BIOLOGICAL ESCAPEMENT GOAL FOR ANVIK RIVER CHUM SALMON

By:

John H. Clark

and

Gene J. Sandone

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AUTHORS

John H. Clark is a Fishery Scientist for the Alaska Department of Fish and Game, Division of Commercial Fisheries, 4240 Jimtown Road, Helena, MT 59602.

Gene J. Sandone is the AYK Regional Supervisor for the Alaska Department of Fish and Game, Division of Commercial Fisheries, 333 Raspberry Road, Anchorage, AK 99518.

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ABSTRACT

Available information was assembled concerning estimated escapements, estimated harvests and age composition of chum salmon *Oncorhynchus keta* returning to the Anvik River, a tributary system to the Yukon River drainage in Alaska, during the years 1972-1998. This information was used to develop brood tables consisting of estimated escapements and estimated resultant age-specific recruits from these escapements. These data were subsequently used to estimate spawner-recruit relationships based upon the estimated escapements of Anvik River chum salmon during the years 1972-1993 and recruits resulting from these escapements 3, 4, 5, and 6 years later. These spawner-recruit relationships were used to estimate the number of spawners (both total spawners and female only spawners) that would, on average, provide for maximum sustained yield of this stock of chum salmon in fisheries that are believed to harvest this stock. Based upon the spawner-recruit relationships developed in this report, it is recommended that the following biological escapement goal be formally adopted by the Alaska Department of Fish and Game:

Anvik River summer chum salmon: 400,000 to 800,000 total spawners per year.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Anvik River, Yukon River, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship

INTRODUCTION

The Anvik River is a large first order tributary to the Yukon River. The confluence of the Anvik and Yukon rivers is located 317 miles upstream of the mouth of the Yukon River. The Anvik River supports a major spawning stock of chum salmon *Oncorhynchus keta*.

The Anvik River stock of chum salmon is likely the largest spawning stock of summer chum salmon in the entire Yukon River drainage. This spawning stock of chum salmon has been assessed since 1972, although stock assessment methodology has varied over the past three decades. From 1972 to 1979, a tower was used to enumerate chum salmon in the Anvik River. Because the tower was located at an upstream location, the annual escapement estimates for those years was based on the tower counts plus expanded aerial surveys for the portion of the stream located below the tower. Since 1980, a downstream-located sonar assessment program has been used to enumerate chum salmon escapements in the Anvik River. Over the 27-year period of 1972 to 1998, estimated escapements of the annual Anvik River chum salmon escapements have ranged from about 250,000 spawners in 1973 to almost 1,500,000 spawners in 1981 (Figure 1).

The Alaska Department of Fish and Game (ADF&G) has managed the salmon fisheries in the Yukon River over the past few decades with the dual goal of maintaining important fisheries while at the same time achieving desired escapements. Escapement objectives for the Anvik River chum salmon population have been in effect over the past 20 years. Buklis (1993) provides the following narrative concerning the historical background for the various escapement goals that ADF&G used for the Anvik River chum salmon stock through the year 1992:

> *"A tower count escapement goal of 200,000 summer chum was proposed in 1979 for the Anvik River at the upriver tower site. In April 1982 goals were proposed of 230,000 aerial survey counts for the Anvik River and its tributaries, and 500,000 sonar counts at the sonar site. In April 1984, using estimated spawner-return relationships, a sonar count escapement goal of 487,000 was established. Additionally, an aerial survey escapement goal range of 209,000 to 356,000 was established for the main-stem Anvik River between Goblet Creek and McDonald Creek (reference: ADF&G. 1984. Yukon Area 1984 annual management report. ADF&G, Commercial Fisheries Division). In 1989, the high end of the range (356,000) was taken as the goal (reference: Bergstrom, D. J. and seven co-authors. 1991. Yukon Area annual management report, 1989. ADF&G, Commercial Fisheries Division, RIR 3A91-14)."*

Buklis (1993) also provides the escapement goal used for the Anvik River chum salmon stock in 1992 as:

> *"A minimum of 500,000 sonar count at the Anvik River sonar site"* and
> *"A minimum of 356,000 aerial survey count for index area Goblet Creek to McDonald Creek."*

In 1994, Gene J. Sandone analyzed available statistics for the Anvik River chum salmon stock and recommended that the aerial survey escapement goal of 356,000 fish counted in the index area of Goblet Creek to McDonald Creek be dropped. He further recommended that the minimum sonar count of 500,000 be changed to a range of 500,000 to 600,000 summer chum salmon having a 57% female component (Sandone 1994a and 1994b). Stock-recruit analysis as presented in the two 1994 memorandums by Sandone were updated in 1996 without a change in recommendations concerning the escapement goal (Sandone 1996). In a 1999 memorandum (Huttunen and Bergstrom 1999) it was recommended that:

"Based on optimum spawner-recruit (Ricker) production calculations from sonar-derived escapement data and total return estimates, we suggest a BEG range of 400,000 to 800,000 chum salmon above the sonar site."

The purposes of this report are to document current analyses relevant to developing a stock-recruit relationship for the Anvik River chum salmon stock and to make a recommendation to ADF&G as to an appropriate biological escapement goal for this important stock of summer chum salmon.

ANVIK RIVER CHUM SALMON ESCAPEMENTS, HARVESTS, RETURNS, AND THE SPAWNER-RECRUIT RELATIONSHIP

Anvik River Escapements

Chum salmon escapements in the Anvik River have been assessed annually since 1972. The first eight years of the data set are based on tower counts coupled with expanded aerial surveys in downstream areas and the latter portion of the data set is based upon sonar counts from a downstream assessment program. Over the 27-year period of 1972 to 1998, summer chum salmon escapement in the Anvik River has averaged 691,304 spawning fish, ranging from a low of 249,015 spawning fish in 1973 to a high of 1,486,182 spawning fish in 1981 (Table 1). Thus contrast in spawning abundance is about 6-fold, a meaningful level of variation in annual spawning abundance. According to the Chinook Technical Committee (CTC) (1999), the following guidelines concerning contrast in spawning abundance can be used in statistical stock-recruit analyses:

"When estimates of spawning abundance are similar – the range is less than 4 times the smallest spawning abundance – statistical stock-recruit analysis is likely to produce a poor estimate of S_{MSY}.

When range in spawning abundance is 4 to 8 times the smallest level, statistical stock-recruit analysis should produce better estimates of S_{MSY}, so long as measurement error is not extreme and some of the production-to-spawner ratios are below one at higher levels of spawning abundance.

When range is more than 8, statistical analysis should produce the best estimates, so long as some of the production-to-spawner ratios are below one at higher levels of spawning abundance."

With a contrast of spawning escapements of 6-fold, the Anvik River chum salmon analysis fits into the middle category identified by the CTC (1999) general methods and thus measurement errors and production-to-spawner levels are important in determining if data will be adequate to conduct a statistical analysis. As can be found later in this report, 22 brood years of recruits are estimated and several of the annual escapements with higher values have production-to-spawner ratios below one. Thus, one of the criteria for the middle category is met. The other criteria, measurement error, is a more difficult problem. Although annual spawning escapements have been estimated, variances associated with these estimates are not available. The escapement assessment methodologies used for Anvik River chum salmon are believed to have been rigorous and without bias. It seems likely to us that the coefficients of variation associated with the annual escapement assessments are likely less than 10%, but that is based on opinion, not on sampling information. If we are correct, measurement errors are minor. In any event, there is good reason to believe that measurement errors associated with annual escapements are not extreme. And thus, the second condition listed by the CTC (1999) is surely met. Thus, there are good technical reasons to believe that stock-recruit analysis will lead to useable estimates of the escapement level that produces maximum sustained yield (S_{MSY}).

Total Runs to the Anvik River

Since 1994, a management plan has allowed for the Anvik River to be opened to summer chum salmon commercial harvest if an adequate surplus of fish is determined by ADF&G to be available. Thus in the years 1994 through 1997, chum salmon harvests occurred in the Anvik River itself. Harvests ranged from 13,548 fish in 1997 to 84,633 fish in 1996 (Table 1). All of these fish are believed to have been of Anvik River origin. Adding these harvests to assessed escapements results in the actual runs to the Anvik River from 1972-1998 averaging 697,804 summer chum salmon (Table 1).

Summer Chum Salmon Harvests Downstream of the Confluence of the Anvik and Yukon Rivers

Although the annual Anvik in-river harvests of summer chum salmon are all believed to be of Anvik origin simply because of salmon homing behavior, it is less clear what portion of the summer chum salmon harvest that takes place in the Yukon River downstream of its confluence with the Anvik River are of Anvik River origin. However, the possible extremes are simple to determine: (1) at one extreme, it could be assumed that none of the downstream chum salmon are of Anvik River origin and (2) at the other extreme, it could be assumed that all of the downstream chum salmon are of Anvik River origin.

A large harvest of summer chum salmon occurs in the lower Yukon River in fishing Districts Y1, Y2, and Y3. The total utilization (commercial harvest, subsistence harvest, personal use harvest, and ADF&G test fishing) of summer chum salmon in Y1, Y2, and Y3 from 1972-1998 averaged 500,243 fish per year, ranging from 90,777 fish in 1998 to 1,160,081 fish in 1988 (Table 1).

There is no stock identification or other program in place that provides technical estimates of the stock composition of the summer chum salmon harvests in the Lower Yukon fisheries. However, there is a relatively new project at Pilot Station (Yukon River mile 138) wherein ADF&G attempts to enumerate the entire Yukon River summer chum salmon run as it moves upstream with sonar gear. In the Anvik River itself, further upstream than Pilot Station, ADF&G enumerates the entire Anvik River origin summer chum salmon escapement as it moves upstream past the sonar gear. There are seven years of paired data wherein the downstream counts of Yukon River summer chum salmon can be compared with Anvik River sonar counts:

Year	Pilot Station Sonar Count of Summer Chum Salmon	Anvik Sonar Count of Summer Chum Salmon
1993	947,000	517,409
1994	1,997,000	1,124,689
1995	3,438,655	1,339,418
1997	1,342,650	609,118
1998	745,919	471,865
1999	939,348	437,631
2000	410,528	205,460

Data Sources: Steve Parry and Tracy Lingnau of ADF&G, Commercial Fisheries Division, Anchorage, AK (personal communication).

The total run of chum salmon enumerated at Pilot Station (S) can be considered as:

$$S = R + I + E + X \qquad \text{where:} \qquad (1)$$

R = catch of chum salmon between Pilot Station and the confluence of the Anvik and Yukon Rivers;

I = in-river catch of chum salmon in the Anvik River;

E = Anvik River escapement as enumerated by the Anvik River sonar project; and

X = run of summer chum salmon that originated in the Yukon or its tributaries upstream of the confluence of the Yukon and Anvik Rivers.

The Pilot Station sonar project is located in the upper portion of statistical area 334-23 of Yukon River Fishing District 2 (Y2). From 1993-2000, an average of 80% of the commercial, 91% of the subsistence, and 87% of the combined total Y2 catch of summer chum salmon took place in statistical areas 334-21, 334-22, and 334-23, downstream of the Pilot Station sonar project. The Anvik-Yukon confluence is located in the lower portion of Yukon Fishing District 4 (Y4) and it is believed that about 30% of the Y4 harvest occurs below the confluence of the two rivers. Thus the catch of summer chum salmon between Pilot Station and the confluence of the Yukon and Anvik rivers can be approximated, on average, as:

$$R = 0.87(Y2) + Y3 + 0.3(Y4) \qquad \text{where:} \qquad (2)$$

Y2, Y3, and Y4 = catch of summer chum salmon in Yukon fishing Districts Y2, Y3, and Y4, respectively.

And, therefore, the Anvik River origin chum salmon run at Pilot Station (A) is:

$$A = pS = pR+I+E) \qquad \text{where:} \qquad (3)$$

p = proportion.

Solving for p:

$$p = (E+I)/(S-R) \quad (4)$$

Summer chum salmon harvests between Pilot Station and the confluence of the Anvik and Yukon rivers in the years when sonar estimates are available for both Pilot Station and the Anvik River were:

Year	Y2 Summer Chum Salmon Harvest (334-24 & 334-25)	Y3 Summer Chum Salmon Harvest	30% Y4 Summer Chum Salmon Harvest	*"R"*
1993	7,477	8,022	18,910	34,409
1994	4,308	8,586	52,957	65,851
1995	14,268	12,143	157,478	183,889
1997	4,013	10,316	40,606	54,935
1998	4,002	6,472	5,414	15,888
1999	6,430	944	3,400	10,774
2000	1,681	1,000	3,000	5,681

Data Sources: 1993-1998 from Bergstrom et al (1999); 1999 commercial and subsistence & 2000 commercial from Tom Vania of ADFG, Commercial Fisheries Division, Anchorage, AK (personal communication); and 2000 subsistence assumed approximately the same as 1999 subsistence.

