BIOLOGICAL ESCAPEMENT GOALS FOR KWINIUK AND TUBUTULIK CHUM SALMON

By

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EXECUTIVE SUMMARY

Available information was assembled concerning estimated escapements, estimated harvests, and estimated age compositions of chum salmon *Oncorhynchus keta* returning to Subdistrict 3 of Norton Sound, the Moses Point Subdistrict, to estimate maximum sustained yield escapement goals. Two chum salmon producing streams are tributary to the Moses Point Subdistrict, the Kwiniuk River and the Tubutulik River. A tagging study conducted in the late 1970s found that catches of chum salmon in the Moses Point Subdistrict are primarily of Kwiniuk and Tubutulik origin.

Tower counts documenting chum salmon total escapements of Kwiniuk River fish are available since 1965. Surveys of chum salmon escapements in the Tubutulik River are available for most of the years since 1965. An analysis of paired data consisting of Kwiniuk River chum salmon surveys and cumulative counts of chum salmon past the Kwiniuk tower on the day of the survey was conducted. The analysis resulted in a relationship wherein rating of the survey as "good", "fair", or "poor" provided predictive power in explaining the portion of total escapement observed during surveys. Use of this methodology resulted in 17% to 36% absolute error in predicting observed Kwiniuk chum counts, depending upon survey rating. The assumption was made that these same "visibility" factors could be directly applied to the Tubutulik River chum salmon survey data. This assumption, coupled with further expansions associated with migratory timing, under the assumption that migratory timing of both stocks is similar, resulted in estimates of the total freshwater runs of Tubutulik River chum salmon. Multiple surveys of Tubutulik River chum salmon in some years provided data indicating that the overall expansion methodology resulted in mean estimates with an average coefficient of variation of 19%. No surveys of Tubutulik River chum salmon were conducted in 7 of the 36 years since 1965. Estimates of the total runs of Tubutulik River chum salmon in these seven years was based upon a significant relationship observed between total runs of chum salmon in the Kwiniuk and Tubutulik rivers during the other 29 years in the data set. Absolute errors associated with this secondary total enumeration methodology averaged 107%.

Once these total inriver runs of Tubutulik River chum salmon were estimated, the assumption that the Moses Point Subdistrict annual marine catches of Kwiniuk and Tubutulik origin fish were proportional to the freshwater runs provided a basis for catch allocations. Freshwater subsistence catches were subtracted from estimated inriver runs to provide chum salmon escapement estimates for Kwiniuk and Tubutulik chum salmon populations from 1965-2000. Allocated annual catch estimates were added to estimated escapements to estimate total runs for both chum salmon stocks. Annual age composition estimates from the commercial fishery from 1965-1991 and estimates from the Kwiniuk escapement from 1992-1998 provided a basis for estimating age-specific total runs of Kwiniuk and Tubutulik chum salmon stocks for each of the years from 1965-2000. This information was used to develop brood tables consisting of estimated escapements and estimated resultant age-specific recruits from these escapements.

Estimated spawner-recruit relationships based upon the estimated escapements of chum salmon in the years 1965-1995 and recruits resulting from these escapements 3, 4, 5 and 6 years later for both stocks of chum salmon were developed. An analysis of the residual patterns in the estimated stock-recruit relationships revealed that environmental conditions for these stocks underwent a significant change in about 1980 for the Kwiniuk stock and about 1983 for the Tubutulik stock. A basic tenet of using historic stock-recruit information to estimate productivity and maximum sustained yield escapement goals for salmon stocks is that the past is representative of the future. Although the reasons for the environmental changes that these stocks have experienced is unknown, it is clear that at least a portion of the past does not currently represent the present nor is it likely to represent the immediate future. Therefore, the stock-recruit data for the Kwiniuk River chum salmon stock was split into a 1965-1979 data set and a more recent 1980-1995 data set, while the Tubutulik stock-recruit data set was split into a 1965-1982 data set and more recent 1983-1995 data set. Subsequently, the more recent data sets for each stock were re-analyzed to estimate productivity factors with Ricker type methodology. Examination of residuals in both of these more recent data sets was relatively stable, fulfilling the environmental stability tenet discussed above.

These spawner-recruit relationships were used to estimate the number of chum salmon in the Kwiniuk and Tubutulik Rivers that would, on average, provide for maximum sustained yield in Moses Point Subdistrict fisheries. Such estimates for the Kwiniuk and Tubutulik chum salmon stocks were 12,839 and 10,426 total fish, respectively. These point values were converted into ranges as follows: Kwiniuk – 10,000 to 20,000 total spawners and Tubutulik – 8,000 to 16,000 total spawners. Maximum sustained yield of chum salmon in the Moses Point Subdistrict was estimated as 8,979 Kwiniuk and 6,677 Tubutulik fish or about 15,000 chum salmon per year in total under current environmental conditions.

Examination of past escapement trends indicates that Kwiniuk River chum salmon escapements have only seldom been below the level estimated to result in maximum sustained yield fisheries (9% of years since 1980). On the contrary, in about 40% of the years since 1980, Kwiniuk escapements have been above the level estimated to result in maximum sustained yield fisheries. The situation with regard to past Tubutulik escapements of chum salmon is different. The number of times the Tubutulik escapement has been in the range estimated to result in maximum sustained yield fisheries since 1983 is about the same (28%) as the number of times the escapement was below (33%) or above (39%) this level.

Recommendations concerning improved stock assessment of chum salmon in the Moses Point Subdistrict of Norton Sound are provided in this report, including the recommendation to initiate an on the grounds total enumeration of Tubutulik River chum salmon escapements and improve age composition sampling. Estimates developed should be accompanied with sampling variances. Additionally, historic total estimates of Kwiniuk and Tubutulik chum salmon escapements should be reviewed and annual sampling variances for the escapements calculated and added to the existing database. Based upon the spawner-recruit relationships developed in this report, it is recommended that the following biological escapement goals be formally adopted by the Alaska Department of Fish and Game:

Kwiniuk River chum salmon: 10,000 to 20,000 total spawners per year, and

Tubutulik River chum salmon: 8,000 to 16,000 total spawners per year.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Kwiniuk River, Tubutulik River, Norton Sound, Moses Point, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship

INTRODUCTION

The Norton Sound Salmon District consists of all waters between Cape Douglas in the north and point Romanof Light in the south. The district is divided into six subdistricts: Subdistrict 1, Nome; Subdistrict 2, Golovin; Subdistrict 3, Moses Point; Subdistrict 4, Norton Bay, Subdistrict 5, Shaktoolik; and Subdistrict 6, Unalakleet. Each of these subdistricts has at least one major salmon-producing stream. Subdistrict boundaries were developed to facilitate management of individual salmon stocks. Gaudet and Schaefer (1982) reported on tagging studies conducted by Alaska Department of Fish and Game (ADF&G) in Norton Sound in 1978 and 1979. Gaudet and Schaefer (1982) concluded that in the Nome, Golovin, Moses Point and Norton Bay Subdistricts harvests are of salmon that originated in the subdistrict, whereas, in the Shaktoolik and Unalakleet Subdistricts, harvests were composed of mixed stocks including fish bound for the Yukon River.

The Moses Point Subdistrict has supported an important fishery with commercial catches as high as 65,000 chum salmon and subsistence catches as high as 10,000 chum salmon a year since 1985. Two streams tributary to the Moses Point Subdistrict support significant populations of chum salmon, the Kwiniuk River and the Tubutulik River. Since 1965, a tower has been used by ADF&G to enumerate total inriver runs of Kwiniuk River chum salmon. Inriver runs of chum salmon in the Tubutulik River have been indexed with surveys during most of the years since 1965.

The ADF&G has attempted to manage the salmon fisheries in the Moses Point Subdistrict over the past few decades with the dual goal of maintaining important fisheries while at the same time achieving desired escapements. Escapement objectives for Moses Point chum salmon stocks have been in effect over the past 20 years.

ADF&G (1981) lists the Kwiniuk River chum salmon escapement goal as 25,000. Buklis (1993) provides the following narrative concerning the initial escapement goal that ADF&G used for the Kwiniuk River chum salmon stock: *"The earlier tower count goal was 25,000 chum salmon, and was in effect as early as 1979."* Methodology and data used to establish this initial 25,000 Kwiniuk River chum salmon goal is undocumented. The biological escapement goal in place at the time of the Buklis (1993) report was: "*18,000 tower count at the Kwiniuk River tower site.*" According to Buklis (1993), methodology used to set this 18,000 escapement goal was: "*Ricker model applied to escapement and return data for the period 1965 through 1990.*" Bromaghin (1998) conducted a stock-recruit analysis of Kwiniuk River chum salmon data based upon the 1965-1997 brood years. He estimated that the escapement producing maximum sustained yield (MSY) fisheries was 15,926 chum salmon and that maximum sustained yield for the stock was 25,690 chum salmon. However, a careful review of the Bromaghin (1998) analysis reveals consistent negative residuals for all brood years after 1984, except for a slightly positive residual for brood year 1996. This indicates environmental instability in the data set and logic would indicate that the MSY estimate and MSY escapement estimate resulting from the analysis would be substantially biased. Fair et al (1999) stated that the current biological escapement goal for the Kwiniuk River was 19,500 chum salmon measured as a counting tower estimate, and recommended converting that goal into a range of 15,600 to 31,200 chum salmon measured as a counting tower estimate.

According to Buklis (1993), the Tubutulik River chum salmon stock first had an escapement goal established in 1984. That initial goal, still in effect at the time the Buklis (1993) report was written, was 12,000 chum salmon counted in an aerial survey. According to Buklis (1993), methodology associated with the initial Tubutulik River chum salmon escapement goal was: "*Peak annual aerial survey counts were averaged for years that produced average or better returns. Surveys that were incomplete or that were conducted under poor survey conditions were excluded. At least five data points were used to calculate these averages*." A more recent analysis by Fair et al (1999) suggested increasing the Tubutulik River escapement goal to a point value of 17,000 with an escapement goal range of 13,600 to 27,200 chum salmon. Methodology employed in the Fair et al (1999) report was similar to the approach documented by Buklis (1993) and was based upon escapement averaging. The major difference was that additional years of aerial survey data were available and the newer average escapement was higher than the initial escapement average documented by Buklis (1993).

This report is written to document current analyses relevant to developing stock-recruit relationships for the Kwiniuk and Tubutulik chum salmon stocks and to make recommendations for definition of appropriate biological escapement goals for these important stocks of Norton Sound chum salmon.

MOSES POINT CHUM SALMON ESCAPEMENTS, HARVESTS, RETURNS, AND SPAWNER-RECRUIT RELATIONSHIPS

Moses Point Escapements, Catches, and Exploitation Rates

The most significant challenge in developing stock-recruit relationships for Moses Point chum salmon stocks is development of annual total escapement estimates for the Tubutulik River. The methodology employed to address this challenge in this report is taken after the methodology employed by Bromaghin (1998). The assumption is made that migratory timing of the Kwiniuk and Tubutulik stocks is similar. And, the assumption is made that the proportion of total chum salmon present that are observed in the Tubutulik River during surveys is the same as that observed in the Kwiniuk River under the same average survey ratings. Thus, the Tubutulik River survey counts of chum salmon are first expanded by a visibility factor and then expanded based upon an estimate of "when" in the migratory run the survey took place. Both of these adjustment factors are based upon available data for the Kwiniuk River.

Tower counts of chum salmon in the Kwiniuk River on a daily basis, cumulative passage basis, and seasonal basis are available for each year since 1965. These data are included for at least some years in Brennan et al (1999) and in Bromaghin (1998). The remainder of the Kwiniuk tower data was provided to me by Fred Bue (personal communication) and Gene Sandone (personal communication). Over the past 36 years, various ADF&G staff have surveyed the Kwiniuk River and recorded the number of chum salmon observed. These observations are memorialized in the *Norton Sound and Kotzebue Stream Survey Catalogue* maintained in the Nome office by ADF&G staff. I reviewed these available data and extracted what I considered to be the most useful data. Extraction rules I employed included:

(1) Surveys were only used if at least 10% of the seasonal Kwiniuk tower count had already passed upstream.
(2) Surveys were not included if the survey rating was not recorded in the *Norton Sound and Kotzebue Stream Survey Catalogue.*
(3) Surveys with catalogue summing errors were not included.
(4) Surveys potentially negatively impacted by pink salmon presence were not included; specifically, if the pink to chum ratio observed during a survey exceeded 6, the surveys were not included.

