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Optimal Production of Chinook Salmon from the Chena and Salcha Rivers

Matthew J. Evenson

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Alaska Department of Fish and Game **Division of Sport Fish**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

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

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
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	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

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	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

FISHERY MANUSCRIPT SERIES NO. 02-01

OPTIMAL PRODUCTION OF CHINOOK SALMON FROM THE CHENA AND SALCHA RIVERS

by

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ABSTRACT

Spawner-recruit analyses were performed for Salcha River and Chena River chinook salmon populations using escapement and harvest data. Abundance of returning adult chinook salmon has been assessed annually in the Chena River since 1986 and in the Salcha River since 1987. These assessments have been conducted using a combination of mark-recapture and counting tower techniques. Age composition for all years were estimated from carcass surveys of the spawning grounds. Estimates of total recreational harvest were gathered from annual statewide harvest postal surveys. Age composition of this harvest was not estimated directly, but was assumed similar to age composition of escapements. Estimates of commercial and subsistence harvests were gathered from fish ticket and household surveys, respectively. Age composition was estimated from scale samples collected from the fisheries. Scale pattern analysis was used to apportion commercial and subsistence harvest to lower, middle, and upper stocks. Chena and Salcha River stocks comprise an unknown proportion of the middle-run stock. A series of run reconstructions was generated assuming various percentages of Chena and Salcha River stocks comprising the middle-run commercial and subsistence harvest. These assumed percentages ranged from 10% to 35% for each river. For each iteration, a given percentage was assumed constant across years. Complete return estimates (for ages 3-8) were generated for years 1986-1991 for the Chena River and 1987-1991 for the Salcha River. Spawning escapements in the Chena River in 1993 and in the Salcha River in 1994 are the largest on record. Inclusion of returns from these years (1992-1994) would provide greater contrast in spawning escapements and would enhance the spawner-recruit relationship. Therefore, returns of age-8 fish from the 1992 brood year, age-7 and 8 fish from the 1993 brood year, and age-6-8 from the 1994 brood year were extrapolated for both rivers and included in the analyses.

Spawning abundance that produces maximum-sustained yield ($\hat{N}_{MSY}$) was estimated with regression analysis using Ricker's two-parameter model. Six estimates of $\hat{N}_{MSY}$ were estimated for each river corresponding to assumed percentages of river-specific harvest of the middle run. Estimates of $\hat{N}_{MSY}$ for the Salcha River population ranged from 4,075-4,144 and for the Chena River population ranged from 3,547-3,854 chinook salmon. These estimates corresponded to average exploitation rates ranging from 0.75-0.83 and 0.70-0.81 and average return per spawner values ranging from 4.0-6.0 and 3.4-5.4 for the Salcha and Chena rivers, respectively.

Because estimates of $\hat{N}_{MSY}$ were similar for the various assumptions of river-specific harvests in the commercial and subsistence fisheries, the estimates with the lowest statistical bias were chosen for the point estimates to develop escapement goal ranges. For the Chena River population, the optimal $\hat{N}_{MSY}$ was 3,547 ($\hat{N}_{MSY(10\%)}$) spawners, and was 4,075 ($\hat{N}_{MSY(10\%)}$) spawners for the Salcha River population. A range of 0.8 to 1.6 times the estimate of $\hat{N}_{MSY}$ was applied to the point estimates to develop the biological escapement objectives.

Based on this analysis, an escapement objective of 3,300-6,500 chinook salmon is recommended for the Salcha River and an objective of 2,800-5,700 chinook salmon is recommended for the Chena River.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Chena River, Salcha River; spawning abundance, age composition, escapement goal, stock-recruit analysis, maximum-sustained yield.

INTRODUCTION

The Salcha and Chena rivers support some of the largest chinook salmon *Oncorhynchus tshawytscha* escapements in the Yukon River drainage (Schultz et al. 1994). Before reaching their spawning grounds in the mid to upper reaches of these rivers, the chinook salmon travel about 1,500 km from the Bering Sea and pass through and are harvested in six different commercial fishing districts in the Yukon and Tanana rivers (Figure 1). Subsistence and personal use fishing also occur in each district. Popular sport fisheries occur in the lower 3 km of the Salcha River and in the lower 72 km of the Chena River.

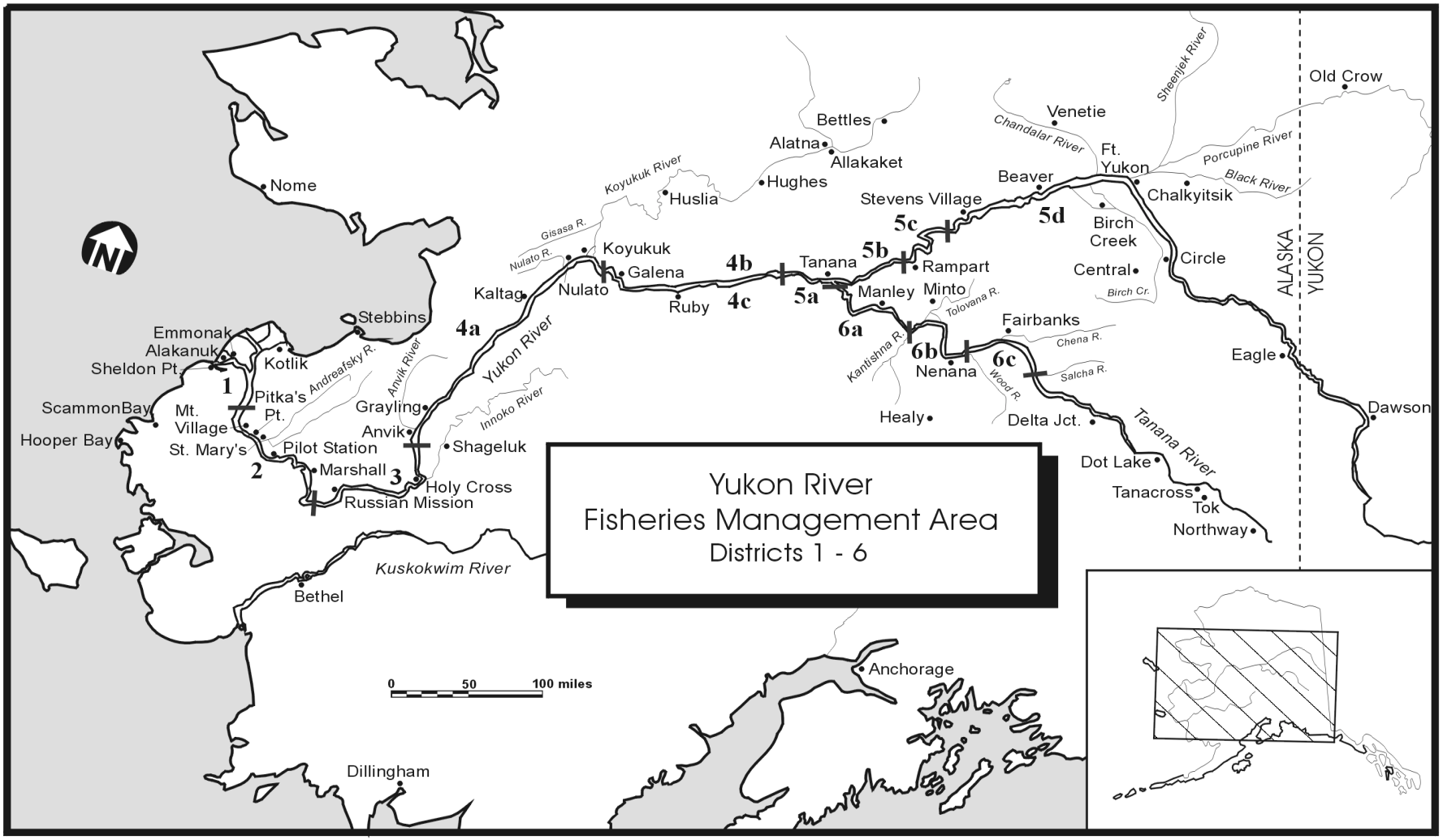


Figure 1.-Fishing districts in the Yukon River drainage.

The ADF&G has managed the salmon fisheries in the Yukon drainage over the past few decades with the dual goals of maintaining important fisheries and achieving desired escapement levels. Escapement objectives for the Chena and Salcha rivers have been established since 1984. However, the technical basis for these escapement goals has been simple escapement averaging methodology. This is primarily because only recently have long-term data sets of accurate estimates of escapement become available for more rigorous analyses.

Buklis (1993) provides the following information concerning the various escapement goals that ADF&G has used for the Chena and Salcha rivers through 2000:

CHENA RIVER CHINOOK SALMON

Biological Escapement Goal and Units of Measure:

>1,700 aerial survey count for index area Moose Cr. Dam to Middle Fork R.(ADF&G 1992).

Method for Establishing this Biological Escapement Goal:

Average from 1978 through 1983 of peak annual aerial surveys, with no years missing or excluded. Resulting average was rounded to the nearest one hundred chinook (1,800). However, that number was reduced approximately 7% and rounded to the nearest one hundred chinook (1,700) for the index area Moose Creek Dam to the Middle Fork River, based upon historic spawner distribution.

Historical Background Regarding Any Prior Escapement Goals for This Stock:

An aerial survey escapement goal range of 300 to 1,800 chinook salmon was proposed for the Chena River in 1981. In April 1982 a goal of 1,300 chinook salmon was proposed. In April 1984 a chinook salmon escapement goal range of 1,000 to 1,700 was established for the Chena River index area from Moose Creek Dam to the Middle Fork confluence. The low end of the range was the average peak aerial survey estimate for the years 1972-1977, while the upper end of the range was the average estimates for the years 1978-1983 (ADF&G 1984). In 1988, the escapement goal was taken as 1,700 chinook, the upper end of the former range (Whitmore et al. 1990).

and,

SALCHA RIVER CHINOOK SALMON

Biological Escapement Goal and Units of Measure:

>2,500 aerial survey count for index area TAPS crossing to Caribou Cr (ADF&G 1992).

Method for Establishing this Biological Escapement Goal:

Goal is the midpoint of the range 1,500 to 3,500 chinook. Low end of range is average from 1972 through 1977 of peak annual aerial surveys, while upper end of range is average from 1978 through 1983 peak annual aerial surveys, with no years missing or excluded for either average. Resulting averages were rounded to the nearest one hundred chinook.

Historical Background Regarding Any Prior Escapement Goals for This Stock:

> *In 1979 a chinook salmon aerial survey escapement goal of 1,500 for the Salcha River was proposed. In 1981 an escapement goal range of 800 to 3,100 was proposed. In April 1982 a goal of 3,000 was proposed. In April 1984 an escapement goal range of 1,500 to 3,500 was established for the index area from the Trans Alaska Pipeline System (TAPS) crossing upstream to Caribou Creek. The low end of the Range was the average peak aerial survey estimate for the years 1972-1977, while the upper end of the range was the average estimates for the years 1978-1983 (ADF&G 1984). In 1988, the goal was taken as 3,500 chinook, the upper end of the former range (Whitmore et al. 1990). The current goal was established beginning with the 1990 season (ADF&G 1991).*

As a result of new escapement monitoring programs beginning in 1986 in the Chena River and 1987 in the Salcha River, which included mark-recapture and tower counting methodologies, Huttunen and Bergstrom (1999) proposed changes to both the escapement goals described above as follows:

Chena River: Biological Escapement Goal Range = 5,600-11,200 chinook salmon based on tower and/or mark-recapture estimates; and, in years when tower or mark-recapture estimates are not available, a Biological Escapement Goal Range = 1,600-3,200 Index Aerial Survey count (same index area as described above).

Salcha River: Biological Escapement Goal Range = 6,800-13,600 chinook salmon based on tower and/or mark-recapture estimates; and, in years when tower or mark-recapture estimates are not available, a Biological Escapement Goal Range = 2,000-4,000 Index Aerial Survey Count (same index area as described above).