Given the relationships described above, the proportions of Anvik River origin chum salmon enumerated at Pilot Station were:

Year	*"R"* as Described in EQ 1	*"I"* as Described in EQ 1	*"E"* as Described in EQ 1	*"S"* as Described in EQ 1	*""p* as Described in EQ 4
1993	34,409	0	517,409	947,000	56.7%
1994	65,851	22,573	1,124,689	1,997,000	59.4%
1995	183,889	54,744	1,339,418	3,438,655	42.8%
1997	54,935	13,548	609,118	1,342,650	48.4%
1998	15,888	0	471,865	745,919	64.6%
1999	10,774	0	437,631	939,348	47.1%
2000	5,681	0	205,460	410,528	50.8%
Average					**52.8%**

Given that about half (1993-2000 average = 52.8%) of the summer chum salmon counted at Pilot Station are later counted at Anvik sonar, it seems plausible that about half of the harvest of summer chum salmon in the lower Yukon River are of Anvik River origin. The assumption that half of the lower Yukon River harvest of summer chum salmon are fish of Anvik River origin is our favored assumption concerning composition in this mixed stock fishery. Alternate assumptions are that none of these fish are of Anvik River origin and that all of these fish are of Anvik River origin. The alternate, but non-favored assumptions provide a means to evaluate the effect of the assumption on the primary statistic of interest, the escapement level predicted to provide for maximum sustained yield fisheries.

Yukon River fishing District 4 also sustains a harvest of summer chum salmon and the combined harvest is comprised of a subsistence fishery, a commercial fishery, and a commercial-related fishery wherein summer chum salmon are commercially taken for their roe but the carcasses are used for subsistence.

From 1972 to 1998, subsistence harvests of summer chum salmon in Y4 have averaged 58,409 fish and ranged from an annual low of 16,425 fish in 1996 to an annual high of 121,799 fish in 1974 (Table 1). The commercial harvests of summer chum salmon in Y4 from 1972 to 1998 have averaged 53,588 fish and ranged from an annual low of 0 fish in 1972, 1973, 1996, and 1998 to an annual high of 364,184 fish in 1978 (Table 1). The commercial-related roe fishery in Y4 from 1972 to 1998 resulted in an average harvest of 192,335 fish with a range of 0 fish in 1972-1977 and 1998 to an annual high of 491,690 fish in 1989 (Table 1).

As in the lower Yukon River, stock composition of the summer chum salmon harvests in Y4 is unknown. The Anvik and Yukon Rivers confluence is located in the lower portion of Y4 (Y4 lower boundary at river mile 306; Y-4 upper boundary at river mile 681; confluence of the Anvik and Yukon Rivers at river mile 317). Based upon location of fishing sites in Y4 and delivery records of various processors, Sandone (1991) determined that at most, 30% of the Y4 harvest takes place downstream of the mouth of the Anvik River and could potentially be composed of Anvik origin summer chum salmon. The other extreme, of course, is to assume that none of the fish in Y4 are of Anvik River origin. Again, our favored assumption is that half of the maximum is comprised of Anvik River origin chum salmon, or in this case, 15% of the Y4 harvests.

Based on these considerations and logic, we have developed three alternate data bases, depending upon which assumptions are made with regard to harvests of Anvik River chum salmon in the Yukon River downstream of its confluence with the Anvik River. To summarize, these assumptions and models are as follows:

	Proportion of Harvests Included and Assumed to be of Anvik River Origin		
Assumption Model	**Anvik In-River Harvests**	**Y1, Y2, and Y3 Total Utilization**	**Y4 Harvests**
Mixed-Stock Fishery Model One	100%	0%	0%
Mixed-Stock Fishery Model Two	**100%**	**50%**	**15%**
Mixed-Stock Fishery Model Three	100%	100%	30%

Estimated Annual Total Returns of Anvik River Chum Salmon to the Yukon Drainage

Results of allocating harvests according to the three alternate assumptions we developed earlier in this report and subsequently coupling these estimated harvest scenarios with escapements resulted in three alternate views toward annual total runs of Anvik River chum salmon to the Yukon Drainage during the years 1972-1998 (Table 2). Under our favored assumptions, which are those associated with mixed-stock fishery model two, annual total runs of Anvik River chum salmon to the Yukon Drainage from 1972 to 1998 ranged from a low of 428,604 fish in 1973 to a high of 2,016,249 fish in 1981 (Figure 1). Again, mixed-stock fishery model one and three analyses were developed to evaluate the effect of the mixed-stock fishery assumptions upon statistics of interest.

Age Composition of Annual Escapements and Catches and Estimated Age-specific Total Runs

Age and sex composition of the escapements of chum salmon in the Anvik River have been annually monitored since 1972. Annual sample sizes of sexed and aged fish have ranged from 320 chum salmon sampled in 1972 to 1,224 chum salmon sampled in 1994 with the average sample size being 571 chum salmon (Table 3). Over this 27-year period, the proportion of females in the spawning population has averaged 56.5% (Table 3), while age composition has averaged 2.7% age 3 fish, 58.3% age 4 fish, 37.9% age 5 fish and 1.1% age 6 fish.

Age composition of summer chum salmon caught in Yukon River fisheries has been monitored annually since 1972 (Table 4). Age composition estimates of the catch of summer chum salmon used in this report for the years 1972-1981 were taken from Buklis (1983), and these age compositions represent chum salmon sampled from the Emmonak fishery where they were harvested with 5 1/2 inch mesh gill nets. The 1972-1981 sample sizes ranged from 223 fish sampled in 1973 to 754 fish sampled in 1981. Age composition estimates of the catch of summer chum salmon used in this report for the years 1982-1998 were taken from Bergstrom et al. (1999), and these age compositions represent weighted averages of the annual age compositions of summer chum salmon in fisheries throughout the river. The 1982-1998 sample sizes of aged fish ranged from 1,147 fish aged in 1998 to 5,112 fish aged in 1988. Because sample sizes are high, only a small loss of precision occurs when going from annual total runs to annual age-specific estimates of total runs. Average age composition of summer chum salmon from 1972-1998 is estimated at 3.9% age 3 fish, 57.2% age 4 fish, 37.3% age 5 fish, and 1.6% age 6 fish (Table 4).

The annual age composition estimates listed in Tables 3 and 4 were multiplied by the respective estimates of annual escapements and catches as provided in Table 1 but adjusted with the three alternate assumptions concerning the portion of Anvik River stock chum salmon in Yukon River fisheries as listed in Table 2 to provide three data bases concerning age-specific estimates of annual total runs (Tables 5, 6, and 7). These three alternate estimates of the age-specific total runs of Anvik River chum salmon were used to develop estimates of recruitments from brood-year escapements.

Estimated Recruits Resulting from 1972 to 1993 Brood-year Escapements

The number of Anvik River origin chum salmon recruits resulting from individual brood-year escapements *(i)* in each of the data sets was estimated as the summation of estimated total returns of age-3 fish in year $i+3$, age-4 fish in year $i+4$, age-5 fish in year $i+5$, and age-6 fish in year $i+6$. The data used for this summation process is that of Tables 5, 6, and 7 and the results are provided in Table 8. Brood years 1972-1993 were included. The age-6 recruits in 1999 for the 1993 brood year were estimated as the average age-6 recruitment. Because very few fish return at age 6, this estimation procedure has little effect on the spawner-recruit relationship discussed later in this report. Total recruits of Anvik River origin chum salmon resulting from the 1972-1993 brood years were estimated to have ranged from a low of 237,394 fish from the 1972 brood year to a high of 2,215,844 fish from the 1981 brood year using the favored mixed-stock fishery model assumptions (Table 8).

These calculations laid the basis for developing three alternate estimated paired data sets each with a sample size of 22 consisting of: (1) estimated escapements during the years 1972-1993 and, (2) estimated recruitment resulting from these escapements. The paired data set associated with mixed-stock fishery model two (Table 8) was used to provide the best available scientific information upon which a technical analysis of the maximum sustained yield escapement level could be estimated. The paired data sets associated with mixed-stock fishery model one and three were used to examine the effect of assumptions associated with mixed-stock model two on estimated escapement level predicted to result in maximum sustained yield.

Because the proportion of females in the 1972-1998 annual escapement varied from 39.1% in 1974 to 69.4% in 1982, about a two-fold level of variation (see Table 3), it was decided to also calculate female spawner versus total recruit relationships. In this case, the independent variable, female escapement only, was the number of female chum salmon estimated to have been in the annual escapements. The annual values were calculated by multiplying the female proportions listed in column 3 of Table 3 by the estimated total escapement listed in column 2 of Table 1 and the respective annual values are provided in column 2 of Table 9 for brood years 1972-1993. These alternate views of the independent variable (escapements) were then used with the same estimates of the dependent variables (recruitments) as provided in columns 3, 4, and 5 of Table 8. Or in other words, the estimated number of females per brood year were paired with estimates of the number of recruits these escapements produced under three alternate views concerning the proportion of Anvik origin fish in mixed-stock Yukon River fisheries (Table 9). Thus, these calculations laid the basis for developing three additional alternate estimated paired data sets each with a sample size of 22 consisting of: (1) estimated female only escapements during the years 1972-1993 and, (2) estimated recruitment resulting from these escapements (Table 9). Full brood tables developed through these analyses are provided in Tables 10 (total escapement) and 11 (female only escapement).

Spawner-Recruit Relationship for Anvik River Origin Chum Salmon

Once the six paired data sets were calculated, spawner-recruit relationships were developed by fitting these paired data sets to the following model:

$$R_y = \alpha S_y e^{-\beta S_y} \exp(\varepsilon_y) \tag{5}$$

where: R_y = estimated total recruitment by brood y;
S_y = spawning escapement (total or female only) that produced brood y;
α = intrinsic rate of population increase in the absence of density-dependent limitations;
β = density-dependent parameter; and
ε_y = process error with mean 0 and variance σ^2_ε.

This model, commonly referred to as a Ricker recruitment curve (Ricker 1975), has two parameters, α and β, to estimate, given a series of spawner and resultant recruitment observations or estimates. We assumed the errors were log-normal (as is common for salmon returns), resulting in the log-transformed linear equation:

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

Linear regression procedures provided estimates of the intercept (ln α) and the slope (β) in equation 6. Hilborn and Walters (1992:271-2) published the following empirical approximation of the estimated spawning size that produces maximum sustained yield or MSY (S_{MSY}) as a function of estimated parameters:

$$\hat{S}_{MSY} \cong \frac{\widehat{\ln\alpha} + \hat{\sigma}^2_\varepsilon/2}{\hat{\beta}}[0.5 - 0.07(\widehat{\ln\alpha} + \hat{\sigma}^2_\varepsilon/2)] \tag{7}$$

where: $\hat{\sigma}^2_\varepsilon$ = the mean square error from the regression.

Analysis of the spawner-recruit relationship for the preferred model data set, mixed-stock fishery model two, and use of total escapement as the independent variable resulted in an estimate of 517,827 spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel A). The spawner-recruit relationship developed estimated that maximum surplus yield from the Anvik River stock of chum salmon is 580,322 fish, on average. If the Anvik River stock of chum salmon were managed at the indicated MSY escapement level of 517,827 spawners per year, a fishery yield of 580,322 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 53%. Replacement escapement, or the point on the spawner-recruit relationship where harvestable surplus falls to zero is estimated at about 1,250,000 spawning chum salmon (Figure 2). The maximum stock size is estimated to occur with an escapement level of about 1,000,000 chum salmon in the Anvik River escapement; estimated total annual average stock size at this level of escapement is about 1,300,000 chum salmon (Figure 2). The residual patterns in the mixed-stock fishery model two spawner-recruit relationship when plotted through time and against brood-year escapements appear random (upper and lower panels of Figure 4) and there is no indication of auto-correlation in the data set, indicating that use of the model described above is appropriate (Figure 5).

Analysis of the spawner-recruit relationship for the mixed-stock fishery model one data set (no Anvik River origin chum salmon harvested in the various main Yukon River fisheries) resulted in an estimate of 425,914 spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel A). This estimate of the MSY escapement level is about 90,000 fewer spawners or 18% less than the estimate based upon the preferred model data set. Analysis of the spawner-recruit relationship for the mixed-stock fishery model three data set (all chum salmon harvested downstream of the confluence of the Anvik and Yukon Rivers are Anvik River origin chum salmon) resulted in an estimate of 567,684 spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel A). This estimate of the MSY escapement level is about 50,000 more spawners or 10% more than the estimate based upon the preferred model data set. Thus the range of possible choices with regard to the proportion of Anvik River origin chum salmon in the main Yukon River below its confluence with the Anvik River during the years used in this analysis has the potential to alter the indicated estimate of MSY escapement level from about 425,000 to 565,000 spawners.

