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Stock Status and Recommended Escapement Goals for Coho Salmon in Selected Waters within the Kodiak Road Zone, 1980-2003

by

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June 2006

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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by

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ABSTRACT

In preparation for the February 2005 Alaska Board of Fisheries meeting, a team of fishery biologists and scientists from Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries were assembled to review and attempt to revise escapement goals for salmon stocks in the Kodiak Management Area. As part of this effort, escapement goals for six coho salmon *Oncorhynchus kisutch* stocks within the Kodiak road zone were selected for review and revision by Sport Fish Division staff. Escapement data from seven additional coho salmon stocks were also reviewed for potential for development of new escapement goals. Cluster analysis of temporal patterns of escapement indicated fairly high correlation amongst escapement counts across combinations of all surveyed streams, with escapements in at least one stream highly correlated (> 0.5) with escapements in at least one other stream. Four systems (American, Olds, Pasagshak, and Buskin) were recommended for further analysis and development of an escapement goal based on availability of yield information and validated escapement surveys or counts. Based on a theoretical spawner-recruit analysis, sustainable escapement goals (SEGs) based on foot surveys of 400 to 900 fish for the American River, 1,000 to 2,200 fish for the Olds River, and 1,200 to 3,300 fish for the Pasagshak River were recommended. A spawner-recruit analysis of available brood year information from the Buskin River indicated that a biological escapement goal (BEG) of 3,200 to 7,200 spawning fish be recommended. Existing escapement goals in Roslyn and Saltery creeks were recommended for elimination due to a lack of yield information and a lack of validation of foot surveys.

Key words: coho salmon, *Oncorhynchus kisutch*, escapement goal, cluster analysis, spawner-recruit analysis, exploitation rate, foot surveys, American River, Olds River, Pasagshak River, Buskin River, Kodiak Island, Kodiak road zone

INTRODUCTION

In preparation for the February 2005 Alaska Board of Fisheries meeting, a team of fishery biologists and scientists from Alaska Department of Fish and Game (ADF&G), Divisions of Sport Fish and Commercial Fisheries were assembled to review and attempt to revise escapement goals for salmon stocks in the Kodiak Management Area (KMA; see Nelson et al. 2005). As part of this effort, escapement goals for six coho salmon *Oncorhynchus kisutch* stocks within the Kodiak road zone (Figure 1) were selected for review and revision by Sport Fish Division staff. Escapement data from seven additional coho salmon stocks were also reviewed for potential for development of new escapement goals. This report details the review and recommendations made to the escapement goal team for these coho salmon stocks.

Schwarz et al. (2002) previously described the Kodiak road zone as having many coho salmon populations. The largest systems include the Buskin, Pasagshak, Saltery, Olds, Miam, Roslyn, and American rivers. Smaller systems include Salonie, Pillar, Monashka, Sargent, Russian, and Chiniak creeks (Figure 1). Fish begin entering these systems in mid August, and peak in mid September. Spawning occurs in late October through early November. Regulations for the Kodiak Road Zone are more restrictive than the Remote Zone because the Road Zone receives more fishing effort and salmon runs are smaller.

METHODS

DATA SOURCES

Coho salmon escapements in the KMA along the Kodiak road zone were enumerated by foot survey (American, Olds, Pasagshak rivers and Roslyn Creek), aerial survey (Saltery Creek), and weir (Buskin River and Saltery Creek). These data were available from 1980 to 2003 (Schwarz et al. 2002 and unpublished data). Accuracy of foot surveys in the American and Olds rivers were investigated during 1997 and 1998 via mark-recapture estimation and found to be adequate for

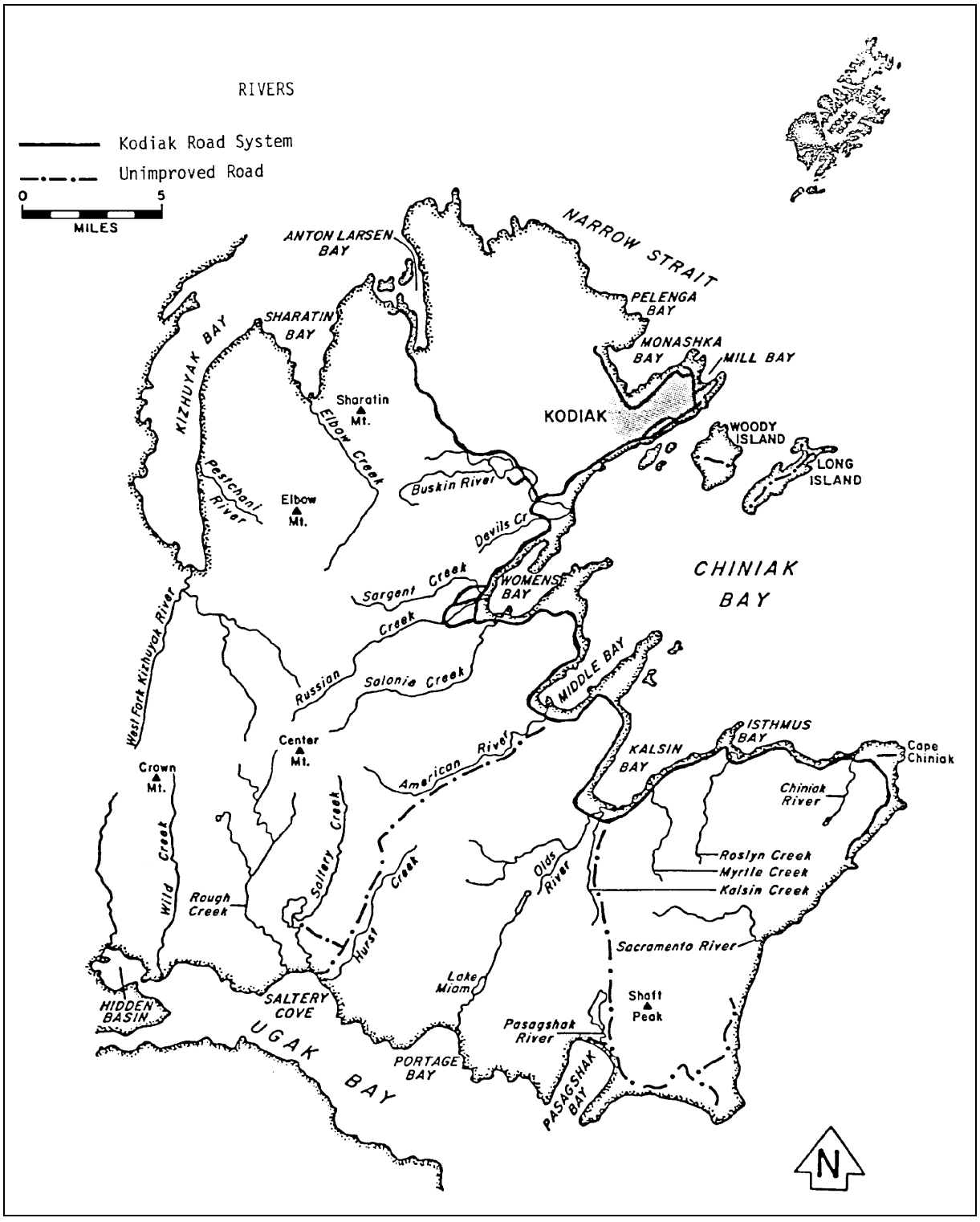

Figure 1.–Geographic boundaries of the Kodiak road zone, with important coho salmon waters shown.

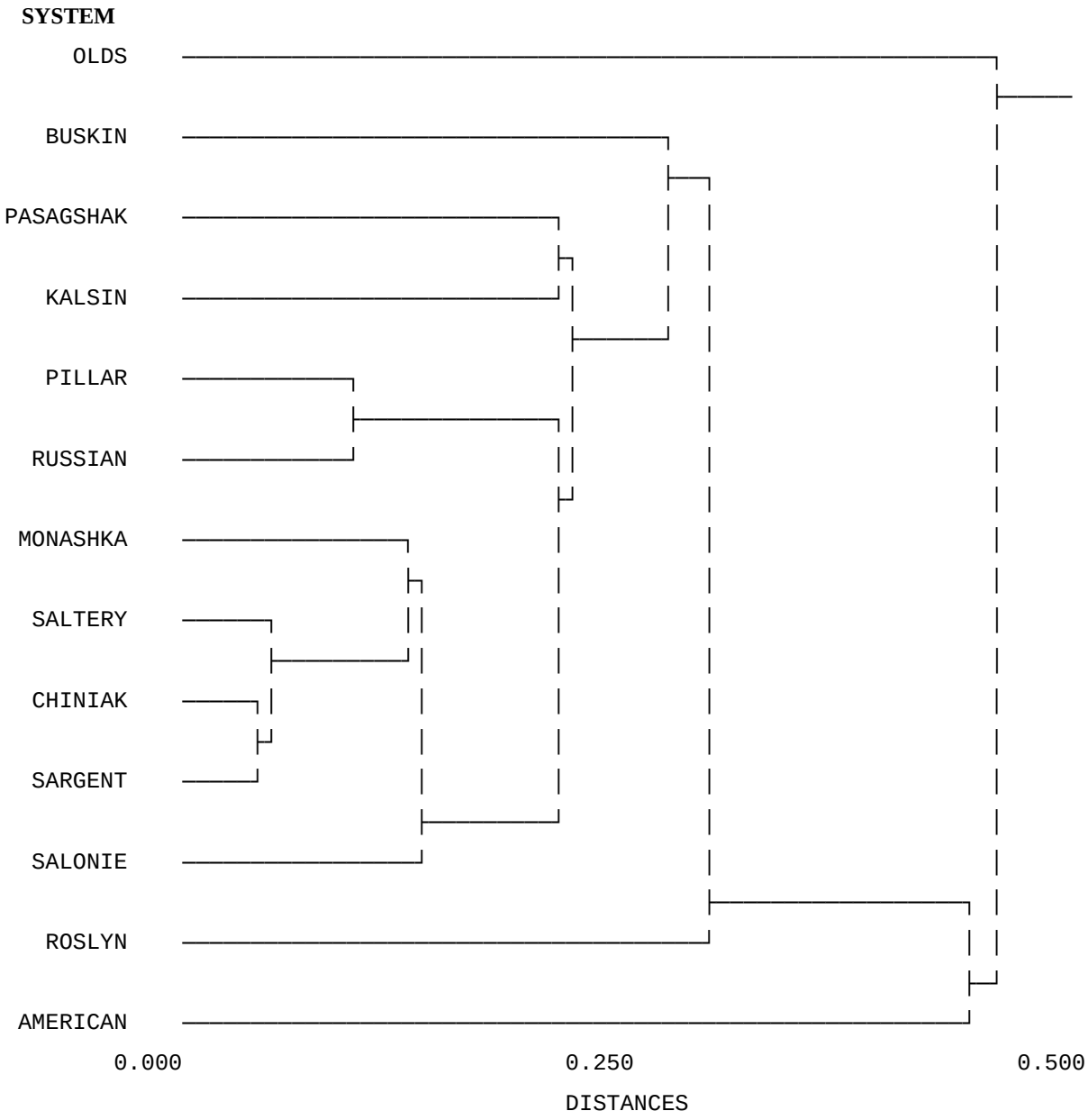

Figure 2.–Cluster diagram of distances (1 – correlations) between time series of coho salmon escapement indices in thirteen systems on the Kodiak road zone (1980-2003).

