11,893	69	731	467	0	0	32
2001	67,503	0	0	0	1,550	63,185	0	2,753	15	0	0	0
2002	24,276	0	0	0	824	22,665	73	654	60	0	0	0
2003	32,323	0	0	0	9,505	18,949	524	3,304	41	0	0	0
2004	66,537	0	0	0	8,781	50,217	3,041	4,424	73	0	0	0
2005	29,324	0	0	0	3,313	20,923	679	4,323	87	0	0	0
2006	119,261	0	0	0	6,096	100,222	759	12,078	107	0	0	0
2007	125,303	0	0	0	6,479	102,622	410	15,425	367	0	0	0
2008	7,483	0	0	0	499	6,296	37	387	247	0	0	17

Table 4.–Total recruits of Chilkoot Lake sockeye salmon by age class, for brood years 1976 to 2003. 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 Year	**Age in Years**											**Total Recruits**
	3		**4**		**5**		**6**			**7**		
	1.1	**0.2**	**0.3**	**1.2**	**1.3**	**2.2**	**2.3**	**1.4**	**3.2**	**3.3**	**2.4**	
1976				8,933	96,992	2,870	1,420	13,097	4		46	123,362
1977				9,556	200,862	2,024	980	78,744		0	464	292,630
1978	24			30,050	223,061	1,981	1,489	23,414	0	152	366	280,537
1979				16,866	296,138	603	4,703	32,148	41	154	455	351,109
1980	89		0	9,870	165,422	3,048	1,156	29,153	0	48	468	209,253
1981	0	232	0	14,971	143,769	3,253	554	102,930	0	33	784	266,526
1982	194	305	0	19,928	296,000	4,458	2,432	38,624	0	2,340	506	364,786
1983	44	552	0	25,731	262,202	10,583	1,534	129,586	0	260	1,828	432,321
1984	0	0	0	20,592	185,395	15,020	1,419	118,093	29	342	496	341,386
1985	0	0	0	12,388	117,326	4,648	1,026	82,667	0	241	469	218,766
1986	0	0	0	8,584	197,825	7,336	1,448	62,745	101	176	377	278,591
1987	0	0	0	25,211	79,009	7,824	305	55,102	0	19	75	167,544
1988	0	0	34	3,861	43,402	2,620	372	16,678	19	0	57	67,041
1989	0	0	0	2,376	43,656	791	182	3,072	0	0	0	50,077
1990	0	0	37	1,184	5,655	490	111	5,600	25	22	0	13,125
1991	0	0	0	5,700	58,191	791	102	5,558	0	14	14	70,368
1992	0	0	25	4,856	65,118	312	170	4,180	0	0	39	74,700
1993	0	0	22	2,038	9,047	354	80	4,134	0	0	50	15,725
1994	0	0	0	750	11,118	1,929	506	12,091	0	0	0	26,394
1995	0	0	0	6,254	37,425	892	45	6,460	0	0	0	51,077
1996	0	0	0	6,710	131,695	130	328	2,113	0	0	30	141,006
1997	0	17	229	5,227	74,933	692	324	10,095	0	0	0	91,518
1998	0	0	0	4,570	52,425	3,659	126	10,562	0	0	0	71,343
1999	0	0	0	40,249	104,004	7,532	164	8,729	0	0	38	160,716
2000	0	0	0	19,909	55,473	2,664	145	22,102	0	0	0	100,294
2001	0	0	0	13,472	177,598	1,576	773	24,626	0	0	109	218,154
2002	0	0	38	13,965	159,974	867	1,714	1,758	0	***88***	***163***	178,568
2003	0	0	0	11,624	32,830	224	***200***	***9,073***	***8***	***22***	***41***	56,492

Table 5.–Results of model fits to the escapement-recruit data for brood years 1976 to 2002 brood years. 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 , autoregressive Ricker relative to straight ,respectively.

	Parameters				**90% MSY Escapement Goal Range**			**Fit Criteria**			
Model	α	β	ϕ	**MSY Escapement**	**Lower**	**Upper**	**MSY Harvest Rate**	**-log l**	**AIC**	**Number of Parameters**	**p-value**
Linear	0.78							37.45	39.45	1	
Straight Ricker	1.68	249		95	61	135	0.646	34.64	38.64	2	0.018
Autoregressive Ricker	2.14	164	0.644	58	38	86	0.751	28.17	34.17	3	0.002

Table 6.–Proposed escapement targets, by ADF&G statistical week, for Chilkat Lake sockeye salmon, based on the 1976 to 2004 average run timing.