After employing the above extraction rules, a total of 17 individual paired observations consisting of chum salmon counted during a survey and the cumulative passage of chum salmon on the day of that survey were identified (Table 1). These data were grouped by survey rating wherein the survey observer noted survey conditions at the time of the survey as "1 = good", "2 = fair", or "3 = poor". Average proportions of chum salmon present that were counted during the survey were calculated and the survey rating groups were averaged. The seven surveys with "good" survey ratings counted 78.9% of the total chum salmon present in the Kwiniuk River, on average (Table 1). Using the average percent observed as a predictor when coupled with those same seven survey counts indicated that average percent absolute error with this methodology was 36% for "good" survey ratings (Table 1). Proportions of chum salmon counted during "fair' and "poor" Kwiniuk surveys averaged 59.4% and 24.7%, respectively with associated average percent errors of 34% and 17%, respectively (Table 1).

These estimated expansion factors specific to surveys rated as "good", "fair", or "poor" were applied to surveys of Tubutulik River chum salmon (Table 2). More specifically, counts of chum salmon during surveys of the Tubutulik River from 1965-2000 were divided by 0.789, by 0.594, or by 0.247, depending upon the recorded survey rating. This calculation provides estimates of the total chum salmon present in the Tubutulik River on the day of that survey. Again, the inherent assumption is that visibility factors that would affect the proportion of chum salmon counted during surveys is similar in the Kwiniuk and Tubutulik rivers.

These expanded counts of chum salmon in the Tubutulik River (Column 6 of Table 2) were again expanded to account for "when" in the run the survey took place. Specifically, the cumulative passage of Kwiniuk River chum salmon on the date and in the year of the Tubutulik survey (Column 8 of Table 2) was divided by the seasonal passage of chum salmon in that year (Column 7 of Table 2) to determine "when" in the run the survey took place. This number was inverted to obtain an expansion factor (Column 9 of Table 2). Then, the expanded count of chum salmon in the Tubutulik River (Column 6 of Table 2) was divided by the "when" expansion factor to estimate total escapement of chum salmon in the Tubutulik River for the year. All surveys of the Tubutulik River during the month of July from 1965-2000 were included in the analysis so long as: (1) the survey rating was recorded in the *Norton Sound and Kotzebue Stream Survey Catalogue* and, (2) the survey took place after at least 10% of the Kwiniuk passage for the year had occurred. As a result, multiple surveys in a given year sometimes occurred. When this happened, the annual inriver run estimate used in subsequent portions of this report was the arithmetic average value (Table 3). Multiple estimates of the annual inriver Tubutulik River chum salmon runs provided the means of estimating potential measurement errors. There were five years in which two or more surveys of the Tubutulik River took place resulting in multiple annual estimates of the same statistic. The coefficients of variation for these five years ranged from a low of 8% to a high of 33%, averaging 19%. This is likely a good indication of the level of measurement error associated with the annual estimates of inriver strength of Tubutulik River chum salmon runs when they were based upon the methodology discussed above.

There were 7 of the 36 years (19% of the years) from 1965-2000 in which no surveys of the Tubutulik River took place, thus there was no basis for developing total inriver run strength using the above methodology for these years. However, Kwiniuk tower counts of chum salmon and estimates of total inriver Tubutulik River chum salmon runs (Figure 1) for the years in which there are paired data are significantly related ($n = 29$, $R = 0.625$, significant at the 0.003 level, Tubutulik inriver run = 2,192 + 0.8686 * Kwiniuk tower count). Although the relationship is significant, estimates of the Tubutulik River inriver run strength of chum salmon based upon Kwiniuk tower counts in the same year potentially have significant measurement error that was estimated to average 107% as measured as absolute percent error (Table 5). Therefore, the reader should keep in mind that potential measurement error of the 1965, 1967, 1968, 1989, 1994, 1999 and 2000 Tubutulik River chum salmon runs is higher than is the case for the other 29 years in the data set.

Significant subsistence fishing takes place in the Moses Point Subdistrict of Norton Sound and a portion of that fishing takes place in freshwater, either after run assessments have been conducted or upstream of where run assessments have been conducted. As a result, estimates of subsistence fishing have to be subtracted from Kwiniuk tower counts and from estimates of the inriver run strengths of Tubutulik River chum salmon in order to estimate spawning escapement. Bromaghin (1998) faced this same technical problem and used a series of assumptions to generate appropriate adjustments and escapement estimates. I elected to use the very same set of assumptions for the most part and they are:

(1) Subsistence catches in the Moses Point Subdistrict in 1983 and 1984, when they were not directly estimated, were 2,035 chum salmon per year, a value equal to the average subsistence catch during the years of 1978-1982 (same as Bromaghin (1998) assumption).
(2) Subsistence catches in the Moses Point Subdistrict in 1986-1990, when they were not directly estimated, were 1,978 chum salmon per year, a value equal to the average subsistence catch during the years of 1979-1982 and 1985 (same as Bromaghin (1998) assumption).
(3) Subsistence catch in the Moses Point Subdistrict in 2000, a year when the estimate is not yet available, was 1,826, a value equal to the average for the years 1995-1999 (not a Bromaghin (1998) assumption).
(4) One third of annual subsistence harvest takes place in the ocean (same as Bromaghin (1998) assumption).

(5) Freshwater subsistence harvests are one half Kwiniuk origin fish and one half Tubutulik origin fish (same as Bromaghin (1998) assumption).
(6) Stock composition in the ocean subsistence fishery is the same as the stock composition in freshwater. In other words, the ocean Kwiniuk stock composition = Kwiniuk tower count divided by the sum of the Kwiniuk tower count and the estimated inriver Tubutulik River chum salmon run. This same assumption was used to allocate commercial harvests between Kwiniuk origin and Tubutulik origin fish (same as Bromaghin (1998) assumption).

Use of the above assumptions and associated calculation algorithm results in estimates of the Kwiniuk River spawning escapements of chum salmon ranging from a low of 6,462 fish in 1976 to a high of 67,438 fish in 1970, averaging 25,032 chum salmon from 1965-2000 (Table 6). The methodology results in estimates of the Tubutulik River spawning escapements of chum salmon ranging from a low of 1,705 fish in 1982 to a high of 87,472 fish in 1970, averaging 19,442 chum salmon from 1965-2000 (Table 7).

Contrast in escapements for the Kwiniuk River chum salmon runs has been over 10-fold since 1965, while contrast in escapements for the Tubutulik River chum salmon runs has been over 100-fold. The initial stock-recruit analysis for the Kwiniuk and Tubutulik chum salmon stocks described later in this report includes brood years 1965-1995. The later data sets used to estimate stock-recruit relationships for the Kwiniuk chum salmon stock include brood years 1980-1995, while the Tubutulik data set includes brood years 1983-1995. Contrast in Kwiniuk escapements for brood years 1980-1995 is 8,697 in 1985 to 56,229 in 1983, a contrast of 6.5 fold. Contrast in Tubutulik escapements for brood years 1983-1995 is 3,032 in 1992 to 45,335 in 1985, a contrast of about 15-fold. These are meaningful levels 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 6.5-fold, the brood year 1980-1995 Kwiniuk River chum salmon analysis fits into the middle category identified by the CTC (1999) general methods. Therefore, 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, 16 brood years of recruits are estimated, and all six escapements of more than 25,000 spawners failed to replace themselves. Thus, one of the criteria for the middle category is met. The other criteria (measurement error) is a more difficult problem to assess. Although annual spawning escapements have been estimated with tower counts minus upstream subsistence catches, variances associated with these estimates are not available. However, subsistence catches are minor compared to escapements, and escapement estimates are considered to be fairly precise (but not censuses because tower counts are expanded from sampled times). The escapement assessment methodologies used for Kwiniuk River chum salmon is believed to have been rigorous and without bias. It seems likely to me that the coefficients of variation associated with the annual escapement assessments are likely less than 10%, but that is based on my guess, not on sampling information. If I am correct, measurement errors are minor. In any event, there is good reason to believe that measurement errors associated with annual escapements are not extreme. Therefore, the second condition listed by the CTC (1999) is surely met. There are good technical reasons to believe that the Kwiniuk River chum salmon stock-recruit analysis will lead to useable estimates of the escapement level that produces maximum sustained yield (S_{MSY}).

With a contrast of spawning escapements of 15-fold, the brood year 1983-1995 Tubutulik River chum salmon analysis fits into the third category identified by the CTC (1999) general methods. And, thus 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, 13 brood years of recruits are estimated, and all four escapements of more than 25,000 spawners failed to replace themselves. Therefore, the criteria for the third category are fully met. Although the CTC (1999) does not indicate measurement error to be as important as contrast when the range is more than eight, the issue of measurement error is still important. Spawning escapements of Tubutulik River chum salmon are not directly enumerated, a series of expansions were used to develop these annual escapement estimates. Most of the annual values have what I consider to be moderate levels of measurement error, but the estimates based on regression methodology have considerably higher measurement error. The 1983-1995 brood year analysis includes two of these estimates, one for 1989 and one for 1994. However, the escapement-return statistics for these two brood years looks very similar to other years in the data set and hence they demonstrate no striking problems. It seems likely to me that the coefficients of variation associated with most the annual escapement assessments for the Tubutulik River are likely less than 25%. If I am correct, measurement errors are moderate, not extreme. Therefore good technical reasons exist to believe that the Tubutulik River chum salmon stock-recruit analysis will lead to useable estimates of the escapement level that produces maximum sustained yield.

Subsistence fishery harvests in the Moses Point Subdistrict were allocated to either Kwiniuk origin or to Tubutulik origin using the assumptions identified above. Commercial fishery harvests in the Moses Point Subdistrict were allocated to either Kwiniuk origin or to Tubutulik origin using assumption six identified above. Total annual runs of Kwiniuk origin and Tubutulik origin chum salmon from 1965-2000 were estimated by adding appropriate escapement and catch data (Figures 2 and 3). Annual exploitation rates of each of the stocks of the Moses Point fishery was calculated (Tables 6 and 7). Results of these calculations indicate that annual exploitation rate of Kwiniuk origin chum salmon has ranged from 3.4% to 71.3%, averaging 29.8% since 1965 (Table 6), while annual exploitation rate of Tubutulik origin chum salmon has ranged from 4.2% to 73.8%, averaging 32.1% since 1965 (Table 7).

Age Composition of Annual Escapements and Catches and Estimated Age Specific Total Runs

In the Moses Point Subdistrict annual fishery catches were sampled for age compositions from 1965 to 1991 with the exception of 1984 (Table 8). Sample sizes of these annual age composition data sets ranged from 19 aged fish to 1,057 fish aged, averaging over three hundred aged fish per year. The Moses Point fisheries have not been sampled for age composition since 1991. However, starting in 1992, age composition of the chum salmon population migrating upstream of the Kwiniuk tower were sampled. Escapement based age composition sampling from 1992 through 1998 included annual sample sizes of from 19 aged fish to 466 aged fish, averaging about 175 fish aged. I elected to use these annual age composition values that were either sampled specifically from the Moses Point catch or the Kwiniuk escapement as proxy annual estimates of the age composition of the total runs for both the Kwiniuk and the Tubutulik chum salmon stocks. Because direct sampling information was not available for the years 1984, 1999 and 2000, I used the long-term average age composition of 2.6% age-3, 61.1% age-4, 35.1% age-5, and 1.2% age-6 as proxy estimates for those three years (Table 8). The annual age composition estimates as listed in Table 8 were multiplied by the respective estimates of annual total runs as provided in Tables 6 and 7 to provide age-specific estimates of the annual total runs to the Kwiniuk and Tubutulik rivers, respectively.

Estimated Recruits Resulting from 1965 to 1995 Brood Year Escapements

The number of Kwiniuk or Tubutulik 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 $i+6$. Brood years 1965 to 1995 were included in this process and results for the Kwiniuk chum salmon stock are provided in Table 9 while results for the Tubutulik chum salmon stock are provided in Table 10. The age-6 recruits in 2001 for the 1995 brood year were estimated as the average age-6 recruitment. Because very few fish return at age 6, this estimation procedure has very little effect on the spawner-recruit relationships discussed later in this report. Total recruits of Kwiniuk River origin chum salmon resulting from the 1965-1995 brood years were estimated to have ranged from a low of 8,591 fish from the 1985 brood year to a high of 97,546 fish from the 1966 brood year (Table 9). Total recruits of Tubutulik River origin chum salmon resulting from the 1965-1995 brood years were estimated to have ranged from a low of 5,104 fish from the 1985 brood year to a high of 118,789 fish from the 1966 brood year (Table 10). Thus, paired data sets were developed for both the Kwiniuk and the Tubutulik stocks of chum salmon with sample sizes of 31, each consisted of: (1) estimated escapements during the years 1965-1995 and, (2) estimated recruitment resulting from those escapements.