The purpose of this report is to develop estimates of total runs for Chena and Salcha rivers chinook salmon populations and use these data to develop stock-recruit relationships, determine escapement levels that will support maximum sustainable yield, and make recommendations to ADF&G as to appropriate biological escapement goals.

SPAWNING ABUNDANCE

Abundance of returning adult chinook salmon has been assessed annually in the Chena River since 1986 and in the Salcha River since 1987 (Table 1). These assessments have been conducted using a combination of mark-recapture and counting tower techniques. Aerial survey index counts have also been conducted for a number of years in both rivers but are poorly correlated with estimates of abundance (Figure 2). Age composition for all years were estimated from carcass surveys of the spawning grounds (Tables 2 and 3).

Commercial/Subsistence Harvests

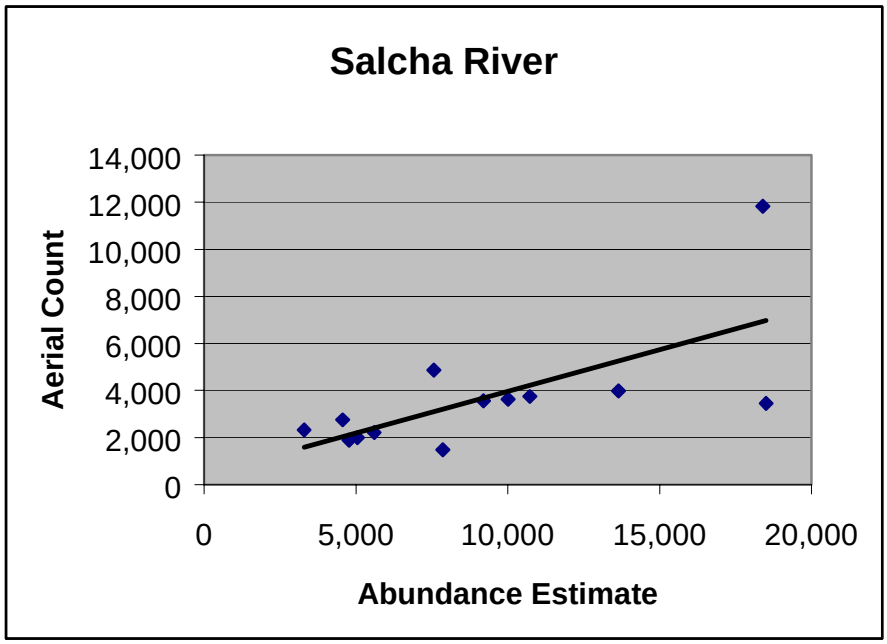
The Alaska portion of the Yukon River is divided into six management districts. The Canadian Department of Fisheries and Oceans conducts corresponding fishery management activities for the Canadian portion of the drainage (Figure 1). Total annual commercial harvests by district were generated from mandatory returns of fish tickets and were considered censuses of total harvest. Subsistence harvests by district were determined from household surveys. Age composition from the commercial and subsistence catch were determined from analysis of scales collected from a sample of the harvest in each district. Scale pattern analysis was used to

Table 1.-Estimated abundance, highest counts during aerial surveys, aerial survey conditions, and proportion of the population observed during aerial surveys for chinook salmon populations in the Salcha and Chena rivers.

River Year	Estimated Abundance	CV	Aerial Survey Count	Aerial Survey Condition	Proportion Observed During Aerial Survey
Salcha:					
1987	4,771[a]	0.11	1,898	Fair	0.40
1988	4,562[a]	0.12	2,761	Good	0.61
1989	3,294[a]	0.19	2,333	Good	0.71
1990	10,728[a]	0.13	3,744	Good	0.35
1991	5,608[a]	0.12	2,212	Poor	0.39
1992	7,862[a]	0.12	1,484	Fair-Poor	0.19
1993	10,007[b]	0.04	3,636	Fair	0.36
1994	18,399[b]	0.03	11,823	Good	0.64
1995	13,643[b]	0.03	3,978	Fair-Good	0.29
1996	7,570[a]	0.16	4,866	Fair-Good	0.64
1997	18,514[b]	0.06	3,458	Poor	0.19
1998	5,055[b]	0.07	1,992	Poor	0.40
1999	9,198[b]	0.03	3,570	Fair	0.39
Min	**3,294**		**1,484**		**0.19**
Max	**18,514**		**11,823**		**0.71**
Average	**9,170**		**3,673**		**0.43**
Median	**7,862**		**3,458**		**0.39**
Chena:					
1986	9,065[a]	0.12	2,031	Fair	0.22
1987	6,404[a]	0.09	1,312	Fair	0.20
1988	3,346[a]	0.17	1,966	Fair-Poor	0.59
1989	2,666[a]	0.09	1,180	Fair-Good	0.44
1990	5,603[a]	0.21	1,436	Fair-Poor	0.26
1991	3,025[a]	0.09	1,276	Poor	0.42
1992	5,230[a]	0.09	825	Fair-Poor	0.16
1993	12,241[b]	0.03	2,943	Fair	0.24
1994	11,877[b]	0.04	1,570	Fair-Poor	0.13
1995	9,680[a]	0.10	3,567	Fair	0.37
1996	7,153[a]	0.13	2,233	Poor-Good	0.31
1997	10,811[a]	0.11	3,495	Fair-Good	0.32
1997	13,390[b]	0.05	3,495	Fair-Good	0.26
1998	4,745[b]	0.11	386	Incomplete	0.08
1999	6,485[b]	0.07	2,412	Fair	0.33
Min	**2,666**		**386**		**0.08**
Max	**13,390**		**3,567**		**0.59**
Average	**7,443**		**2,008**		**0.29**
Median	**6,485**		**1,966**		**0.26**

[a] Estimate from mark-recapture study.

[b] Estimate from counting tower.



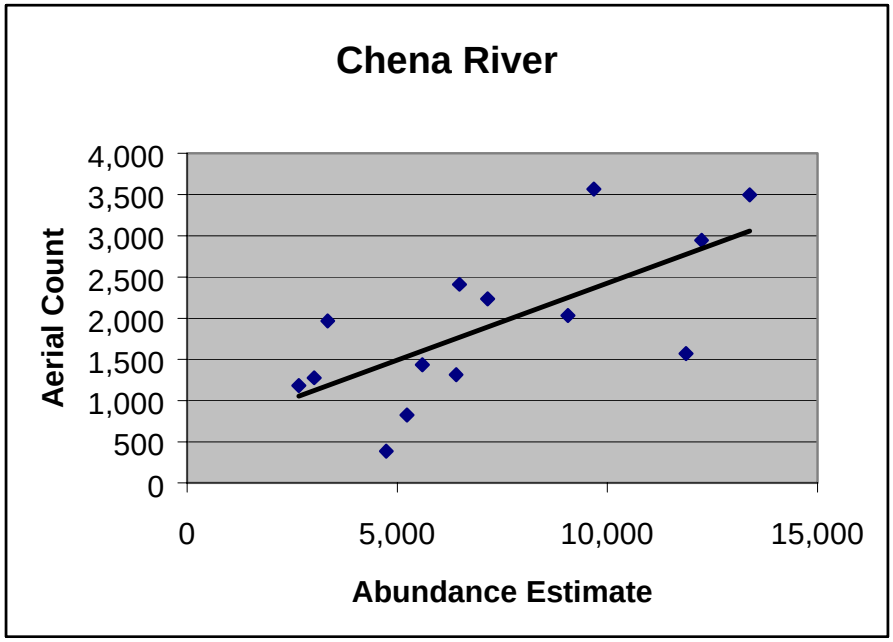


Figure 2.-Estimated abundance of chinook salmon in the Salcha River (1987-1999) and Chena River (1986-1999) against their respective aerial survey counts.

Table 2.-Return by age from escapements in the Salcha River from brood years 1987-1994.

		Return By Age											
Brood		3	4		5		6		7		8		Total
Year	Escapement	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Return
1987	4,771	20	426	0	2,641	37	3,093	22	885	0	0	0	7,124
1988	4,562	11	2,811	0	3,910	0	9,659	35	350	75	0	0	16,851
1989	3,294	97	2,805	0	7,218	0	8,561	0	1,261	0	0	0	19,942
1990	10,728	88	496	0	2,803	0	1,765	0	309	0	0	0	5,461
1991	5,608	106	1,852	0	3,572	0	12,857	0	123	0	0	0	18,510
1992	7,862	0	670	0	2,674	0	899	0	30	0	**1**[a]	**0**[a]	4,274
1993	10,007	303	2,674	0	3,637	0	6,112	0	**651**[a]	**11**[a]	**2**[a]	**0**[a]	13,391
1994	18,399	0	245	0	2,217	0	**2,765**[a]	**4**[a]	**268**[a]	**4**[a]	**1**[a]	**0**[a]	5,505

[a] Estimate was extrapolated from partial return.

Table 3.-Return by age from escapements in the Chena River from brood years 1986-1994.

		Return By Age											
Brood		3	4		5		6		7		8		Total
Year	Escapement	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Return
1986	9,065	16	1,277	0	1,124	0	1,408	22	135	0	0	0	3,982
1987	6,404	0	259	0	1,196	13	3,403	0	278	0	0	0	5,149
1988	4,183	0	2,470	0	5,043	0	6,031	46	332	37	0	0	13,959
1989	3,333	113	3,599	0	5,173	0	6,863	0	1,277	0	0	0	17,025
1990	7,004	61	348	0	2,017	0	1,399	0	83	19	0	0	3,927
1991	3,781	0	430	0	3,698	0	4,143	0	228	0	0	0	8,500
1992	6,538	0	576	0	1,598	0	874	0	92	0	**0**[a]	**1**	3,141
1993	12,241	202	4,929	0	3,434	0	3,818	0	**725**[a]	**11**[a]	**1**[a]	**5**	13,125
1994	11,877	38	208	0	1,656	0	**1,392**[a]	**11**[a]	**194**[a]	**3**[a]	**0**[a]	**1**	3,503

[a] Estimate was extrapolated from partial return.

identify run of origin from the commercial and subsistence catch. Runs were identified as **Lower** (tributary streams in Alaska that drain the Andreafsky Hills and Kaltag Mountains between river miles 100 and 500), **Middle** (Upper Koyukuk River and Tanana River tributaries in Alaska between river miles 800 and 1,100), and **Upper** (tributary streams in Canada that drain the Pelly and Big Salmon mountains between river miles 1,300 and 1,800) **River Run stocks**. Chinook salmon bound for the Chena and Salcha rivers comprise a portion of the middle run and are harvested in all six districts. Harvest in districts 1-4 is a mixture of all three stocks, harvest in district 5 is a mixture of Middle and Upper River Run stocks (in subdistrict 5a), and harvest in district 6 (Tanana drainage) is considered entirely Middle River Run fish.

Estimates of middle run harvest by age, fishery and district are given in annual *Origins of Chinook Salmon in the Yukon River Fisheries* reports, and have been updated in the most recent report (Lingnau 2000; Table 4).

Recreational Harvests

Estimates of total annual recreational harvest in the Chena and Salcha rivers are obtained through the Division of Sport Fish statewide harvest survey (e.g. Howe et al. 2001d). Age composition of the harvest is not known. Since 1986, harvests have ranged from 39 to 1,280 chinook salmon in the Chena River and 47-1,448 in the Salcha River. As a means of estimating age-specific harvest in each river, it was assumed that age composition of the recreational harvest was similar to that of the escapement. Thus,

$$\hat{H}_{\mathrm{Rec},a} = \hat{\Theta}_{escape,a} \hat{H}_{\mathrm{Rec}} \qquad (1)$$

where:

$\hat{\Theta}_{escape,a}$ = the proportion of the escapement that is age *a*; and,

$\hat{H}_{\mathrm{Rec}}$ = the total recreational harvest estimated from the statewide harvest survey.