indexing escapement of coho salmon in these systems (Begich et al. 2000). Stock specific harvests were estimated from recreational harvest in freshwater (see Jennings et al. 2004). Except for the Buskin River, there are no stock specific harvest information available for subsistence and commercial fisheries. However, annual catch data are available from ADF&G Division of Commercial Fisheries databases for nearby statistical areas (unpublished data).

CLUSTER ANALYSIS OF ESCAPEMENTS

To investigate potential spatial relationships between escapement survey counts in 13 coho salmon systems along the Kodiak road zone, cluster analysis was performed on the untransformed and log-transformed escapement data. The distance metric used was the Pearson product moment correlation and clusters were formed using single linkages (Everett 1981).

THEORETICAL SPAWNER-RECRUIT ANALYSIS

Theoretical spawner-recruit (S-R) relationships were investigated for the major yield producing systems along the Kodiak road zone that have ongoing coho salmon assessment programs (American, Olds, Pasagshak, Buskin). Given that the long-term yields and escapements in these systems have stable trends and have occurred with little or no change in the regulations, it seems reasonable to assume that they are in equilibrium. Moreover, annual escapement and run (escapement plus harvest) averaged over a long time period likely represent x-y coordinates on the true S-R relationship. Assuming that the S-R relationship follows the form of Ricker (Ricker 1975), several S-R relationships can be realized that encompass a range of productivity commonly seen for coho salmon. Defensible escapement goal ranges that incorporate known yields, stock productivity, data uncertainty, and maximization of yields can be developed from this analysis.

Average harvests and average escapement survey counts were estimated from available data for each river (generally 1980-2003 with some missing years):

$$\bar{h} = \frac{1}{n}\sum_{i}^{n} h_i \text{ and } \bar{s} = \frac{1}{n}\sum_{i}^{n} s_i \tag{1}$$

Foot surveys do not count all salmon that are in the escapement to these streams so that the exploitation rate calculated from these data were assumed to be the maximum exploitation rate. From mark-recapture experiments (Begich et al. 2000) and managers insight, it is thought that 80 to 100% of the escapement is counted via foot surveys each year. Assuming that harvest and escapements are in equilibrium, average maximum exploitation rate was estimated as:

$$\bar{u} = \frac{\bar{h}}{\left(\bar{s} + \bar{h}\right)} \tag{2}$$

Exploitation rate at maximum sustained yield (MSY) depends solely on the Ricker productivity parameter α (Ricker 1975). However, the productivity of coho salmon stocks in Kodiak is unknown so a range of productivity parameter was chosen (4 to 8) that represents the likely range of productivity commonly observed in coho salmon. Clark et al. (1994) found that the α-parameter of several coho salmon stocks in southeast Alaska likely ranged from 3 to 17, with values of 4 to 8 being most common. Assuming α is known and the observed average exploitation rate and the average foot survey count over a number of years are in equilibrium, an estimate of escapement (in terms of survey units) that will produce MSY (from Hilborn and Walters (1992) and Ricker (1975)) can be calculated:

$$s_{MSY} = \bar{s}\frac{0.5\ln(\alpha) - 0.07\ln(\alpha)^2}{\ln\left(\alpha\left(1-\bar{u}\right)\right)} \tag{3}$$

To compare estimates of s_{MSY} and S-R relationships derived from different assumed α's, the β parameter was estimated for each S-R relationship by first estimating the exploitation rate at MSY by solving:

$$\ln(\alpha) = u_{MSY} - \ln(1 - u_{MSY}) \quad (4)$$

for u_{MSY} (from Ricker 1975). The β parameter was then calculated from (Ricker 1975):

$$\beta = \frac{u_{MSY}}{s_{MSY}} \quad (5)$$

From these S-R relationships the range around s_{MSY} that produces 90% or more of MSY was also calculated. Since the resulting ranges were based on foot surveys (an index of escapement) rather than the actual escapement they were considered sustainable escapement goal (SEG) ranges.

BUSKIN RIVER SPAWNER-RECRUIT ANALYSIS

Spawning stock and recruitment data from the Buskin River were analyzed using a Ricker spawner-recruit model (Ricker 1975) with multiplicative error structure considered (Quinn and Deriso 1999). If a Ricker spawner-recruit model was significant, then S_{msy} was estimated along with the range of escapements that would produce 90 to 100% of MSY.

RESULTS AND DISCUSSION

CLUSTER ANALYSIS OF ESCAPEMENTS

Results for the untransformed escapement counts were identical to the log-transformed data so results are presented for the untransformed data only (Appendix A1). No analysis was performed for two systems (Twin and Myrtle creeks) because of small sample sizes. Overall, there was fairly high correlation amongst escapement counts across combinations of all surveyed streams (Appendix A2), with escapements in at least one stream highly correlated (> 0.5) with escapements in at least one other stream. Streams did not cluster along geographic lines (north to south) or by bay (Figures 1 and 2), although Sargent and Salonie creeks are both in Women's Bay and clustered at a distance of 0.13. Escapement trends in the American and Olds were least similar to the remaining systems (Figure 2).

After preliminary review of the available data, it was decided to review and attempt to revise escapement goals for coho salmon in the American, Olds, Pasagshak, and Buskin rivers, and drop existing escapement goals (see Nelson and Lloyd 2001) for Saltery and Roslyn creeks.

AMERICAN RIVER

The SEG range in the American River has been 300 to 400 coho salmon enumerated by foot survey. This goal range was established in 1999 (Nelson and Lloyd 2001). Since 1980 the SEG range has never been achieved, has been underachieved 11 times and exceeded 10 times (Table 1).

Theoretical Spawner-Recruit Analysis

Average foot survey from 1980-2003 was 504 fish and average harvest was 1,048 fish (Table 1). Assuming Ricker α for coho salmon ranges from 4 to 8 (ln(α) ranges from 1.4 to 2.1) and that the average survey count and average harvest represented an equilibrium exploitation rate of

Table 1.–Foot surveys and harvests of coho salmon in or adjacent to the American River, 1980-2003.

Year	Foot Survey	Harvest: Recreational[a]	Subsistence[b]	Commercial[c]	Total
1980	903		8	433	
1981	627		1	30	
1982	266		95	121	
1983	114	378	43	73	494
1984	277	486	0	2	488
1985	439	349	15	298	662
1986	221	826	2	71	899
1987	555	435	33	359	827
1988		1,710	0	89	1,799
1989		1,500	0	0	1,500
1990	419	849	14	1	864
1991		722	60	4	786
1992	167	583	0	0	583
1993	412	2,340	3	73	2,416
1994	194	642	0	0	642
1995	169	794	2	1,303	2,099
1996	69	549	15	0	564
1997	2,204	1,749	6	31	1,786
1998	1,360	700	0	129	829
1999	284	1,090	0	29	1,119
2000	133	480	0	0	480
2001	233	860	18	0	878
2002	1,034	1,195	5	0	1,200
2003	511	1,051	42	4	1,097
# surveys	21	21	24	24	21
Avg	504	918	15	127	1,048
SD	510	523	24	278	560
Min	69	349	0	0	480
Max	2,204	2,340	95	1,303	2,416

[a] Recreational harvests from the Statewide Harvest Survey (Jennings et al. 2004).

[b] Subsistence harvests from the ADF&G Division of Commercial Fisheries database.

[c] Commercial harvests from the ADF&G Division of Commercial Fisheries database for statistical area 259-23.

0.68, two theoretical S-R relationships that have these same equilibrium values were calculated (Figures 3 and 4). In addition, from the two theoretical S-R relationships, escapements (based on the surveys) that would produce MSY and a range of escapements that produce 90% or more of MSY were also calculated (Table 2). These reference points were then compared to the average escapements based on surveys to help identify a potential SEG range that was robust to differences in the shape of the S-R relationship.

True exploitation was likely to average somewhat less than 0.68 (surveys do not count all fish), given that mark-recapture experiments show that foot surveys average ~80% of the total escapement (Begich et al. 2000). However, the true exploitation rate was likely greater or within the range of what would produce MSY for a range of productivity parameters from 4 to 8. Given the uncertainty in which relationship was more likely than another, a conservative approach was taken and the range of escapements that could produce at or near MSY was recommended.

Foot surveys of 400 to 900 fish appeared to theoretically provide for nearly 90% of MSY given α may have actually ranged from 4 to 8 and average harvests and foot surveys represented an equilibrium situation (Figure 3). Actual escapements have been below this range in 11, in this range in six, and above this range in four of the 21 years (Table 1). Escapements have never been below 400 in four consecutive years, but have been below 400 in three consecutive years three times (1982-1984, 1994-1996, and 1999-2001).

The existing escapement goal for the American River was recommended for change to a SEG of 400 to 900 fish by foot survey. Exploitation rate in the American River was likely at or slightly above the rate that produces MSY. Development of a biological escapement goal (BEG) for this system was also recommended. Development of a BEG would be facilitated by improved assessment of returns to the American River through collection of age composition of escapement and harvests, continued validation of foot surveys, and analysis of saltwater harvests to improve catch allocation.