Spawner-Recruit Relationship for Kwiniuk and Tubutulik Origin Chum Salmon

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

$$R_y = \alpha S_y e^{-\beta S_y} \exp(\varepsilon_y) \tag{1}$$

where: R_y = estimated total recruitment by brood y;
S_y = spawning escapement 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. I assumed the errors were log-normal (as is common for salmon returns), resulting in the log-transformed linear equation:

$$\ln(R_y/S_y) = \ln(\alpha) - \beta S_y + \varepsilon_y \tag{2}$$

Linear regression procedures provided estimates of the intercept (ln α) and the slope (β) in equation 2. 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:

$$\hat{S}_{MSY} \cong \frac{\widehat{\ln\alpha} + \hat{\sigma}^2_\varepsilon/2}{\hat{\beta}}[0.5 - 0.07(\widehat{\ln\alpha} + \hat{\sigma}^2_\varepsilon/2)] \tag{3}$$

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

Analysis of the 1965-1995 Kwiniuk spawner-recruit data with the above model resulted in a problematic residual pattern (Table 11). All residuals after brood year 1979 except for a small positive residual for brood year 1990 were negative implying a strong trend in the data (Figure 4). This residual pattern indicates that the environment was not stable across the period of time that the data extended (1965-2000), but instead a significant change occurred that first effected brood year 1980. A basic tenet of using historic stock-recruit information from salmon stocks to estimate productivity and to estimate the maximum sustained yield escapement goal for use in future fishery management is that the past is representative of the future. Although the reasons for the environmental change that the Kwiniuk River chum salmon stock has obviously experienced is unknown, it is clear that at least a portion of the past does not currently represent the present nor is it likely to represent the immediate future. Therefore, the stock-recruit data for the Kwiniuk River chum salmon stock was split into a brood year 1965-1979 data set and a more recent brood year 1980-1995 data set.

Analysis of the 1965-1995 Tubutulik spawner-recruit data with the above model resulted in a second problematic residual pattern (Table 12). All residuals after brood year 1982 were negative again implying a strong trend in the data (Figure 4). This residual pattern indicates that the environment was not stable across the period of time that the data extended (1965-2000), but instead a significant change occurred that first effected the brood year 1983 Tubutulik River chum salmon stock. Therefore, the stock-recruit data for the Tubutulik River chum salmon stock was split into a brood year 1965-1982 data set and a more recent brood year 1983-1995 data set.

Analysis of the Kwiniuk spawner-recruit relationship using the data set developed for brood years 1980-1995 resulted in a pattern of random residuals implying a stable environment across the time period (Table 13 and Figure 5 and 6). Auto-correlation of the stock-recruit data was not significant (Figure 7). Similarly, analysis of the Tubutulik spawner-recruit relationship using the data set developed for brood years 1983-1995 resulted in a pattern of random residuals implying a stable environment across that time period (Table 14).

Analysis of the Kwiniuk spawner-recruit relationship using the data set developed for brood years 1980-1995 resulted in an estimate of 12,839 spawners as the current MSY escapement level for the Kwiniuk River stock of chum salmon (Table 15). The spawner-recruit relationship estimated that maximum surplus yield from the Kwiniuk River stock of chum salmon given current environmental conditions is 8,979 fish, on average. If the Kwiniuk River stock of chum salmon were managed at the indicated MSY escapement level of 12,839 spawners per year, a fishery yield of 8,979 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 41%. Replacement escapement, or the point on the spawner-recruit relationship where harvestable surplus falls to zero is estimated at about 29,000 fish.

Conversely, analysis of the Kwiniuk spawner-recruit relationship using the early data set (brood years 1965-1979) resulted in an estimate of 19,139 spawners as the MSY escapement level. This early data set estimates that maximum sustained yield is 44,769, almost five-fold the late period estimate of MSY. Estimated Kwiniuk MSY exploitation rate for the early data set is 70%, much higher than the level indicated for the late data set (41%). Reasons for this substantial loss of productivity are unknown.

Analysis of the Tubutulik spawner-recruit relationship using the data set developed for brood years 1983-1995 resulted in an estimate of 10,426 spawners as the current MSY escapement level for the Tubutulik River stock of chum salmon (Table 15, Figures 8-9). Auto-correlation of the spawner-recruit data was not significant (Figure 10). The spawner-recruit relationship estimated that maximum surplus yield from the Tubutulik River stock of chum salmon given current environmental conditions is 6,677 fish, on average. If the Tubutulik River stock of chum salmon were managed at the indicated MSY escapement level of 10,426 spawners per year, a fishery yield of 6,677 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 39%. Replacement escapement, or the point on the spawner-recruit relationship where harvestable surplus falls to zero is estimated at about 24,000 fish.

On the other hand, analysis of the Tubutulik spawner-recruit relationship using the early data set (brood years 1965-1982) resulted in an estimate of 17,494 spawners as the MSY escapement level. This early data set estimates that maximum sustained yield is 61,067, about nine-fold the late period estimate of MSY. Estimated Tubutulik MSY exploitation rate for the early data set is 79%, about twice as high as the level indicated for the late data set (39%). And again, reasons for this substantial loss of productivity and potential fishery yield are unknown.

Bootstrap Analysis of the Spawner-Recruit Relationship for Kwiniuk and Tubutulik 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:

$$\zeta_y = Y_y - \hat{\mathrm{E}}[Y_y] \tag{4}$$

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:

$$\tilde{Y}_y = \zeta^*_y + \hat{E}[Y_y] \tag{5}$$

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 variable (spawning abundance) 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^2_ε. These new parameter estimates were plugged into EQ 3 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):

$$v(\hat{S}_{MSY}) = \frac{\sum_{b=1}^{1000}(\tilde{S}_{MSY(b)} - \bar{S}_{MSY})^2}{1000-1} \tag{6}$$

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 $\tilde{S}_{MSY}$ 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 Kwiniuk River stock of chum salmon using the brood year 1980-1995 data set is 12,749 spawners and the coefficient of variation for this mean statistic is 11.3% (Table 16). The 90% confidence interval for the estimated MSY escapement level for the Kwiniuk River chum salmon stock is estimated at 10,643 to 15,266 spawners (Table 16). The bootstrap mean estimate of the MSY escapement level for Kwiniuk chum salmon stock is lower than the regression estimate of 12,839 spawners, and differs by 90 fish, indicating bias is negligible at 0.7% (Table 16).

The mean bootstrap estimate of MSY escapement for the Tubutulik River stock of chum salmon using the brood year 1983-1995 data set is 9,938 spawners and the coefficient of variation for this mean statistic is 24.1% (Table 16). The 90% confidence interval for the estimated MSY escapement level for the Tubutulik River chum salmon stock is estimated at 6,128 to 13,899 spawners (Table 16). The bootstrap mean estimate of the MSY escapement level for Tubutulik chum salmon is lower than the regression estimate of 10,426 spawners, and differs by 488 fish, indicating bias is minor at 4.7% (Table 16).

Biological Escapement Goals for Kwiniuk and Tubutulik Origin Chum Salmon

The best available scientific estimate of the current MSY escapement point value for the Kwiniuk River stock of chum salmon is about **12,800** spawners. The biological escapement goal for the Kwiniuk River stock of chum salmon should be set at **10,000 to 20,000 total spawners** per year. This range is based upon the current estimate of the point value and the approximate application of the methodology of Eggers (1993). This range encompasses the 90% confidence interval of MSY escapement (about 10,600 to 15,300) based on the bootstrap analysis (Table 16).

The best available scientific estimate of the current MSY escapement point value for the Tubutulik River stock of chum salmon is about **10,500** spawners. The biological escapement goal for the Tubutulik River stock of chum salmon should be set at **8,000 to 16,000 total spawners** per year. This range is based upon the current estimate of the point value and the approximate application of the methodology of Eggers (1993). This lower end of this range is higher than the lower bound of the 90% confidence interval of MSY escapement based upon the bootstrap analysis (about 6,100). The upper end of this range is higher than the upper bound of the 90% confidence interval of MSY escapement (about 13,900) based on the bootstrap analysis (Table 16).

STOCK STATUS OF KWINIUK AND TUBUTULIK CHUM SALMON GIVEN THE RECOMMENDED MSY ESCAPEMENT GOAL

From 1980 to 2000, two of the twenty-one (9%) annual Kwiniuk River chum salmon escapements were below the range of escapements that are currently estimated to produce maximum sustained yield fisheries in the Moses Point Subdistrict (Table 17). Of the nineteen other annual total escapements, 10 (48%) were within the range of total escapements estimated to produce maximum sustained yield fisheries while the remaining nine (43%) were above that range. Examination of escapement patterns since 1990 shows that all but the 1999 escapement were either within the recommended range or they exceeded the recommended range. There was no commercial fishery in 1999 (Table 6) and hence the 1999 escapement of chum salmon in the Kwiniuk River was due to low abundance, not over-fishing. And, the 1999 Kwiniuk chum salmon escapement was 89% of the lower bound of the recommended biological escapement goal range. All in all, the pattern of escapements since 1980 indicates that the Kwiniuk River stock of chum salmon is fully healthy, but has been underutilized in about 40% of the years.

From 1983 to 2000, six of the eighteen (33%) annual Tubutulik River chum salmon escapements were below the range of escapements that are currently estimated to produce maximum sustained yield fisheries in the Moses Point Subdistrict (Table 17). Of the twelve other annual total escapements, five (28%) were within the range of total escapements estimated to produce maximum sustained yield while the remaining seven (39%) were above that range. Examination of escapement patterns since 1990 shows that five of the 11 escapements (46%) were below the range of escapements estimated to produce current maximum sustained yield fisheries. The 1990, 1992, 1997, 1999 and 2000 estimated total Tubutulik chum salmon escapements were 83%, 38%, 44%, 65%, and 98%, respectively, of the lower bound of the recommended biological escapement goal range. Moses Point Subdistrict commercial fisheries resulted in the harvest of 3,723 chums in 1990, 2,683 chums in 1997, and 535 chums in 2000, while none were harvested in 1992 or 1999. Thus, of these five years, only in 1997 was there a substantial chum harvest while the Tubutulik escapement was well short of the level recommended in this report. As a result, it is clear that the Tubutulik escapement shortfalls of the 1990s were primarily the result of low abundance, not overfishing. All in all, the pattern of escapements since 1983 indicates that the Tubutulik River stock of chum salmon is reasonably healthy, but that ADF&G should carefully monitor the stock to help ensure annual escapements in the recommended biological escapement goal range.

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 analysis and the two technical reviews concerning these draft analyses were submitted to the Alaska Board of Fisheries in December and January and the AYK BEG analyses became quite controversial during the January Board of Fisheries meeting. The Alaska Board of Fisheries formally adopted "optimal escapement goals" (OEGs) in regulation for the Kwiniuk (11,500-23,000) and Tubutulik (9,200-18,400) stocks of chum salmon. These goals were slightly higher than the BEGs identified in this report. A discussion of the two 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 Kwiniuk and Tubutulik analyses (the topics of this report) only in a general manner while other aspects of the discussion relate directly to the Kwiniuk and Tubutulik chum salmon BEG analyses 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, including myself, 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. I 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 author of this report and as a member of the ADF&G committee charged with developing biological escapement goals for the salmon stocks of AYK, I agree with these assessments. Further, I 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, I 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, I 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. I 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 my 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. I 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. I 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. I would agree if only such information existed in the current AYK database. For instance, there are currently no estimates of the sampling variances associated with Kwiniuk tower counts. I know there is measurement error in those estimates, I simply have no estimates of the magnitude, even though I believe the magnitude to be small. And, until better estimates complete with variances are made available for the basic data used in these stock-recruit analyses, it is my 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) recommend that more precise harvest management capabilities be developed including better catch apportionment and escapement monitoring. I 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) recommend that standard methods be developed for incorporation of error introduced throughout the process of preparing data for use in stock-recruitment analysis. Again I concur, but point out to achieve this objective would require a policy decision by ADF&G's leadership that in the salmon stock assessment program, variances 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) recommend 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. I concur. Mundy et al. (2001) recommends the expected performance of an escapement goal or range within the management plan be evaluated in view of critical uncertainties. I believe AYK BEG report authors have done so to the extent possible and my analyses concerning "Stock Status" in this report is intended to assist the reader in this regard.

Conclusions of the Mundy et al. (2001) review include 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*." I concur, and agree that gathering improved data concerning catches, escapements, age compositions, and stock compositions and that frequent scientific analysis of these stock-recruit data to identify appropriate escapement goals is the surest means of ADF&G fully achieving its constitutional mandate.

Mundy et al. (2001) includes comments that specifically address this Kwiniuk/Tubutulik BEG chum salmon report. Mundy et al. (2001) states: "*Methods for estimating parameters may need to be revised. Kwiniuk data appear to show an autoregressive process, which should have been modeled ARMA (1,0). Model residuals were not reported to have been tested for autocorrelation or partial autocorrelation*." Actually, auto-regressive analysis was conducted, but I failed to include the analysis in the draft report. This problem has been rectified in the current version of this report and reference to Figures 7 and 10 clearly show that auto-regressive features were not statistically significant in either the Kwiniuk or the Tubutulik models.