Estimates of age-specific recreational harvests are shown in Tables 5 and 6.

Run Reconstruction

Estimates of age-specific escapement, recreational harvest, and commercial and subsistence harvests of middle run fish were combined to estimate total brood return by year for each river. Unknown is the proportion of the middle run harvest (from the commercial and subsistence catch) that is comprised of Chena and Salcha rivers chinook salmon. A series of run reconstructions was produced that assumed various percentages of Chena or Salcha rivers origin fish of the middle run commercial and subsistence harvest. Percentages considered were 10, 15, 20, 25, 30 and 35%. Because there are many spawning stocks that contribute to the Middle River Run, and because the populations of the Chena and Salcha rivers are among the largest of these stocks, it is believed that this range of assumed values includes the true proportion of the stock-specific harvest. It was also assumed that a percentage was the same across ages and years. Thus, the age specific harvest of Chena or Salcha rivers chinook salmon ($\hat{H}_{river}$) in the commercial and subsistence catch was calculated as the total middle harvest ($\hat{H}_{middle}$) multiplied by the assumed proportion (π):

Table 4.-Total commercial and subsistence harvest of middle run stocks in the Yukon River, 1986-1999.

	Total Harvest by Age						
Year	3	4	5	6	7	8	Total
1986	604	5,232	4,389	3,560	1,288	40	15,113
1987	70	2,037	4,242	30,696	2,761	0	39,807
1988	265	3,196	3,245	12,877	6,433	44	26,061
1989	280	744	9,876	13,885	2,131	56	26,973
1990	8	5,649	9,176	24,591	2,554	13	41,991
1991	1	3,808	24,945	12,885	1,982	76	43,698
1992	145	7,089	6,207	26,436	603	2	40,482
1993	369	10,483	14,478	18,112	631	26	44,098
1994	387	1,715	27,366	23,273	1,025	0	53,766
1995	28	4,126	5,421	32,769	2,077	17	44,438
1996	342	1,254	9,149	1,208	1,291	40	13,284
1997	2	4,635	2,043	23,740	393	0	30,814
1998	36	501	12,447	4,110	959	9	18,062
1999[a]	104	1,098	3,281	12,374	266	0	17,122

[a] Harvest estimates for 1999 are preliminary. Age composition information was applied to the harvest according to Price 2000. Proportion of middle run harvest was assumed to be 15% for districts Y1-Y4 and 100% for district Y6.

Table 5.-Harvest by age from the recreational fishery in the Salcha River from brood years 1987-1994.

		Harvest By Age											
Brood		3	4		5		6		7		8		Total
Year	Escapement	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Harvest
1987	4,771	1	28	0	16	0	186	1	34	0	0	0	266
1988	4,562	1	17	0	235	0	375	1	37	8	0	0	674
1989	3,294	1	169	0	280	0	909	0	227	0	0	0	1,585
1990	10,728	5	19	0	298	0	318	0	12	0	0	0	652
1991	5,608	4	197	0	644	0	499	0	3	0	0	0	1,347
1992	7,862	0	121	0	104	0	22	0	1	0	**0**[a]	**0**[a]	248
1993	10,007	55	104	0	88	0	296	0	**38**[a]	**1**[a]	**0**[a]	**0**[a]	581
1994	18,399	0	6	0	107	0	**123**[a]	**0**[a]	**17**[a]	**0**[a]	**0**[a]	**0**[a]	254

[a] Estimate was extrapolated from partial return.

Table 6.-Harvest by age from the recreational fishery in the Chena River from brood years 1986-1994.

		Harvest By Age											
Brood		3	4		5		6		7		8		Total
Year	Escapement	1.1	1.2	2.1	1.3	2.2	1.4	2.3	1.5	2.4	1.6	2.5	Harvest
1986	9,065	2	15	0	41	0	10	0	8	0	0	0	76
1987	6,404	0	9	0	9	0	204	0	23	0	0	0	245
1988	4,183	0	18	0	302	0	504	4	21	2	0	0	852
1989	3,333	1	216	0	433	0	441	0	269	0	0	0	1,359
1990	7,004	4	29	0	130	0	294	0	8	2	0	0	467
1991	3,781	0	28	0	778	0	398	0	14	0	0	0	1,218
1992	6,538	0	121	0	154	0	55	0	6	0	**0**[a]	**0**[a]	336
1993	12,241	43	474	0	216	0	260	0	**71**[a]	**1**[a]	**0**[a]	**0**[a]	1,065
1994	11,877	4	13	0	113	0	**91**[a]	**0**[a]	**16**[a]	**0**[a]	**0**[a]	**0**[a]	237

[a] Estimate was extrapolated from partial return.

$$\hat{H}_{river,a} = \pi \hat{H}_{middle,a} \,. \tag{2}$$

Complete return estimates (for ages 3-8) were available for years 1986-1991 for the Chena River and 1987-1991 for the Salcha River. Spawning escapements in the Chena River in 1993 and in the Salcha River in 1994 are the largest on record (see Table 1). Inclusion of returns from these years (1992-1994) would provide greater contrast in spawning escapements and would enhance the estimated spawner-recruit relationship. Therefore, returns of age-8 fish from the 1992 brood year, ages 7 and 8 fish from the 1993 brood year, and ages 6-8 from the 1994 brood year were extrapolated for both rivers. On average, ages 7 and 8 fish represented an estimated 8% of the total return (combined), while age-6 fish represented an estimated 50% of the total return.

Production at age for a year class was estimated as the sum of escapement by age and harvest by age within a calendar year:

$$\hat{R}_{a,y} = \hat{N}_{a,y+a} + \hat{H}_{rec,a,y+a} + \hat{H}_{river,a,y+a} \tag{3}$$

where y denotes year class and $y+a$ the calendar year. Production for year classes 1986 through 1991 was estimated for each as the sum production at age over age:

$$\hat{R}_y = \sum_{a=3}^{8} \hat{R}_{a,y} \tag{4}$$

For year classes 1992 through 1994, production was estimated by summing across younger ages, then prorating these sums for the older ages yet to mature:

$$\hat{R}_{1992} = \frac{\sum_{a=3}^{7} \hat{R}_{a,1992}}{1-\hat{\bar{\tau}}_8} \qquad \hat{R}_{1993} = \frac{\sum_{a=3}^{6} \hat{R}_{a,1993}}{1-\hat{\bar{\tau}}_{7+}} \qquad \hat{R}_{1994} = \frac{\sum_{a=3}^{5} \hat{R}_{a,1994}}{1-\hat{\bar{\tau}}_{6+}} \tag{5}$$

where $\hat{\bar{\tau}}_8$ is the average fraction of production represented by eight-year-olds for year classes 1986 through 1991, $\hat{\bar{\tau}}_{7+}$ the average fraction for seven-year-olds and older for year classes 1986 through 1990, and $\hat{\bar{\tau}}_{6+}$ six-year olds and older for year classes 1986 through 1989.

Estimated production for Chena River and Salcha River populations are shown in Tables 7 and 8.

ANALYSIS

Spawner-Recruit Model and Analysis of Error

Spawning abundance that produces maximum-sustained yield (MSY) was estimated by regressing the log of estimated production-to-spawner ratios against estimates of spawning abundance, setting the first derivative of the result to one, and solving the relationship for $\hat{N}_{MSY}$. Ricker's two-parameter model (Ricker 1975: section 11.6) was used in the regression analysis:

$$\ln(R_y) - \ln(N_y) = \ln(\alpha) - \beta N_y + \varepsilon_y \tag{6}$$

where α is the density-independent parameter, β the density-dependent parameter, and ε_y represents process error with mean 0 and variance σ_ε^2. Because spawning abundance and

Table 7.-Estimates of escapement and their resulting returns by age for the population of chinook salmon in the Salcha River for various assumed proportions of stock-specific harvest of the middle run.

Proportion=10%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	21	835	3,315	5,113	1,022	2	10,308	2.2
1988	4,562	12	3,537	5,592	12,398	678	4	22,220	4.9
1989	3,294	112	4,022	10,235	12,747	1,617	0	28,733	8.7
1990	10,728	131	687	3,643	2,204	360	1	7,025	0.7
1991	5,608	149	2,461	5,131	15,730	221	0	23,693	4.2
1992	7,862	3	916	2,982	1,332	58	1	5,293	0.7
1993	10,007	392	3,242	4,970	7,645	809	4	17,061	1.7
1994	18,399	0	301	2,652	3,309	318	2	6,582	0.4

Proportion=15%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	22	1,026	3,625	6,019	1,073	3	11,767	2.5
1988	4,562	12	3,891	6,316	13,561	782	6	24,568	5.3
1989	3,294	119	4,546	11,603	14,385	1,682	0	32,336	10.0
1990	10,728	149	773	3,914	2,264	380	1	7,480	0.8
1991	5,608	168	2,667	5,588	16,917	269	0	25,611	4.6
1992	7,862	4	979	3,085	1,537	71	1	5,678	0.7
1993	10,007	409	3,473	5,592	8,264	862	5	18,606	2.0
1994	18,399	0	326	2,816	3,517	332	2	6,994	0.4

Proportion=20%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	22	1,216	3,935	6,924	1,124	3	13,226	2.8
1988	4,562	12	4,246	7,040	14,725	885	8	26,916	5.9
1989	3,294	126	5,071	12,971	16,024	1,747	0	35,939	10.9
1990	10,728	167	858	4,185	2,325	399	2	7,936	0.7
1991	5,608	187	2,874	6,046	18,104	317	0	27,529	4.9
1992	7,862	6	1,042	3,187	1,743	85	2	6,063	0.8
1993	10,007	426	3,705	6,214	8,883	916	6	20,150	2.0
1994	18,399	0	351	2,980	3,725	347	2	7,406	0.4

-continued-

Table 7.-Page 2 of 2.

Proportion=25%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	23	1,406	4,246	7,830	1,176	4	14,684	3.1
1988	4,562	12	4,600	7,764	15,888	989	10	29,264	6.4
1989	3,294	134	5,595	14,340	17,662	1,811	0	39,541	12.0
1990	10,728	186	944	4,456	2,385	419	2	8,392	0.8
1991	5,608	207	3,080	6,503	19,291	365	0	29,447	5.3
1992	7,862	7	1,104	3,289	1,948	98	2	6,449	0.8
1993	10,007	443	3,937	6,837	9,501	970	7	21,695	2.2
1994	18,399	0	376	3,144	3,934	361	2	7,818	0.4

Proportion=30%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	23	1,597	4,556	8,735	1,227	5	16,143	3.4
1988	4,562	12	4,955	8,488	17,052	1,093	12	31,611	6.9
1989	3,294	141	6,119	15,708	19,301	1,876	0	43,144	13.1
1990	10,728	204	1,030	4,727	2,446	439	3	8,848	0.8
1991	5,608	226	3,286	6,961	20,478	413	0	31,365	5.6
1992	7,862	9	1,167	3,391	2,154	111	2	6,834	0.9
1993	10,007	460	4,169	7,459	10,120	1,024	8	23,240	2.3
1994	18,399	1	401	3,308	4,142	375	2	8,230	0.4

Proportion=35%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1987	4,771	23	1,787	4,866	9,641	1,278	6	17,602	3.7
1988	4,562	12	5,309	9,211	18,216	1,197	14	33,959	7.4
1989	3,294	148	6,643	17,076	20,939	1,940	0	46,747	14.2
1990	10,728	223	1,116	4,998	2,506	458	3	9,303	0.9
1991	5,608	245	3,493	7,418	21,665	461	0	33,283	5.9
1992	7,862	10	1,230	3,493	2,359	125	2	7,219	0.9
1993	10,007	477	4,400	8,081	10,739	1,078	9	24,784	2.5
1994	18,399	1	426	3,472	4,350	390	3	8,642	0.5

Table 8.–Estimates of escapement and their resulting returns by age for the population of chinook salmon in the Chena River for various assumed proportions of stock-specific harvest of the middle run.