Statistical Week	Weekly Point Goal	Weekly Point Cum. Goal	Weekly Cum. Lower end Bound	Weekly Cum. Upper end Bound
23	577	577	378	856
24	2,359	2,936	1,924	4,354
25	4,075	7,011	4,593	10,396
26	3,448	10,459	6,852	15,508
27	2,259	12,718	8,333	18,858
28	2,701	15,420	10,102	22,863
29	4,859	20,279	13,286	30,069
30	6,720	26,998	17,689	40,032
31	8,467	35,466	23,236	52,587
32	7,679	43,145	28,267	63,973
33	5,034	48,179	31,565	71,437
34	4,282	52,461	34,371	77,787
35	2,906	55,367	36,275	82,096
36	1,906	57,274	37,524	84,923
37	726	58,000	38,000	86,000

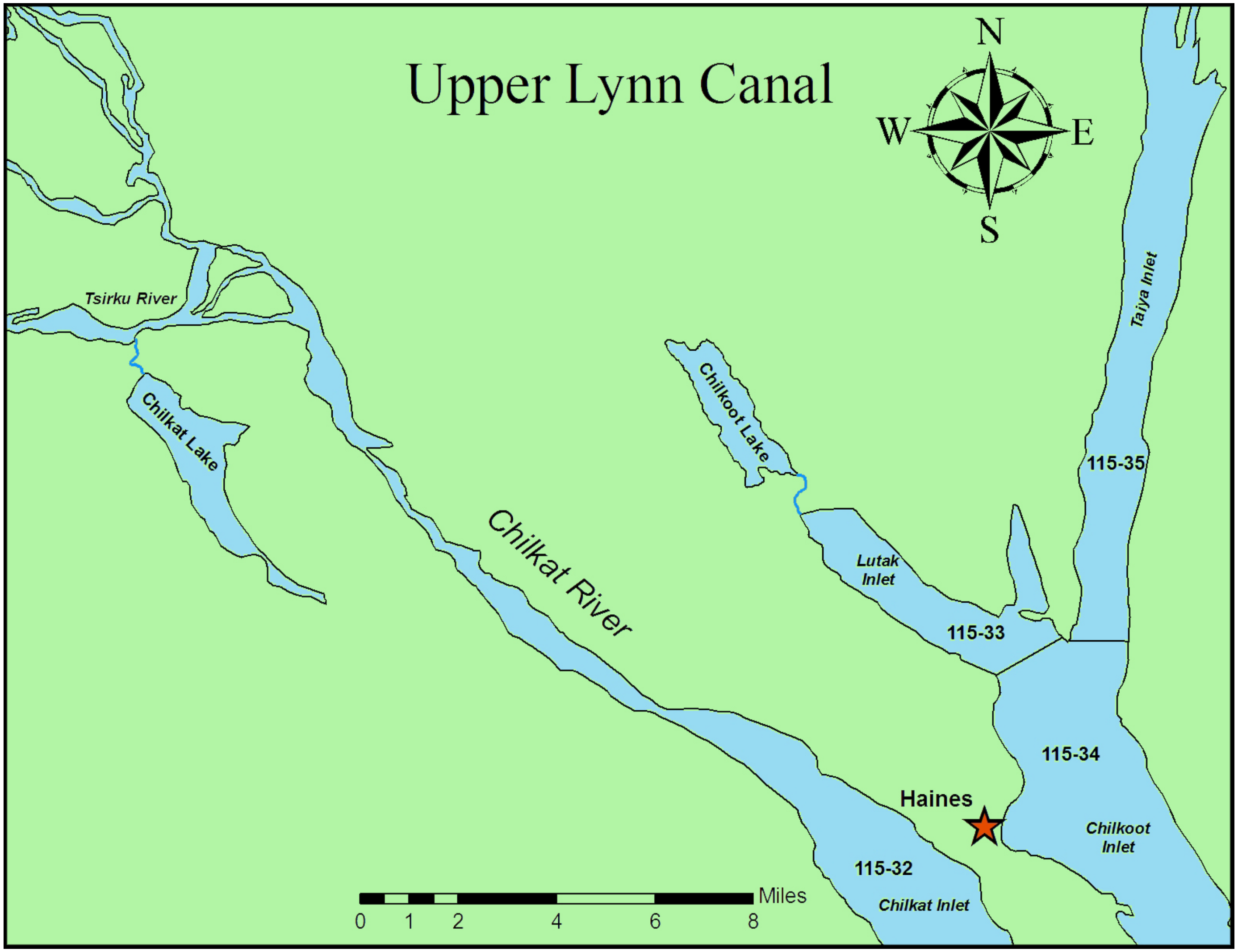

Figure 1.–Map of upper Lynn Canal showing Chilkoot and Chilkat Lakes.