The Mundy et al. (2001) review states: "*The Kwiniuk paper states a belief that the measurement error in the estimate of spawning escapement is not large, and proposes that the coefficient of variation is under 10%, but this is an informal appraisal, and is not presented with the backing of a paper trail of calculations*." This is true; my "guess" is that measurement errors associated with Kwiniuk spawning escapements of chum salmon are small. That belief is based upon knowledge that when other tower based estimates of salmon escapements in Alaska have been made and the sampling variance determined, the sampling variance is small compared to the escapement estimate. I recommend the historic Kwiniuk River tower counts of chum salmon be reviewed and that sampling variance for each of the historic years be calculated with standard statistical methodologies. Only after these calculations are complete can this issue be completely resolved. The Mundy et al. (2001) review goes on to say: "*The document does not state any quantification of likely measurement error for the recruitment estimates. It is expected that recruitment estimates are subject to more error than escapement estimates, since these involve possible error in the apportionment of catches to stock of origin, age composition estimates in selective gear types, and possible error in the harvest estimates themselves*." I agree that measurement errors associated with recruitment estimates are likely larger than measurement errors associated with escapement estimates. My "guess" would be twice the level associated with escapement estimates. However, this potential concern is mitigated to some extent by the following: (1) historic exploitation is relatively low and hence most of the recruitment is measured as escapement, (2) some of the subsistence harvest is counted by tower prior to the fish being removed through fishing, and (3) commercial catch estimates are a census, not an estimate. These factors tend to minimize the potential increases in measurement error. Again, I recommend that sampling variances for all the historic data be calculated (age composition sampling variances, subsistence catch estimation sampling variances, etc.). Until the existing AYK database includes sampling variances accompanying estimates, getting a handle on measurement error associated with recruitment estimates will remain a "guessing" game.

Mundy et al. (2001) under recommendations for the Kwiniuk/Tubutulik analyses state: "*A more sophisticated fitting procedure, with partitioning of the variance terms is recommended. The author makes important recommendations for data collection efforts to support improved analyses in the future and these should be fully supported. Additionally, analyses of the relationships between stock productivity and possible environmental drivers may reveal potential terms to add to future population modeling*." I agree, once sampling variances are computed for the existing database, a more sophisticated modeling approach can be undertaken. I am hopeful that the stock assessment recommendations made in this report will be positively acted upon. And, I recommend that these escapement goals should be used only in the short term (next two years) and another analysis should be completed in 2002 based upon an improved stock assessment data set. Relative to the review comment concerning environmental drivers and potential terms to add to future population modeling, I concur. But I point out that to fully accomplish this recommendation concerning mortality drivers would require a substantial investment in the Kwiniuk/Tubutulik chum salmon stock assessment program beyond that presently existing as well as implementation of such a program for an extended period of time (more than 10 years).

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 BEGs proposed as being 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, Anderson 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. Anderson et al. (2001) was silent on 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 Anderson et al. (2001) follow along with m responses and other report authors 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. I 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. Anderson 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. 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 Kwiniuk River counted from a tower), or AYK BEG report authors have expressed uncertainty as estimated variances (i.e., chinook salmon in the Salcha and Chena rivers). Although I agree that "average percent error" is not the best measure of uncertainty in estimates of escapement, report authors left them as originally reported. We did so because cross-validation or predictions from linear models as proposed by Anderson 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. Attempts to calculate historic sampling variances are possible for some stocks (including the Kwiniuk chum salmon stock), but will require considerably more time and effort than that available for these BEG analyses. My recommendation is that the database be expanded to include sampling variances and that re-analysis in 2002 take these uncertainties into account more fully than I was able to in this report. In those cases 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 formal fishery science literature (see Hilborn and Walters 1992:290), we, as report authors, 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. 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 described before, many sources of variation (measurement error) were likely negligible in their affect on estimated S_{MSY} (i.e., chum salmon counted by tower in the Kwiniuk River) or in estimates of harvest (i.e., chinook salmon in the Salcha and Chena rivers). In other cases, no estimates of variance were available. I believe that further guessing at what they might be, would have been counter productive.

Andersen et al. (2001) criticized evaluation of residuals included in the six draft reports. 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 of 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 of the affect of contrast on estimates of S_{MSY}.

Andersen et al. (2001) criticizes the AYK BEG report authors 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. 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 part of the time series of data was censored (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 I do not know, but I 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, I censored the earlier data and re-estimated the stock-recruit relationship. I realize that 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 had an impact on salmon returns in recent years, there is evidence consisting of poor returns from abundant spawners, not just in recent years, but in earlier years when spawners had been 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 includes some comments that specifically address this Kwiniuk/Tubutulik chum salmon BEG report. Andersen et al. (2001) make comments concerning measurement errors associated with the Kwiniuk and Tubutulik database; agreeing with my assessment for the Kwiniuk and disagreeing with my assessment for the Tubutulik.

Again, I recommend sampling variances be calculated and added to the database to settle this issue (see discussion under Mundy et al. for additional details).

Andersen et al. (2001) states: "*Personal knowledge of the fisheries in this area suggests subsistence harvest estimates used in the analysis are unrealistically low for the years prior to 1994, being based upon substantially incomplete household visits. ... Subsistence harvests are thought to have been on the order of 10,000 in 1965, and to have gradually declined to near 3,500 chum salmon in 1994. If this assumption was implemented, the exploitation rates from 1985-1994 would be most affected, more than doubling in some cases.*" I assume that "*personal knowledge*" represented the opinion of federal review team members who had previously worked for ADF&G with responsibilities in the Norton Sound Area. This issue was raised during the early stage of this analysis. Accordingly, James Magdanz, the ADF&G Subsistence Biologist for Norton Sound, was asked for his professional opinion on subsistence catches at Moses Point (James Magdanz, ADF&G, Kotzebue, personal communication; see Acknowledgements section). The data he provided were used in this report. Additionally, those data consisted of published subsistence catches, as per the methodology used at the time, not "*personal knowledge*". Further, I checked to see what Bromaghin (1998) used in the previous stock recruit analysis that he prepared for the prior Norton Sound Area Biologist and found that he likewise used the existing database, not "*personal knowledge*". That analysis was fully accepted by the ADF&G at that time. Consequently, I felt and still feel compelled to use the available ADF&G subsistence catch database, not make alternate "guesses" concerning historic subsistence catches. Although I do not have "*personal knowledge*" concerning historic subsistence catches at Moses Point, I feel the criticism concerning this issue was unfounded. More criticism would have probably been directed at this paper had I used alternate subsistence catch estimates or "guesses", as suggested by Andersen et al. (2001).

Andersen et al. (2001) state: "*It is an error to assume that ratios of actual abundance to aerial survey observations are similar between these two rivers. The substrate of the Kwiniuk River is more consistently colored than that of the Tubutulik River. The Tubutulik River passes through a canyon or eroding volcanic plugs. The basalt from these plugs is scattered as salmon sized rocks from some distance downstream, through a productive chum salmon spawning area. The current in this stretch of river is swift and causes some distortion. These problems are compounded if the river becomes turbid during the time the aerial survey is conducted. Consequently, aerial surveys are probably more accurate on the Kwiniuk River than on the Tubutulik River. An example of the potential errors in reconstructing escapements to the Tubutulik River, perhaps caused by these factors, is provided by a tower estimate of abundance on the Tubutulik River in 1980. The project leader reported chum salmon escapement to be approximately 23,000, more than twice the estimate of approximately 11,000 contained in the report.*" The reviewers may be correct, it may be that the portion of total chum salmon escapement counted by aerial survey in the Kwiniuk River is higher than the portion counted during aerial surveys of the Tubutulik River. If so, run re-constructions for the Kwiniuk stock are too high and those for the Tubutulik too low; and estimated S_{MSY} in the case of the Kwiniuk too high and in the case of the Tubutulik, too low. The 1980 tower count of 23,000 chum salmon supports this point of view. Bromaghin (1998) estimated that the Tubutulik chum salmon escapement in 1980 was 11,837 based upon a Kwiniuk tower count of 18,908 chums and the assumption that 61.5% of the total escapement from the Moses Point fishery were of Kwiniuk origin while 38.5% were of Tubutulik River origin. My estimate of about 11,000 chum salmon as the total 1980 escapement was based upon expansion of the July 7, 1980, count of 2,800 chum salmon in an aerial survey rated as a "2". I do not think one year of total escapement is adequate to answer the question. I have recommended that an on-the-grounds assessment of total chum salmon escapement in the Tubutulik River be implemented. A few years of paired data wherein sampling based total escapements of chum salmon in the Tubutulik River are contrasted with estimates derived through the algorithm used in this report will address the question; further speculation will not resolve the issue.

The Andersen et al. (2001) review states: "*A variety of assumptions and expansions are used to approximate Tubutulik River escapements and to apportion harvests between the two systems. However the uncertainty associated with these approximations is not assessed in the report. Potential biases and the large variation associated with the expanded estimates cause a high level of uncertainty in the quality of data used in the analysis*." Yes, a variety of assumptions and expansions are required to reconstruct historic Tubutulik (and Kwiniuk) chum salmon runs and escapements because on-the-grounds stock assessment activities for the Tubutulik stock have not been conducted (except in 1980). Estimates associated with the Tubutulik analysis are natural by-products of the Kwiniuk analysis, which in the Bromaghin (1998) report are ignored and in this report are used to assess the Tubutulik River chum salmon stock. And, there is more uncertainty associated with the Tubutulik analysis than with the Kwiniuk analysis. Whether or not biases exist and whether or not variation is large is unknown at the current time. Validation of the methods used herein and in Bromaghin (1998) will only occur if actual total Tubutulik River chum salmon escapement assessments are implemented in future years.

Andersen et al. (2001) state: "*Although a variety of questionable expansions are used to approximate harvests of Kwiniuk River chum salmon, the run reconstruction is likely useful for estimating productivity parameters of the Kwiniuk River stock. However for reasons summarized in Using Full Data Series, escapement goals should be based upon the full data set*." These "questionable expansions" are the exact same expansions used by Bromaghin (1998) and deemed acceptable to the majority of these very same reviewers at that time. I don't understand the present concern of these reviewers. Bromaghin (1998) failed to carefully review residuals in the Kwiniuk relationship when estimating S_{MSY} and making an escapement goal recommendation; this report corrects that technical oversight. It makes little sense to continue to regulate a fishery for production levels that have failed to exist for almost two decades.

Andersen et al. (2000) state: "*The run reconstruction for the Tubutulik River is wholly a product of the various assumptions and expansion factors used in the analysis, and is not of the quality necessary to provide a useable estimate of S_{MSY}. The Kwiniuk River tower project provides reliable information to guide management, and the need for an aerial survey goal on the Tubutulik River is questionable. If a ground-based project is ever established on the Tubutulik River, a productivity analysis should be completed after a sufficient quantity of reliable data becomes available*." I disagree. The Tubutulik chum salmon run reconstruction is a by-product of the Kwiniuk analysis. Tubutulik total escapement estimates are required to allocate mixed stock catches of chum salmon in the Moses Point fishery for the Kwiniuk analysis. And those fish not assumed to be of Kwiniuk origin are thereby assumed to be of Tubutulik origin. If the Tubutulik estimates are so bad as to be unusable for stock-recruit analysis, then the total recruit estimates for the Kwiniuk analysis are also a serious concern. The Bromaghin (1998) methodology that I adhered to has this intertwining as a technical reality. The two analyses (Kwiniuk and Tubutulik) are completely intertwined and co-dependent, a fact the Andersen et al. (2001) reviewers apparently failed to understand. One cannot be "good" and the other "bad", they are either both "useable" or they are both "unusable" for S_{MSY} estimation purposes. I believe they are both "useable" but could be improved with an improved basic stock assessment program. Relative to the Andersen et al. (2001) comment concerning the need for a Tubutulik chum salmon escapement goal, this opinion too is misguided. The Tubutulik chum salmon runs are of about the same magnitude as the Kwiniuk chum salmon runs and they are co-mingled in the Moses Point fishery. Assuming that simply managing for the Kwiniuk stock of chum salmon will completely take care of the Tubutulik stock is a simplistic and naïve assumption. Note that Table 17 indicates that the Tubutulik chum escapements have historically been about four times more likely to have been less than the recommended BEG than is the case for the Kwiniuk stock.

As is obvious from reading the above passages, Anderson et al. (2001) often disparaged the quality of the data describing several of the stocks in the draft reports. While my view is not as pessimistic as theirs, I concede that the quality of the data describing some of the stocks could have been better, much better. With limited funding, ADF&G has not been able to adeqately assess 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 Anderson et al. (2001) resolved.