Analysis of the spawner-recruit relationship for the preferred model data set, mixed-stock fishery model two, and use of female only escapement as the independent variable resulted in an estimate of 288,298 female spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel B). The spawner-recruit relationship developed, in this case, estimated that maximum surplus yield from the Anvik River stock of chum salmon is 588,041 fish, on average. If the Anvik River stock of chum salmon were managed at the indicated MSY escapement level of 288,298 female spawners per year, a fishery yield of 588,041 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 54%. Replacement escapement, or the point on the spawner-recruit relationship where harvestable surplus falls to zero is estimated at about 700,000 female spawning chum salmon (Figure 3). The residual patterns in the mixed-stock fishery model two spawner-recruit relationship when using female spawners as the independent variable and when plotted through time and against brood-year escapements appear random (upper and lower panels of Figure 6).

Analysis of the spawner-recruit relationship for the female only mixed-stock fishery model one data set (no Anvik River origin chum salmon harvested in the various main Yukon River fisheries) resulted in an estimate of 240,592 female spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel 2). This estimate of the MSY escapement level is about 48,000 fewer spawners or 16% less than the estimate based upon best available scientific information. Analysis of the spawner-recruit relationship for the female only mixed-stock fishery model three data set (all chum salmon harvested downstream of the confluence of the Anvik and Yukon Rivers are Anvik River origin chum salmon) resulted in an estimate of 312,565 female spawners as the MSY escapement level for the Anvik River stock of chum salmon (Table 12, Panel 2). This estimate of the MSY escapement level is about 24,000 more spawners or 8% more than the estimate based upon best available scientific information. Thus, the range of possible choices with regard to the proportion of Anvik River origin chum salmon in the main Yukon River below its confluence with the Anvik River during the years used in this analysis has the potential to alter the indicated estimate of MSY escapement level from about 241,000 to 313,000 spawners.

Bootstrap Analysis of the Spawner-Recruit Relationship for Anvik Origin Chum Salmon

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

$$\zeta_y = Y_y - \hat{\mathrm{E}}[Y_y] \tag{8}$$

where: ζ_y = the residual for brood y;
$Y_y = \ln(R_y/S_y)$;
$\hat{\mathrm{E}}[Y_y]$ = the predicted value.

A new set of dependent variables was generated by sampling the residuals from the original regression:

$$\tilde{Y}_y = \zeta_y^* + \hat{E}[Y_y] \tag{9}$$

where the ζ_y^* were drawn randomly with replacement from the original vector of the n original residuals $\{\zeta_y\}$ (n = the number of brood years in the analysis). In this fashion a new data set was created comprised of the original values for the independent variables (spawning abundance, either total or female only) and corresponding simulated values $\tilde{Y}_y$. The $\tilde{Y}_y$ were then regressed against the original values of the independent variables to produce a new, simulated set of parameter estimates for ln α, β, and σ_ε^2. These new parameter estimates were plugged into Equation 7 to produce a simulated estimate $\tilde{S}_{MSY}$. This process was repeated 1,000 times to produce 1,000 simulated estimates of $\tilde{S}_{MSY}$. From Efron and Tibshirani (1993:47):

$$v(\hat{S}_{MSY}) = \frac{\sum_{b=1}^{1000} (\tilde{S}_{MSY(b)} - \bar{S}_{MSY})^2}{1000 - 1} \tag{10}$$

where $\bar{S}_{MSY} = 1000^{-1} \sum_{b=1}^{1000} \tilde{S}_{MSY(b)}$. Ninety percent confidence intervals about $\hat{S}_{MSY}$ were estimated from the 1,000 simulations with the percentile method (Efron and Tibshirani 1993:124-126). The 1,000 values of $\tilde{S}_{MSY}$ for each scenario were sorted in ascending order making the 51st and the 950th values the lower and upper bounds of a 90% confidence interval.

A maximum sustained yield escapement goal range was estimated using the 0.8 ($\hat{S}_{MSY}$), to 1.6 ($\hat{S}_{MSY}$) procedure of Eggers (1993). This method examined optimizing harvests over a wide range of management scenarios. The initial estimate of S_{MSY} was used as the point value for recommending a biological escapement goal and this biological escapement goal is expressed as a range.

The mean bootstrap estimate of MSY escapement for the Anvik River stock of chum salmon using total escapement as the independent variable and mixed-stock model two estimates of recruitment as the dependent variable is 562,053 spawners and the coefficient of variation for this mean statistic is 42.8% (Table 13). The 90% confidence interval for the estimated MSY escapement level for the Anvik River chum salmon stock is estimated at 390,611 to 819,490 spawners (Table 13) using total escapement and model two mixed-stock fishery assumptions. The bootstrap mean estimate of the MSY escapement level is higher than the mixed-stock fishery model two regression estimate of 517,827 spawners, and differs by 44,226 fish, indicating bias is moderate at 8.5% (Table 13).

The mean bootstrap estimate of MSY escapement for the Anvik River stock of chum salmon using female only escapement as the independent variable and mixed-stock model two estimates of recruitment as the dependent variable is 299,911 female spawners and the coefficient of variation for this mean statistic is 27.3% (Table 13). The 90% confidence interval for the estimated MSY female escapement level for the Anvik River chum salmon stock is estimated at 221,674 to 415,626 spawners (Table 13) using female escapement only and model two mixed-stock fishery assumptions. The bootstrap mean estimate of the MSY escapement level is higher than the mixed-stock fishery model two regression estimate of 288,298 female spawners, and differs by 11,613 fish, indicating bias is moderate at 4.0% (Table 13).

Biological Escapement Goal for Anvik River Origin Chum Salmon

We believe that the best available scientific estimate of the MSY escapement point value for the Anvik River stock of chum salmon if measured as total escapement is about **520,000** spawners. We believe that the biological escapement goal for the Anvik River stock of chum salmon should be set at **400,000 to 800,000 total spawners** per year. This range is based upon our best estimate of the point value and the approximate application of the methodology of Eggers (1993). This range approximately:

(1) encompasses the 90% confidence interval of MSY total escapement (about 390,00 to 820,000) based on the bootstrap analysis (Table 13), as well as

(2) encapsulates the point values derived from the mixed-stock fishery models 1, 2, and 3 analyses used to bracket the MSY total escapement level (about 426,000 to 568,000) depending upon assumptions regarding the portion of Anvik River origin chum salmon that are caught in Yukon River fisheries downstream of the confluence of the Yukon and Anvik Rivers (Table 12).

Further, we believe that the best available scientific estimate of the MSY escapement point value for the Anvik River stock of chum salmon if measured as female only escapement is about 290,00 female spawners. Consequently, we believe that the biological escapement goal for the Anvik River stock of chum salmon could be set at 230,000 to 460,000 female spawners per year, were ADF&G to desire to set the goal based upon females. This range is based upon our best estimate of the point value and the approximate application of the methodology of Eggers (1993). This range approximately:

(1) encompasses the 90% confidence interval of MSY female escapement (about 222,000 to 416,000) based on the bootstrap analysis (Table 13), as well as

(2) encapsulates the point values derived from the mixed-stock fishery models 1, 2, and 3 analyses used to bracket the MSY level (about 241,000 to 313,000) depending upon assumptions regarding the portion of Anvik River origin chum salmon that are caught in Yukon River fisheries downstream of the confluence of the Yukon and Anvik Rivers (Table 12).

STOCK STATUS OF ANVIK RIVER CHUM SALMON GIVEN THE RECOMMENDED MSY ESCAPEMENT GOAL

From 1972 to 1998, five of the twenty-seven (19%) annual Anvik River chum salmon total escapements and seven (26%) of the female escapements were below the range of escapements that we have estimated will produce maximum sustained yield (Table 14). Of the twenty-four other annual total escapements, 12 (44%) were within the range of total escapements estimated to produce maximum sustained yield while the remaining 10 (37%) were above that range. Of the twenty other annual female escapements, 10 (37%) were within the range of female escapements estimated to produce maximum sustained yield while the other 10 (37%) were above that range.

An examination of female only patterns from 1990-1998 shows that only in 1990 did the female escapement fail to at least reach the range recommended (Table 14). Examination of escapement patterns during the 1990's also shows that all of the total escapements from 1990 through 1998 were either within the recommended range or they exceeded the recommended range. The 1999 Anvik River sonar count of 437,631 chum salmon indicates that the escapement was within the range recommended in this report. The 2000 Anvik sonar count of 223,072 chum salmon indicates that the escapement was less than the range recommended in this report. All in all, the pattern of escapements since 1972 indicates that the Anvik River stock of chum salmon is healthy, but has been somewhat underutilized in some years.

REVIEW COMMENTS AND AUTHORS RESPONSE

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. Oral and written reports concerning the six AYK BEG analyses 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. A discussion of these reviews and the ADF&G author's response to these reviews is provided herein to better inform the reader of aspects of the technical issues involved and to provide a more complete discussion of the topic. Some of the following discussion relates to the Anvik analysis (the topic of this report) only in a general manner while other aspects of the discussion relate directly to the Anvik River chum salmon BEG analysis reported herein.

Mundy et al. (2001) Review

An independent scientific peer review of data and analysis included in the six draft reports was conducted at the request of ADF&G, and on January 15, 2001, this review was completed. The 42 page written review was titled "*A Preliminary Review of Western Alaskan Biological Escapement Goal Reports for the Alaska Board of Fisheries.*" Members of the peer review committee were Drs. Philip R. Mundy (Chief Scientist for Exxon Valdez Oil Spill Trustee Council and chair of the committee), Milo Adkison (University of Alaska), Eric Knudsen (United States Geological Survey), Daniel Goodman (Montana State University), and Ray Hilborn (University of Washington). These scientists have published 50 or more scientific articles on the technical topic of stock-recruit analysis. In general, their review was supportive of the analyses developed by ADF&G staff and adoption of the draft BEG goals was recommended with some revision. The committee understood the conundrum that while these draft BEG escapement goals were not perfect and should not be considered as long-term answers to the problem, they did represent a significant improvement over the existing escapement goals for these salmon stocks of the AYK region. The committee did suggest ways that various analyses could be improved in the long run to develop better escapement goals as the existing database for these stocks gains strength through time. AYK BEG authors appreciated the committee's technical review efforts and we appreciated the committee making positive suggestions for improvement. Hereafter this independent scientific peer review will be referred to as Mundy et al. (2001).

The Mundy et al. (2001) review includes findings, recommendations, and conclusions directed generally at all six draft BEG reports and specific comments directed at individual reports. We first address the general comments in this narrative. Findings by Mundy et al. 2001 were: "(1) *Were the analyses as presented done correctly? Yes;* (2) *Were the analyses appropriate to the available data? Yes;* and (3) *Are the estimates of S_{MSY} reasonable as long-term escapement goals? No.*"

Relative to item 3 above, Mundy et al. 2001 went on to state: "*The estimates of S_{MSY} appear reasonable short-term starting points for developing adaptive strategies for setting escapement goals appropriate to protecting the long-term interests of subsistence, commercial, and other types of uses. Any escapement goals based on these analyses must take into account the uncertainty of the S_{MSY} estimates, and they would need to be revised as soon as possible based on additional analyses and types of information described in this report. Due to a number of uncertainties regarding the data, the estimates of S_{MSY} are not acceptable as long-term escapement goals, nor do they meet the standards for knowledge set by the Sustainable Salmon Fishery Policy.*" As authors of this report and as members of the ADF&G committee charged with developing biological escapement goals for the salmon stocks of AYK, we agree with these assessments. Further, we agree that the estimates of S_{MSY} should be used as short-term goals not as long-term goals due to uncertainty in many of the estimates used in the analyses. And, we agree that the S_{MSY} estimates should be revised as soon as possible taking into account new information as recommended in the draft reports themselves and in the Mundy et al. (2001) review document. Lastly, we agree that the standards for knowledge as discussed above are not fully met for any of the stocks described in the six draft ADF&G reports that were reviewed by Mundy et al. (2001). And until such time as a massive infusion of funding is made available for salmon stock assessment in the AYK region, this lack of basic information will unfortunately continue. We anticipate that approximately an order of magnitude of increase in funding would be needed to realistically address this problem.

Mundy et al. (2001) included several recommendations, including that a full detailed peer review of the six draft reports be undertaken and that all such reports be peer reviewed in the future. As authors we have extended the review period for these reports by several months, no additional written comments beyond the two reviews discussed herein have been provided. These draft reports have been reviewed more than any other draft escapement goal reports developed by ADF&G to the author's knowledge. Mandatory scientific peer review of future ADF&G BEG reports would require a policy decision by ADF&G's leadership.