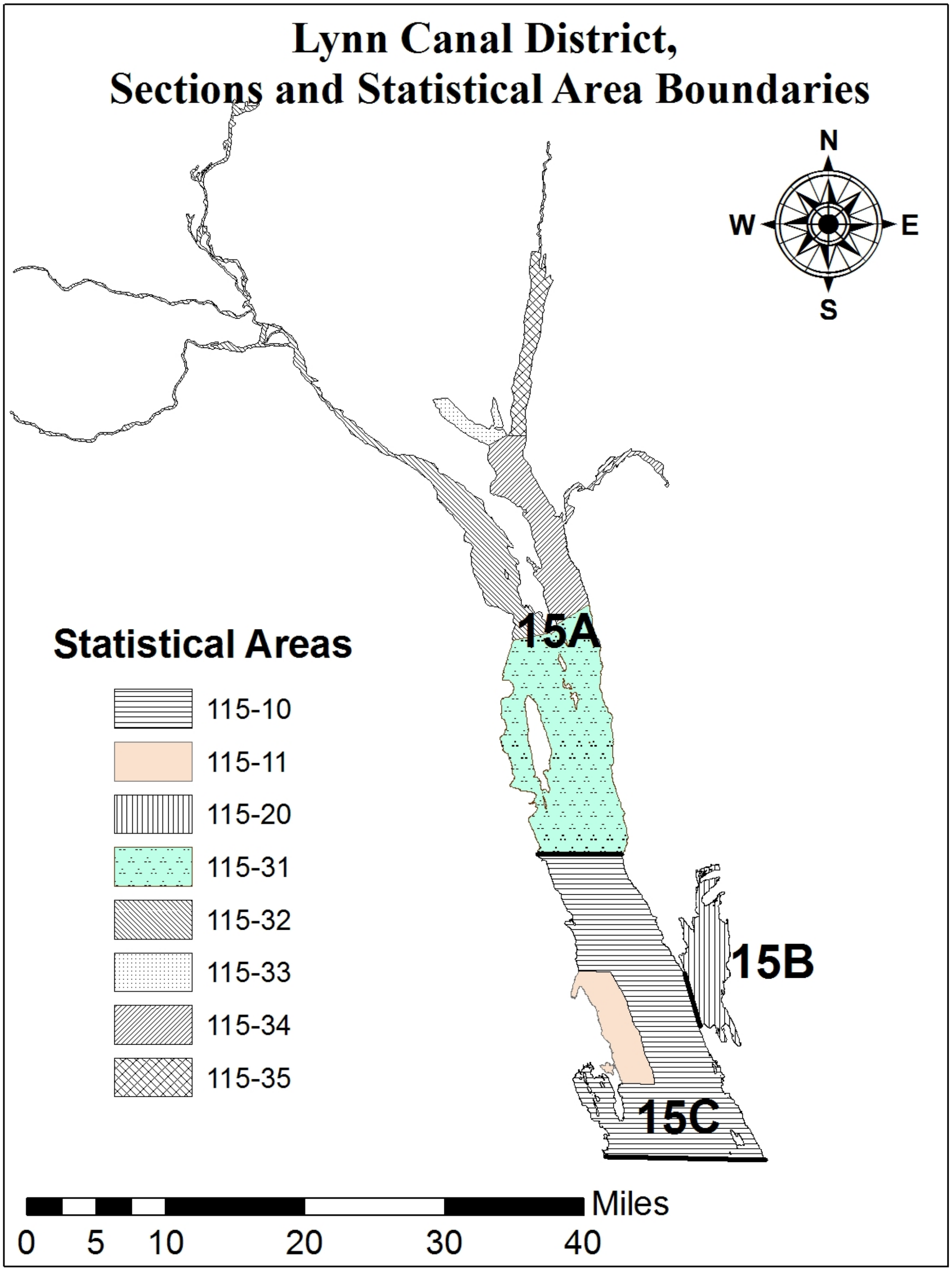

Figure 2.–Map of the Lynn Canal district and statistical area boundaries.