Proportion=10%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	46	1,856	3,659	4,084	206	0	9,852	1.1
1987	6,404	1	649	1,839	5,418	404	2	8,312	1.3
1988	3,346	0	3,197	6,793	8,912	600	4	19,507	5.8
1989	2,666	128	4,863	8,342	10,581	1,675	0	25,589	9.6
1990	5,603	102	549	2,689	1,814	151	1	5,305	0.9
1991	3,025	39	871	5,391	6,915	339	0	13,554	4.5
1992	5,231	3	823	1,956	1,340	125	2	4,248	0.8
1993	12,241	279	5,866	4,895	5,316	977	9	17,341	1.4
1994	11,876	42	271	2,097	1,972	261	2	4,645	0.4

Proportion=15%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	60	2,139	4,907	5,406	237	0	12,749	1.4
1987	6,404	1	840	2,149	6,324	455	3	9,771	1.5
1988	3,346	0	3,552	7,517	10,076	704	6	21,855	6.5
1989	2,666	136	5,387	9,710	12,220	1,739	0	29,192	10.9
1990	5,603	120	634	2,960	1,875	171	1	5,761	1.0
1991	3,025	58	1,077	5,848	8,102	387	0	15,472	5.1
1992	5,231	4	885	2,058	1,546	138	2	4,634	0.9
1993	12,241	296	6,098	5,517	5,934	1,061	10	18,916	1.5
1994	11,876	42	296	2,261	2,211	285	3	5,098	0.4

Proportion=20%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	74	2,421	6,154	6,728	269	0	15,646	1.7
1987	6,404	2	1,030	2,459	7,229	506	3	11,230	1.8
1988	3,346	0	3,906	8,241	11,240	808	8	24,203	7.2
1989	2,666	143	5,911	11,079	13,858	1,804	0	32,795	12.3
1990	5,603	139	720	3,231	1,935	190	2	6,217	1.1
1991	3,025	77	1,283	6,306	9,289	435	0	17,390	5.7
1992	5,231	6	948	2,160	1,751	151	3	5,019	1.0
1993	12,241	313	6,330	6,140	6,553	1,145	11	20,492	1.7
1994	11,876	42	321	2,425	2,450	309	3	5,550	0.5

-continued-

Table 8.–Page 2 of 2.

Proportion=25%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	88	2,704	7,401	8,050	300	0	18,543	2.0
1987	6,404	2	1,220	2,770	8,135	558	4	12,689	2.0
1988	3,346	0	4,261	8,965	12,403	912	10	26,551	7.9
1989	2,666	150	6,435	12,447	15,497	1,869	0	36,397	13.7
1990	5,603	157	806	3,502	1,995	210	2	6,673	1.2
1991	3,025	97	1,490	6,763	10,476	483	0	19,309	6.4
1992	5,231	7	1,011	2,262	1,957	165	3	5,405	1.0
1993	12,241	330	6,562	6,762	7,172	1,230	12	22,067	1.8
1994	11,876	42	346	2,589	2,689	334	3	6,003	0.5

Proportion=30%		Return by Age							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	102	2,986	8,648	9,371	332	0	21,440	2.4
1987	6,404	2	1,411	3,080	9,040	609	5	14,148	2.2
1988	3,346	0	4,615	9,689	13,567	1,016	12	28,899	8.6
1989	2,666	157	6,959	13,815	17,135	1,933	0	40,000	15.0
1990	5,603	176	892	3,773	2,056	230	3	7,128	1.3
1991	3,025	116	1,696	7,221	11,663	531	0	21,227	7.0
1992	5,231	9	1,073	2,365	2,162	178	3	5,790	1.1
1993	12,241	347	6,793	7,385	7,790	1,314	13	23,642	1.9
1994	11,876	42	371	2,753	2,927	358	4	6,455	0.5

Proportion=35%		Return							
Brood Year	Escapement	3	4	5	6	7	8	Total Return	Return/ Spawner
1986	9,065	116	3,269	9,896	10,693	363	0	24,337	2.7
1987	6,404	3	1,601	3,390	9,946	660	6	15,606	2.4
1988	3,346	0	4,970	10,412	14,731	1,120	14	31,247	9.3
1989	2,666	164	7,483	15,184	18,774	1,998	0	43,603	16.4
1990	5,603	194	977	4,044	2,116	249	3	7,584	1.4
1991	3,025	135	1,902	7,678	12,850	579	0	23,145	7.7
1992	5,231	10	1,136	2,467	2,368	191	3	6,175	1.2
1993	12,241	364	7,025	8,007	8,409	1,398	14	25,218	2.1
1994	11,876	42	396	2,917	3,166	382	4	6,908	0.6

production are not known for the Chena or Salcha rivers, but were estimated, $\hat{R}_y \rightarrow R_y$ and $\hat{N}_y \rightarrow N_y$ into the stock-production model. In reality:

$$\hat{R}_y = R_y \exp(v_y) \tag{7}$$

$$\hat{N}_y = N_y \exp(u_y) \tag{8}$$

where v_y and u_y represent measurement error with means 0 and variance σ_v^2 and σ_u^2.

Similarity across years among CVs for estimates of spawning abundance (see Table 1) is evidence that measurement error in these data are log normal. Transforming the above relationships accordingly produces:

$$\ln(\hat{R}_y) = \ln(R_y) + v_y \tag{9}$$

$$\ln(\hat{N}_y) = \ln(N_y) + u_y \tag{10}$$

Measurement error in the independent variable, spawning abundance, is a function of sampling. From Cochran (1977:274-6), variance in $\ln(\hat{N})$ would have a two-stage structure with annual variation among the N plus measurement error for each estimate $\hat{N}_y$:

$$V[\ln(\hat{N})] = V[\ln(N)] + \sigma_u^2 \tag{11}$$

These variances were estimated as follows:

$$v[\ln(\hat{N})] = \frac{\sum[\ln(\hat{N}_y) - \overline{\ln(\hat{N})}]^2}{n-1} \tag{12}$$

$$\hat{\sigma}_u^2 = \frac{\sum \hat{\sigma}_{u,y}^2}{n} \tag{13}$$

$$v[\ln(N)] = v[\ln(\hat{N})] - \hat{\sigma}_u^2 \tag{14}$$

where n is the number of year classes in the data. The estimates $\hat{\sigma}_{u,y}^2$ are related to the sampling variances represented in Tables 7 and 8 in the form of CVs. Those sampling variances were log transformed as were estimates. From the delta method (Seber 1982:7-9):

$$\hat{\sigma}_{u,y}^2 = v[\ln(\hat{N}_y)] \cong v(\hat{N}_y)\hat{N}_y^{-2} = \mathrm{CV}^2(\hat{N}_y) \tag{15}$$

For the population in the Salcha River, $v[\ln(\hat{N})]$ = 0.3149 and $\hat{\sigma}_u^2$ = 0.0139, and for the population in the Chena River, $v[\ln(\hat{N})]$ = 0.3277 and $\hat{\sigma}_u^2$ = 0.0134. Thus, measurement error in spawning abundance represents about 4% of the overall variation in the independent variable in both rivers, and was ignored in the regression analysis.

Measurement error in the dependent variable (the ratio of production to spawning abundance) was not calculated because true estimates of variance for the river-specific harvests in the

commercial and subsistence fisheries and estimates of variance for the recreational harvests were not known.

Plots of residuals against predicted values of the dependent variable and residuals against year showed random distribution indicating that there was no influence of spawning abundance beyond that expressed in the Ricker two-parameter model (Figures 3 and 4). There was no evidence of autocorrelation among residuals implying there was no time-series bias associated with the data (Figure 5).

PARAMETER ESTIMATES

Spawning abundance that on average produces maximum sustained yield (N_{MSY}) was estimated by solving the following relationship derived from Ricker (1975: p. 347, Model 1, entry 17):

$$1 = (1 - \hat{\beta} N_{MSY}) \exp[\ln(\hat{\alpha}) - \hat{\beta} N_{MSY} + \hat{\sigma}_{\varepsilon}^{2} / 2] \tag{16}$$

The term $\exp(\hat{\sigma}_{\varepsilon}^{2} / 2)$ in the equation above represents a correction for process error (Hillborn 1985) where $\hat{\sigma}_{\varepsilon}^{2} \approx \hat{\sigma}_{r}^{2}$ (the residual mean squares in the fitted model). Estimates of optimal spawning escapement ($\hat{N}_{MSY}$) ranged from 4,075-4,144 for the Salcha River population and from 3,547-3,854 for the Chena River population with percentages of river-specific middle run harvests ranging from 10%-35% (Table 9). These spawning escapements corresponded to optimal exploitation (μ_{MSY}) rates that ranged from 0.75-0.83 for Salcha River chinook salmon, and 0.70-0.81 for Chena River chinook salmon. Average return per spawner values ranged from 4.0-6.0 for the Salcha River population and from 3.4-5.4 for the Chena River population.

ESTIMATION OF VARIANCE THROUGH SIMULATION

The estimated variance $v(\hat{N}_{MSY})$ and 90% confidence intervals for $\hat{N}_{MSY}$ were calculated through non-parametric boot-strapping of residuals from the regression (Efron and Tibshirani 1993:111-5). Residuals were calculated as differences between observed and predicted values:

$$\zeta_{y} = Y_{y} - \hat{\mathrm{E}}[Y_{y}] \tag{17}$$

where $Y_y \equiv \ln(\hat{R}_y / \hat{N}_y)$ and $\hat{\mathrm{E}}[Y_y]$ is the predicted value. A new set of dependent variables was then generated by sampling the residuals from the original regression:

$$\tilde{Y}_{y} = \zeta_{y}^{*} + \hat{E}[Y_{y}] \tag{18}$$

where the ζ_{y}^{*} are drawn randomly with replacement from the original vector $\boldsymbol{\zeta}$ of the n original residuals. The $\tilde{Y}_y$ were regressed against the $\hat{N}_y$, and the result used to calculate a simulated estimate, $\tilde{N}_{MSY}$. This process was repeated 1,000 times to generate 1,000 new estimates $\{\tilde{N}_{MSY(k)}\}$. Over all K (=1,000) simulations, the estimated variance is (from Efron and Tibshirani 1993:47):

$$v(\hat{N}_{MSY}) = \frac{\sum_{k=1}^{K} (\tilde{N}_{MSY(k)} - \overline{N}_{MSY})^{2}}{K - 1} \tag{19}$$