RECOMMENDATIONS

After full consideration of review comments, I recommend that the Alaska Department of Fish and Game formally adopt the following biological escapement goals for the Moses Point Subdistrict of Norton Sound:

Kwiniuk River Chum Salmon: 10,000 to 20,000 total spawners per year and

Tubutulik River Chum Salmon: 8,000 to 16,000 total spawners per year.

I recommend that this biological escapement goal analysis be updated in the fall of 2002. At that time, significantly more information should be available for further development and refinement of the overall spawner-recruit relationships. As part of the analysis in 2002, residual patterns in the stock-recruit relationships should be carefully examined to determine if the productivity patterns have remained the same as in recent years or have increased as was the case in earlier years or have decreased. Refinement and further development of these relationships may lead to improved escapement goals that will better result in MSY fisheries.

I recommend that the existing chum salmon stock assessment program for the Moses Point Subdistrict of Norton Sound be continued, advanced, and improved upon. Changes I recommend include:

1. Implement an on-the-grounds total escapement enumeration project for the Tubutulik River chum salmon stock. This program could take the form of a tower project similar to the existing project on the Kwiniuk River or perhaps an annual mark-recapture project. In either event, project goals should include the total enumeration or estimation of the Tubutulik River chum salmon escapement on an annual basis based upon sampling information, including estimation of sampling variances. Project goals should also include estimation of the annual age composition of the escapement (with sampling variances) based upon active sampling efforts to capture, sample, and age 300 to 500 chum salmon per year. This on-the-grounds assessment is important to confirm the expansion methodology used herein or to replace it with an improved methodology.

2. Implement an improved age composition sampling program for chum salmon in the Moses Point Subdistrict of Norton Sound. Specifically, 300 to 500 chum salmon from the Kwiniuk escapement per year should be captured, sampled and aged. Additionally, 300 to 500 chum salmon per year from the commercial fishery should be sampled and aged in any year when the Moses Point commercial fishery harvests 1,000 or more chum salmon. Lastly, chum salmon caught in the Moses Point subsistence fishery should be sampled for age composition; sample sizes should be in the 300 to 500 range per year. Sampling variances should be calculated and accompany the age composition estimates.

3. The existing historic database of total chum salmon escapements in the Kwiniuk and Tubutulik Rivers should be carefully reviewed and annual sampling variances calculated and added to the existing database.

4. The tagging study conducted by ADF&G in the late 1970s should be repeated. With significant changes in productivity, it would be appropriate to reaffirm that Moses Point Subdistrict harvests are largely comprised of Kwiniuk and Tubutulik origin chum salmon and that Kwiniuk and Tubutulik origin chum salmon are not caught in other Norton Sound Subdistricts in significant numbers. And, when the study is repeated, project managers should strive to achieve larger numbers of chum salmon tagged and recaptured. If well implemented, this suggested activity should provide direct estimates of stock composition (and sampling variances) of the Moses Point mixed stock fishery.

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Table 1. Survey counts of chum salmon in the Kwiniuk River and the portion of chum salmon observed compared to tower counts on the day of the survey. Data are grouped by survey rating (1 = good, 2 = fair, and 3 = poor). Estimates of the average percent observed by survey rating are included; and, the average absolute errors associated with these averages are also provided.

Survey Rating	Year	Date	Survey Chum Count	Tower Count on Date	Percent Observed. During Survey	Predicted Tower Count	Absolute Residual (Observed Minus Predicted)	Absolute Percent Error
1	1965	31-Jul	32,565	32,861	99.1%	41,269	8,408	26%
1	1967	08-Jul	16,722	15,691	106.6%	21,191	5,500	35%
1	1970	25-Jul	70,400	72,060	97.7%	89,216	17,156	24%
1	1979	12-Jul	6,118	5,644	108.4%	7,753	2,109	37%
1	1979	08-Jul	3,081	3,669	84.0%	3,904	235	6%
1	1985	06-Jul	730	2,563	28.5%	925	1,638	64%
1	1986	28-Jun	780	2,771	28.1%	988	1,783	64%
1				**Sample size = 7**				
1				**Average =**	**78.9%**		**5,261**	**36%**
1				**Minimum =**	**28.1%**			
1				**Maximum =**	**108.4%**			
2	1968	12-Jul	15,630	18,349	85.2%	26,316	7,967	43%
2	1969	09-Jul	8,567	11,727	73.1%	14,424	2,697	23%
2	1972	23-Jul	15,750	30,077	52.4%	26,518	3,559	12%
2	1972	12-Jul	9,000	22,191	40.6%	15,153	7,038	32%
2	1975	15-Jul	2,175	3,217	67.6%	3,662	445	14%
2	1978	03-Jul	1,521	9,815	15.5%	2,561	7,254	74%
2	1980	07-Jul	3,857	8,219	46.9%	6,494	1,725	21%
2	1989	30-Jun	2,178	2,318	94.0%	3,667	1,349	58%
2				**Sample size = 8**				
2				**Average =**	**59.4%**		**4,004**	**34%**
2				**Minimum =**	**15.5%**			
2				**Maximum =**	**94.0%**			
3	1971	10-Aug	8,000	39,046	20.5%	32,353	6,693	17%
3	1981	02-Jul	2,310	7,975	29.0%	9,342	1,367	17%
3				**Sample size = 2**				
3				**Average =**	**24.7%**		**4,030**	**17%**
3				**Minimum =**	**20.5%**			
3				**Maximum =**	**29.0%**			

Note: Survey data included in the table was limited by the following rules;

1. Surveys were only included for dates when at least 10% of the annual chum salmon run had passed upstream of the Kwiniuk tower.
2. Surveys were not included if the survey rating was not recorded in the *Norton Sound and Kotzebue Stream Catalogue* (for instance, the 7/13/77 survey was not included).
3. Surveys with excessive numbers of pinks were not included; when pink to chum ratios exceeded 6, the surveys were not included (for instance, the 7/11/76 and 7/10/96 surveys were not included).
4. Surveys with catalogue summing errors were not included (for instance the 7/7/78 and 7/8/78 surveys were not included).

Table 2. Tubutulik River chum salmon surveys, expansion factors associated with survey visibility and migratory timing, and estimates of total chum salmon runs in the Tubutulik River.

Year	Tubutulik Survey Date	Survey Rating and Observer	Survey Count of Chum Salmon	Survey Visibility Expansion Factor	Exp Count	Kwiniuk Annual Tower Count	Kwiniuk Tower Count On Date	Migratory Timing Expansion Factor	Tubutulik Total Chum Salmon Estimate
1966	28-Jul	2-unk	5,514	0.594	9,283	33,184	33,184	1.000	9,283
1969	09-Jul	2-CY	12,040	0.594	20,269	19,749	11,727	1.684	34,135
1970	25-Jul	2-CH	53,290	0.594	89,714	69,758	69,697	1.001	89,792
1971	20-Jul	2-unk	16,820	0.594	28,316	39,046	34,510	1.131	32,038
1972	23-Jul	3-unk	8,070	0.247	32,672	30,686	30,077	1.020	33,334
1973	28-Jul	1-PC	5,383	0.789	6,823	28,618	28,618	1.000	6,823
1974	06-Jul	2-unk	9,560	0.594	16,094	35,899	19,461	1.845	29,689
1975	20-Jul	2-PC	9,086	0.594	15,296	14,344	12,942	1.108	16,953
1975	31-Jul	1-PC	17,141	0.789	21,725	14,344	14,344	1.000	21,725
1976	15-Jul	2-RR	1,095	0.594	1,843	6,978	3,953	1.765	3,254
1977	08-Jul	1-RR	7,470	0.789	9,468	22,757	12,200	1.865	17,660
1977	13-Jul	1-FK	8,540	0.789	10,824	22,757	19,853	1.146	12,407
1978	08-Jul	1-RR	5,865	0.789	7,433	21,002	15,247	1.377	10,239
1978	07-Jul	2-GS	4,343	0.594	7,311	21,002	14,106	1.489	10,886
1978	03-Jul	3-GS	860	0.247	3,482	21,002	9,815	2.140	7,450
1979	08-Jul	1-FK	812	0.789	1,029	12,355	3,669	3.367	3,466
1980	07-Jul	2-RR	2,800	0.594	4,714	19,372	8,219	2.357	11,110
1981	02-Jul	3-CL	2,105	0.247	8,522	34,566	7,975	4.334	36,938
1982	15-Jul	1CL	2,044	0.789	2,591	44,099	39,609	1.113	2,884
1983	05-Jul	1-CL	8,020	0.789	10,165	56,907	31,905	1.784	18,130
1984	11-Jul	1-RR	56,210	0.789	71,242	54,043	47,847	1.129	80,468
1985	06-Jul	1-CL	13,645	0.789	17,294	9,013	2,563	3.517	60,816
1985	13-Jul	1-CL	13,253	0.789	16,797	9,013	4,966	1.815	30,486
1986	14-Jul	1-CL	5,975	0.789	7,573	24,705	18,130	1.363	10,319
1987	15-Jul	1-CL	9,605	0.789	12,174	16,134	14,288	1.129	13,746
1988	11-Jul	1-CL	4,660	0.789	5,906	13,302	11,038	1.205	7,118
1990	27-Jul	2-CL	4,350	0.594	7,323	13,957	13,957	1.000	7,323
1991	09-Jul	2-CL	7,085	0.594	11,928	19,800	9,008	2.198	26,217
1992	22-Jul	1-FB	2,595	0.789	3,289	12,077	11,506	1.050	3,452
1993	13-Jul	1-FB	1,302	0.247	5,271	15,823	11,888	1.331	7,016
1993	22-Jul	1-CL	8,740	0.789	11,077	15,823	15,241	1.038	11,500
1995	19-Jul	1-FB	16,518	0.789	20,935	42,703	41,372	1.032	21,609
1996	10-Jul	2-FB	10,790	0.594	18,165	28,493	25,660	1.110	20,170
1997	22-Jul	1-CL	3,105	0.789	3,935	20,118	19,478	1.033	4,065
1998	21-Jul	1-CL	10,180	0.789	12,902	24,248	23,931	1.013	13,073

Table 3. Estimates of the mean annual total chum salmon runs in the Tubutulik River of Norton Sound when multiple surveys occurred in a given year along with estimates of the coefficients of variation for those mean values.

Year	Tubutulik Survey Date	Survey Rating and Observer	Survey Count of Chum Salmon	Survey Visibility Expansion Factor	Estimated Total Count	Kwiniuk Annual Tower Count	Kwiniuk Tower Count On Date	Migratory Timing Expansion Factor	Tubutulik Total Chum Salmon Estimate
1975	20-Jul	2-PC	9,086	0.594	15,296	14,344	12,942	1.108	16,953
1975	31-Jul	1-PC	17,141	0.789	21,725	14,344	14,344	1.000	21,725
1975 Average									**19,339**
1975 Standard Error									**2,386**
1975 Coefficient of Variation									**12%**
1977	08-Jul	1-RR	7,470	0.789	9,468	22,757	12,200	1.865	17,660
1977	13-Jul	1-FK	8,540	0.789	10,824	22,757	19,853	1.146	12,407
1977 Average									**15,034**
1977 Standard Error									**2,627**
1977 Coefficient of Variation									**17%**
1978	08-Jul	1-RR	5,865	0.789	7,433	21,002	15,247	1.377	10,239
1978	07-Jul	2-GS	4,343	0.594	7,311	21,002	14,106	1.489	10,886
1978	03-Jul	3-GS	860	0.247	3,482	21,002	9,815	2.140	7,450
1978 Average									**9,525**
1978 Standard Error									**745**
1978 Coefficient of Variation									**8%**
1985	06-Jul	1-CL	13,645	0.789	17,294	9,013	2,563	3.517	60,816
1985	13-Jul	1-CL	13,253	0.789	16,797	9,013	4,966	1.815	30,486
1985 Average									**45,651**
1985 Standard Error									**15,165**
1985 Coefficient of Variation									**33%**
1993	13-Jul	1-FB	1,302	0.247	5,271	15,823	11,888	1.331	7,016
1993	22-Jul	1-CL	8,740	0.789	11,077	15,823	15,241	1.038	11,500
1993 Average									**9,258**
1993 Standard Error									**2,242**
1993Coefficient of Variation									**24%**
Average Coefficient of Variation									**19%**

Table 8 Estimated age composition of chum salmon (listed as percents) sampled from the Moses Point commercial fishery (CF), subsistence fishery (SF) and from the Kwiniuk River spawning escapement (SE).