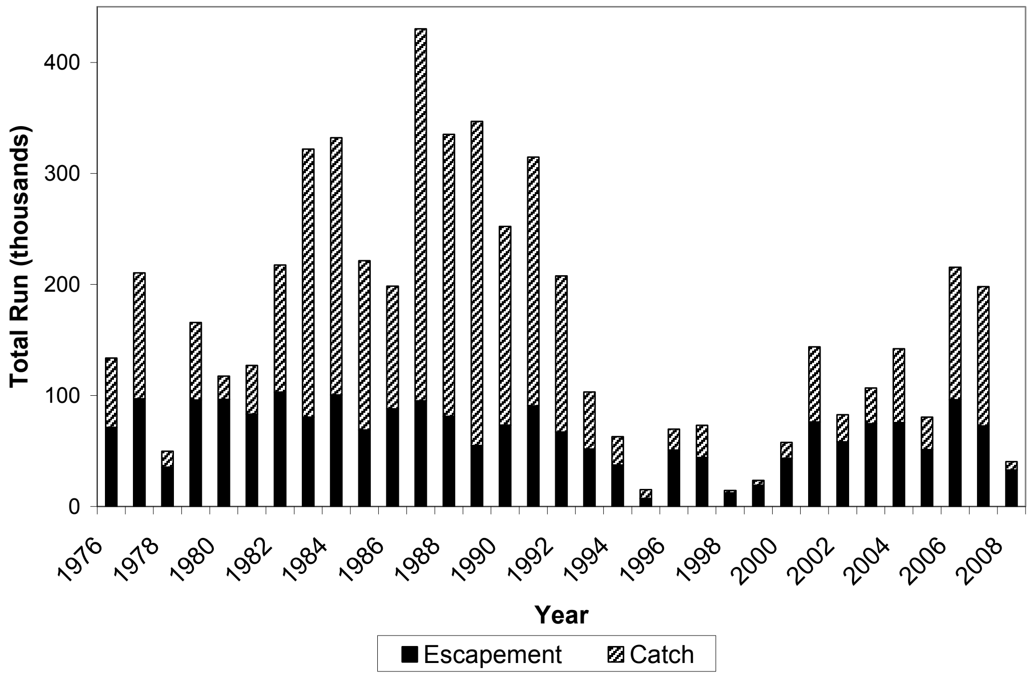

Figure 3.–Annual weir count escapement and commercial catch of Chilkoot Lake sockeye salmon from 1976 to 2008.

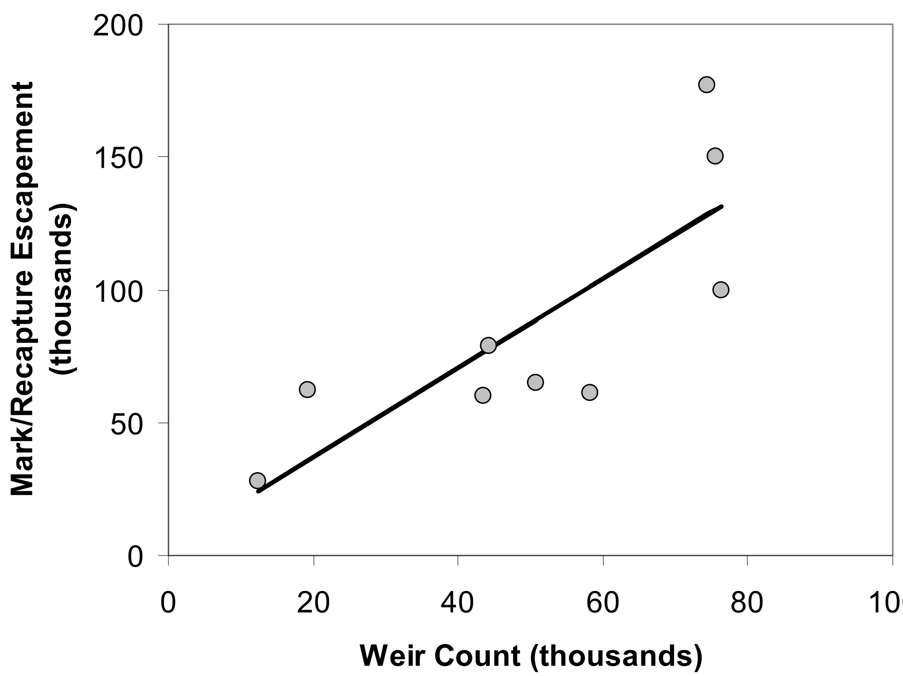

Figure 4.–Relationship between mark recapture estimates of escapement weir counts for paired observations, 1996 to 2004.