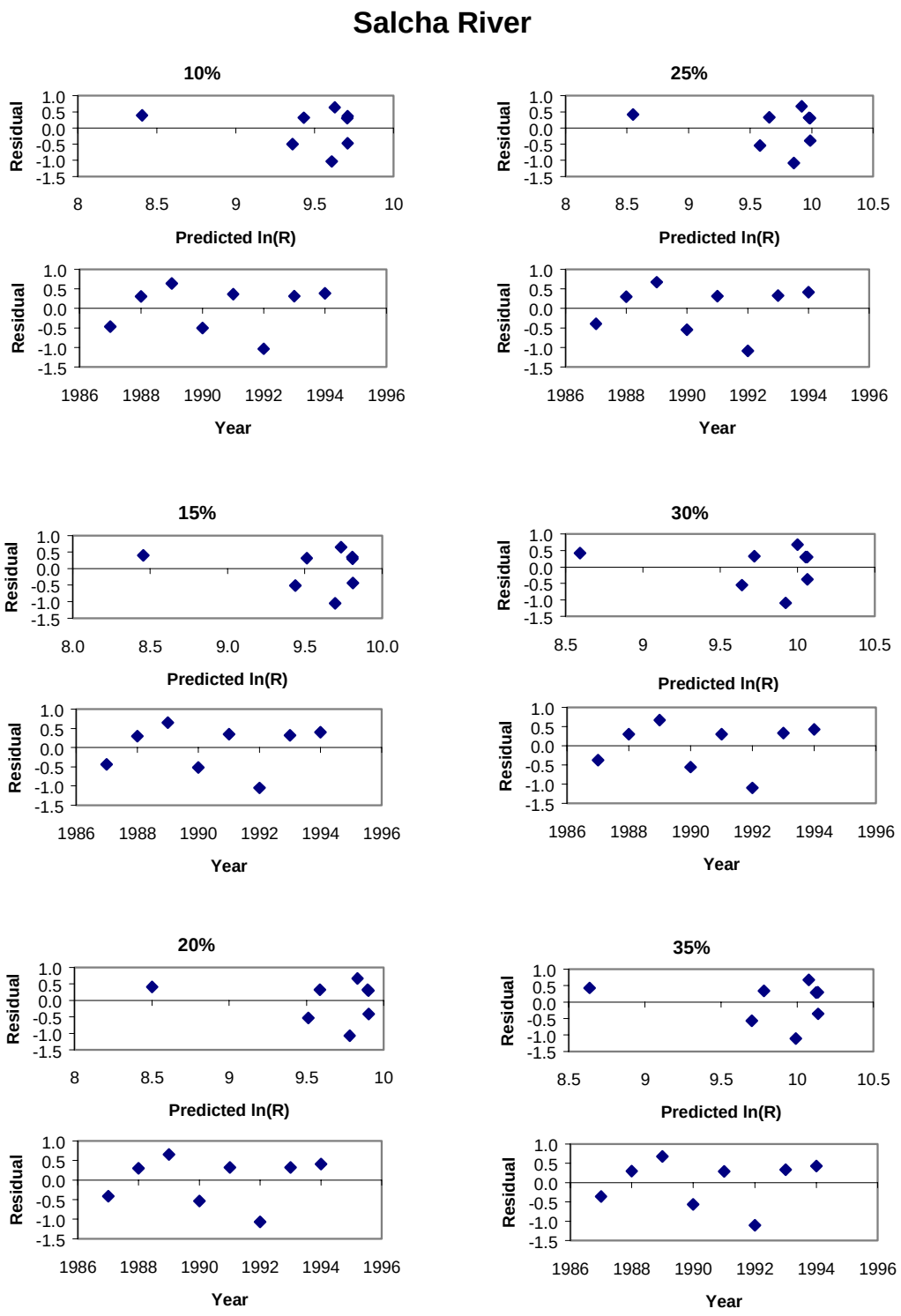


Figure 3.-Plot of residuals versus predicted estimates of ln R and residuals against year for the Salcha River for proportions of middle-run harvest ranging from 10-35%.

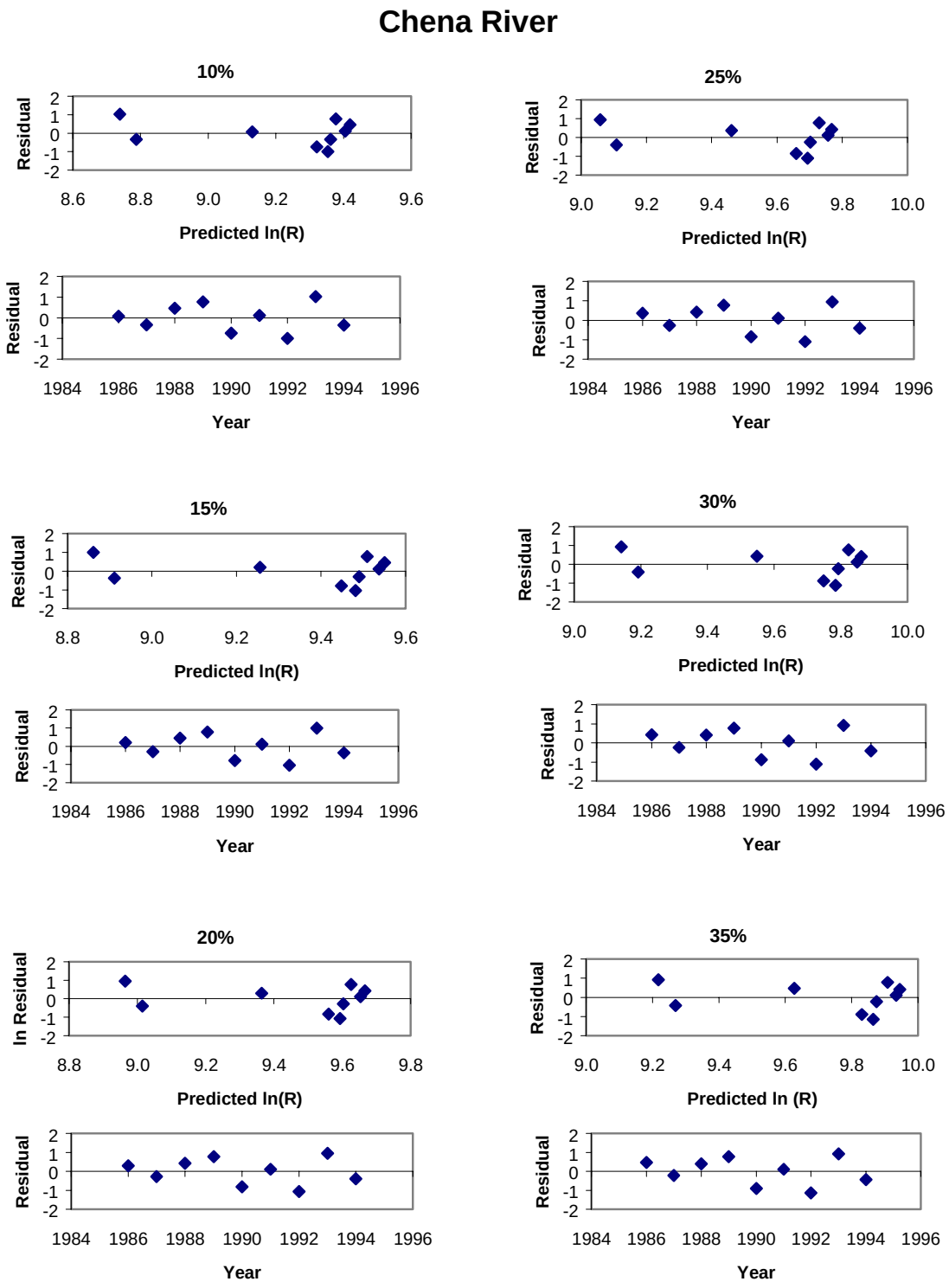


Figure 4.-Plot of residuals versus predicted estimates of ln R and residuals against year for the Chena River for proportions of middle-run harvest ranging from 10-35%.

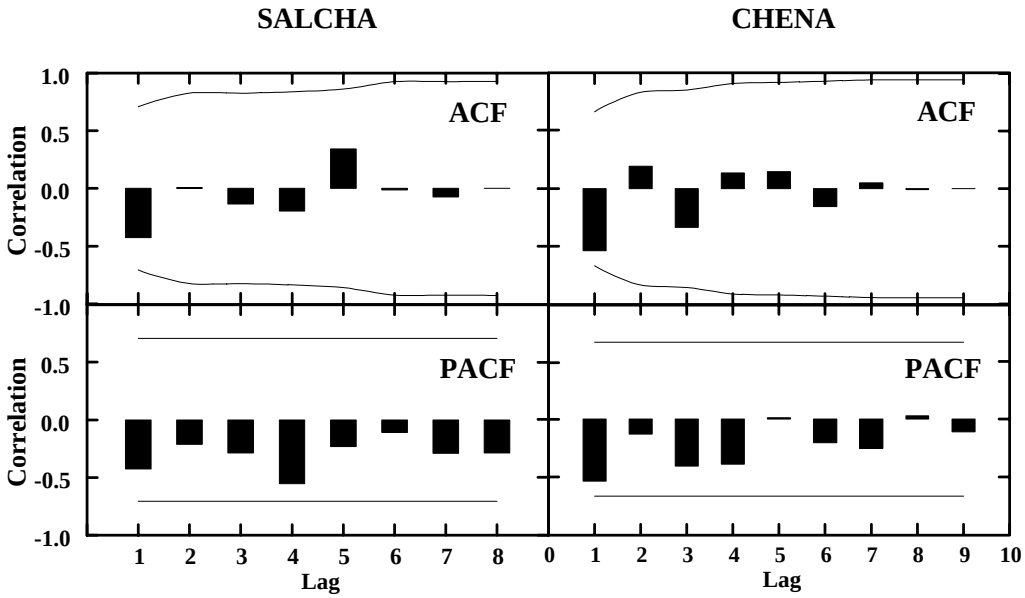


Figure 5.-Autocorrelations and partial autocorrelations among residuals assuming 10% harvest rate of middle-run stocks.

Table 9.-Estimates of optimal spawning (N_{MSY}), production (R_{MSY},) harvest (C_{MSY}), exploitation rate (μ_{MSY}), return per spawner (R/S), and alpha (α) and beta (β) parameters for the population of chinook salmon in the Salcha and Chena rivers for various assumed proportions of stock-specific harvest of the middle run.

Salcha River							
Proportion of Middle Run Harvest	N_{MSYy}	R_{MSY}	C_{MSY}	μ_{MSY}	**Return/** Spawner	α	β
10%	4,075	16,115	12,039	0.75	4.0	8.74	0.00019
15%	4,098	17,908	13,810	0.77	4.4	9.86	0.00020
20%	4,115	19,691	15,576	0.79	4.8	10.98	0.00020
25%	4,127	21,466	17,339	0.81	5.2	12.10	0.00020
30%	4,136	23,235	19,099	0.82	5.6	13.22	0.00021
35%	4,144	25,000	20,856	0.83	6.0	14.35	0.00021

Chena River							
Proportion of Middle Run Harvest	N_{MSYy}	R_{MSY}	C_{MSY}	μ_{MSY}	**Return/** Spawner	α	β
10%	3,547	12,012	8,464	0.70	3.39	7.33	0.000218
15%	3,643	13,781	10,138	0.74	3.78	8.40	0.000219
20%	3,716	15,528	11,812	0.76	4.18	9.47	0.000220
25%	3,772	17,259	13,487	0.78	4.58	10.55	0.000221
30%	3,817	18,980	15,162	0.80	4.97	11.63	0.000223
35%	3,854	20,691	16,837	0.81	5.37	12.71	0.000224

where $\overline{N}_{MSY} = K^{-1}\sum_{k=1}^{K}\tilde{N}_{MSY(k)}$. The difference between $\hat{N}_{MSY}$ and $\overline{N}_{MSY}$ is an indication of statistical bias in the former statistic (note this statistical bias is assumed to arise only from process error in the regressions). The percentile method (Efron and Tibshirani 1993:124-126) was used to provide 90% confidence intervals about $\hat{N}_{MSY}$.

Estimated relative bias in $\hat{N}_{MSY}$ ranged from 4%-8% for Salcha River chinook salmon and 11%-22% for Chena River chinook salmon (Tables 10 and 11). Coefficient of variation for estimates of $\hat{N}_{MSY}$ were relatively low and stable for the Salcha River iterations (range 0.15-0.18), however because of the larger relative bias associated with the Chena River simulations, CVs ballooned to much larger values (0.32-0.47). Ninety percent confidence intervals were reasonably narrow for all estimates, suggesting that a small number of extreme bootstrap estimates of $\hat{N}_{MSY}$ were the cause of the large variances for the Chena River estimates.