Mundy et al. (2001) recommended use of 90% confidence intervals as BEG ranges. We disagree. Doing so would put those stocks with the least reliable data at the most risk relative to the lower bound of the range due to the fact that more uncertainty (larger variance) is associated with those stocks with poorer information. We believe a range based on the estimated productivity, a method such as that developed by the Eggers (1993) approach used herein is a less risky approach. An adequate management range is thus defined and those stocks with poorer information are not unduly disenfranchised. Mundy et al. (2001) suggested incorporation of additional measurement error and simulation studies. We would agree if only such information existed. For instance, there is currently no technical means of estimating the variance associated with historic sonar passage estimates; we know there is measurement error in those estimates, we simply have no way of estimating its magnitude. And, until better estimates complete with variances are made available for the basic data used in these stock-recruit analyses, it is our opinion that simulation studies will not be especially helpful, but rather will simply mirror the assumptions made in the simulation itself. Mundy et al. (2001) recommended that more precise harvest management capabilities be developed including better catch apportionment and escapement monitoring. We concur, however, again, it must be pointed out that a very large increase in funding for the salmon stock assessment program would be required to fully achieve this objective. Mundy et al. (2001) recommended that standard methods be developed for incorporation of error introduced throughout the process of preparing data for use in stock-recruitment analysis. Again we concur, but point out that to achieve this objective would require a policy decision by ADF&G's leadership in the salmon stock assessment program for variances to be calculated in all cases where possible to accompany point estimates. Such a policy is in place in Sport Fish Division, but not in Commercial Fisheries Division at the current time. Mundy et al. (2001) recommended basic biological and physical data be substantially improved and that recommendations to improve the extent and quality of necessary data as identified in the draft reports be implemented. We concur. Mundy et al. (2001) recommended the expected performance of an escapement goal or range within the management plan be evaluated in view of critical uncertainties. We believe we have done so to the extent possible, and our analyses concerning "Stock Status" is intended to assist the reader in this regard.

Conclusions of the Mundy et al. (2001) review included the following: "*The eventual choices of escapement goals need to take account of how (1) natural variation, (2) inherent imprecision of estimates of catch and escapement, and (3) the circumstances where some harvest occurs no matter what the run size, interact to produce actual escapements. These three factors also interact with the requirements of the management plan and the capabilities of each harvest management program to influence the escapements that reach the spawning grounds each year. ... Bear in mind that "more is not necessarily better" when it comes to salmon escapement goals. Setting the goal far too high is not precautionary, because it could lead to lost production and smaller runs. Gathering quality data at all times, and relentless periodic evaluations are the surest means of adopting escapement goals that provide sustainable use for Alaska's salmon resources.*" We concur, and agree that gathering improved data concerning catches, escapements, age compositions, and stock compositions and frequent scientific analysis of these stock-recruit data to identify appropriate escapement goals is the surest means for ADF&G to fully achieve its constitutional mandate.

Mundy et al. (2001) included comments that specifically address this Anvik River chum salmon report. The Mundy et al. (2001) review states: "*Good contrast in stock sizes and temporal pattern in escapements do not leave much room for bias.*" We concur and believe the estimate of S_{MSY} developed in this report is appropriate and that the management range identified, if consistently achieved through active fishery management, will lead to MSY production for this stock of chum salmon. The Mundy et al. (2001) review states: "*The data used for spawner-recruit analysis suffers somewhat from unknown and unmeasured error structure.*" We concur but have no way of solving this general problem. Of most significance is how to estimate measurement error of historic Anvik escapements when sonar estimates of passage do not have accompanying variance estimates. The Mundy et al. (2001) review recommended additional data be collected as identified in the draft report as well as obtaining an understanding of freshwater density dependence and the effects of estuarine and marine factors on productivity. We concur, but point out that to fully accomplish this recommendation would require a substantial investment in the Anvik chum salmon stock assessment program beyond that presently existing.

Andersen et al. (2001) Review

Another review of the six draft ADF&G BEG reports entitled: "*Summary Review Comments*" was prepared by 12 staff from several federal agencies. Unlike Mundy et al. (2001), who largely accepted the proposed BEGs as improvements over current goals, the federal review, hereafter referred to as Anderson et al. (2001), rejected them, writing that they had "little scientific merit." This comment on scientific merit notwithstanding, Andersen et al. (2001) concentrated on statistical, not scientific issues in the six draft reports. Some of these statistical issues were identified in Mundy et al. (2001) and in the reports themselves; the rest of the federal comments were largely invalid or were valid with little relevance. Andersen et al. (2001) provided no alternatives to the current BEGs, even though these BEGs were based in most cases on little more than averages of the same data disparaged in Anderson et al. (2001). General comments by Andersen et al. (2001) follow along with our responses.

Andersen et al. (2001) states: "*The importance of having precise estimates of escapements in a productivity analysis cannot be overestimated. If escapements are known with little error, uncertainty is limited to only one variable in the analysis, the harvest (return). If escapement estimates have moderate to high levels of variability, knowledge of both variables in the model is uncertain and confidence in the analysis is greatly reduced. Unfortunately, most of the subject analyses have incomplete records of total escapement, and these missing data must be estimated in order to reconstruct the entire runs*." The first statement is overstated, the second true, the third sentence needs qualification, and the last is misleading. We won't comment further on the first two sentences. As to the third, importance of measurement error is relative to the contrast in the estimates of escapements over the years (Hilborn and Walters 1992, p. 288-9). The larger the range of estimates, the less important their measurement error. It's largely on consideration of contrast that AYK BEG report authors recommended BEGs and Mundy et al. (2001) accepted the proposed BEGs. Authors of AYK BEG reports and Mundy et al. (2001) recognized that in cases with potentially great measurement error in estimated escapements, the contrast of escapements was sufficiently large to render a scientific judgement in support of the analyses. Andersen et al. (2001) comments on contrast only to say there is more than one kind without explaining what they mean. As to the final sentence, records were incomplete only for some of the stocks analyzed in the six draft reports, not for most of the stocks. Anvik River chum salmon escapements have been monitored with on-the grounds methodology each year since 1972 and the escapement record is not incomplete, contrary to the Andersen et al. (2001) insinuation. Full and complete historic escapement records were also available for the Chena River chinook salmon stock, the Salcha River chinook salmon stock, and the Kwiniuk River chum salmon stock. When measurement error information was available from the historic AYK database, it was quantified and shown not to be a problem and was reported as such.

Andersen et al. (2001) goes on to state: "*The authors commonly report "average percent errors" as a measure of uncertainty or variability associated with the estimation. This is not a reliable method of assessing variability, especially when the relationships are based upon small sample sizes. This method produces estimates of variability that are artificially small. At a minimum, cross-validation should be used (a model is built excluding a data point, and the model is then used to estimate that data point). Standard statistical methods of assessing the variance of predictions based on linear models could also be used*." Uncertainty in estimates of escapement was reported as "average percent error" for some of the stocks analyzed. In the others, experience has shown that uncertainty should be negligible (i.e., chum salmon escapement in the Anvik River counted from a tower), or we have expressed uncertainty as estimated variances (i.e., chinook salmon in the Salcha and Chena rivers). Although we agree that "average percent error" is not the best measure of uncertainty in estimates of escapement, we left them as originally reported. We did so because cross-validation or predictions from linear models as proposed by Andersen et al. (2001) are flawed measures as well. The "right fix" would be to go back to the basic data (escapements, age compositions, harvest sampling efforts, etc.) and where possible, use sampling variances as estimated variances. The problem is that sampling variances were not reported or even calculated in most cases in the existing AYK database. Such statistics are currently readily available only for chinook salmon in the Salcha and Chena rivers. For many other stocks, information needed to calculate sampling variances has been lost or has never been collected. Some attempt to calculate historic sampling variances might be possible for some stocks, but would require considerably more time and effort than that available for these BEG analyses. In those cases, and in those where no calculations are possible at all, only subjective judgements are currently available as to the size of uncertainty in the estimated escapements.

Andersen et al. (2001) states: "*A weakness of most of the reports is that no attempt is made to assess how uncertainty in the estimation of missing escapement data might affect confidence in the estimates of the escapement producing maximum yield (S_{MSY}). The sensitivity of the estimates of S_{MSY} to the various assumptions used to estimate escapements should be explored through careful application of simulation techniques*." The first sentence in this critique is misleading. Measurement error was assessed when that information was available from the historic database (as described above). Accuracy in estimates of S_{MSY} for the other stocks undoubtedly suffered to some degree from measurement error in estimates of escapement. But without sampling variances for estimated escapements, there is no objective way to measure the specific impact of measurement error on estimated S_{MSY}. As to the second sentence, simulation would show that the more uncertain we are in the data, the greater the negative bias in estimated S_{MSY}. Since this effect is well documented in the literature (see Hilborn and Walters 1992:290), we saw no need to confirm the effect again. Our response in the draft reports was to qualify those estimates of S_{MSY} that we believed might be biased low because of measurement error. Our discussion of the estimated S_{MSY} for Norton Sound stocks typifies this approach. Note that the suggestion to simulate in Anderson et al. (2001) is not the same as the suggestion in Mundy et al. (2001). The former kind of simulation would have simulated variance for estimates of S_{MSY} as functions of estimated variances for estimated escapements. The simulation suggested by Mundy et al. (2001) would be a risk assessment for maintaining stock size as production is stochastically projected into the future. The former would be a statistical analysis while the latter would be a scientific investigation.

Andersen et al. (2001) criticized the bootstrapping approach used in the six draft reports for developing variances around estimates of S_{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 we have described before, many sources of variation (measurement error) were negligible in their affect on estimated S_{MSY} (i.e., chum salmon in the Anvik River and chinook salmon in the Salcha and Chena rivers) or in estimates of harvest (i.e., chinook salmon in the Salcha and Chena rivers). In other cases, no estimates of variance were available. We believe that 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. This criticism is unfounded. Residuals are presented to the readers, and important information gleaned from residual analysis is fully addressed in the reports.

Andersen et al. (2001) takes issue with the concept of contrast as used in the six draft reports without fully describing what a better concept would be. The definition we used is implicitly given in Hilborn and Walters (1992:288) as the range of spawning escapements over the years (or their estimates) or the variance of spawning escapements over the years (or their estimates) (as implied in Quinn and Deriso 1999:108 taken from Fuller 1987). These definitions are standard within the research done on the affect of contrast on estimates of S_{MSY}.

Andersen et al. (2001) criticized our sometimes use of an approximation developed by Hilborn (1985) to estimate S_{MSY} instead of the usual "exact solution" derived by solving the first derivative of the estimated stock-recruit relationship through trial and error. This is a difference without a distinction. The expected difference in solutions from these two approaches would be in terms of tenths of a percent.

Andersen et al. (2001) was critical of situations where we censored part of the data (chum salmon of the Kwiniuk and Tubutulik rivers). Data were censored because examination of residuals from the stock-recruit relationships estimated from the entire data series clearly showed that a significant change had occurred midway through the time series. Such a change implies that earlier productivity was not representative of later productivity. What the productivity in the immediate years ahead will be we do not know, but we believe that productivity in the next three years will be more like the last three years than the productivity estimated in the early years of the full time series. For this reason, we censored the earlier data and re-estimated the stock-recruit relationship. We realize this is a scientifically subjective decision, but so too would be to use the early data given the differential pattern of residuals.

Andersen et al. (2001) implied that recent large escapements producing poor returns are not indications of density dependence, but rather the result of reduced marine survival and criticized ADF&G analyses that fail to include factors other than escapement in the stock-recruit relationships. No estimates of the marine survival rates of smolts are available for any of the stocks in the draft reports. Without such information, no definitive scientific judgement on a marine cause behind poor returns is possible. Although reduced marine survival may have an impact on recent salmon returns, there is evidence of poor returns from abundant spawners, not just in recent years, but in earlier years when spawners were abundant. In contrast, fewer spawners produced better returns in many instances scattered throughout the years for many stocks. Such a relationship is the necessary condition consistent with density-dependent survival of young salmon. That there are several brood years represented along this spectrum, as is the case with stocks of chum salmon in Norton Sound, only strengthens the scientific judgements drawn.