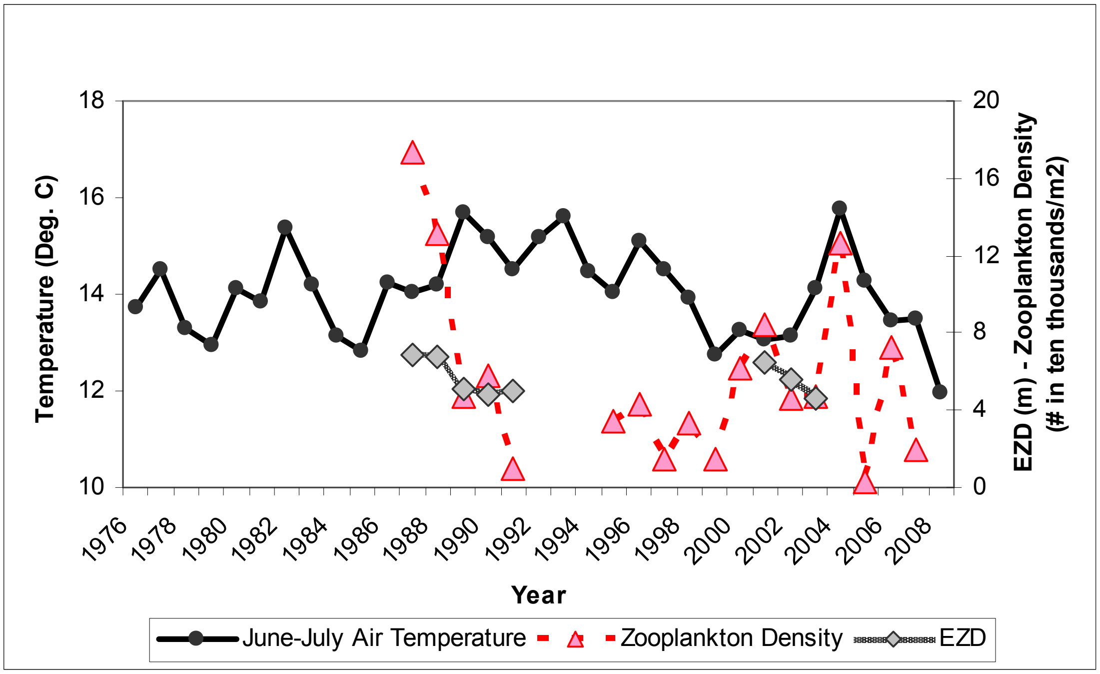

Figure 5.–Average air temperature in June and July (° C), average euphotic zone depth (EZD, m) from May to October and average zooplankton density (number in 10 thousands per m^2) from May to October.