DISCUSSION

This analysis suffers from three major shortfalls: a relatively small contrast in estimates of spawning abundance, few paired data points of spawning abundance and subsequent production, and an incomplete understanding of total return. Contrast in escapements (measured as maximum observed escapement divided by minimum observed escapement) is 4.59 for the Chena River population and 5.59 for the population from the Salcha River. Normally, contrasts between 4-8 are considered minimum for conducting stock-recruit analysis, while ranges > 8 should produce the best estimates (CTC 1999). Without sufficient contrast, the ability to understand how recruitment will respond to different spawning stock sizes is limited and the estimates of $\hat{N}_{MSY}$ are prone to severe bias. The contrast in estimated spawning abundance observed for these two populations is likely small due to the high exploitation rates of these stocks in the various fisheries. The consequence is that the strong effects from density dependence from large escapements are not known and the estimates of μ_{MSY} are artificially high. Given that escapements in years since 1994 have all been between the bounds of the maximum and minimum observed, stock-recruit analyses with a contrast greater than that used in this analysis will not be possible for at least seven more years.

The estimates of spawning abundance of chinook salmon in the Chena and Salcha rivers that on average will produce MSY are known to be biased somewhat low ($\hat{N}_{MSY} < N_{MSY}$) due to measurement error. Measurement error in estimates of spawning abundance, if ignored will make a salmon population appear more productive than it is (Hilborn and Walters 1992:288). For the Chena and Salcha populations, known measurement error in estimates of spawning abundance was minimal and was ignored in the calculations of $\hat{N}_{MSY}$. There was no correction applied to the Ricker model to adjust for measurement error in estimates of the dependant variable (R_y). To make this correction, explicit knowledge of the age-specific variances of the Chena River and Salcha River harvests in the commercial and subsistence fisheries, and estimates of age-specific variance in the recreational harvest are required. Assumptions regarding the unknown portion of the middle run harvest in the commercial and subsistence fisheries that were of Chena or Salcha rivers origin did not prove problematic in terms of

Table 10.-Comparison of model and bootstrapped estimates of N_{msy} including CV's, 90% confidence intervals, and statistical bias for the chinook salmon population in the Salcha River.

Proportion of Middle Run Harvest	Estimate	N_{MSY}	Statistical Bias	CV	L90%CI	U90%CI
10%	Model	4,075				
	Bootstrap	4,219	0.04	0.15	3,378	5,044
15%	Model	4,098				
	Bootstrap	4,313	0.05	0.16	3,382	5,199
20%	Model	4,115				
	Bootstrap	4,358	0.06	0.16	3,433	5,221
25%	Model	4,127				
	Bootstrap	4,410	0.07	0.18	3,412	5,402
30%	Model	4,136				
	Bootstrap	4,440	0.07	0.17	3,460	5,428
35%	Model	4,144				
	Bootstrap	4,478	0.08	0.18	3,434	5,534

Table 11.-Comparison of model and bootstrapped estimates of N_{msy} including CV's, 90% confidence intervals, and statistical bias for the chinook salmon population in the Chena River.

Proportion of Middle Run Harvest	Estimate	N_{MSY}	Statistical Bias	CV	L90%CI	U90%CI
10%	Model	3,547				
	Bootstrap	3,936	0.11	0.32	2,854	5,275
15%	Model	3,643				
	Bootstrap	4,122	0.13	0.32	2,922	5,709
20%	Model	3,716				
	Bootstrap	4,388	0.18	0.38	2,964	6,201
25%	Model	3,772				
	Bootstrap	4,513	0.20	0.42	2,999	6,397
30%	Model	3,817				
	Bootstrap	4,626	0.21	0.47	2,967	6,622
35%	Model	3,854				
	Bootstrap	4,702	0.22	0.44	3,006	6,908

estimating $\hat{N}_{MSY}$. Model iterations of Chena or Salcha rivers stock-specific harvests from the total middle run harvest ranging from 15%-35% produced relatively similar estimates of $\hat{N}_{MSY}$ (Tables 10 and 11). However, these simulations were performed with the assumption that the assumed percentage of harvest was constant across ages and years.

There did not appear to be strong density dependence associated with either the Chena or Salcha populations, as the data fit the Ricker model poorly, especially for Chena River chinook salmon (Figures 6 and 7). However, generally speaking, the smallest observed escapements have produced large returns and the largest observed escapements have produced small returns. Estimates of total return are suspect due to the unknown harvest of Chena and Salcha rivers fish in the commercial and subsistence fisheries. However, estimates of escapement are generally quite good. When escapements from one year are compared to escapements six years later (corresponding to the dominant age class), the same general trend of small escapements producing large returns and visa versa is apparent (Figure 8). More data from more year classes may improve the fit of these models. Other biological or environmental variables would likely provide a more descriptive and useful model.

Although estimates of spawning escapement are precise, they were obtained from a combination of mark-recapture and counting tower techniques (see Table 1). The mark-recapture estimates may underestimate total abundance, because the sections of river sampled during the experiments do not include all known spawning areas. For the Chena River, paired tower count and mark-recapture estimates obtained in 1997 were 10,811 (SE=1,160) chinook salmon for the mark-recapture estimate and 13,390 (SE=699) for the counting tower estimate, but were not significantly different (Stuby and Evenson 1998). To investigate the effects of using the mixture of tower count and mark-recapture estimates on the estimate of $\hat{N}_{MSY}$, all mark-recapture estimates were expanded by 25% and $\hat{N}_{MSY}$ was recalculated (for assumption of 20% middle-run harvest). Estimates of $\hat{N}_{MSY}$ were slightly lower for expanded data than for unexpanded data for both the Chena River (6%) and Salcha River (2%) populations.

Because estimates of $\hat{N}_{MSY}$ were similar for the various assumptions of river-specific harvests in the commercial and subsistence fisheries, the estimates with the lowest statistical bias were chosen for the point estimates to develop escapement goal ranges. For the Chena River population, the optimal $\hat{N}_{MSY}$ estimate was 3,547 ($\hat{N}_{MSY(10\%)}$), and was 4,075 ($\hat{N}_{MSY(10\%)}$) for the Salcha River population. Eggers (1993) determined through simulation that a range of 0.8 to 1.6 times the estimate of $\hat{N}_{MSY}$ produces on average yields >90% of MSY.

Based on this analysis, an escapement objective of 3,300-6,500 chinook salmon is recommended for the Salcha River and an objective of 2,800-5,700 chinook salmon is recommended for the Chena River.

For the Salcha River, five of 13 (38%) observed escapements have been within this range, while the remaining eight have exceeded the range. For the Chena River, five of 14 (36%) observed escapements have been within this range, one has been below the range, and eight have exceeded the range.

These analyses were conducted with a minimal number of paired estimates of spawners and production. Three of these paired points were based on extrapolations of returns of cohorts still

Salcha River

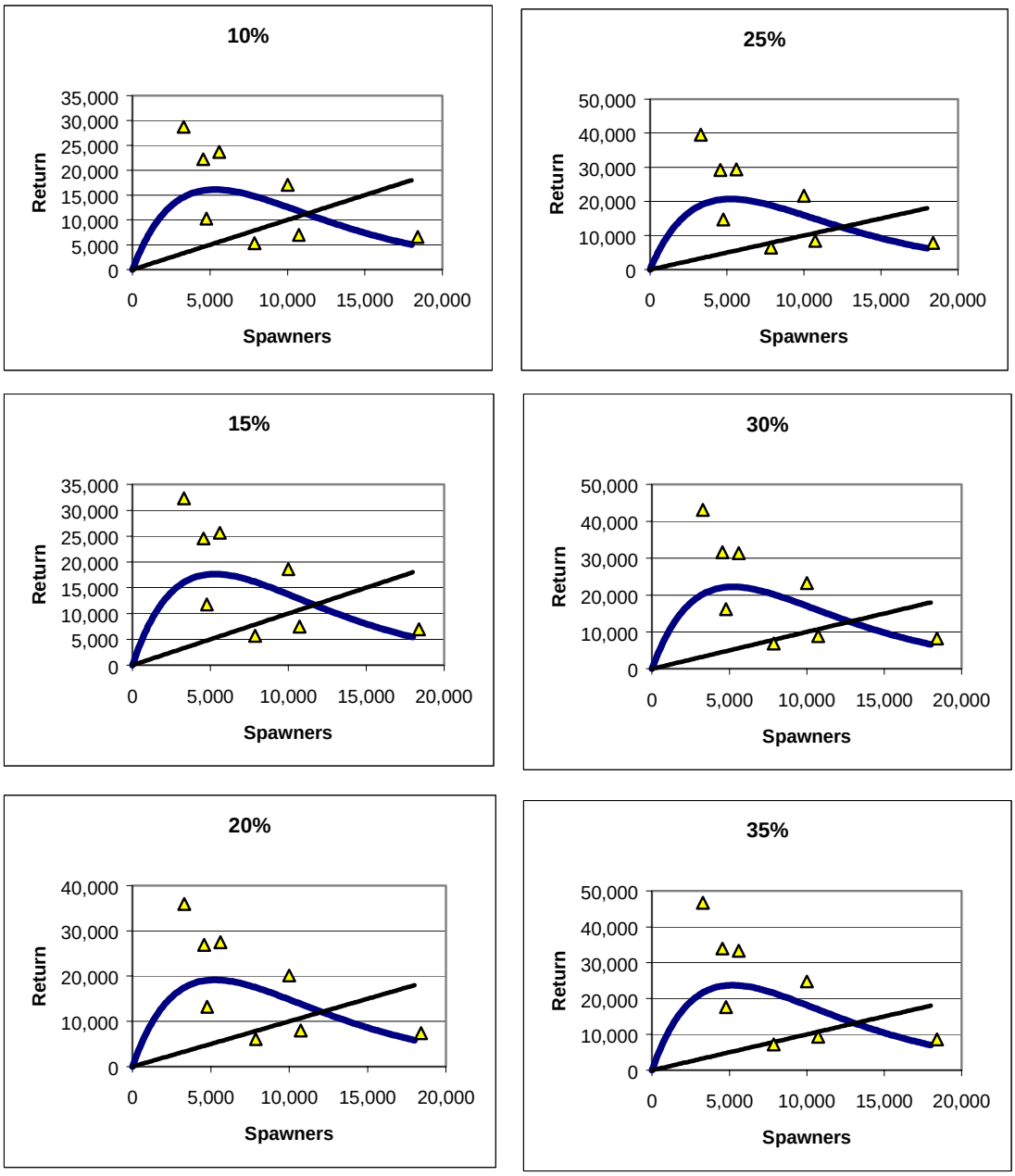


Figure 6.-Estimated return of chinook salmon in year classes 1987-1994 against the estimated spawning abundance of parent years for the population in the Salcha River.