The Andersen et al. (2001) review included some comments that specifically address this Anvik River chum salmon report. Andersen et al. (2001) states: "*...the analysis suffers to an unknown extent from unmeasured error structure. Compound variances introduced through the series of expansions of tower estimates and aerial surveys of abundance are unaccounted for in the analysis*." We concur, and point out that this problem cannot be rectified until the AYK database is expanded such that estimates are accompanied with sampling variances. In the case of the Anvik chum salmon analysis, data since 1972 would have to be carefully reviewed and massaged. And, although this could be a valuable and useful process, it is not in the scope of this analysis to undertake such a task. The Andersen et al. (2001) review states: "*.. the method of bracketing the assumed harvest contribution does not address the sensitivity of the results to violations of that assumption*." We heartily disagree, the extreme of no downstream harvest of Anvik fish in all years versus the alternate extreme of all downstream fish being of Anvik origin in all years was tested, any other simulation approach would introduce less variability into the analysis, not more. The Andersen et al. (2001) review favored the adoption of a female only escapement goal, ADFG fishery managers felt that the total escapement goal was more appropriate for management purposes. Both are presented and future escapements can be evaluated against both potential standards.

As is obvious from reading the above passages, Andersen et al. (2001) often disparaged the quality of the data describing several of the stocks in the draft reports. While our view is not as pessimistic as theirs, we do concede that the quality of the data describing some of the stocks could have been better, much better. In the past, limited funding has hampered ADF&G in assessing harvests and escapements of salmon stocks in Western Alaska. Since then, circumstances have changed. With a new emphasis on the importance of stock assessment, the quality of future data should be greatly improved, and many of the statistical issues listed by Andersen et al. (2001) resolved.

RECOMMENDATIONS

After conducting this analysis and fully considering review comments, we recommend that the following biological escapement goal for the Anvik River stock of summer chum salmon be formally adopted by the ADF&G.

Anvik River Summer Chum Salmon: 400,000 to 800,000 total spawners per year

We also recommend that this biological escapement goal analysis be updated in three years before the next regularly scheduled Board of Fisheries meeting. At that time, significantly more information will be available for further development and refinement of the overall spawner-recruit relationship. And, hopefully, sampling variances for the historic database will be made available. Refinement and further development of this relationship may lead to an improved escapement goal that will better result in MSY fisheries.

We also recommend the existing stock assessment program be continued, advanced, and improved upon. Changes we recommend include:

1. Develop estimates of the sampling variance associated with Anvik River escapement estimates. Such estimates could be developed with independent stock assessments such as mark-recapture studies.

2. Develop improved estimates of the portion of Anvik River chum salmon that are harvested in Yukon River fisheries downstream of the confluence of the Anvik and Yukon Rivers. Such estimates could be obtained through a tagging program (either traditional or radio tags).

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Table 1. Anvik River chum salmon escapements, harvests of chum salmon in the Anvik River, total utilization of chum salmon in mixed-stock fisheries of the Lower Yukon River (Districts Y-1, Y-2, and Y-3), and subsistence, commercial, and commercial-related mixed-stock harvests of chum salmon in District Y-4 of the Yukon River, 1972-1998a.

	Known Anvik River Stock:			Unknown Anvik River Stock Composition:			
Year	Estimated Escapement of Anvik River Chum Salmon	Estim. Anvik In-River Harvest	Estimated Anvik River Total Return	Lower Yukon (Y-1, 2, 3) Total Utilization	Upper Yukon (Y-4) Subsistence Harvest	Upper Yukon (Y-4) Commercial Harvest	Upper Yukon (Y-4) Commercial Related Harvest
1972	457,800	0	457,800	167,761	57,745	0	0
1973	249,015	0	249,015	333,353	86,085	0	0
1974	411,133	0	411,133	609,570	121,799	27,866	0
1975	900,967	0	900,967	580,423	113,285	165,054	0
1976	511,475	0	511,475	437,724	99,911	211,307	0
1977	358,771	0	358,771	407,138	85,277	169,541	0
1978	307,270	0	307,270	702,623	93,139	364,184	16,920
1979	280,537	0	280,537	631,738	81,838	169,430	35,317
1980	492,676	0	492,676	780,118	117,305	147,560	135,824
1981	1,486,182	0	1,486,182	946,465	48,452	59,718	270,727
1982	444,581	0	444,581	478,680	57,967	3,647	254,072
1983	362,912	0	362,912	770,540	46,713	6,672	248,716
1984	891,028	0	891,028	593,500	49,230	1,009	277,061
1985	1,080,243	0	1,080,243	485,208	59,839	12,007	415,476
1986	1,189,602	0	1,189,602	762,584	53,020	300	465,235
1987	455,876	0	455,876	477,345	48,911	29,991	179,809
1988	1,125,449	0	1,125,449	1,160,081	86,623	24,051	466,023
1989	636,906	0	636,906	1,005,073	40,935	18,554	491,690
1990	403,627	0	403,627	357,290	26,534	12,364	210,186
1991	847,772	0	847,772	380,645	35,269	6,381	303,263
1992	775,626	0	775,626	394,010	35,812	2,659	208,737
1993	517,409	0	517,409	162,584	20,076	27	42,930
1994	1,124,689	22,573	1,147,262	140,404	27,488	3,611	145,423
1995	1,339,418	54,744	1,394,162	306,479	25,084	8,873	490,970
1996	933,240	84,633	1,017,873	199,159	16,425	0	425,607
1997	609,118	13,548	622,666	145,282	24,230	2,062	109,061
1998	471,885	0	471,885	90,777	18,046	0	0
Average	**691,304**	**6,500**	**697,804**	**500,243**	**58,409**	**53,588**	**192,335**
Minimum	**249,015**	**0**	**249,015**	**90,777**	**16,425**	**0**	**0**
Maximum	**1,486,182**	**84,633**	**1,486,182**	**1,160,081**	**121,799**	**364,184**	**491,690**

[a] Data source: Annual Management Report, Yukon River, 1998 (Bergstrom et al 1999); escapement data taken from page 204 and harvest related data taken from page 105 and 106. Because subsistence catches for the years 1972-1977 were not directly estimated and reported by district, the average district specific distribution from 1978-1982 was assumed and used to develop district specific estimates for the first six years of the data set.

Table 2. Estimated total annual runs of Anvik River chum salmon in 1972-1998 under three alternate assumptions concerning stock composition in Yukon River mixed-stock fisheries downstream of the confluence of the Anvik and Yukon Rivers.

	Estimated Total Annual Runs of Anvik River Chum Salmon:		
Year	**Mixed-Stock Fishery Model One**: Assumes: No chum salmon **(0%)** from columns 5, 6, 7, and 8 of Table 1 are Anvik River Stock)	**Mixed-Stock Fishery Model Two** Assumes: Y-1, Y-2, and Y-3 chum salmon utilization is composed of **50%** Anvik River Stock (column 5 of Table 1), and, Y-4 chum salmon utilization is **15%** Anvik River stock (columns 6, 7, and 8 of Table 1)	**Mixed-Stock Fishery Model Three** Assumes: Y-1, Y-2, and Y-3 chum salmon utilization is composed of **100%** Anvik River Stock (column 5 of Table 1) and Y-4 chum salmon utilization is **30%** Anvik River Stock (columns 6, 7, and 8 of Table 1)
1972	457,800	550,342	642,885
1973	249,015	428,604	608,193
1974	411,133	738,368	1,065,602
1975	900,967	1,232,930	1,564,892
1976	511,475	777,020	1,042,564
1977	358,771	600,563	842,355
1978	307,270	729,718	1,152,166
1979	280,537	639,394	998,251
1980	492,676	942,838	1,393,001
1981	1,486,182	2,016,249	2,546,316
1982	444,581	731,274	1,017,967
1983	362,912	793,497	1,224,082
1984	891,028	1,236,873	1,582,718
1985	1,080,243	1,395,945	1,711,648
1986	1,189,602	1,648,677	2,107,753
1987	455,876	733,355	1,010,834
1988	1,125,449	1,791,994	2,458,539
1989	636,906	1,222,119	1,807,333
1990	403,627	619,635	835,642
1991	847,772	1,089,831	1,331,891
1992	775,626	1,009,712	1,243,798
1993	517,409	608,156	698,903
1994	1,147,262	1,243,942	1,340,623
1995	1,394,162	1,626,141	1,858,119
1996	1,017,873	1,183,757	1,349,642
1997	622,666	715,610	808,554
1998	471,885	519,980	568,076

Table 3. Estimated age and sex compositions of the annual escapements of chum salmon returning to the Anvik River, 1972-1998 [a].

Year	Sample Size	Percent Females	Age 3 Composition (%)	Age 4 Composition (%)	Age 5 Composition (%)	Age 6 Composition (%)
1972	320	47.8	0.0	19.4	79.0	1.6
1973	783	66.2	6.1	77.3	16.3	0.3
1974	402	39.1	9.0	78.9	11.4	0.7
1975	584	53.8	3.6	92.6	3.8	0.0
1976	601	53.2	1.5	13.0	85.5	0.0
1977	589	67.6	22.2	73.3	3.7	0.8
1978	552	47.6	0.2	70.6	29.2	0.0
1979	579	52.8	2.4	59.9	37.0	0.7
1980	425	60.7	0.2	87.8	12.0	0.0
1981	333	54.7	0.0	34.8	64.3	0.9
1982	382	69.4	5.5	67.0	26.7	0.8
1983	421	56.5	1.0	57.2	41.1	0.7
1984	353	60.9	2.3	86.7	11.0	0.0
1985	527	55.8	2.1	75.3	22.2	0.4
1986	486	57.8	0.4	30.5	67.7	1.4
1987	545	65.1	1.8	66.7	28.6	2.9
1988	531	66.1	5.8	77.4	16.0	0.8
1989	588	65.6	1.2	37.9	60.8	0.1
1990	399	51.3	3.2	65.1	30.1	1.6
1991	552	57.9	0.0	44.2	55.6	0.2
1992	424	56.6	0.3	26.5	69.0	4.2
1993	660	52.0	0.6	64.8	32.4	2.2
1994	1,224	58.7	0.0	35.0	63.8	1.2
1995	667	39.8	2.7	53.3	39.6	4.4
1996	674	59.9	0.5	55.4	42.3	1.8
1997	864	53.6	0.5	43.7	55.0	0.8
1998	948	55.9	0.0	80.4	18.3	1.3
Avg.	**571**	**56.5**	**2.7**	**58.3**	**37.9**	**1.1**

[a] Data source: Escapement sex and age compositions for the years 1972-1996 from the Anvik River Salmon Escapement Study, 1996, a technical report by Fair (1997). Escapement age and sex compositions for 1997 and 1998 from draft Anvik River Salmon Escapement Study, 1998.

Table 4. Estimated age compositions of annual catches of chum salmon assumed to be returning to the Anvik River, 1972-1998 [a].

Year	Age Composition Sample Size	Age 3 Composition (%)	Age 4 Composition (%)	Age 5 Composition (%)	Age 6 Composition (%)
1972	224	6.5	52.0	41.5	0.0
1973	223	5.8	63.7	29.6	0.9
1974	382	32.2	65.7	2.1	0.0
1975	432	0.5	94.6	4.9	0.0
1976	368	12.8	38.6	48.6	0.0
1977	434	19.1	72.4	8.0	0.5
1978	654	5.8	85.0	8.8	0.4
1979	707	11.0	70.9	17.8	0.3
1980	678	0.9	94.3	4.9	0.0
1981	754	0.4	44.3	55.3	0,0
1982	3,419	2.0	61.2	34.4	2.4
1983	4,110	1.0	53.8	44.4	0.8
1984	2,722	2.0	73.7	23.9	0.5
1985	2,472	1.4	68.6	29.2	0.8
1986	3,473	0.1	29.1	69.8	1.0
1987	2,184	0.4	60.8	31.8	6.9
1988	5,112	0.0	70.1	29.1	0.8
1989	3,778	0.4	38.7	60.5	0.4
1990	3,155	0.4	38.3	58.9	2.4
1991	5,015	1.3	48.0	49.8	0.9
1992	4,303	0.2	31.0	65.0	3.8
1993	2,011	0.4	47.5	47.7	4.5
1994	3,820	0.1	51.3	46.6	2.0
1995	4,740	0.6	51.9	45.3	2.1
1996	3,863	0.4	46.2	48.8	4.5
1997	3,195	0.2	29.0	67.2	3.6
1998	1,147	0.3	62.8	34.2	2.7
Average	-	**3.9**	**57.2**	**37.3**	**1.6**

[a] Data source: Values for the years 1982-1998 from Annual Management Report, Yukon River, 1998 (Bergstrom et al 1999); data taken from page 114. The 1982-1998 data represent weighted averages of the annual age compositions of Yukon chum salmon catches in fisheries throughout the river. Values for the years 1972-1981 from Buklis (1983) and these age compositions are from chum salmon sampled from the Emmonak fishery where they were harvested in 5 ½ inch gill net mesh.

Table 5. Estimated age-specific total runs of Anvik River chum salmon in 1972-1998 under mixed-stock fishery model one (assumes that none of the chum salmon caught downstream of the confluence of the Anvik and Yukon Rivers are of Anvik River stock).