Year	Sample Source	Sample Size	Age 3	Age 4	Age 5	Age 6	Sum
1965	SF	568	0.8	89.8	9.0	0.4	100.0
1966	CF	479	7.3	65.1	27.6	-	100.0
1967	SF	784	1.4	86.1	12.2	0.3	100.0
1968	CF	759	6.1	32.7	60.6	0.6	100.0
1969	CF	1,057	2.9	93.2	3.9		100.0
1970	CF	306	0.7	97.0	2.3	-	100.0
1971	CF	521	0.6	75.4	24.0	-	100.0
1972	CF	492	4.2	20.6	74.8	0.4	100.0
1973	CF	343	15.5	56.6	27.3	0.6	100.0
1974	CF	176	13.1	60.2	26.1	0.6	100.0
1975	CF	344	0.3	86.6	13.1	-	100.0
1976	CF	213	-	37.1	61.5	1.4	100.0
1977	CF	577	11.2	75.4	12.8	0.6	100.0
1978	CF	271	3.0	60.8	35.8	0.4	100.0
1979	CF	279	1.5	72.8	25.7	-	100.0
1980	CF	526	4.0	86.1	9.5	0.4	100.0
1981	CF	460	0.7	65.4	33.7	0.2	100.0
1982	CF	429	1.9	66.9	28.9	2.3	100.0
1983	CF	446	0.4	62.6	36.1	0.9	100.0
1984	AVG	None	2.6	61.1	35.1	1.2	100.0
1985	CF	451	0.5	67.5	31.0	1.0	100.0
1986	CF	222	7.7	49.1	42.8	0.4	100.0
1987	CF	200	0.5	45.0	52.0	2.5	100.0
1988	CF	82	1.0	68.0	29.0	2.0	100.0
1989	CF	19	-	21.1	73.7	5.2	100.0
1990	CF	131	1.0	65.0	31.0	3.0	100.0
1991	CF	46	-	41.0	59.0	-	100.0
1992	SE	19	-	32.0	68.0	-	100.0
1993	SE	68	-	38.0	59.0	3.0	100.0
1994	SE	83	-	65.0	33.0	2.0	100.0
1995	SE	341	-	56.0	40.0	4.0	100.0
1996	SE	57	-	46.0	49.0	5.0	100.0
1997	SE	466	-	53.0	46.0	1.0	100.0
1998	SE	217	0.5	77.8	21.2	0.5	100.0
1999	AVG	None	2.6	61.1	35.1	1.2	100.0
2000	AVG	None	2.6	61.1	35.1	1.2	100.0
Average		**346**	**2.6**	**61.1**	**35.1**	**1.2**	
Minimum		**19**	**0.0**	**20.6**	**2.3**	**0.0**	
Maximum		**1,057**	**15.5**	**97.0**	**74.8**	**5.2**	

Table 9. Estimated brood year spawning escapements of Kwiniuk River chum salmon and estimated recruits resulting from those escapements.

Brood Year	Estimated Escapement of Kwiniuk River Chum Salmon	Estimated Age-3 Recruits	Estimated Age-4 Recruits	Estimated Age-5 Recruits	Estimated Age-6 Recruits	Estimated Total Chum Salmon Recruits	Estimated Recruits per Spawner
1965	29,575	1,869	27,639	1,927	-	31,434	1.06
1966	31,381	860	81,256	15,247	183	97,546	3.11
1967	23,327	586	47,901	34,286	324	83,098	3.56
1968	19,134	381	9,442	14,754	399	24,977	1.31
1969	19,315	1,925	30,589	17,348	-	49,863	2.58
1970	67,438	8,377	40,014	4,494	207	53,091	0.79
1971	38,304	8,707	29,706	9,075	309	47,798	1.25
1972	29,996	103	5,475	6,601	208	12,386	0.41
1973	28,519	-	38,883	18,603	-	57,486	2.02
1974	35,325	5,776	31,594	10,706	116	48,192	1.36
1975	14,175	1,559	30,326	2,759	98	34,743	2.45
1976	6,462	625	25,007	16,579	1,904	44,115	6.83
1977	22,367	1,162	32,174	23,923	966	58,225	2.60
1978	20,592	344	55,379	38,737	703	95,163	4.62
1979	11,957	1,573	67,173	20,424	131	89,301	7.47
1980	18,908	429	35,489	4,061	159	40,137	2.12
1981	33,626	1,529	8,842	17,012	645	28,029	0.83
1982	42,920	65	19,517	13,426	517	33,525	0.78
1983	56,229	3,061	11,619	7,493	768	22,940	0.41
1984	53,365	129	17,570	10,881	505	29,085	0.55
1985	8,697	258	3,115	5,218	-	8,591	0.99
1986	24,046	-	10,940	12,111	-	23,051	0.96
1987	15,475	168	8,416	8,434	488	17,507	1.13
1988	12,643	-	3,969	9,601	674	14,244	1.13
1989	13,623	-	6,183	11,124	1,773	19,080	1.40
1990	13,298	-	21,911	17,726	1,443	41,080	3.09
1991	18,913	-	24,817	14,137	228	39,182	2.07
1992	11,657	-	13,272	10,489	130	23,891	2.05
1993	15,278	-	12,085	5,511	108	17,704	1.16
1994	31,678	-	20,226	3,133	156	23,515	0.74
1995	41,445	130	5,444	4,543	376	10,493	0.25
Avg	**26,118**	**1,278**	**25,031**	**12,592**	**436**	**39,338**	**1.97**
Min	**6,462**	**0**	**3,115**	**1,927**	**0**	**8,591**	**0.25**
Max	**67,438**	**8,707**	**81,256**	**38,737**	**1,904**	**97,546**	**7.47**

Table 10. Estimated brood year spawning escapements of Tubutulik River chum salmon and estimated recruits resulting from those escapements.

Brood Year	Estimated Escapement of Tubutulik River Chums	Estimated Age-3 Recruits	Estimated Age-4 Recruits	Estimated Age-5 Recruits	Estimated Age-6 Recruits	Estimated Total Chum Salmon Recruits	Estimated Recruits per Spawner
1965	23,068	1,418	47,772	2,480	-	51,670	2.24
1966	7,480	1,486	104,592	12,511	199	118,789	15.88
1967	17,638	755	39,305	37,244	77	77,381	4.39
1968	14,319	313	10,257	3,517	330	14,417	1.01
1969	33,701	2,091	7,293	14,347	-	23,731	0.70
1970	87,472	1,997	33,092	6,059	96	41,244	0.47
1971	31,296	7,201	40,051	4,232	204	51,689	1.65
1972	32,644	139	2,553	4,361	94	7,147	0.22
1973	6,723	-	25,687	8,437	-	34,124	5.08
1974	29,114	3,816	14,329	3,003	67	21,214	0.73
1975	19,170	707	8,507	1,582	105	10,901	0.57
1976	2,738	175	14,342	17,717	125	32,359	11.82
1977	14,644	666	34,382	1,565	308	36,921	2.52
1978	9,115	368	3,622	12,341	1,047	17,378	1.91
1979	3,067	103	21,401	30,411	663	52,578	17.14
1980	10,646	137	52,841	20,567	66	73,612	6.91
1981	35,998	2,276	44,784	7,106	550	54,716	1.52
1982	1,705	332	8,152	11,439	277	20,200	11.85
1983	17,452	1,278	9,899	4,009	549	15,736	0.90
1984	79,789	110	9,401	7,782	265	17,558	0.22
1985	45,335	138	2,228	2,738	-	5,104	0.11
1986	9,660	-	5,740	16,037	-	21,777	2.25
1987	13,087	88	11,144	2,411	286	13,929	1.06
1988	6,458	-	1,135	5,617	541	7,293	1.13
1989	9,555	-	3,618	8,921	897	13,436	1.41
1990	6,664	-	17,571	8,970	1,021	27,563	4.14
1991	25,331	-	12,558	10,008	46	22,612	0.89
1992	3,032	-	9,395	2,119	70	11,585	3.82
1993	8,713	-	2,442	2,971	67	5,480	0.63
1994	25,174	-	10,905	1,938	108	12,950	0.51
1995	20,351	70	3,367	3,133	233	6,803	0.33
Avg	**21,005**	**828**	**19,754**	**8,889**	**267**	**29,739**	**3.36**
Min	**1,705**	**0**	**1,135**	**1,565**	**0**	**5,104**	**0.11**
Max	**87,472**	**7,201**	**104,592**	**37,244**	**1,047**	**118,789**	**17.14**

Table 11. Residuals in the spawner-recruit relationship developed for the Kwiniuk River chum salmon population, brood years 1965-1995.

Brood Year	Estimated Kwiniuk Escapements	Estimated Total Recruits	Predicted Recruits per Spawner	Predicted Total Recruits	Residuals (Estimated minus Predicted)
1965	29,575	31,434	1.59	46,925	(15,491)
1966	31,381	97,546	1.49	46,878	50,669
1967	23,327	83,098	1.95	45,593	37,505
1968	19,134	24,977	2.25	43,015	(18,038)
1969	19,315	49,863	2.23	43,160	6,703
1970	67,438	53,091	0.45	30,240	22,851
1971	38,304	47,798	1.19	45,415	2,383
1972	29,996	12,386	1.56	46,929	(34,543)
1973	28,519	57,486	1.64	46,872	10,613
1974	35,325	48,192	1.31	46,261	1,931
1975	14,175	34,743	2.65	37,602	(2,859)
1976	6,462	44,115	3.43	22,174	21,941
1977	22,367	58,225	2.02	45,140	13,085
1978	20,592	95,163	2.14	44,094	51,069
1979	11,957	89,301	2.86	34,155	55,146
1980	18,908	40,137	2.27	42,828	(2,691)
1981	33,626	28,029	1.39	46,605	(18,577)
1982	42,920	33,525	1.02	43,623	(10,098)
1983	56,229	22,940	0.65	36,653	(13,713)
1984	53,365	29,085	0.72	38,275	(9,190)
1985	8,697	8,591	3.18	27,699	(19,108)
1986	24,046	23,051	1.91	45,884	(22,832)
1987	15,475	17,507	2.54	39,307	(21,800)
1988	12,643	14,244	2.79	35,297	(21,053)
1989	13,623	19,080	2.70	36,809	(17,729)
1990	13,298	41,080	2.73	36,323	4,757
1991	18,913	39,182	2.26	42,833	(3,651)
1992	11,657	23,891	2.89	33,633	(9,743)
1993	15,278	17,704	2.56	39,063	(21,359)
1994	31,678	23,515	1.48	46,855	(23,339)
1995	41,445	10,493	1.07	44,249	(33,756)

Table 12. Residuals in the spawner-recruit relationship developed for the Tubutulik River chum salmon population, brood years 1965-1995.

Brood Year	Estimated Tubutulik Escapements	Estimated Total Recruits	Predicted Recruits per Spawner	Predicted Total Recruits	Residuals (Estimated minus Predicted)
1965	23,068	51,670	2.34	54,093	(2,423)
1966	7,480	118,789	4.46	33,328	85,461
1967	17,638	77,381	2.93	51,724	25,657
1968	14,319	14,417	3.36	48,141	(33,724)
1969	33,701	23,731	1.51	51,004	(27,273)
1970	87,472	41,244	0.17	14,459	26,784
1971	31,296	51,689	1.67	52,295	(607)
1972	32,644	7,147	1.58	51,602	(44,456)
1973	6,723	34,124	4.60	30,905	3,219
1974	29,114	21,214	1.83	53,223	(32,009)
1975	19,170	10,901	2.75	52,780	(41,878)
1976	2,738	32,359	5.42	14,831	17,528
1977	14,644	36,921	3.32	48,579	(11,658)
1978	9,115	17,378	4.17	37,970	(20,592)
1979	3,067	52,578	5.34	16,390	36,188
1980	10,646	73,612	3.91	41,637	31,974
1981	35,998	54,716	1.38	49,563	5,154
1982	1,705	20,200	5.65	9,638	10,561
1983	17,452	15,736	2.96	51,572	(35,836)
1984	79,789	17,558	0.23	18,098	(540)
1985	45,335	5,104	0.94	42,493	(37,389)
1986	9,660	21,777	4.07	39,346	(17,569)
1987	13,087	13,929	3.54	46,289	(32,360)
1988	6,458	7,293	4.65	30,013	(22,721)
1989	9,555	13,436	4.09	39,087	(25,651)
1990	6,664	27,563	4.61	30,707	(3,145)
1991	25,331	22,612	2.14	54,114	(31,502)
1992	3,032	11,585	5.35	16,226	(4,642)
1993	8,713	5,480	4.24	36,901	(31,421)
1994	25,174	12,950	2.15	54,127	(41,177)
1995	20,351	6,803	2.62	53,371	(46,568)

Table 13. Residuals in the spawner-recruit relationship developed for the Kwiniuk River chum salmon population, brood years 1980-1995.