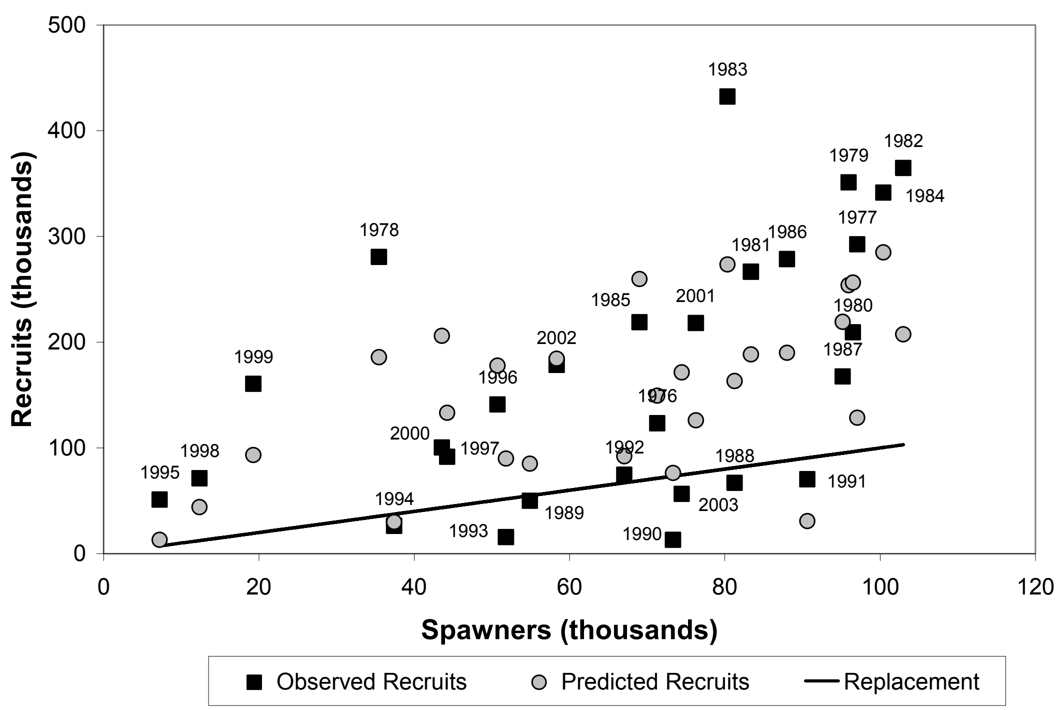

Figure 6.–Stock-recruitment relationship for Chilkoot Lake sockeye salmon, 1976 to 2002 brood years; (solid squares) are observed recruits from parental escapements, grey circles are the autoregressive Ricker (Model 3) predicted recruits, and the straight line is replacement.

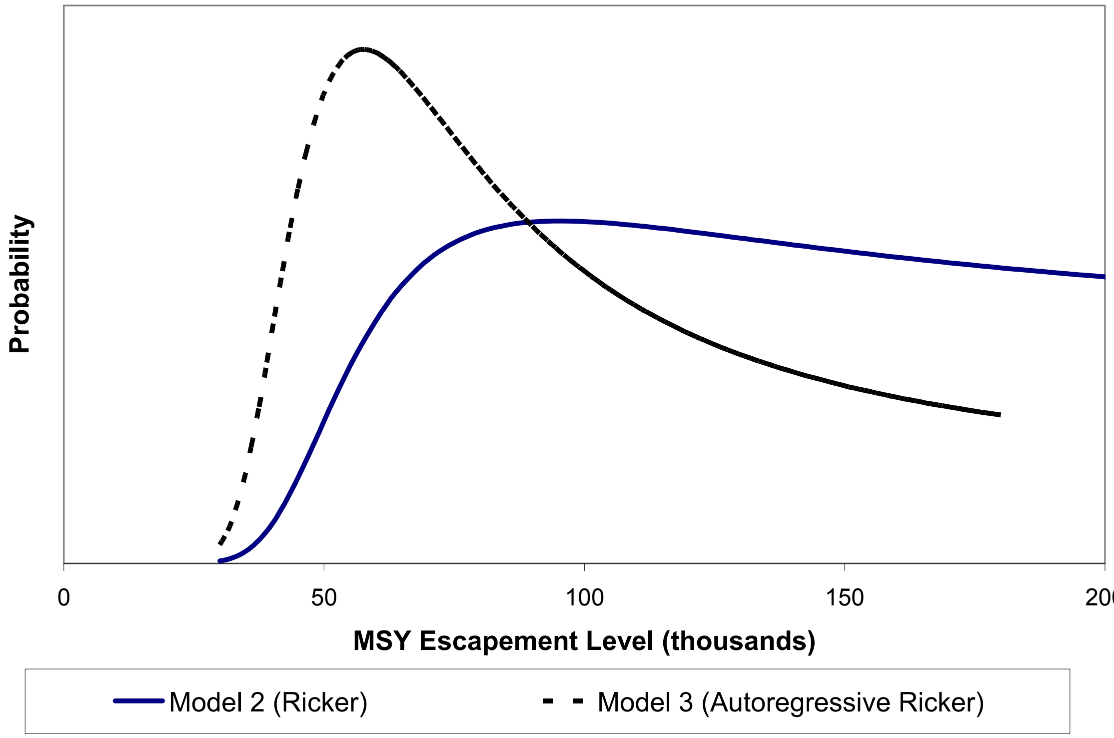

Figure 7.–Likelihood profiles for MSY escapement levels, for alternative stock recruit models fit to Chilkoot Lake escapement-recruit data for brood years 1976 to 2002.