OLDS RIVER

The SEG range in the Olds River has been 450 to 675 coho salmon enumerated by foot survey. This goal range was established in 1999 (Nelson and Lloyd 2001). Since 1980 the SEG range has been achieved once, has been underachieved three times and exceeded 16 times (Table 3).

Theoretical Spawner-Recruit Analysis

Average foot survey from 1980-2003 was 1,408 fish and average harvest was 2,566 fish (Table 3). Assuming Ricker α for coho salmon ranges from 4 to 8 ($\ln(\alpha)$ ranges from 1.4 to 2.1) and that the average survey count and average harvest represent an equilibrium exploitation rate of 0.63, two theoretical S-R relationships that have these same equilibrium values were calculated (Figure 4-6). In addition, from the two theoretical S-R relationships, escapements (based on the surveys) that would produce MSY and a range of escapements that produce 90% or more of MSY were also calculated (Table 2). These reference points were then compared to the average escapements based on surveys to help identify a potential SEG range that was robust to differences in the shape of the S-R relationship.

True exploitation was likely to average somewhat less than 0.63 (surveys do not count all fish), given that mark-recapture experiments showed that foot surveys averaged ~80% of the total escapement (Begich et al. 2000). Moreover, the true exploitation rate was likely within or slightly lower than the range that would produce MSY for a range of productivity parameter from 4 to 8. Given the uncertainty in which relationship was more likely than another, a conservative approach was taken and a range of escapements that could produce at or near MSY was recommended.

Foot surveys of 1,000 to 2,200 appeared to theoretically provide for nearly 90% MSY given α may have actually ranged from 4 to 8 and average harvests and foot surveys represented an equilibrium situation (Figure 4). Actual escapements have been below this range in eight, in this

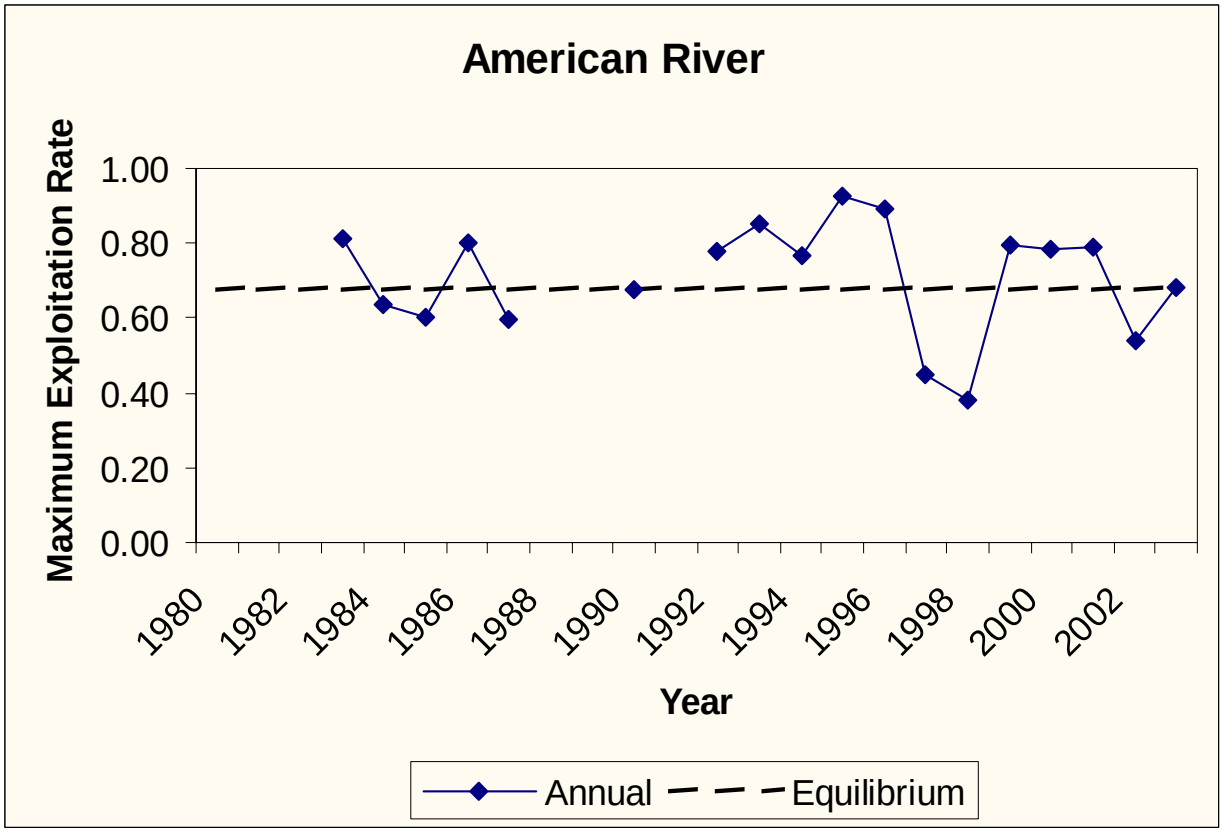

Figure 3.–Annual maximum exploitation rate (solid line) and assumed equilibrium exploitation rate (dashed line) of coho salmon in the American River, 1980-2003.

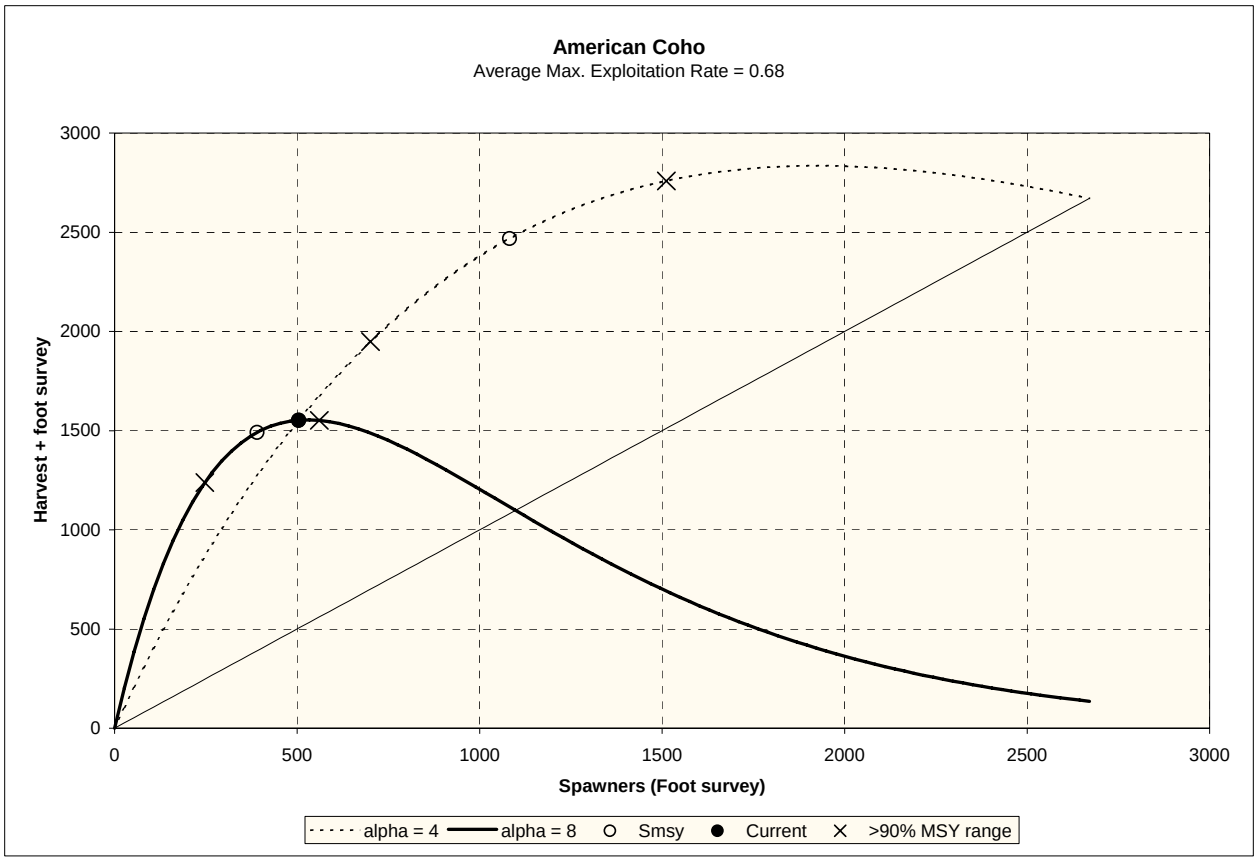

Figure 4.–Theoretical Ricker stock-recruitment relationships based on an average foot survey of 504 and average harvest of 1,048 coho salmon (1980-2003; •). The dotted line represents the Ricker curve with an α-parameter of 4; the solid line represents the Ricker curve with an α-parameter of 8, and the solid straight line represents replacement. Smsy (o) and escapements that produce 90% of MSY (×) are also shown.

Table 2.–Value of β, and sMSY and range of sMSY given the average exploitation rate $(\bar{u})$ and assumed α-parameter for coho salmon in the American, Olds, Pasagshak, and Buskin rivers.

System	$\bar{u}$	α	β	s_{MSY}	s_{MSY} range
American	0.68	4	5.19×10^{-4}	1,082	701 – 1,511
	0.68	8	1.89×10^{-3}	390	247 – 561
Olds	0.63	4	2.59×10^{-4}	2,167	1,403 – 3,027
	0.63	8	7.22×10^{-4}	1,023	648 – 1,471
Pasagshak	0.48	4	2.28×10^{-4}	2,459	1,593 – 3,435
(all years)	0.48	8	4.45×10^{-4}	1,659	1,051 – 2,385
Pasagshak	0.29	4	2.34×10^{-4}	2,405	1,558 – 3,359
(1996-2003)	0.29	8	3.88×10^{-4}	1,901	1,204 – 2,733
Buskin	0.36	4	1.09×10^{-4}	5,175	3,352 – 7,228
	0.36	8	1.88×10^{-4}	3,920	2,482 – 5,636

Table 3.–Foot surveys and harvests of coho salmon in or adjacent to the Olds River, 1980-2003.