Brood Year	Estimated Kwiniuk Escapements	Estimated Total Recruits	Predicted Recruits per Spawner	Predicted Total Recruits	Residuals (Estimated minus Predicted)
1980	18,908	40,137	1.40	26,451	13,687
1981	33,626	28,029	0.87	29,349	(1,320)
1982	42,920	33,525	0.65	27,809	5,715
1983	56,229	22,940	0.42	23,781	(841)
1984	53,365	29,085	0.46	24,739	4,346
1985	8,697	8,591	1.94	16,878	(8,287)
1986	24,046	23,051	1.19	28,531	(5,479)
1987	15,475	17,507	1.56	24,166	(6,659)
1988	12,643	14,244	1.71	21,620	(7,376)
1989	13,623	19,080	1.66	22,575	(3,495)
1990	13,298	41,080	1.67	22,268	18,813
1991	18,913	39,182	1.40	26,454	12,728
1992	11,657	23,891	1.76	20,574	3,316
1993	15,278	17,704	1.57	24,010	(6,306)
1994	31,678	23,515	0.93	29,430	(5,914)
1995	41,445	10,493	0.68	28,154	(17,661)

Table 14. Residuals in the spawner-recruit relationship developed for the Tubutulik River chum salmon population, brood years 1983-1995.

Brood Year	Estimated Tubutulik Escapements	Estimated Total Recruits	Predicted Recruits per Spawner	Predicted Total Recruits	Residuals (Estimated minus Predicted)
1983	17,452	15,736	1.26	22,006	(6,270)
1984	79,789	17,558	0.12	9,748	7,810
1985	45,335	5,104	0.44	20,124	(15,020)
1986	9,660	21,777	1.69	16,308	5,469
1987	13,087	13,929	1.48	19,433	(5,504)
1988	6,458	7,293	1.90	12,291	(4,999)
1989	9,555	13,436	1.69	16,194	(2,758)
1990	6,664	27,563	1.89	12,585	14,977
1991	25,331	22,612	0.94	23,781	(1,169)
1992	3,032	11,585	2.16	6,561	5,024
1993	8,713	5,480	1.75	15,240	(9,760)
1994	25,174	12,950	0.94	23,773	(10,823)
1995	20,351	6,803	1.13	23,022	(16,219)

Table 15. Stock-recruitment relationship statistics for the Kwiniuk and Tubutulik River chum salmon populations.

Stock-Recruit Relationship Statistic	Kwiniuk River Chum Salmon Brood Years 1980-1995	Tubutulik River Chum Salmon Brood Years 1983-1995
Ricker Alpha	2.564541	2.423855
Ricker Beta	0.00003205	0.00003744
Adjusted R Square	0.56	0.52
Significance of Relationship	0.0005	0.0003
Number of Brood Years	16	13
MSY Escapement Level	**12,839**	**10,426**
Estimated Maximum Yield	8,979	6,677
Est. MSY Exploitation Rate	41%	39%

Table 16. Bootstrap estimates of the precision associated with maximum sustained yield escapement levels estimated for the Kwiniuk and Tubutulik chum salmon populations (n = 1,000 bootstraps for each of the data sets).

Statistic	Kwiniuk River Chum Salmon Brood Years 1980-1995	Tubutulik River Chum Salmon Brood Years 1983-1995
Mean	12,749	9,938
Standard Deviation	1,439	2,394
Coefficient of Variation	11.3%	24.1%
Lower 90% C. I.	10,643	6,128
Upper 90% C. I.	15,266	13,899
Indicated Bias	-90	-488
Indicated % Bias	-0.7%	-4.7%

Table 17. Years when annual Kwiniuk and Tubutulik 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
Kwiniuk	1985 & 1999	1980, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1997, & 2000	1981, 1982, 1983, 1984, 1986, 1994, 1995, 1996, & 1998
10,000 to 20,000 Total Spawners	2 of the 21 years since 1980 9%	**10 of the 21 years since 1980 48%**	9 of the 21 years since 1980 43%
	1 Year since 1990 9%	**6 Years since 1990 55%**	4 Years since 1990 36%
Tubutulik	1988, 1990, 1992, 1997, *1999*, & *2000*	1986, 1987, *1989*, 1993, & 1998	1983, 1984, 1985, 1991, *1994*, 1995, & 1996
	6 of the 18 years since 1983 33%	**5 of the 18 years since 1983 28%**	7 of the 18 years since 1983 39%
8,000 to 16,000 Total Spawners	5 Years since 1990 46%	**2 Years since 1990 18%**	4 Years since 1990 36%

Note: The Tubutulik chum salmon escapement estimates for the years 1989, 1994, 1999, and 2000 (listed above in italics) are not based upon expanded surveys wherein direct observations concerning the run strength is used as a basis for expansion. Instead, they were based upon a regression of run strength in the Kwiniuk and Tubutulik rivers when estimates were available for both streams in the same year. As a result, the associated accuracy of these four annual escapements is considered less than for the other 14 years of the data set (see Table 5). And, the probability of correctly assigning stock status categories to these four years is less than is the case for other 14 years in the data set.

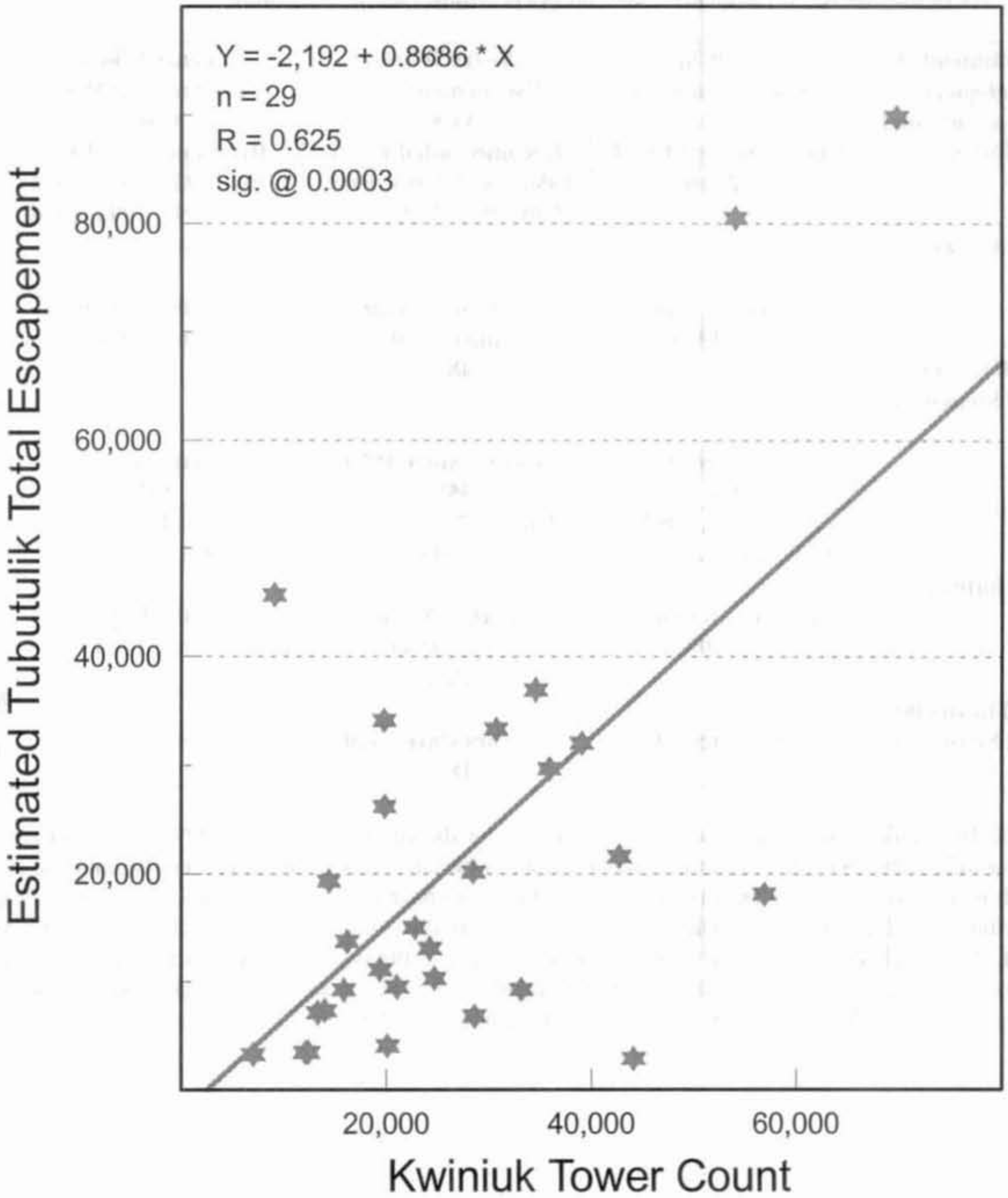


Figure 1. Relationship between Kwiniuk tower counts of chum salmon and total estimates of Tubutulik River chum salmon.

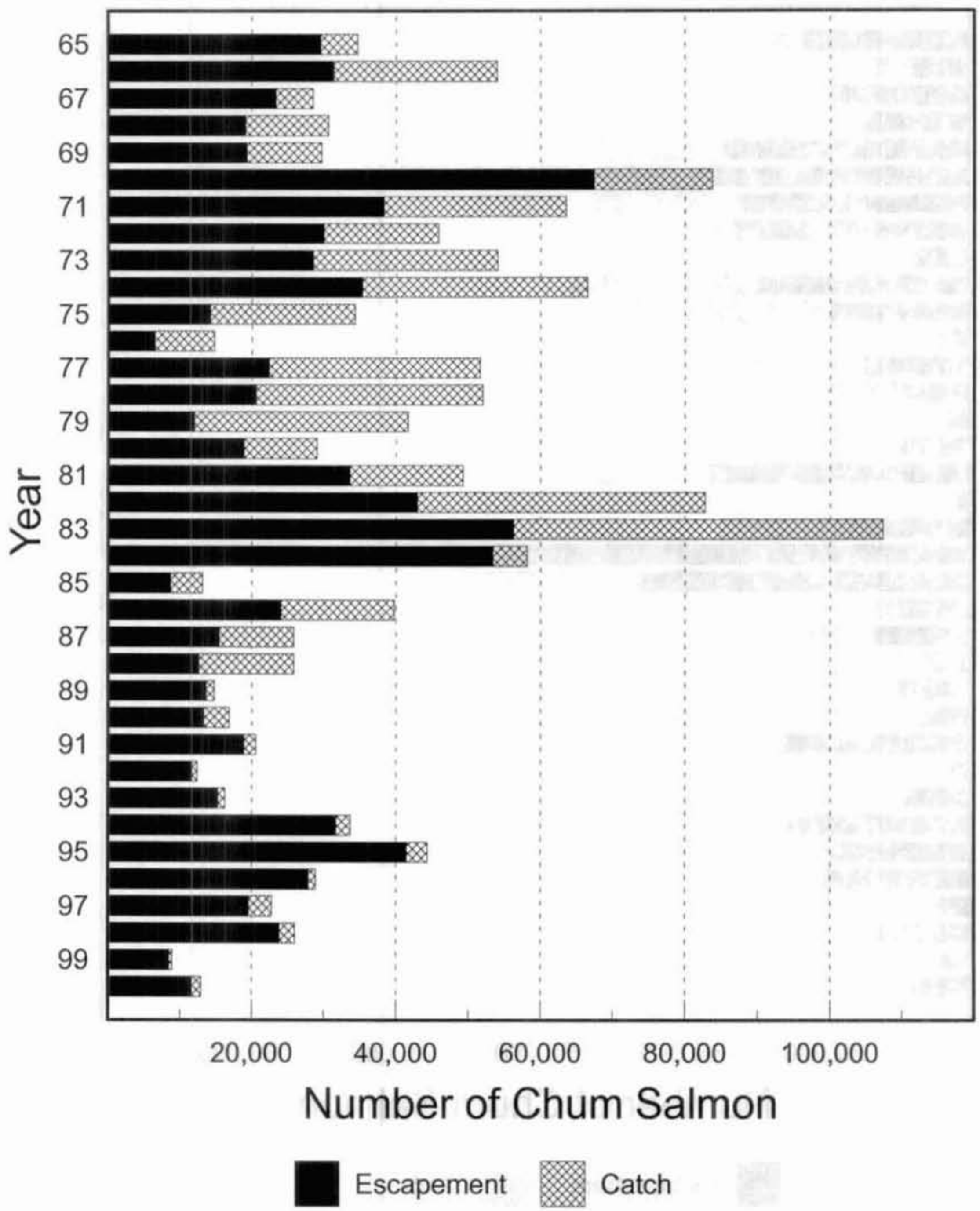


Figure 2. Estimated Kwiniuk River origin chum salmon total runs, 1965-2000.