Year	Estimated Age 3 Total Return of Anvik River Chum Salmon	Estimated Age 4 Total Return of Anvik River Chum Salmon	Estimated Age 5 Total Return of Anvik River Chum Salmon	Estimated Age 6 Total Return of Anvik River Chum Salmon
1972	0	88,813	361,662	7,325
1973	15,190	192,489	40,589	747
1974	37,002	324,384	46,869	2,878
1975	32,435	834,295	34,237	0
1976	7,672	66,492	437,311	0
1977	79,647	262,979	13,275	2,870
1978	615	216,933	89,723	0
1979	6,733	168,042	103,799	1,964
1980	985	432,570	59,121	0
1981	0	517,191	955,615	13,376
1982	24,452	297,869	118,703	3,557
1983	3,629	207,586	149,157	2,540
1984	20,494	772,521	98,013	0
1985	22,685	813,423	239,814	4,321
1986	4,758	362,829	805,361	16,654
1987	8,206	304,069	130,381	13,220
1988	65,276	871,098	180,072	9,004
1989	7,643	241,387	387,239	637
1990	12,916	262,761	121,492	6,458
1991	0	374,715	471,361	1,696
1992	2,327	205,541	535,182	32,576
1993	3,104	335,281	167,641	11,383
1994	0	401,542	731,953	13,767
1995	37,642	743,088	552,088	61,343
1996	5,089	563,902	430,560	18,322
1997	3,113	272,105	342,466	4,981
1998	0	379,396	86,355	6,135
Averages	**14,875**	**389,381**	**284,816**	**8,732**

Table 6. Estimated age-specific total runs of Anvik River chum salmon in 1972-1998 under mixed-stock fishery model two (assumes that 50% of the chum salmon caught in Yukon fishing Districts Y-1, Y-2, and Y-3 are of the Anvik River stock and that 15% of the chum salmon caught in Yukon fishing District Y-4 are of the Anvik River stock).

Year	Estimated Age 3 Total Return of Anvik River Chum Salmon	Estimated Age 4 Total Return of Anvik River Chum Salmon	Estimated Age 5 Total Return of Anvik River Chum Salmon	Estimated Age 6 Total Return of Anvik River Chum Salmon
1972	6,015	136,935	400,067	7,325
1973	25,606	306,887	93,748	2,363
1974	142,372	539,377	53,741	2,878
1975	34,095	1,148,332	50,503	0
1976	41,662	168,992	566,366	0
1977	125,829	438,036	32,618	4,079
1978	25,117	576,013	126,898	1,690
1979	46,207	422,471	167,675	3,040
1980	5,037	857,073	81,179	0
1981	2,120	752,011	1,248,742	13,376
1982	30,186	473,325	217,325	10,437
1983	7,935	439,240	340,337	5,985
1984	27,411	1,027,409	180,670	1,383
1985	27,105	1,029,995	331,999	6,847
1986	5,217	496,420	1,125,795	21,245
1987	9,316	472,777	218,619	32,644
1988	65,276	1,338,346	374,036	14,336
1989	9,984	467,865	741,293	2,978
1990	13,780	345,492	248,720	11,642
1991	3,147	490,904	591,907	3,874
1992	2,795	278,108	687,338	41,472
1993	3,467	378,386	210,927	15,376
1994	97	451,139	777,006	15,701
1995	39,034	863,485	657,174	66,447
1996	5,753	640,540	511,512	25,952
1997	3,299	299,059	404,925	8,327
1998	144	409,599	102,804	7,433
Averages	**26,222**	**564,749**	**390,516**	**12,105**

Table 7. Estimated age-specific total runs of Anvik River chum salmon in 1972-1998 under mixed-stock fishery model three (assumes that 100% of the chum salmon caught in Yukon fishing Districts Y-1, Y-2, and Y-3 are of the Anvik River stock and that 30% of the chum salmon caught in Yukon fishing District Y-4 are of the Anvik River stock).

Year	Estimated Age 3 Total Return of Anvik River Chum Salmon	Estimated Age 4 Total Return of Anvik River Chum Salmon	Estimated Age 5 Total Return of Anvik River Chum Salmon	Estimated Age 6 Total Return of Anvik River Chum Salmon
1972	12,031	185,057	438,472	7,325
1973	36,022	421,285	146,906	3,980
1974	247,741	754,370	60,613	2,878
1975	35,754	1,462,369	66,769	0
1976	75,652	271,492	695,421	0
1977	172,012	613,094	51,961	5,288
1978	49,619	935,094	164,074	3,380
1979	85,681	676,901	231,552	4,117
1980	9,088	1,281,576	103,237	0
1981	4,241	986,831	1,541,869	13,376
1982	35,920	648,781	315,948	17,318
1983	12,241	670,895	531,516	9,430
1984	34,327	1,282,297	263,327	2,767
1985	31,525	1,246,567	424,184	9,372
1986	5,677	630,010	1,446,230	25,836
1987	10,426	641,484	306,857	52,067
1988	65,276	1,805,594	568,001	19,668
1989	12,325	694,343	1,095,347	5,319
1990	14,644	428,223	375,949	16,826
1991	6,294	607,092	712,452	6,053
1992	3,263	350,674	839,494	50,367
1993	3,830	421,491	254,213	19,369
1994	193	500,736	822,059	17,634
1995	40,426	983,882	762,261	71,550
1996	6,416	717,179	592,463	33,583
1997	3,485	326,013	467,383	11,673
1998	289	439,803	119,252	8,732
Averages	**37,570**	**740,116**	**496,215**	**15,478**

Table 8. Estimated brood-year escapements from 1972 to 1993 and resultant estimated recruitments from these brood years under three alternate mixed-stock fishery models.

Year	Estimated Brood-year Escapement of Anvik River Chum Salmon	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model One	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model Two	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model Three
1972	457,800	112,201	237,394	362,587
1973	249,015	362,338	609,637	856,936
1974	411,133	400,378	869,518	1,338,657
1975	900,967	241,153	542,142	843,132
1976	511,475	1,398,474	2,162,459	2,926,444
1977	358,771	639,420	980,358	1,321,297
1978	307,270	447,026	817,166	1,187,305
1979	280,537	334,372	656,943	979,514
1980	492,676	1,032,619	1,388,588	1,744,558
1981	1,486,182	1,652,498	2,215,844	2,779,191
1982	444,581	524,898	756,479	988,061
1983	362,912	489,536	855,008	1,220,480
1984	891,028	1,273,000	2,100,596	2,928,193
1985	1,080,243	429,851	785,735	1,141,620
1986	1,189,602	774,342	988,854	1,203,367
1987	455,876	934,196	1,207,398	1,480,599
1988	1,125,449	386,949	507,882	628,815
1989	636,906	1,130,904	1,224,634	1,318,363
1990	403,627	975,056	1,137,733	1,300,410
1991	847,772	1,178,630	1,383,421	1,588,212
1992	775,626	950,145	1,091,932	1,233,719
1993	517,409	372,281	419,720	467,159
Average	**644,857**	**729,103**	**1,042,702**	**1,356,301**
Minimum	**249,015**	**112,201**	**237,394**	**362,587**
Maximum	**1,486,182**	**1,652,498**	**2,215,844**	**2,928,193**

Table 9. Estimated brood-year escapements of female chum salmon only from 1972 to 1993 and resultant estimated total recruitments from these brood years under three alternate mixed-stock fishery models.

Year	Estimated Brood-year Escapement of Female Anvik River Chum Salmon	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model One	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model Two	Estimated Total Recruitment of Anvik River Chum Salmon Under Mixed-Stock Fishery Model Three
1972	218,828	112,201	237,394	362,587
1973	164,848	362,338	609,637	856,936
1974	160,753	400,378	869,518	1,338,657
1975	484,720	241,153	542,142	843,132
1976	272,105	1,398,474	2,162,459	2,926,444
1977	242,529	639,420	980,358	1,321,297
1978	146,261	447,026	817,166	1,187,305
1979	148,124	334,372	656,943	979,514
1980	299,054	1,032,619	1,388,588	1,744,558
1981	812,942	1,652,498	2,215,844	2,779,191
1982	308,539	524,898	756,479	988,061
1983	205,045	489,536	855,008	1,220,480
1984	542,636	1,273,000	2,100,596	2,928,193
1985	602,776	429,851	785,735	1,141,620
1986	687,590	774,342	988,854	1,203,367
1987	296,775	934,196	1,207,398	1,480,599
1988	743,922	386,949	507,882	628,815
1989	417,810	1,130,904	1,224,634	1,318,363
1990	207,061	975,056	1,137,733	1,300,410
1991	490,860	1,178,630	1,383,421	1,588,212
1992	439,004	950,145	1,091,932	1,233,719
1993	269,053	372,281	419,720	467,159
Average	**370,965**	**729,103**	**1,042,702**	**1,356,301**
Minimum	**146,261**	**112,201**	**237,394**	**362,587**
Maximum	**812,942**	**1,652,498**	**2,215,844**	**2,928,193**

Table 10. Spawner-recruit estimates using total spawners as the independent variable and recruits as estimated with mixed-stock fishery model two as the dependent variable.

Year	Total Spawners	Age 3 Recruits	Age 4 Recruits	Age 5 Recruits	Age 6 Recruits	Total Recruits	Recruits per Spawner
1972	457,800	34,095	168,992	32,618	1,690	237,394	0.52
1973	249,015	41,662	438,036	126,898	3,040	609,637	2.45
1974	411,133	125,829	576,013	167,675	0	869,518	2.11
1975	900,967	25,117	422,471	81,179	13,376	542,142	0.60
1976	511,475	46,207	857,073	1,248,742	10,437	2,162,459	4.23
1977	358,771	5,037	752,011	217,325	5,985	980,358	2.73
1978	307,270	2,120	473,325	340,337	1,383	817,166	2.66
1979	280,537	30,186	439,240	180,670	6,847	656,943	2.34
1980	492,676	7,935	1,027,409	331,999	21,245	1,388,588	2.82
1981	1,486,182	27,411	1,029,995	1,125,795	32,644	2,215,844	1.49
1982	444,581	27,105	496,420	218,619	14,336	756,479	1.70
1983	362,912	5,217	472,777	374,036	2,978	855,008	2.36
1984	891,028	9,316	1,338,346	741,293	11,642	2,100,596	2.36
1985	1,080,243	65,276	467,865	248,720	3,874	785,735	0.73
1986	1,189,602	9,984	345,492	591,907	41,472	988,854	0.83
1987	455,876	13,780	490,904	687,338	15,376	1,207,398	2.65
1988	1,125,449	3,147	278,108	210,927	15,701	507,882	0.45
1989	636,906	2,795	378,386	777,006	66,447	1,224,634	1.92
1990	403,627	3,467	451,139	657,174	25,952	1,137,733	2.82
1991	847,772	97	863,485	511,512	8,327	1,383,421	1.63
1992	775,626	39,034	640,540	404,925	7,433	1,091,932	1.41
1993	517,409	5,753	299,059	102,804	*12,105*[a]	419,720	0.81
Avg.	**644,857**	**24,117**	**577,595**	**426,341**	**14,650**	**1,042,702**	**1.89**
Min.	**249,015**	**97**	**168,992**	**32,618**	**0**	**237,394**	**0.45**
Max.	**1,486,182**	**125,829**	**1,338,346**	**1,248,742**	**66,447**	**2,215,844**	**4.23**

[a] The age 6 recruits for the 1993 brood year were calculated as the average age-6 return for calendar years 1972-1998.

Table 11. Spawner-recruit estimates using female spawners only as the independent variable and recruits as estimated with mixed-stock fishery model two as the dependent variable.