Year	Foot Survey	Harvest: Recreational[a]	Subsistence[b]	Commercial[c]	Total
1980	780		0	6,069	
1981			152	1,366	
1982	1,375		279	1,839	
1983		31	64	766	861
1984	325	611	445	4,252	5,308
1985	1,648	304	337	332	973
1986	1,849	1,651	312	447	2,410
1987	842	307	379	3,310	3,996
1988		1,273	209	1,773	3,255
1989	743	2,571	143	0	2,714
1990	1,706	948	379	7	1,334
1991		1,778	247	178	2,203
1992	308	1,085	276	0	1,361
1993	525	1,876	82	40	1,998
1994	395	1,083	225	2	1,310
1995	2,642	833	116	3,988	4,937
1996	2,200	864	305	0	1,169
1997	4,064	1,519	363	3,011	4,893
1998	2,296	951	269	10	1,230
1999	1,382	1,349	258	320	1,927
2000	1,097	1,712	383	0	2,095
2001	3,454	1,268	295	4,948	6,511
2002	790	1,346	215	0	1,561
2003	1,534	1,233	595	9	1,837
# surveys	20	21	24	24	21
Avg	1,498	1,171	264	1,361	2,566
SD	1,031	591	132	1,868	1,628
Min	308	31	0	0	861
Max	4,064	2,571	595	6,069	6,511

[a] Recreational harvests from the Statewide Harvest Survey (Jennings et al. 2004).

[b] Subsistence harvests from the ADF&G Division of Commercial Fisheries database.

[c] Commercial harvests from the ADF&G Division of Commercial Fisheries database for statistical area 259-24.

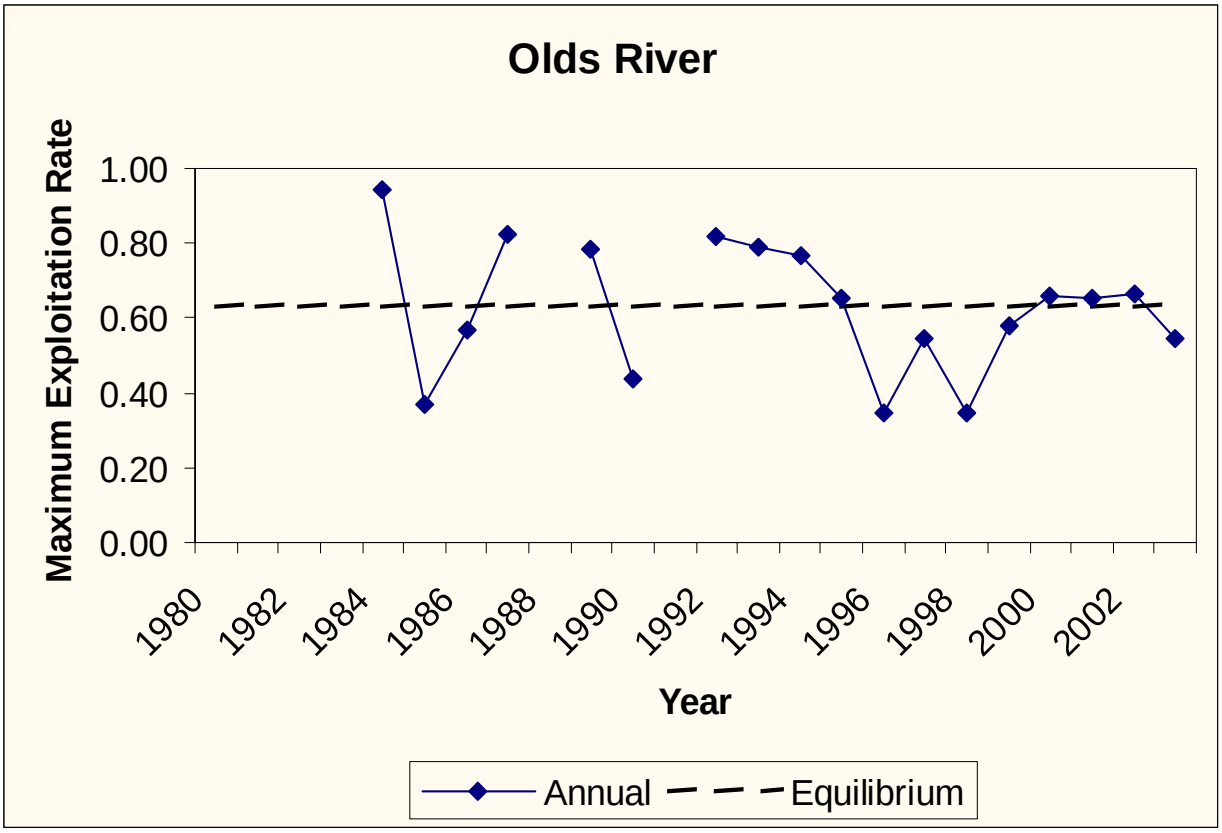

Figure 5.–Annual maximum exploitation rate (solid line) and assumed equilibrium exploitation rate (dashed line) of coho salmon in the Olds River, 1980-2003.

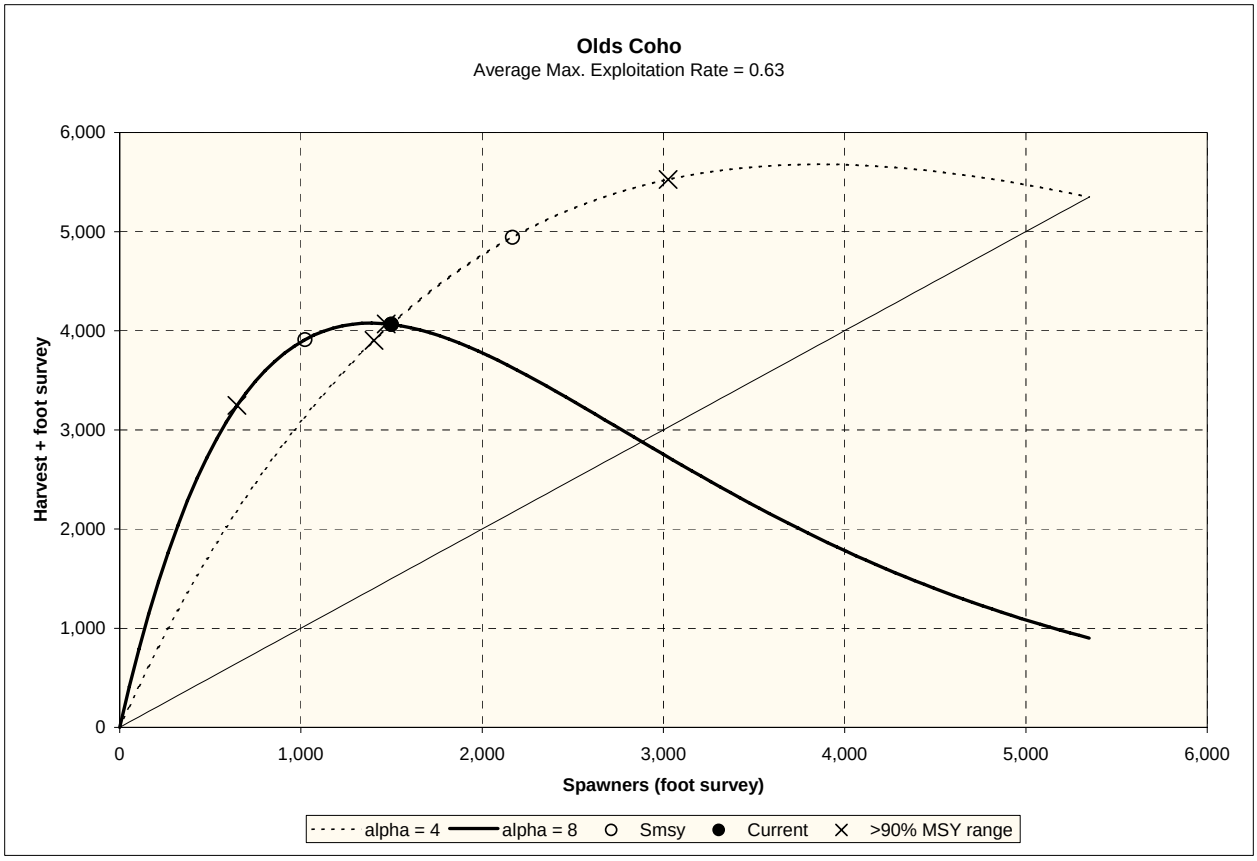

Figure 6.–Theoretical Ricker stock-recruitment relationships based on an average foot survey of 1,498 and average harvest of 2,566 coho salmon (1980-2003; •). The dotted line represents the Ricker curve with an α-parameter of 4; the solid line represents the Ricker curve with an α-parameter of 8, and the solid straight line represents replacement. Smsy (o) and escapements that produce 90% of MSY (×) are also shown.

range in eight, and above this range in four of the 20 years (Table 3). Escapements have never been below 1,000 in four consecutive years, but have been below 1,000 in the three consecutive years ranging from 1992-1994.

The existing escapement goal for the Olds River was recommended for change to a SEG of 1,000 to 2,200 fish by foot survey. The current exploitation rate for the Olds River was likely at or approaching the rate that produces MSY. Development of a BEG for this system was also recommended. Development of a BEG would be facilitated by improved assessment of returns to the Olds River through collection of age composition of escapement and harvests, continued validation of foot surveys, and analysis of saltwater harvests to improve catch allocation.

PASAGSHAK RIVER

The SEG range in the Pasagshak River has been 1,500 to 3,000 coho salmon enumerated by foot survey. This goal range was established in 1999 (Nelson and Lloyd 2001). Since 1980 the SEG range has been achieved nine times, has been underachieved twice and exceeded six times (Table 4).

Theoretical Spawner-Recruit Analysis

Average foot survey counts from 1980-2003 was 3,197 fish and average harvest was 2,965 fish (Table 4). Assuming Ricker α for coho salmon ranges from 4 to 8 ($\ln(\alpha)$ ranges from 1.4 to 2.1) and that the average survey count and average harvest represent an equilibrium exploitation rate of 0.48, two theoretical S-R relationships that have these same equilibrium values were calculated (Figures 7 and 8). In addition, from the two theoretical S-R relationships escapements (based on the surveys) that would produce MSY and a range of escapements that produce 90% or more of MSY were also calculated. These reference points were then compared to the average escapements based on surveys to help identify a potential SEG range that was robust to differences in the shape of the S-R relationship.