Chena River

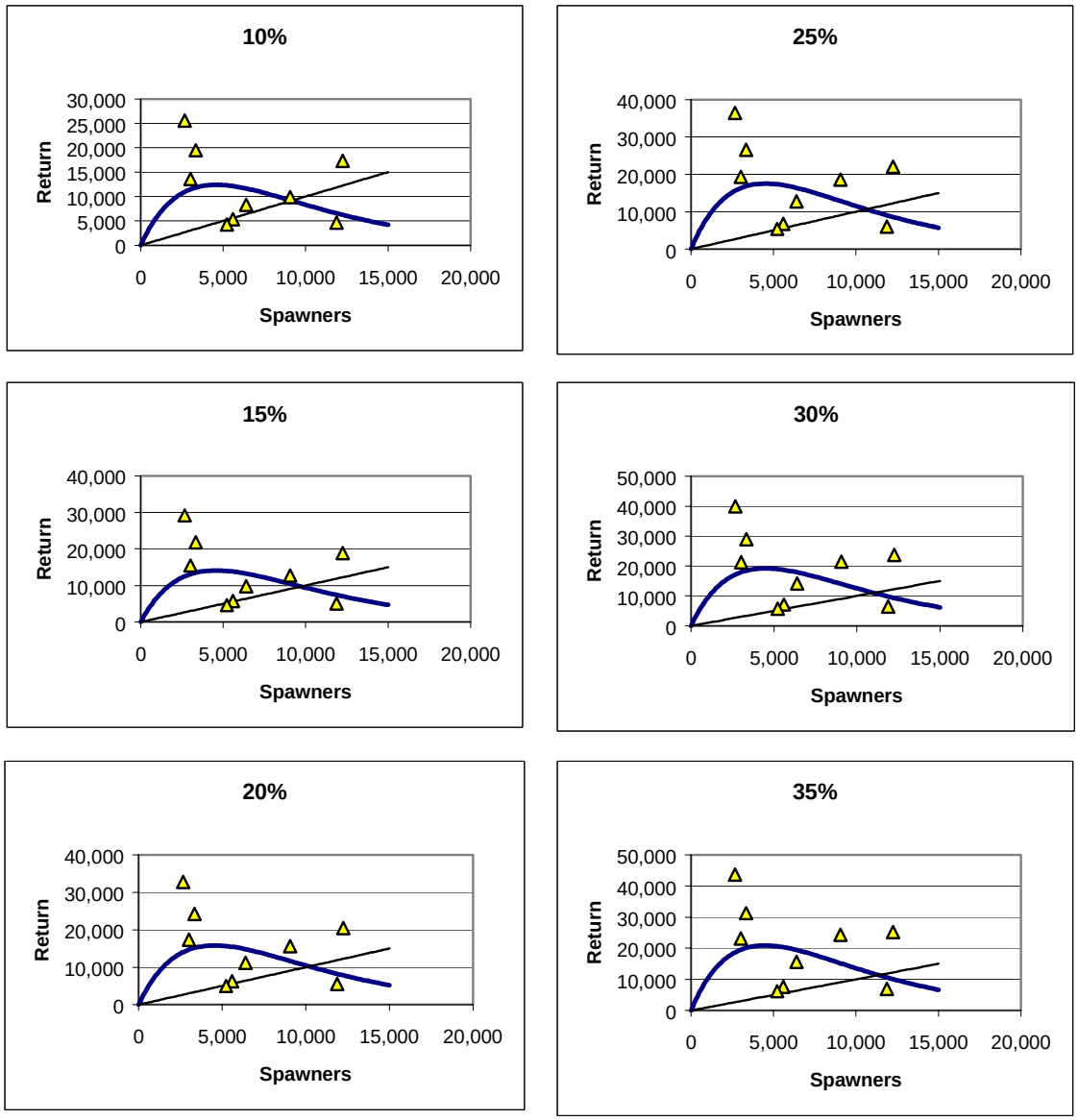
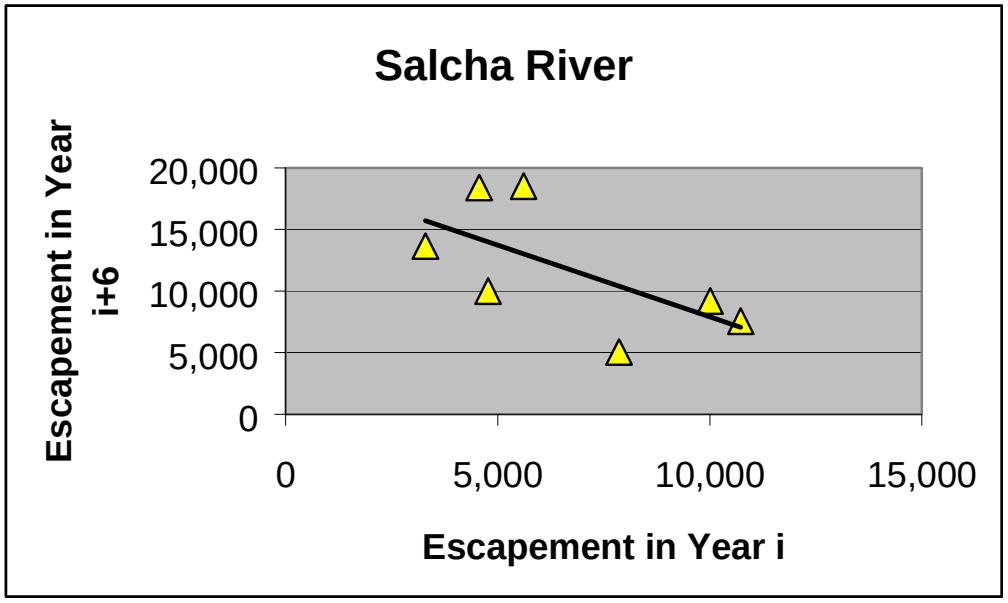


Figure 7.-Estimated return of chinook salmon in year classes 1986-1994 against the estimated spawning abundance of parent years for the population in the Chena River.



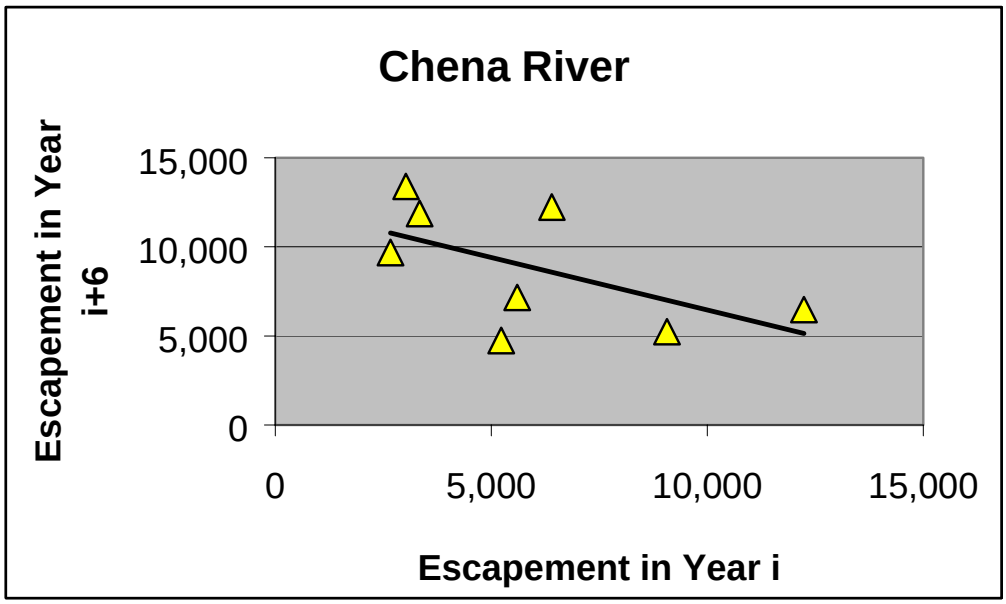


Figure 8.-Estimated escapement of chinook salmon in the Chena and Salcha rivers in year i (i=1986-1993 for the Chena River and i=1987-1993 for the Salcha River) versus estimated escapement in year i+6.

at large. Therefore, I recommend that estimation of escapements, harvest, scale pattern analysis, and age compositions from harvests and escapements be continued for a minimum of three more years (through 2003), and that this analysis be redone at that time (prior to next Board of Fisheries meeting).

The biggest data gap in this analysis was a lack of information concerning exact Chena River and Salcha River chinook catches in the commercial and subsistence fisheries. Although the assumptions regarding this harvest were not problematic in terms of estimating $\hat{N}_{MSY}$, the error about these estimates was unknown, thus the estimates could not be corrected. The most precise method of assessing stock-specific harvest in these fisheries would be to use coded wire tagging (CWT) techniques. If implemented next season, CWT data could not be used reliably to evaluate stock-specific harvest until 2007 when age-3 - 6 fish would be present in the harvest. Information from the radio-tagging program planned for 2001 could be used to estimate proportions of Chena and Salcha rivers chinook salmon vulnerable to harvest in each district and period and this proportion applied to the measured harvest as a means of estimating harvests of these stocks. An evaluation of the precision in estimates of stock-specific harvest that could be expected from this approach should be conducted to determine if proposed sample sizes are adequate.

INDEPENDENT REVIEWER COMMENTS

This and five other draft reports concerning biological escapement goals (BEGs) for salmon stocks in the Arctic-Yukon-Kuskokwim (AYK) Region of Alaska were prepared by ADF&G staff and released for public review in November and December of 2000. Two written reviews concerning the draft BEG technical reports were prepared and submitted to ADF&G. The first review was titled "*A Preliminary Review of Western Alaskan Biological Escapement Goal Reports for the Alaska Board of Fisheries*" and is hereafter referred to as Mundy et al. (2001). Another review of the six draft ADF&G BEG reports entitled: "*Summary Review Comments on Alaska Department of Fish and Game Draft Reports on Biological Escapement Goal Recommendations*" was prepared by staff from several federal agencies and is hereafter referred to as Andersen et al. (2001). Oral and written reports concerning the six AYK BEG analysis and the two technical reviews concerning these draft analyses were submitted to the Alaska Board of Fisheries in December and January and the AYK BEG analyses became quite controversial during the January Board of Fisheries meeting. During the meeting, the Alaska Board of Fisheries discussed and approved the department's biological escapement goals (BEGs) for chinook salmon in the Salcha River (3,300 to 6,500 total fish) and Chena River (2,800 to 5,700 total fish) as presented in this report. Important comments from these two reviews are paraphrased below and discussed to better inform the reader of aspects of the technical issues involved and to provide a more complete discussion of the topic. Readers are encouraged to read both reviews as they provide more detail than is presented here. Some of the following discussion relates to comments regarding the general approach taken in all six ADF&G reports to estimate optimal spawning escapement while other aspects of the discussion relate to specific comments for the Salcha and Chena rivers chinook salmon BEG analyses reported herein.

MUNDY ET AL. (2001) REVIEW

In general, this review was supportive of the analyses developed by ADF&G staff. The review indicated that the analyses as presented were done correctly and were appropriate to the available data. However, it was recommended that N_{MSY} (the notation S_{MSY} is used in both reviews) not be considered long-term escapement goals, but reasonable starting points for adaptive strategies for setting escapement goals appropriate to protecting long term use of the resource. I agree with the last statement and recommended in the Discussion section to continue data collection and review the analysis prior to the next Board of Fisheries cycle.

The report listed a number of general recommendations including: full peer review of this and all future BEG analyses; use of 90% confidence intervals about estimates of N_{MSY} for ranges of a BEG; collection and incorporation of biological and physical data regulating population growth; simulation analyses investigating scenarios of conditions of measurement error, process error, and autocorrelation or trends in the process error to investigate bias in estimates of N_{MSY}; evaluate the expected performance of an escapement goal within the management plan before adopting the goal; develop more precise harvest management capabilities; develop standard methods for incorporation of error in stock-recruitment analyses; and, improve data collection programs as recommended in the draft BEG reports. My response to these comments is provided below.

This and the other BEG reports were distributed extensively and the review period was extended to allow for complete and thorough reviews. It is likely that there will be a department policy developed for review of future BEG analyses.

Use of 90% confidence intervals about estimates of N_{MSY} for ranges of the BEGs would yield roughly the same lower limits for both Chena River and Salcha River stocks as recommended in this report, but would result in upper bounds that are substantially lower than what I have recommended using the Eggers (1993) method (Tables 10 and 11). I felt the larger upper bounds were more appropriate for these data sets given their uncertainty resulting from the short time series and incomplete harvest composition.

I concur that collection and incorporation of biological and physical data regulating population growth could substantially improve the spawner recruit model, and collection of such data should be considered in long term research planning. However, few such data are currently available for the Chena and Salcha rivers.