Year	Female Spawners Only	Age 3 Recruits	Age 4 Recruits	Age 5 Recruits	Age 6 Recruits	Total Recruits	Recruits per Spawner
1972	218,828	34,095	168,992	32,618	1,690	237,394	1.08
1973	164,848	41,662	438,036	126,898	3,040	609,637	3.70
1974	160,753	125,829	576,013	167,675	0	869,518	5.41
1975	484,720	25,117	422,471	81,179	13,376	542,142	1.12
1976	272,105	46,207	857,073	1,248,742	10,437	2,162,459	7.95
1977	242,529	5,037	752,011	217,325	5,985	980,358	4.04
1978	146,261	2,120	473,325	340,337	1,383	817,166	5.59
1979	148,124	30,186	439,240	180,670	6,847	656,943	4.44
1980	299,054	7,935	1,027,409	331,999	21,245	1,388,588	4.64
1981	812,942	27,411	1,029,995	1,125,795	32,644	2,215,844	2.73
1982	308,539	27,105	496,420	218,619	14,336	756,479	2.45
1983	205,045	5,217	472,777	374,036	2,978	855,008	4.17
1984	542,636	9,316	1,338,346	741,293	11,642	2,100,596	3.87
1985	602,776	65,276	467,865	248,720	3,874	785,735	1.30
1986	687,590	9,984	345,492	591,907	41,472	988,854	1.44
1987	296,775	13,780	490,904	687,338	15,376	1,207,398	4.07
1988	743,922	3,147	278,108	210,927	15,701	507,882	0.68
1989	417,810	2,795	378,386	777,006	66,447	1,224,634	2.93
1990	207,061	3,467	451,139	657,174	25,952	1,137,733	5.49
1991	490,860	97	863,485	511,512	8,327	1,383,421	2.82
1992	439,004	39,034	640,540	404,925	7,433	1,091,932	2.49
1993	269,053	5,753	299,059	102,804	*12,105*[a]	419,720	1.56
Avg.	**370,965**	**24,117**	**577,595**	**426,341**	**14,650**	**1,042,702**	**3.36**
Min.	**146,261**	**97**	**168,992**	**32,618**	**0**	**237,394**	**0.68**
Max.	**812,942**	**125,829**	**1,338,346**	**1,248,742**	**66,447**	**2,215,844**	**7.95**

[a] The age 6 recruits for the 1993 brood year were calculated as the average age-6 return for calendar years 1972-1998.

Table 12. Stock-recruitment relationship statistics under three alternate mixed-stock fishery assumptions and with the use of total escapement (males plus females) as the independent variable (upper panel: A) or with the use of female escapement only as the independent variable (lower panel: B). Note: "favored" mixed-stock fishery model statistics shown in bold.

PANEL A: TOTAL ESCAPEMENT AS INDEPENDENT VARIABLE:

Stock-Recruit Relationship Statistic	Statistics Using Mixed-Stock Fishery Model One	Statistics Using Mixed-Stock Fishery Model Two	Statistics Using Mixed-Stock Fishery Model Three
Ricker Alpha	2.290681	**3.597337**	4.926078
Ricker Beta	0.000000866	**0.000001020**	0.00000110
Adjusted R Square	0.141	**0.266**	0.308
Significance of Relationship	0.048	**0.008**	0.004
Number of Brood Years	22	**22**	22
MSY Escapement Level	425,914	**517,827**	567,684
Estimated Maximum Yield	248,820	**580,322**	933,779
Est. MSY Exploitation Rate	37%	**53%**	62%

PANEL B: FEMALE ESCAPEMENT ONLY AS INDEPENDENT VARIABLE:

Stock-Recruit Relationship Statistic	Statistics Using Mixed-Stock Fishery Model One	Statistics Using Mixed-Stock Fishery Model Two	Statistics Using Mixed-Stock Fishery Model Three
Ricker Alpha	3.990126	**6.504885**	9.042288
Ricker Beta	-0.00000151	**-0.00000186**	-0.00000202
Adjusted R Square	0.164	**0.313**	0.360
Significance of Relationship	0.035	**0.004**	0.002
Number of Brood Years	22	**22**	22
MSY Escapement Level	240,592 females	**288,298 females**	312,565 females
Estimated Maximum Yield	242,509	**588,041**	949,590
Est. MSY Exploitation Rate	36%	**54%**	63%

Table 13. Estimates of the maximum sustained yield escapement levels and associated precision of each for two bootstrap data sets (n = 1,000). Note: the two data sets used include the total escapement and the female spawners only for the 50% mixed-stock fishery assumptions (the mixed-stock harvest of Anvik River chum salmon is 50% of the lower Yukon total utilization and 15% of the District 4 total utilization).

Statistic	Maximum Sustained Yield Escapement Level Using Total Escapement as Independent Variable	Maximum Sustained Yield Escapement Level Using Female Escapement Only as Independent Variable
Mean	562,053	299,911
Standard Deviation	240,423	81,877
Coefficient of Variation	42.8%	27.3%
Lower 90% C. I.	390,611	221,674
Upper 90% C. I.	819,490	415,626
Indicated Bias	44,226	11,613
Indicated % Bias	8.5%	4.0%

Table 14. Years when annual Anvik River chum salmon escapements were below, within, or above the biological escapement goal ranges recommended in this report.

Recommended Biological Escapement Goal Range	Years When Escapement Was Below Recommended Level	**Years When Escapement Was Within Recommended Level**	Years When Escapement Was Above Recommended Level
400,000 to 800,000 Total Spawners	1973, 1977, 1978, 1979, 1983	1972, 1974, 1976, 1980, 1982, 1987, 1989, 1990, 1992, 1993, 1997, 1998	1975, 1981, 1984, 1985, 1986, 1988, 1991, 1994, 1995, 1996
	5 of 27 years 19%	**12 of the 27 years 44%**	10 of the 27 years 37%
	0 years since 1990	**5 of the years since 1990**	4 of the years since 1990
230,000 to 460,000 Female Spawners	1972, 1973, 1974, 1978, 1979, 1983, 1990	1976, 1977, 1980, 1982, 1987, 1989, 1992, 1993, 1997, 1998	1975, 1981, 1984, 1985, 1986, 1988, 1991, 1994, 1995, 1996
	7 of the 27 years 15%	**10 of the 27 years 37%**	10 of the 27 years 37%
	1 of the years since 1990	**4 of the years since 1990**	4 of the years since 1990

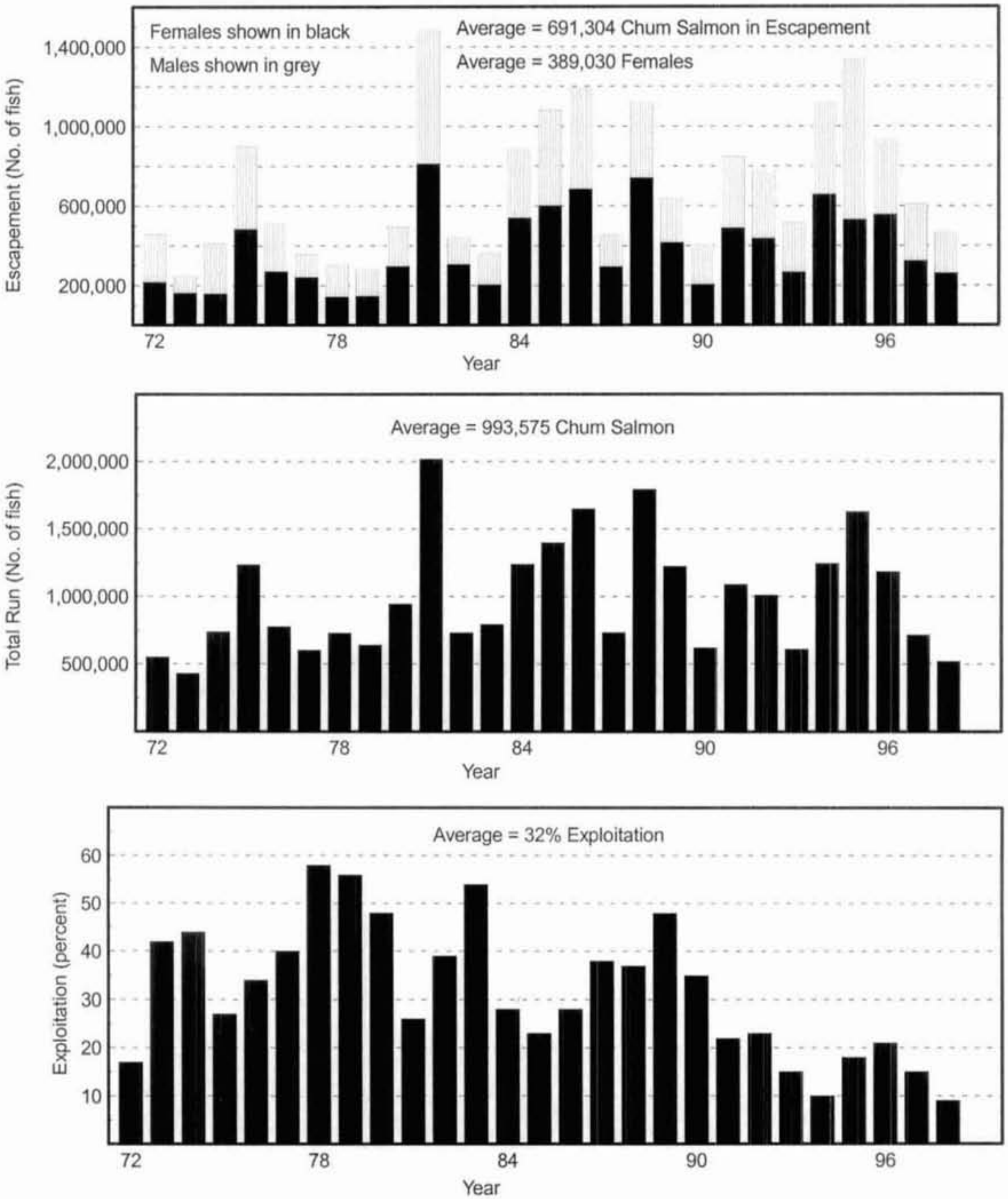

Figure 1. Estimated female, male, and total escapements, estimated total runs, and estimated exploitation rate of Anvik River chum salmon, 1972-1998 using the mixed-stock fishery model two estimates of harvest.

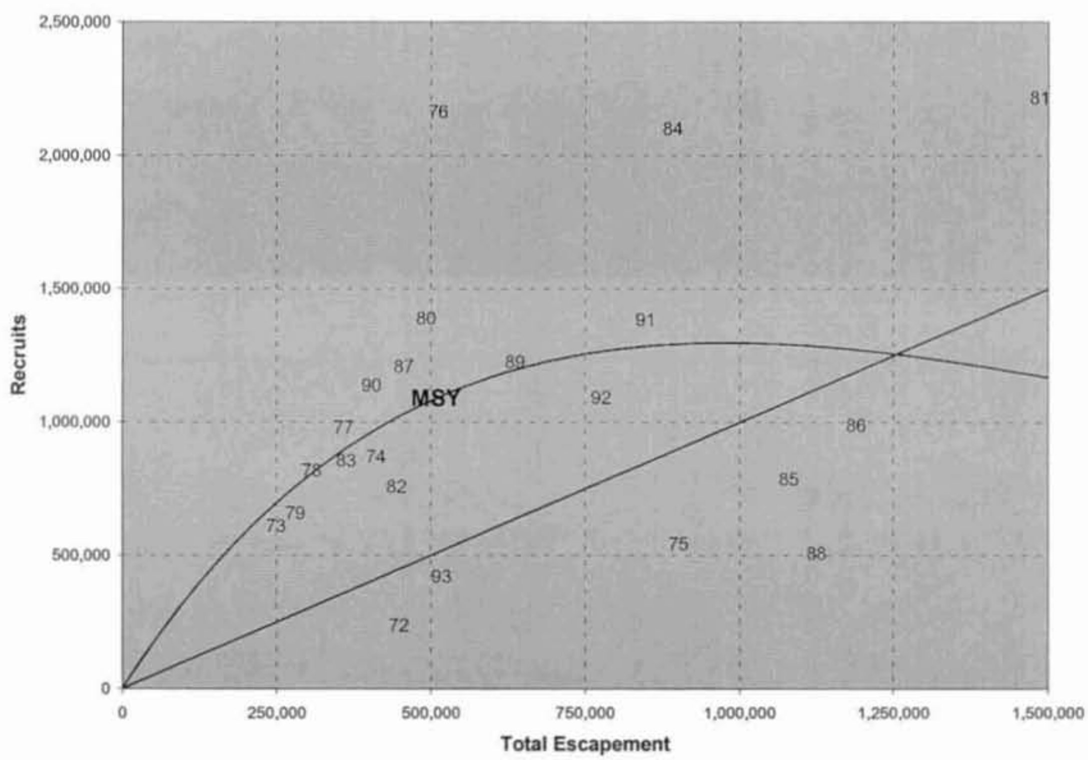

Figure 2. Stock-recruit relationship for Anvik River chum salmon using total escapement and the mixed-stock fishery model two estimates of harvest.