True exploitation likely averaged somewhat less than 0.48 (surveys do not count all fish), given that area biologists judgments were that recent foot surveys averaged nearly 100% of the total escapement. Moreover, the true exploitation rate was likely lower than or within the range that would produce MSY for a range of productivity parameters from 4 to 8. Given the uncertainty in which relationship was more likely than another, an adaptive approach was taken and a fairly wide range of escapements that could produce at or near MSY was recommended.

Local management biologists indicated that foot survey counts were improved during 1996 through 2003 resulting in much lower estimates of exploitation rate, so that this time period was analyzed separately from data gathered prior to this time to see if this changed the outcome based on this method. Average foot survey counts from 1996-2003 was 4,478 fish and average harvest was 1,816 fish for an exploitation rate of 0.29. Results from the two S-R relationships are shown in Figure 5 and Table 2.

The analysis from 1996-2003 indicated that foot surveys of 1,200 to 3,300 appeared to provide for MSY (Appendix P12). Actual escapements were below this range in one, in this range in 10, and above this range in six of the 17 years (Table 4). Escapements have never been below 1,200 in four consecutive years or three consecutive years.

Table 4.–Foot surveys and harvests of coho salmon in or adjacent to the Pasagshak River, 1980-2003.

		Harvest:			
Year	Foot Survey	Recreational[a]	Subsistence[b]	Commercial[c]	Total
1980	2,664	2,480	18	1,832	4,330
1981	2,621	1,015	16	1,048	2,079
1982	175	1,100	17	2,787	3,904
1983	1,920	1,322	20	2,316	3,658
1984	1,540	1,870	76	1,485	3,431
1985		2,292	117	1,691	4,100
1986	3,571	2,951	35	1,184	4,170
1987	2,519	3,459		9,425	12,884
1988		2,601	0	778	3,379
1989		2,065	28	0	2,093
1990	2,173	2,105	60	46	2,211
1991		1,296	216	94	1,606
1992		1,765	118	222	2,105
1993	1,337	2,274	276	714	3,264
1994		994	112	106	1,212
1995		1,215	65	927	2,207
1996	2,248	1,458	196	0	1,654
1997	2,813	1,468	88	41	1,597
1998	1,906	969	140	48	1,157
1999	3,409	1,195	75	226	1,496
2000	4,526	2,691	348	374	3,413
2001	6,209	804	181	44	1,029
2002	5,825	945	112	81	1,138
2003	8,886	2,547	353	143	3,043
n	17	24	23	24	24
Avg	3,197	1,787	116	1,067	2,965
SD	2,123	745	103	1,954	2,373
Min	175	804	0	0	1,029
Max	8,886	3,459	353	9,425	12,884

[a] Recreational harvests from the Statewide Harvest Survey (Jennings et al. 2004).

[b] Subsistence harvests from the ADF&G Division of Commercial Fisheries database.

[c] Commercial harvests from the ADF&G Division of Commercial Fisheries database for statistical area 259-41.

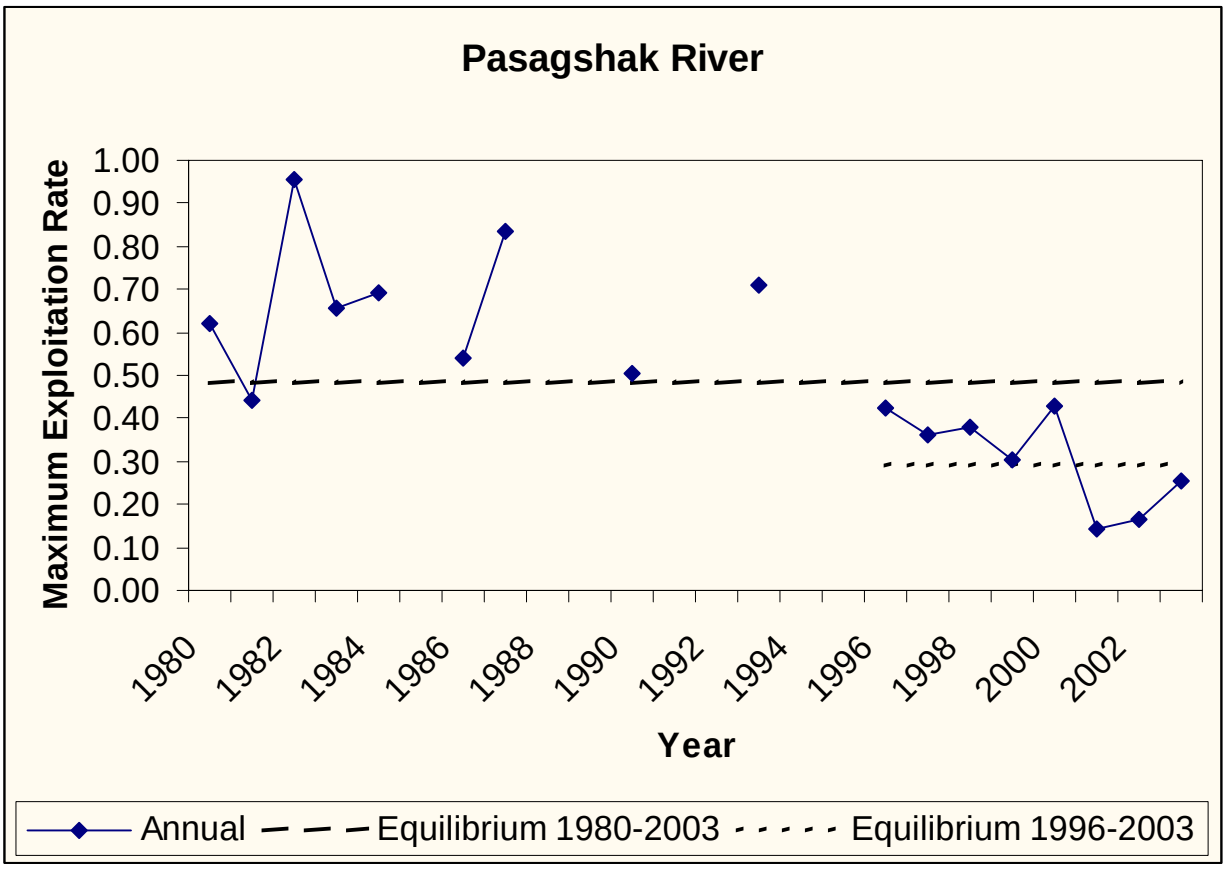

Figure 7.–Annual maximum exploitation rate (solid line) and assumed equilibrium exploitation rate (dashed lines) of coho salmon in the Pasagshak River, 1980-2003 and 1996-2003.

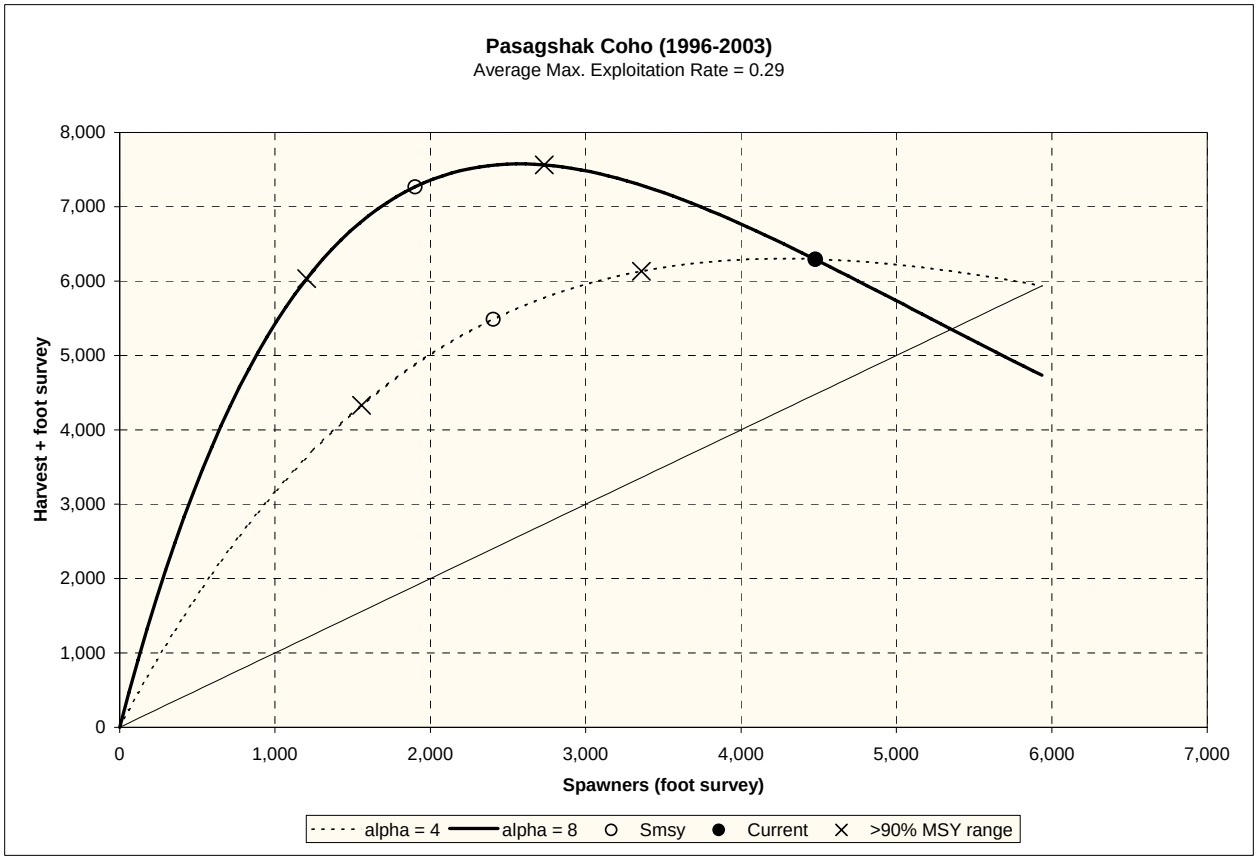

Figure 8.–Theoretical Ricker stock-recruitment relationships based on an average foot survey of 4,478 and average harvest of 2,965 coho salmon (1996-2003; •). The dotted line represents the Ricker curve with an α-parameter of 4; the solid line represents the Ricker curve with an α-parameter of 8, and the solid straight line represents replacement. Smsy (o) and escapements that produce 90% of MSY (×) are also shown.