The effects of measurement and process error were considered in this analysis. As reported, measurement error in spawning abundance represented about 4% of the overall variation in the independent variable in both rivers, and was ignored in the regression analysis. Measurement error in the dependent variable (the ratio of production to spawning abundance) was not calculated because true estimates of variance for the river-specific harvests in the commercial and subsistence fisheries and estimates of variance for the recreational harvests were not known. An autocorrelation analysis was conducted to investigate trends in the process error and potential bias in estimates of N_{MSY} and although the time series was relatively short, no significant trends were observed.

Relative to the comment of developing standard methods for incorporation of error in stock-recruitment analyses, there currently is no set protocol used by the department. The six reports

covered in this review followed the guidelines put forth in the CTC (1999) report to the extent possible.

The Mundy et al. (2001) review also included specific comments regarding this report. The comments were partitioned into three categories: data issues, application to BEGs, and recommendations. My response to these comments is given below.

Relative to data issues, the review indicated a concern that the accuracy of scale pattern analysis for stock separation was not quantified in the report. The accuracy of the stock identification varies by year and by age class, but typically is greater than 90% accurate (Lingnau 1999). Because I had no way of calculating variance for stock specific harvest of the middle run component, I had no way to estimate total variance of the age specific harvest, so I elected not to include the variance components that are available. The review also voiced concerns with age sampling from the spawning grounds and apportionment of recreational harvests, but did not elaborate, so I am unsure what those concerns are. The review also identified a data issue with the assumption that age structure in the recreational harvest is the same as that of spawners. This assumption likely does not pose a serious problem in estimating total age-specific return because the magnitude of the recreational harvest is small relative to the total return. Using the assumption of 10% Chena River or Salcha River chinook salmon harvest in the commercial and subsistence fisheries, recreational harvests in each river range from 1% to 9% of the total return annually. Mundy et al. (2001) also identified apportionment of the middle Yukon River catches by stock as a data issue. I concur that this is the greatest data issue associated with this analysis and will continue to be until a method for estimating stock specific harvest is developed which is not likely in the near future. I did attempt to investigate the sensitivity of different assumptions regarding stock-specific harvest in the middle Yukon River on $\hat{N}_{MSY}$ and found the estimates to be robust to different harvest rate assumptions. The last data issue the review identified was not considering abundance of chum salmon *Oncorhyncus keta* in the spawner recruit analysis. While abundance of chum salmon in these two systems may influence growth and survival of juvenile chinook salmon, data regarding abundance of chum salmon are either incomplete or nonexistent over the span of the data set. Inclusion of such data would likely add more noise than benefit to the analysis. In recent years, tower counting operations on the Chena and Salcha rivers have been extended into August (prior studies terminated counting on July 31) in attempt to estimate total passage of chum salmon, so this information may be useful in future analyses.

Relative to Application to BEGs, the review indicated that using the N_{MSY} estimates as escapement goals for the Chena and Salcha chinook populations may be premature because the model has too few data points to capture all the variety of conditions that would influence production capacity and carrying capacity. I agree that this is a weakness in the analysis, but the short data base should not prohibit use of the N_{MSY} estimates for establishing BEGs. Recall that the previous escapement goals for these rivers were based on simple averages of aerial index counts. Thus, I believe that the goals recommended in this report and subsequently adopted by the Board of Fisheries represent a substantial step forward from the previous goals.

The Mundy et al. (2001) review listed a number of recommendations with continued data collection (assumed to mean harvest and escapement data) being “essential”. I concur. It also recommended expanding efforts to detect the proportion of Chena and Salcha chinook salmon harvested in the various fisheries as a priority. The radio telemetry, mark-recapture study of chinook salmon in the Yukon River planned for 2002 by Commercial Fisheries Division should

provide insight into relative abundance and run timing of middle river stocks, which should allow for more refined assumptions regarding harvest of Chena and Salcha rivers stocks. Finally, the review recommended further biological research into the factors controlling chinook freshwater, estuarine and marine survival to resolve uncertainties about carrying capacity. I view these as admirable goals, but probably not fiscally realistic for ADF&G to investigate without a large infusion of funding.

ANDERSEN ET AL. (2001) REVIEW

The Andersen et al. (2001) reviewers were unable to come to a consensus regarding the recommended BEGs presented in this report. One perspective indicated that the available data indicate existing goals are too large and might lead to unnecessary fishery restrictions and that the recommended goals would be closer to N_{MSY}. The other perspective indicated that existing data were insufficient to develop BEGs based on the simple production model used in this analysis and that this analysis included flaws (discussed below) that cast sufficient doubt on the recommended goals to preclude their adoption until a more thorough analysis can be conducted. General comments included discussions of estimating missing escapement data (does not apply to this report), estimating missing harvest data, bootstrapping residuals, evaluation of residuals, definition of contrast, using full data series (does not apply to this report), approximation of the escapement producing MSY (does not apply to this report), escapement goal ranges, density dependence, and limited information. My responses to these general comments are provided below.

Relative to the comments regarding estimating missing harvest data, the review indicated that the reports contained almost no assessment of how accurately the missing harvest data might be estimated, or how bias or variance associated with the estimates might affect estimates of N_{MSY}. The review did acknowledge my attempts to explore the sensitivity of the estimates of N_{MSY} to the various assumptions regarding harvest proportions, but indicated a simulation that assumed different (random) proportions of Chena River or Salcha River proportion each year would be more appropriate. My simulations examined the simplest scenario, that stock-specific harvest rates are constant over time for a given stock. Obviously, they are different between lower, middle, and upper Yukon River stocks, and these differences are already apportioned from the scale pattern analysis. The argument is then whether or not stocks within the middle portion of the drainage experience different exploitation rates in the commercial and subsistence fisheries. I believe there is some variation in annual stock-specific exploitation within the middle river, but it is probably considerably less than the variation between lower, middle, and upper stocks because the differences in run timing of middle river stocks is likely less than the difference between lower, middle, and upper stocks. There is no information available regarding run timing of the various middle river stocks (in the mainstem river where the fisheries occur) to design a simulation that would put realistic bounds on this year-to-year variability. As mentioned above, the radio telemetry, mark-recapture study of chinook salmon in the Yukon River planned for 2002 by Commercial Fisheries Division should provide insight into relative abundance and run timing of middle river stocks, which should allow for more refined assumptions regarding harvest of Chena and Salcha rivers stocks. Until such information is available, it is in my opinion premature to make detailed assumptions regarding the variation in harvest estimates.

The Andersen et al. (2001) review criticized the bootstrapping approach used in the six draft reports for developing variances around estimates of N_{MSY}, pointing out that not every potential

source of variation was accounted for in these bootstrap analyses. Such omissions would only be of concern if the potential sources of variation were something other than negligible. As described in this report, variation in measurement error was investigated and thought to be negligible in it's affect on estimated N_{MSY}. In the case of variance of estimates of total return, no estimates of variance for the stock-specific harvest were available. As mentioned above, further guessing at what they might be would have been counter productive.

Andersen et al. (2001) criticized evaluation of residuals included in the six draft reports because they were most often not expressed on the scale of the log return-per-spawner ratio versus the number of spawners. This criticism is unfounded for this report as residuals are presented on this scale.

Andersen et al. (2001) indicated that too much emphasis was placed on the definition of contrast as used in the six draft reports, and indicated that the overall distribution of escapements, particularly at the larger levels was more important in determining the declining right tail of the productivity model. The definition of contrast used in this report is implicitly given in Hilborn and Walters (1992:288) as the range of spawning escapements over the years (or their estimates). All of the estimates of spawning escapement were presented and were plotted against their resulting return to allow the reader to interpret the importance of the contrast statistic.

The Andersen et al. (2001) review criticized the (Eggers 1993) method used to develop escapement goal ranges and suggested a method that they thought to be more consistent with *the Sustainable Salmon Fisheries Policy for the State of Alaska*. Relative to establishing escapement goals and ranges the policy states:

> "Escapement goals, whether biological, optimal, or in-river run goals, should be established in a manner consistent with sustained yield. Unless otherwise directed, the Alaska Department of Fish and Game (department) will manage Alaska's salmon fisheries, to the extent possible, for maximum sustained yield" and,
>
> "Escapement goal ranges should allow for uncertainty associated with measurement techniques, observed variability in the stock measured, changes in climatic and oceanographic conditions, and varying abundance within related populations of the stock measured".

While it could be argued that the Andersen et al. (2001) method for establishing BEG ranges would also satisfy the criteria put forth in this policy, I believe that the Eggers (1993) method used in this report is consistent with the policy, and includes a larger range, thus better incorporating the uncertainty in the data than the Andersen et al. (2001) suggestion.

The last two general comments given in the Andersen et al. (2001) review concerned estimation of the density dependent parameter being affected by few data for returns at large escapement levels and having limited data for which to develop productivity models. The Chena River and Salcha River analyses do suffer from these shortfalls. The issues really are: is there a need to establish escapement objectives, is there enough data to establish escapement objectives, and if so, is there a better method for establishing these objectives than what is presented in this report. The Chena and Salcha rivers support some of the largest chinook salmon escapements in the Yukon River drainage, they are harvested in mixed stock and terminal fisheries, and management of Yukon River chinook stocks is escapement-based. Clearly these are systems that should have meaningful and measurable escapement objectives. Although the data sets of Chena

River and Salcha River escapements are shorter than desired, they are relatively high quality estimates (compared to say aerial survey counts), and are, with the exception of the Canada border escapement program, the best and longest available data sets in the Yukon River drainage. The Andersen et al. (2001) review did not provide any recommendations relative to alternative approaches for developing BEGs. The options as I see them, considering the data that are available, are to maintain the existing or develop a modified aerial count-based goal or use a simple statistic based on existing escapement estimates (e.g. a measure of central tendency or percentile limits). I do not believe either option is a defensible method for developing escapement objectives that sustain high yields. I agree with the recommendation given in the Andersen et al. (2001) review that it is essential to continue to dedicate resources to remedy current information gaps and extend the data sets so that more comprehensive productivity analyses can be conducted in the future.

The Andersen et al. (2001) review also included a section with specific comments relative to this analysis which I discuss below. The first comment accurately pointed out that the draft report did not state that harvest of Chena River and Salcha River chinook stocks occur in District 5A. Harvest of these stocks does occur in this subdistrict and I have changed the text to clarify this.

The second comment, which was touched on above in the discussion of general comments, related to my assumptions regarding stock-specific harvest of the middle-river runs. Rather than assuming a constant proportion of harvest for each stock, their suggestion was to consider the two stocks in aggregate and assume the harvest of each stock in the middle river was proportional to their relative escapements. As mentioned above, there is no information available to suggest what the stock-specific harvest rates are in the middle river. I chose to use the simplest assumption, that stock-specific harvests were constant. There is no evidence to suggest that other assumptions are more valid.

The review cited that a limitation of the analysis was the failure to incorporate available information on the sex compositions of the escapements. Development of a BEG based on number of female chinook salmon was brought up during the BEG committee review, and ADFG fishery managers felt that the total escapement goal was more appropriate for management purposes.

The review also included a comment specific to this analysis that was a reiteration of the general comment already discussed concerning too few data points and the potential bias in estimates of N_{MSY} that may arise.

Lastly, the review commented that further data regarding accurate assessment of each system's carrying capacity and the factors that mediate juvenile survival are needed, and that the effects of chum salmon escapements, such as nutrient delivery, may be important for chinook salmon rearing capacity. I concur, but little or no such data exist for the Chena or Salcha rivers to include in an analysis at this time.

ACKNOWLEDGEMENTS

Data for this report was collected by numerous ADF&G personnel. Critical review of this document was provided by members of the BEG committee including Gene Sandone, Doug Eggers, John Clark, Tracy Lingnau, Charlie Swanton, Dave Bernard, and Tom Vania. Dave Bernard assisted with much of the data analysis and interpretation. Lisa Stuby developed the brood tables used for run reconstruction.

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