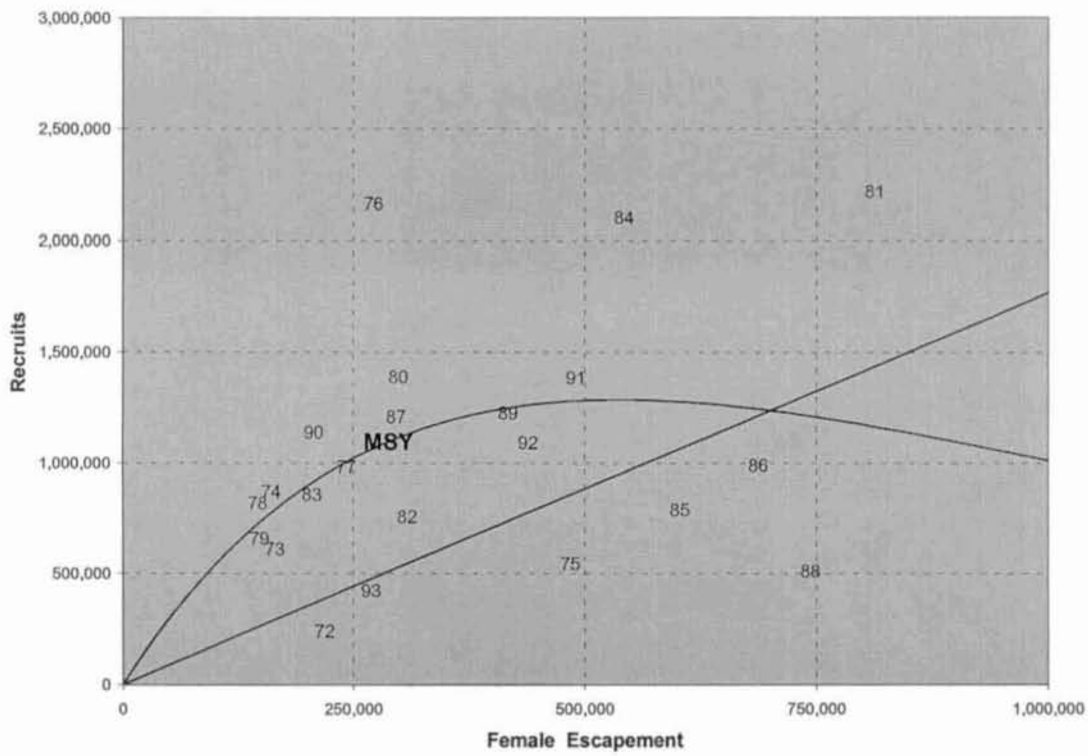

Figure 3. Stock-recruit relationship for Anvik River chum salmon using female escapement only and the mixed-stock fishery model two estimates of harvest.

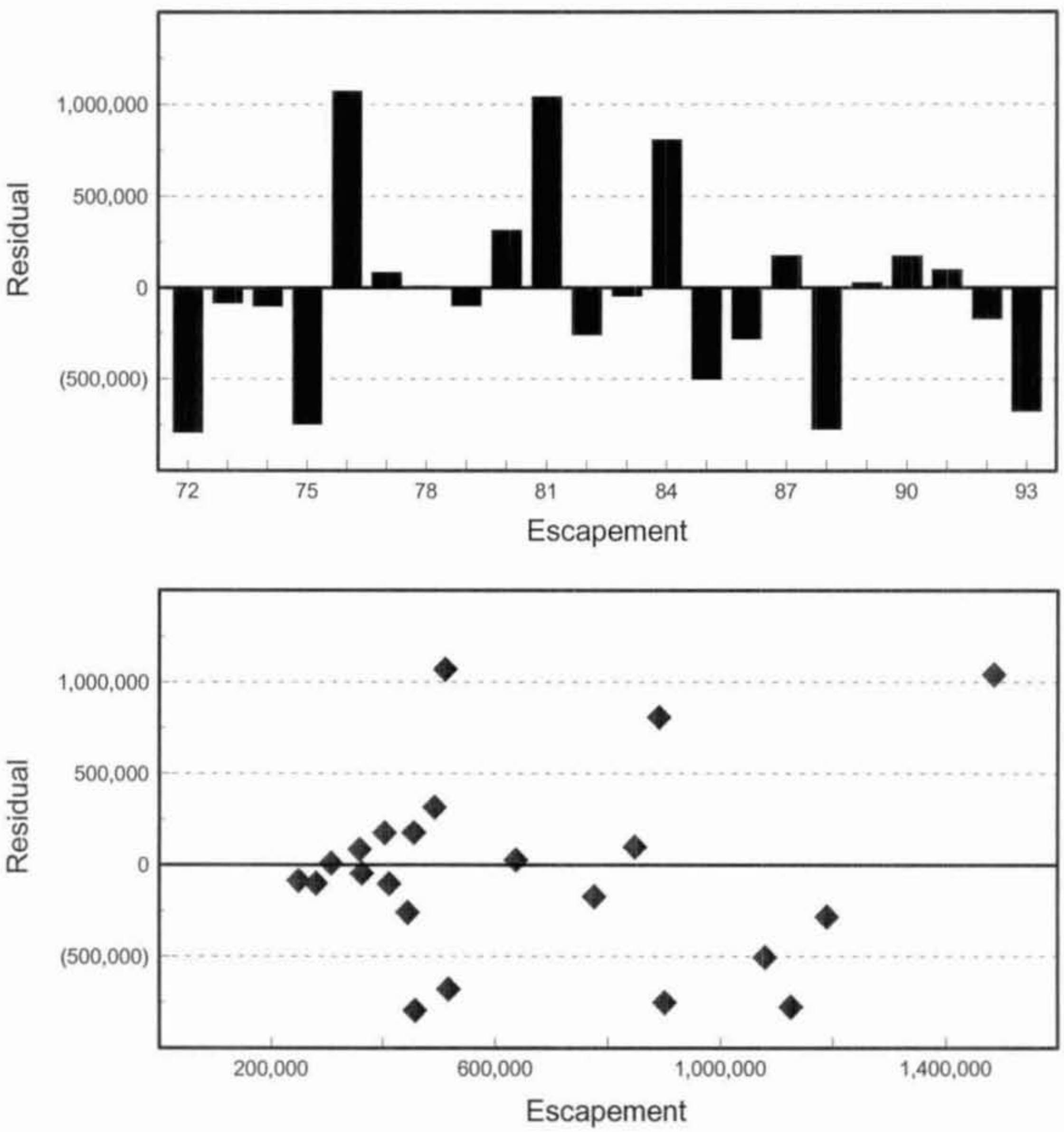

Figure 4. Plots of residuals in the spawner-recruit relationship for Anvik River chum salmon using total escapement and the mixed-stock fishery model two estimates of harvest; upper panel is brood year versus residuals and lower panel is brood escapement versus residuals.

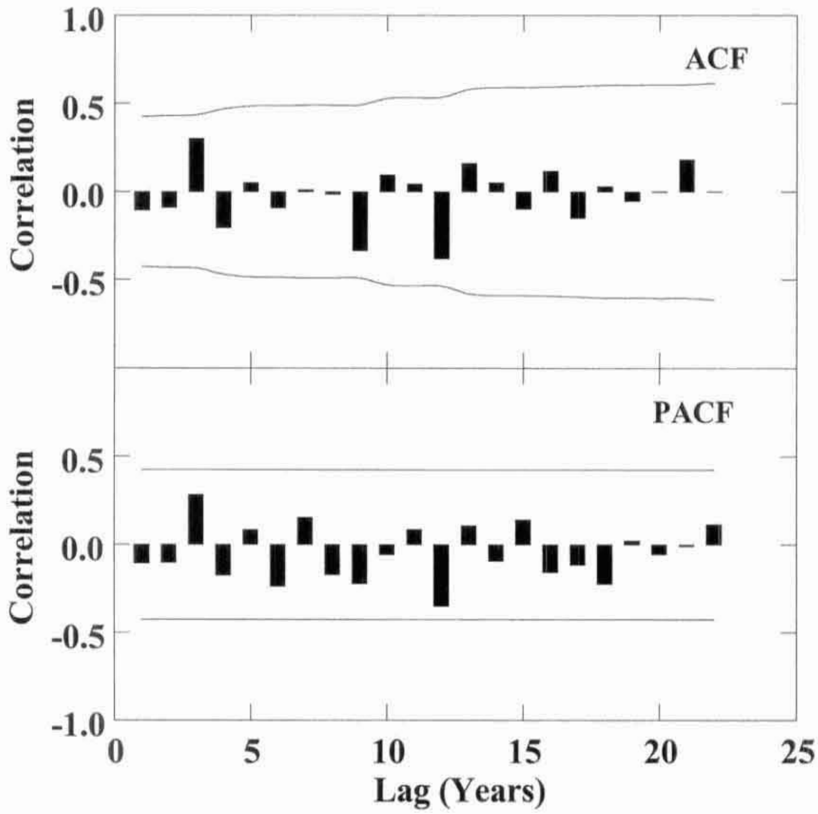

Figure 5. Auto-correlation functions (ACF) and partial auto-correlation functions (PACF) of residuals in the spawner-recruit relationship for Anvik River chum salmon using total escapement and the mixed-stock fishery model two estimates of harvest (note: auto-correlation is not significant).

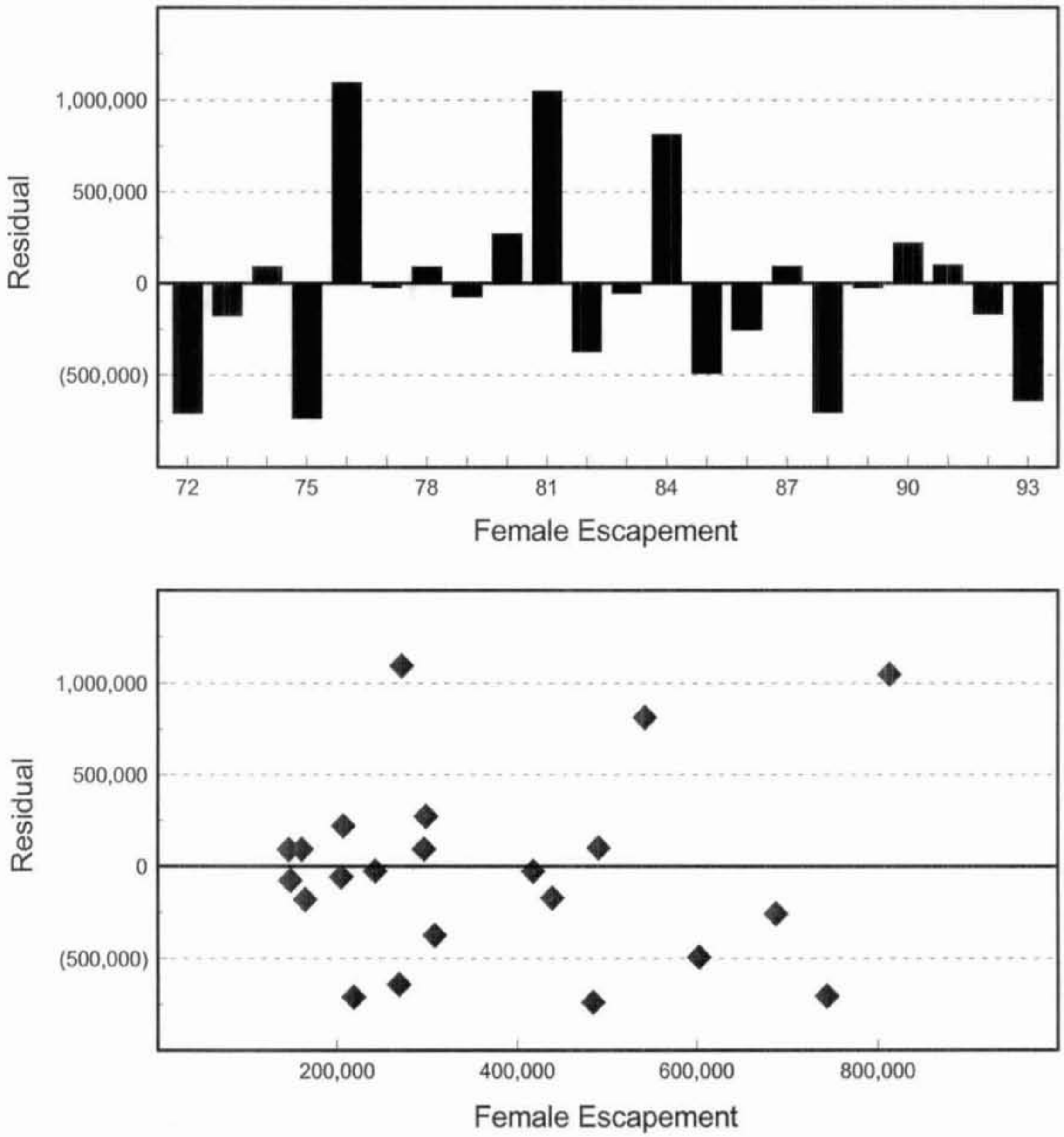

Figure 6. Plots of residuals in the spawner-recruit relationship for Anvik River chum salmon using female escapement only and the mixed-stock fishery model two estimates of harvest; upper panel is brood year versus residuals and lower panel is brood escapement versus residuals.