The existing escapement goal for Pasagshak River was recommended for change to a SEG of 1,200 to 3,300 fish by foot survey. Current exploitation rate in the Pasagshak River was likely below the rate that produces MSY.

BUSKIN RIVER

The SEG range in the Buskin River has been 6,000 to 9,000 coho salmon enumerated by weir. This goal range was established in 1999 (Nelson and Lloyd 2001). Since 1985 the SEG range has been achieved eight times, has been underachieved three times and exceeded eight times (Table 5).

Theoretical Spawner-Recruit Analysis

Average weir count from 1980-2003 was 9,270 fish and average harvest was 4,852 fish (Table 5). Escapements in the Buskin River are thought to be somewhat lower than the weir count due to sport harvest of coho salmon upstream of the weir. To account for this, escapements were estimated by subtracting 20% of the sport harvest from the weir count. Average escapement using this method was 8,684 fish (SD = 2,016, minimum = 5,918, maximum = 13,028 fish). Assuming Ricker α for coho salmon ranges from 4 to 8 ($\ln(\alpha)$ ranges from 1.4 to 2.1) and that the average escapement and average harvest represent an equilibrium exploitation rate of 0.36, two theoretical S-R relationships that have these same equilibrium values were calculated (Figures 9 and 10). In addition, from the two theoretical S-R relationships, escapements (based on the surveys) that would produce MSY and a range of escapements that produce 90% or more of MSY were also calculated (Table 2). These reference points were then compared to the average escapements based on surveys to help identify a potential BEG range that was robust to differences in the shape of the S-R relationship.

Given the uncertainty in which relationship was more likely than another, an adaptive approach was taken and a fairly wide range of escapements that could produce at or near MSY was recommended. Escapements of 3,000 to 7,200 appeared to theoretically provide for MSY given α may actually range from 4 to 8 and average harvests and escapements represented an equilibrium situation. Actual escapements have never been below this range, within this range in four, and above this range in 15 of the 19 years (Table 5). Escapements have never been below 3,000 in four consecutive years.

Spawner-Recruit Analysis

An S-R analysis of return data (Appendix B1) arranged as a brood table (Table 6) indicate that: 1) estimated α for this stock was 4.65 (SE = 1.20); 2) MSY was produced with an escapement of 5,073 fish; and 3) 90% or more of MSY was produced with a range of escapement of 3,268 to 7,131 (see also Table 7). There was no significant autocorrelation of residuals of this regression analysis (Appendices B2 through B4). These results fall within the range of two previously discussed theoretical S-R relationships (Figure 6).

It was recommended that the existing escapement goal for Buskin River be changed to a BEG of 3,200 to 7,200 spawning fish. The number of spawning fish must take into account 20% of the sport harvest that occurs upstream of the weir. This recommendation is based primarily on the updated brood table and S-R analysis, but is corroborated by the theoretical S-R relationships.

Table 5.–Weir counts and harvests of coho salmon in or adjacent to the Buskin River, 1980-2003.

		Harvest:			
Year	Weir Count	Recreational[a]	Subsistence[b]	Commercial[c]	Total
1980		2,643			
1981		2,269			
1982		2,431			
1983		2,307			
1984		1,871			
1985	9,474	2,178	2,554	666	5,398
1986	9,939	4,098	2,618	1,065	7,781
1987	11,103	3,133	1,747	2,334	7,214
1988	6,782	3,474	1,556	254	5,284
1989	9,930	4,782	1,301	0	6,083
1990	6,222	1,521	1,821	1	3,343
1991	8,929	4,149	1,473	15	5,637
1992	6,535	1,474	1,563	0	3,037
1993	6,813	4,125	1,723	7	5,855
1994	8,146	2,429	2,193	15	4,637
1995	8,694	2,132	1,309	224	3,665
1996	8,439	2,481	1,372	0	3,853
1997	10,926	2,864	1,445		4,309
1998	9,062	2,669	1,555	9	4,233
1999	9,794	3,422	1,467	3	4,892
2000	8,048	2,631	2,011	0	4,642
2001	13,494	2,332	1,430	0	3,762
2002	10,646	2,497	1,514	0	4,011
2003	13,150	3,302	1,247	6	4,555
n	19	24	19	18	19
Avg	9,270	2,801	1,679	256	4,852
SD	2,042	854	400	592	1,259
Min	6,222	1,474	1,247	0	3,037
Max	13,494	4,782	2,618	2,334	7,781

[a] Recreational harvests from the Statewide Harvest Survey (Jennings et al. 2004).

[b] Subsistence harvests from the ADF&G Division of Commercial Fisheries database.

[c] Commercial harvests from the ADF&G Division of Commercial Fisheries database for statistical area 259-22.

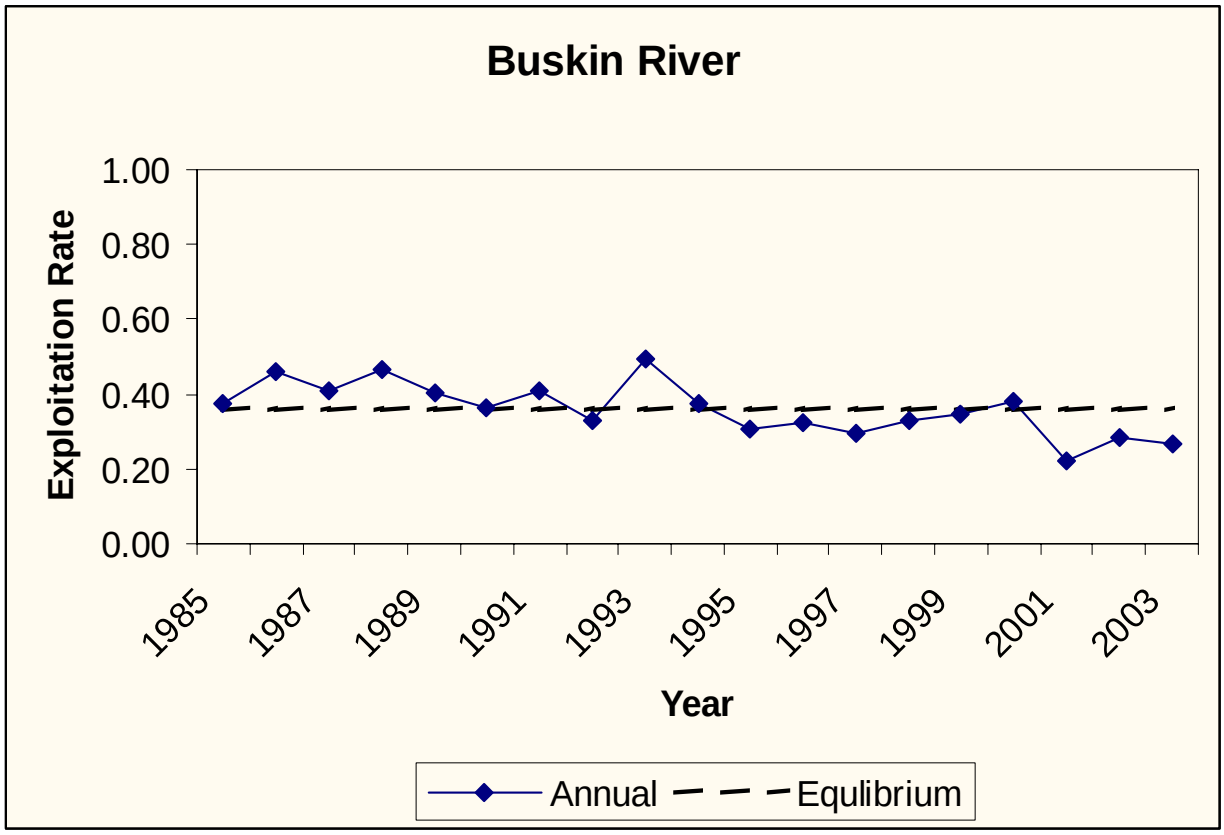

Figure 9.–Annual exploitation rate (solid line) and assumed equilibrium exploitation rate (dashed line) of coho salmon in the Buskin River, 1980-2003.