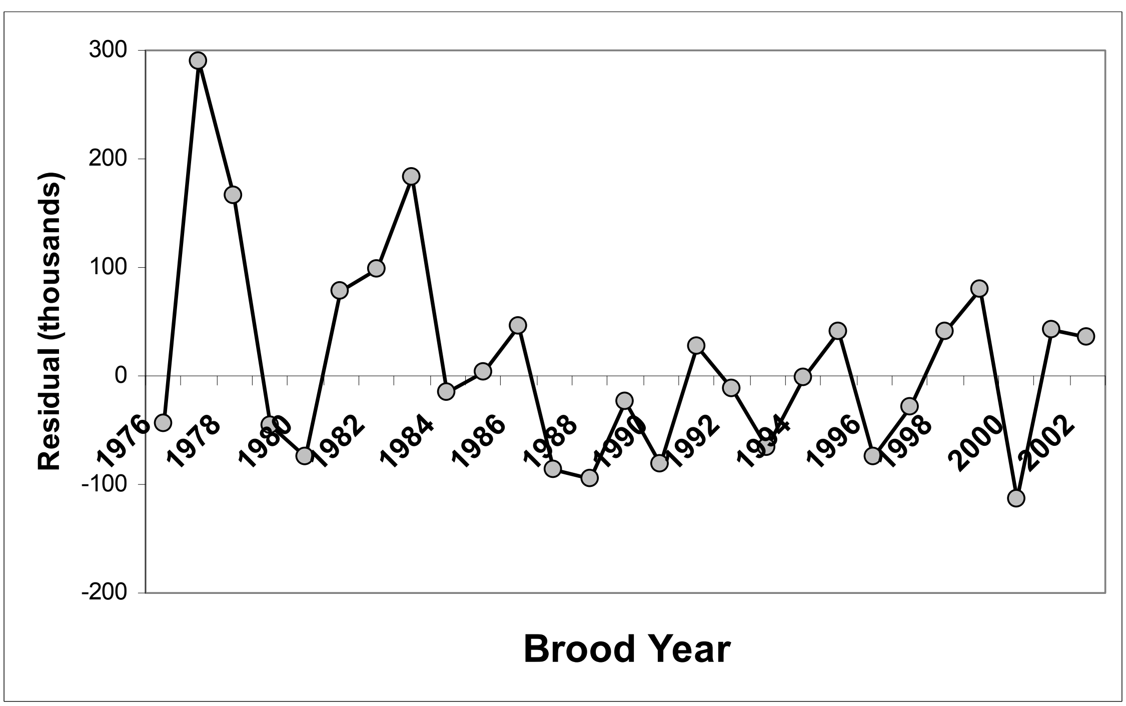

Figure 8.–Residual (thousands) plots for the autoregressive Ricker (Model 3) stock-recruit relationship fit to the 1976 to 2002 brood years for Chilkoot Lake sockeye salmon.