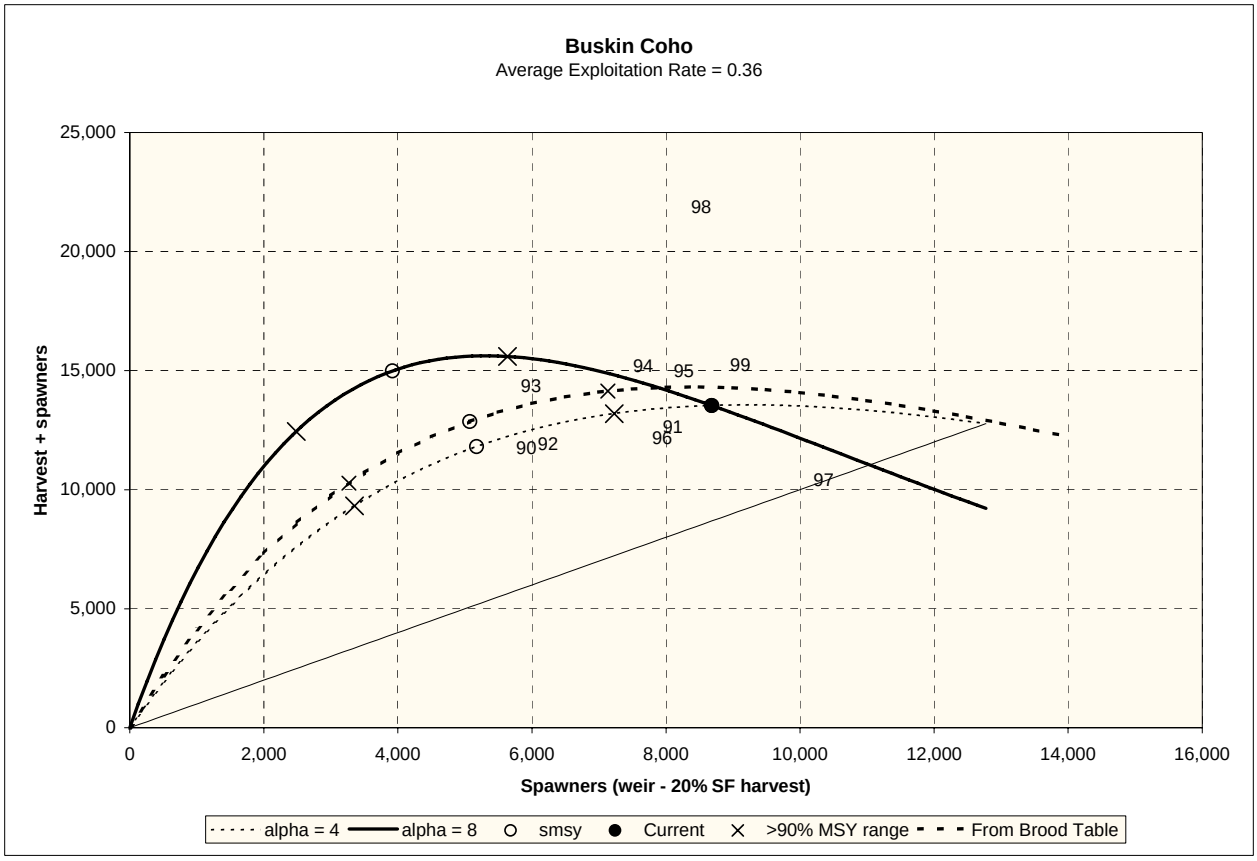

Figure 10.–Theoretical Ricker stock-recruitment relationships based on an average escapement of 8,684 and average harvest of 4,852 coho salmon (1980-2003; •). The dotted line represents the Ricker curve with an α-parameter of 4; the solid line represents the Ricker curve with an α-parameter of 8, and the solid straight line represents replacement. Smsy (o) and escapements that produce 90% of MSY (×) are also shown. The heavy dotted line represents the Ricker stock-recruitment relationship from the 1990-1999 brood table (data indicated by brood years).

Table 6.–Brood table for coho salmon production in the Buskin River, 1988-1999.

Brood Year	Escapement (S)	Age 3 Return	Age 4 Return	Age 5 Return	Total Return (R)	R/S
1988	5,487			940		
1989	8,974		9,073	281		
1990	5,918	1,829	9,547	344	11,720	1.98
1991	8,105	2,469	9,220	930	12,619	1.56
1992	6,240	2,368	8,019	1,529	11,916	1.91
1993	5,988	2,847	10,215	1,276	14,338	2.39
1994	7,660	2,919	9,155	3,099	15,173	1.98
1995	8,268	2,330	11,709	952	14,991	1.81
1996	7,943	2,985	9,149	22	12,156	1.53
1997	10,353	2,131	7,843	427	10,401	1.00
1998	8,528	8,924	11,481	1,456	21,861	2.56
1999	9,110	2,250	11,963	1,023[a]	15,236	1.67

[a] Assumed from average of age 5 returns from 1988-1998.

Table 7.–Ricker stock-recruit parameters for coho salmon production in the Buskin River, brood years 1990-1999.

Parameter	Estimate	SE	p-value
$\ln(\alpha')$[a]	1.54	0.39	0.005
β	1.19×10^{-4}	4.90×10^{-5}	0.042
σ	0.21		
Adjusted r^2	0.35		

[a] $\ln(\alpha') = \ln(\alpha) + \sigma^2/2$

RECOMMENDATIONS

- Escapement trends are fairly similar among all surveyed streams. Escapement goals were recommended for the major systems (American, Olds, Buskin, Pasagshak) where there is yield information available, and reasonably accurate and validated estimates of escapement. Formal escapement goals were not needed for the minor systems and not all minor systems need to be monitored to gain an understanding of escapement trends in these systems.
- The existing escapement goal for Roslyn Creek should be dropped because of a lack of yield information, lack of validation of foot surveys to actual escapements, and reasonably high correlation (> 0.5) with temporal escapement patterns in American and Olds rivers.
- The existing escapement goal for Saltery Creek should be dropped because of no consistent assessment method (varies between weir and aerial surveys) and no validation of aerial surveys to actual escapements. There is some indication that exploitation rate in Saltery Creek is likely low (< 25% in years of complete weir counts), but an improved and consistently fielded assessment program, along with existing estimates of harvest would provide information necessary to set an escapement goal in the future.
- Any other coho salmon escapement goals or management objectives developed for minor systems on the Kodiak road zone should be dropped in favor of developing escapement goals on the main yield-producing systems.
- The existing escapement goal for American River should be changed to a SEG of 400 to 900 fish by foot survey. Current exploitation rate in the American River is likely at or slightly above the rate that produces MSY. Development of a BEG for this system is recommended. Development of a BEG would be facilitated by improved assessment of returns to the American River (age composition of escapement and harvests, continued validation of foot surveys, analysis of saltwater harvests to improve catch allocation).
- The existing escapement goal for Olds River should be changed to a SEG of 1,000 to 2,200 fish by foot survey. Current exploitation rate in the Olds River is likely at or approaching the rate that produces MSY. Development of a BEG for this system is recommended. Development of a BEG would be facilitated by improved assessment of returns to the Olds River (age composition of escapement and harvests, continued validation of foot surveys, analysis of saltwater harvests to improve catch allocation).
- The existing escapement goal for Pasagshak River should be changed to a SEG of 1,200 to 3,300 fish by foot survey. Current exploitation rate in the Pasagshak River is likely below the rate that produces MSY.
- The existing escapement goal for Buskin River should be changed to a BEG of 3,200 to 7,200 spawning fish. The number of spawning fish must take into account 20% of the sport harvest that occurs upstream of the weir. This recommendation is based primarily on the updated brood table and S-R analysis, but is corroborated by the theoretical S-R relationships.

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APPENDIX A: CLUSTER ANALYSIS OF ESCAPEMENTS

Appendix A1.–Escapement counts of coho salmon from streams along the Kodiak road zone (1980-2003). Escapements to the Buskin River are from weir counts; escapements to Saltery Creek are from aerial surveys; and all other escapements are from foot surveys. Blanks indicate no survey or a different survey technique was used.

Year	American	Buskin	Chiniak	Kalsin	Monashka	Myrtle	Olds	Pasagshak	Pillar	Roslyn	Russian	Salonie	Saltery	Sargent	Twin
1980	903		32	240			780	2,664	62	628	30	741	212		1
1981	627		170	166	57			2,621	33	314	47	393		44	
1982	266		155				1,375	175			87	388	3,500	130	
1983	114		25	32	24			1,920	15	49	23	127	700	16	
1984	277		76	12			325	1,540		168			2,100	61	
1985	439	9,474	86		135		1,648		140	189	358	189		87	
1986	221	9,939	75		44		1,849	3,571	25	405		179			
1987	555	11,103	75	53			842	2,519		280		317			
1988		6,782													
1989		9,930					743			235					
1990	419	6,222	48	64	52		1,706	2,173	45	676	16	142		60	
1991		8,929			55				70	882					
1992	167	6,535		570			308			70		98	1,000		
1993	412	6,813			145		525	1,337	69	148	133	274	1,500	83	
1994	194	8,146					395		199	130		226			
1995	169	8,694					2,642			322		521	5,000		
1996	69	8,439			62		2,200	2,248	27	6		88			
1997	2,204	10,926			199		4,064	2,813	83	1,043		594	1,500		
1998	1,360	9,062	31		51		2,296	1,906	45	57		153	1,200		
1999	284	9,794			71		1,382	3,409	432	537		396			
2000	133	8,048			90		1,097	4,526	27	205		142			
2001	233	13,494	500		83		3,454	6,209	121	832	183	594		282	
2002	1,034	10,646	609		343	122	790	5,825	124	660	364	920		378	
2003	511	13,150	286		45	63	1,534	8,886	103	497		670		130	61
#surveys	21	19	13	7	15	2	20	17	17	22	9	20	9	10	2
Avg	504	9,270	167	162	97	93	1,498	3,197	95	379	138	358	1,857	127	31
SD	510	2,042	188	197	82	42	1,031	2,123	100	299	138	243	1,504	115	42
Min	69	6,222	25	12	24	63	308	175	15	6	16	88	212	16	1
Max	2,204	13,494	609	570	343	122	4,064	8,886	432	1,043	364	920	5,000	378	61

Appendix A2.–Correlation matrix (A) and sample sizes (B) of paired time series of coho salmon escapement counts from streams along the Kodiak road zone during 1980-2003 (correlations ≥ 0.500 are in bold).

A.

System	American	Buskin	Chiniak	Kalsin	Monashka	Olds	Pasagshak	Pillar	Roslyn	Russian	Salonie	Saltery
American												
Buskin	0.263											
Chiniak	0.110	**0.596**										
Kalsin	-0.055	-0.466	0.187									
Monashka	0.497	0.113	**0.715**	**0.780**								
Olds	0.432	0.432	0.247	-0.426	-0.127							
Pasagshak	0.009	**0.735**	**0.688**	**0.789**	0.174	0.172						
Pillar	-0.085	0.179	**0.661**	**0.753**	0.146	-0.156	0.203					
Roslyn	**0.537**	0.454	**0.623**	-0.169	0.318	**0.546**	0.416	0.162				
Russian	0.315	**0.511**	**0.614**	**0.580**	**0.795**	0.036	**0.691**	**0.907**	0.070			
Salonie	0.438	**0.680**	**0.745**	-0.048	**0.662**	0.166	**0.537**	0.213	**0.704**	0.350		
Saltery	-0.297	0.146	**0.953**	-0.302	**0.875**	0.286	-0.823	0.437	-0.013	**0.546**	0.187	
Sargent	**0.565**	**0.570**	**0.962**	-0.002	**0.753**	0.303	**0.566**	**0.689**	**0.712**	**0.657**	**0.866**	**0.912**

B.