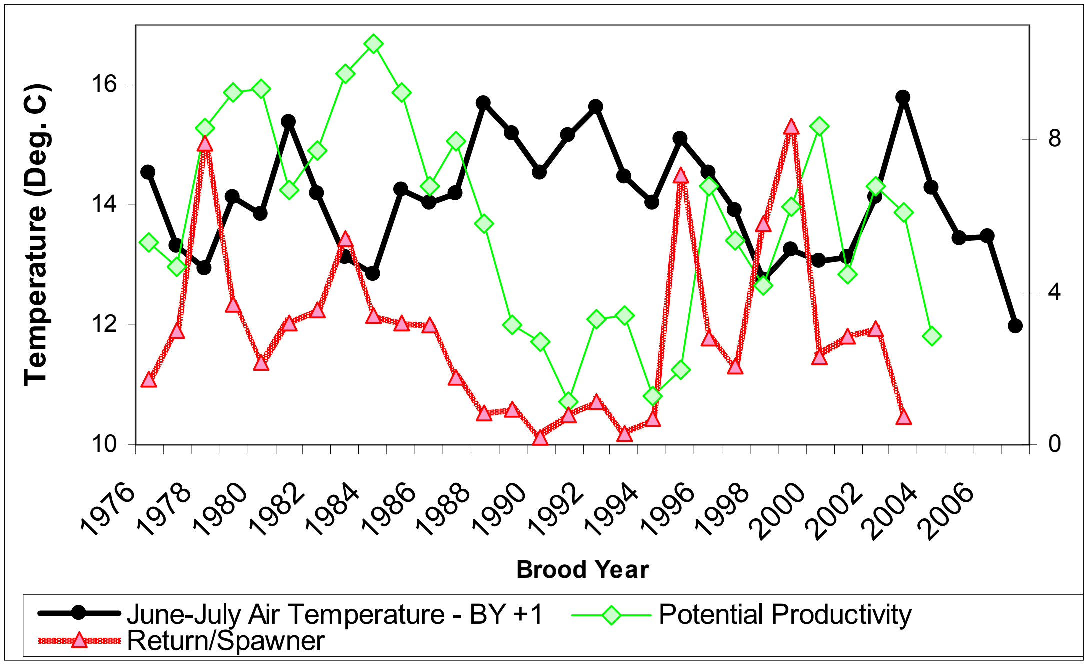

Figure 9.–Average air temperature in June and July (°C) in year following spawning, return/spawner, and potential productivity of Chilkoot Lake sockeye salmon.

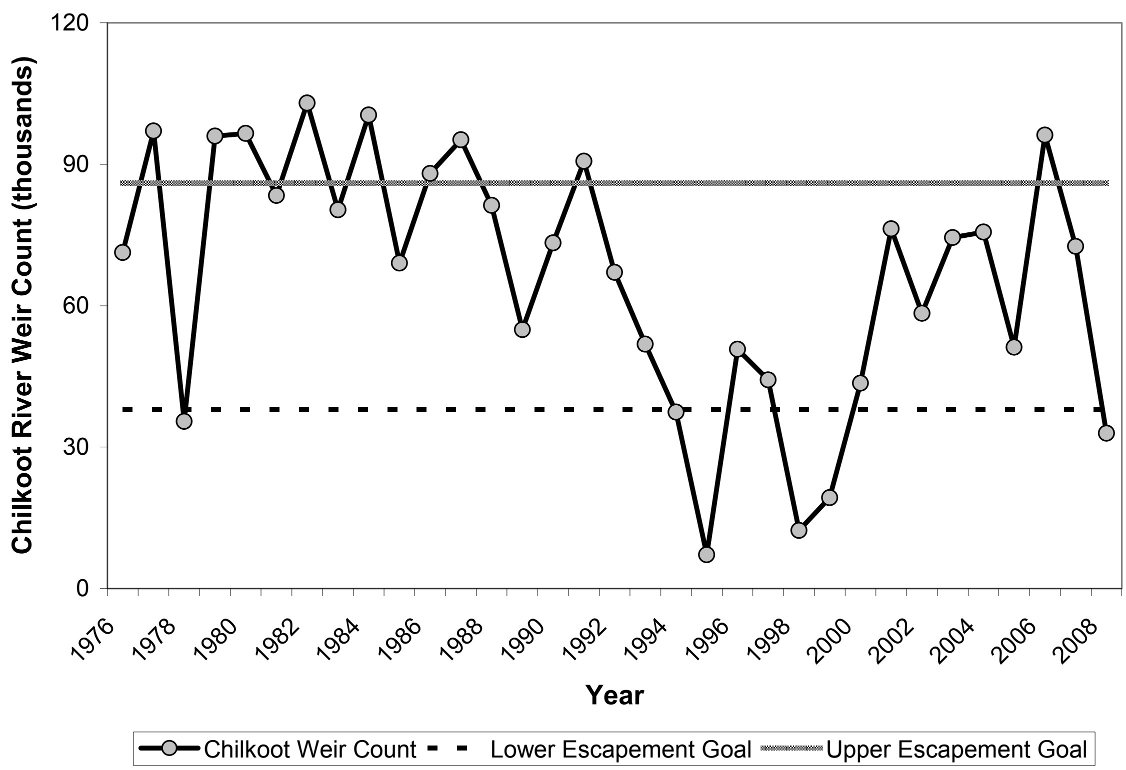

Figure 10.–Chilkoot Lake sockeye salmon escapements from 1976 to 2008 plotted along with the recommended sustainable escapement goal.