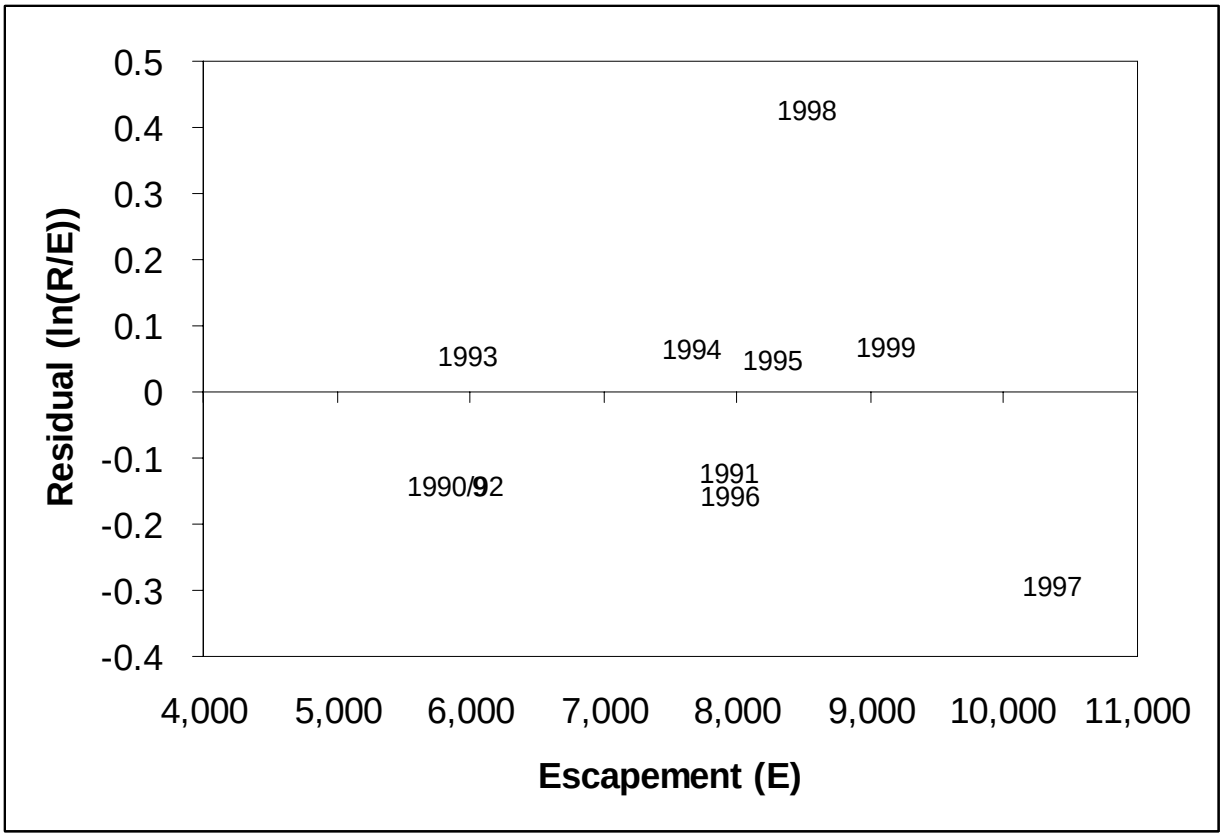
System	American	Buskin	Chiniak	Kalsin	Monashka	Olds	Pasagshak	Pillar	Roslyn	Russian	Salonie	Saltery
American												
Buskin	16											
Chiniak	13	8										
Kalsin	7	3	6									
Monashka	14	13	9	3								
Olds	19	17	11	5	12							
Pasagshak	17	12	12	6	13	15						
Pillar	16	14	10	4	15	14	14					
Roslyn	20	18	12	7	15	19	16	17				
Russian	9	5	8	4	7	7	8	8	8			
Salonie	20	16	12	6	14	18	16	16	19	9		
Saltery	9	5	5	4	4	8	7	5	8	4	8	
Sargent	10	6	9	4	8	8	9	8	9	8	9	4

APPENDIX B: BUSKIN RIVER RUN DATA AND STOCK-RECRUIT ANALYSIS DIAGNOSTICS

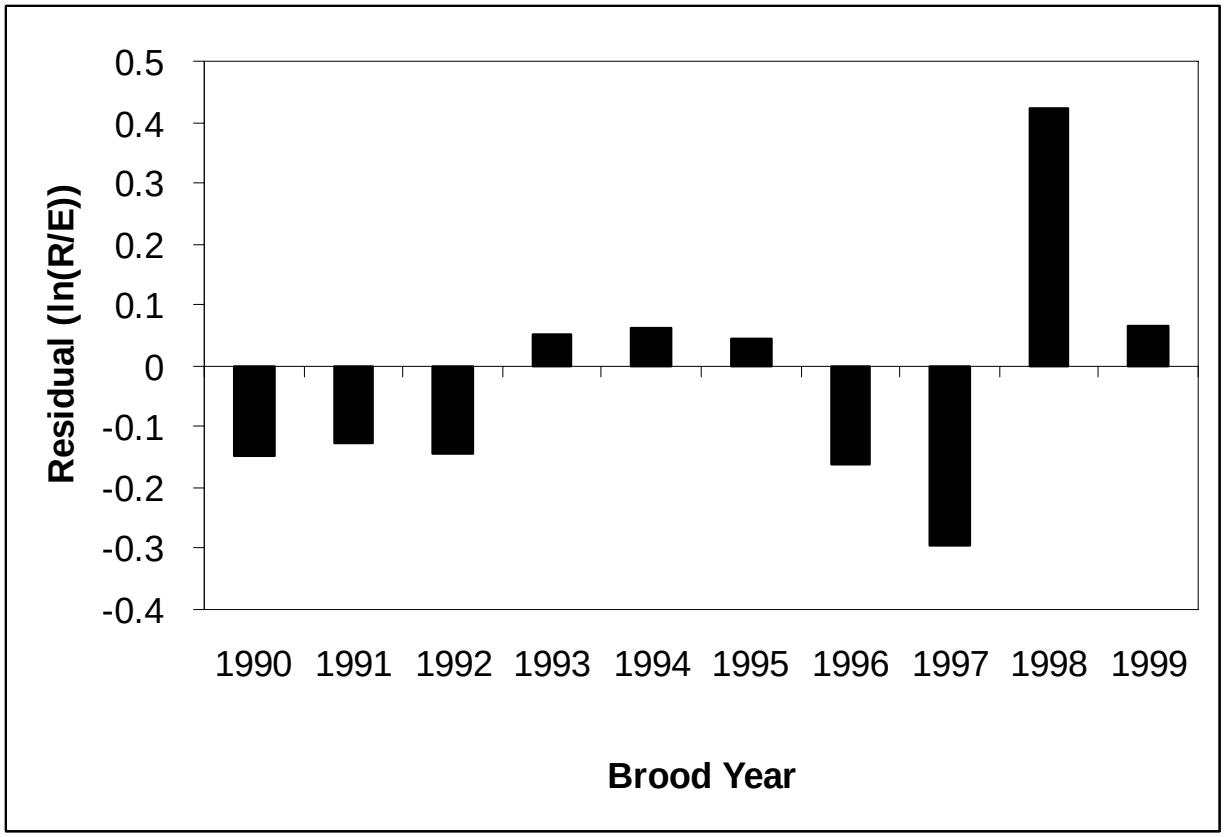
Appendix B1.–Sport harvest, subsistence and commercial harvest, escapement, and total run by age of coho salmon in the Buskin River, 1993-2003.

		Age			
Year	Source	1.1	2.1	3.1	Total
1993	Escapement	769	4,889	330	5,988
	Subs/Comm	222	1,413	95	1,730
	Sport Harvest	838	2,771	516	4,125
	Total Run	1,829	9,073	940	11,843
1994	Escapement	1,288	6,304	68	7,660
	Subs/Comm	371	1,817	20	2,208
	Sport Harvest	810	1,425	194	2,429
	Total Run	2,469	9,547	281	12,297
1995	Escapement	1,550	6,459	258	8,268
	Subs/Comm	287	1,198	48	1,533
	Sport Harvest	531	1,563	38	2,132
	Total Run	2,368	9,220	344	11,933
1996	Escapement	1,917	5,400	626	7,943
	Subs/Comm	331	933	108	1,372
	Sport Harvest	599	1,686	196	2,481
	Total Run	2,847	8,019	930	11,796
1997	Escapement	2,061	7,213	1,079	10,353
	Subs/Comm	288	1,007	151	1,445
	Sport Harvest	570	1,995	299	2,864
	Total Run	2,919	10,215	1,529	14,662
1998	Escapement	1,557	6,118	853	8,528
	Subs/Comm	286	1,122	156	1,564
	Sport Harvest	487	1,915	267	2,669
	Total Run	2,330	9,155	1,276	12,761
1999	Escapement	1,528	5,995	1,587	9,110
	Subs/Comm	882	3,462	916	5,261
	Sport Harvest	574	2,252	596	3,422
	Total Run	2,985	11,709	3,099	17,793
2000	Escapement	1,316	5,653	588	7,558
	Subs/Comm	356	1,528	159	2,043
	Sport Harvest	458	1,968	205	2,631
	Total Run	2,131	9,149	952	12,232
2001	Escapement	6,925	6,086	17	13,028
	Subs/Comm	760	668	2	1,430
	Sport Harvest	1,240	1,089	3	2,332
	Total Run	8,924	7,843	22	16,790
2002	Escapement	1,612	8,228	306	10,147
	Subs/Comm	241	1,228	46	1,514
	Sport Harvest	397	2,025	75	2,497
	Total Run	2,250	11,481	427	14,158
2003	Escapement	2,657	8,766	1,067	12,490
	Subs/Comm	267	879	107	1,253
	Sport Harvest	702	2,318	282	3,302
	Total Run	3,626	11,963	1,456	17,045

Appendix B2.–Plot of residuals of the regression of ln(Return/Escapement) on Escapement against escapements of coho salmon in the Buskin River for brood years 1990-1999.



Appendix B3.–Plot of residuals of the regression of ln(Return/Escapement) on Escapement against brood year of coho salmon in the Buskin River, 1990-1999.



Appendix B4.–Autocorrelation (ACF) and partial-autocorrelation (PACF) plots for the first five lags of residuals of regression of ln(Return/Escapement) on Escapement of coho salmon in the Buskin River. Bars are estimates of correlation at lag; dotted lines are ± 2 SE's.