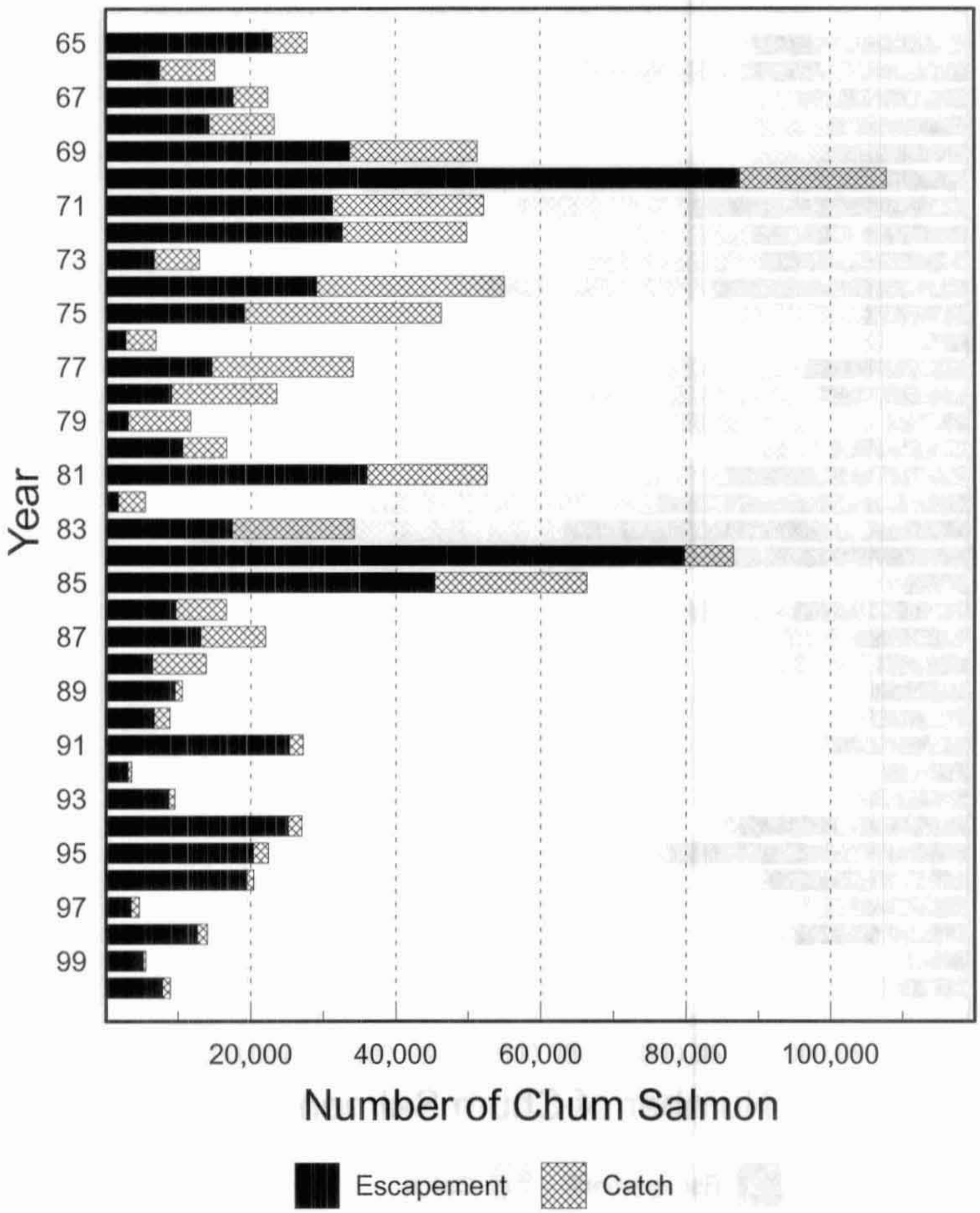
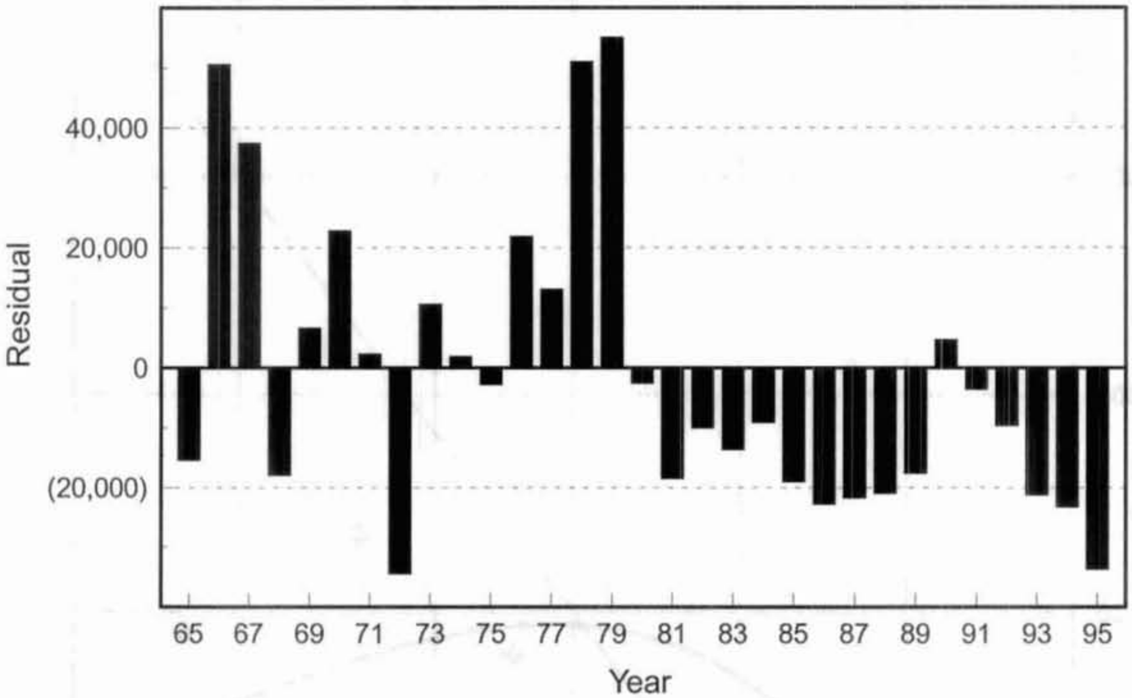


Figure 3. Estimated Tubutulik River origin chum salmon total runs, 1965-2000.



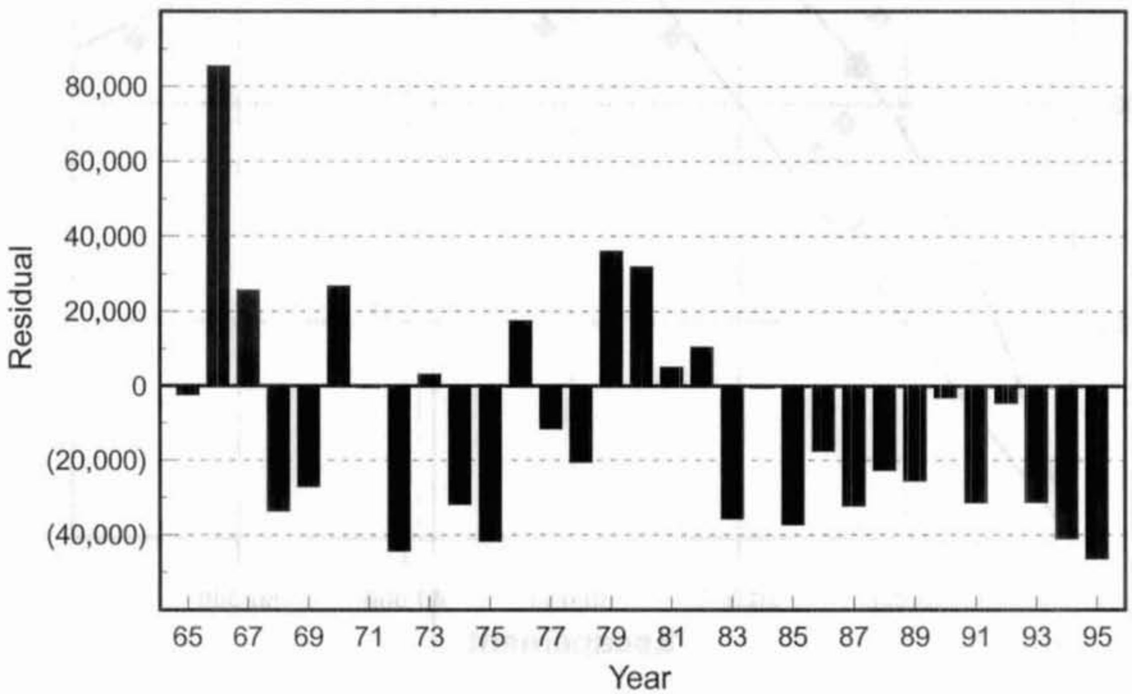


Figure 4. Residuals in the Kwiniuk stock-recruit relationship estimated for brood years 1965-1995 (upper panel) and residuals in the Tubutulik stock-recruit relationship estimated for brood years 1965-1995 (lower panel).

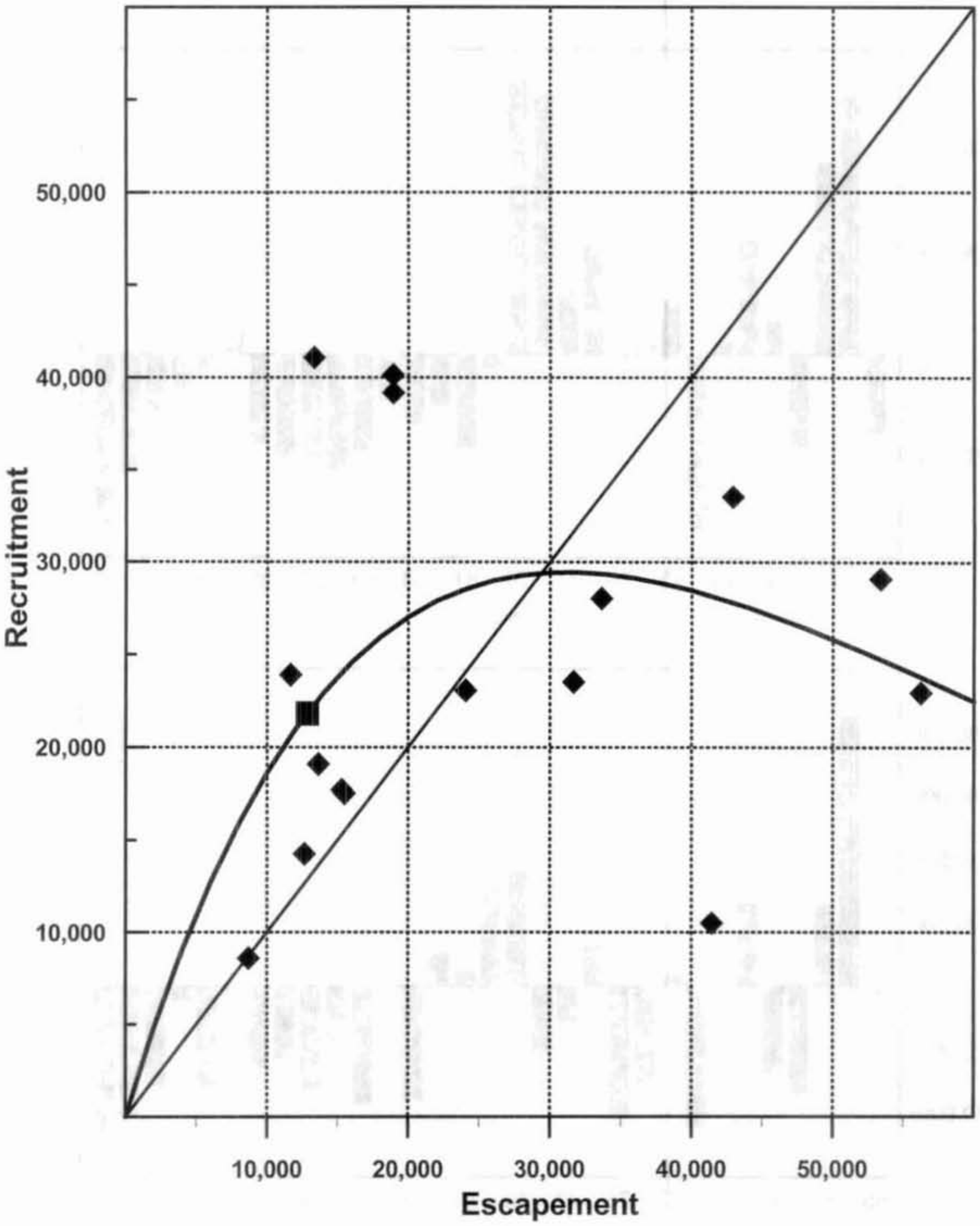


Figure 5. Stock-recruit relationship for Kwiniuk River chum salmon, brood years 1980-1995.

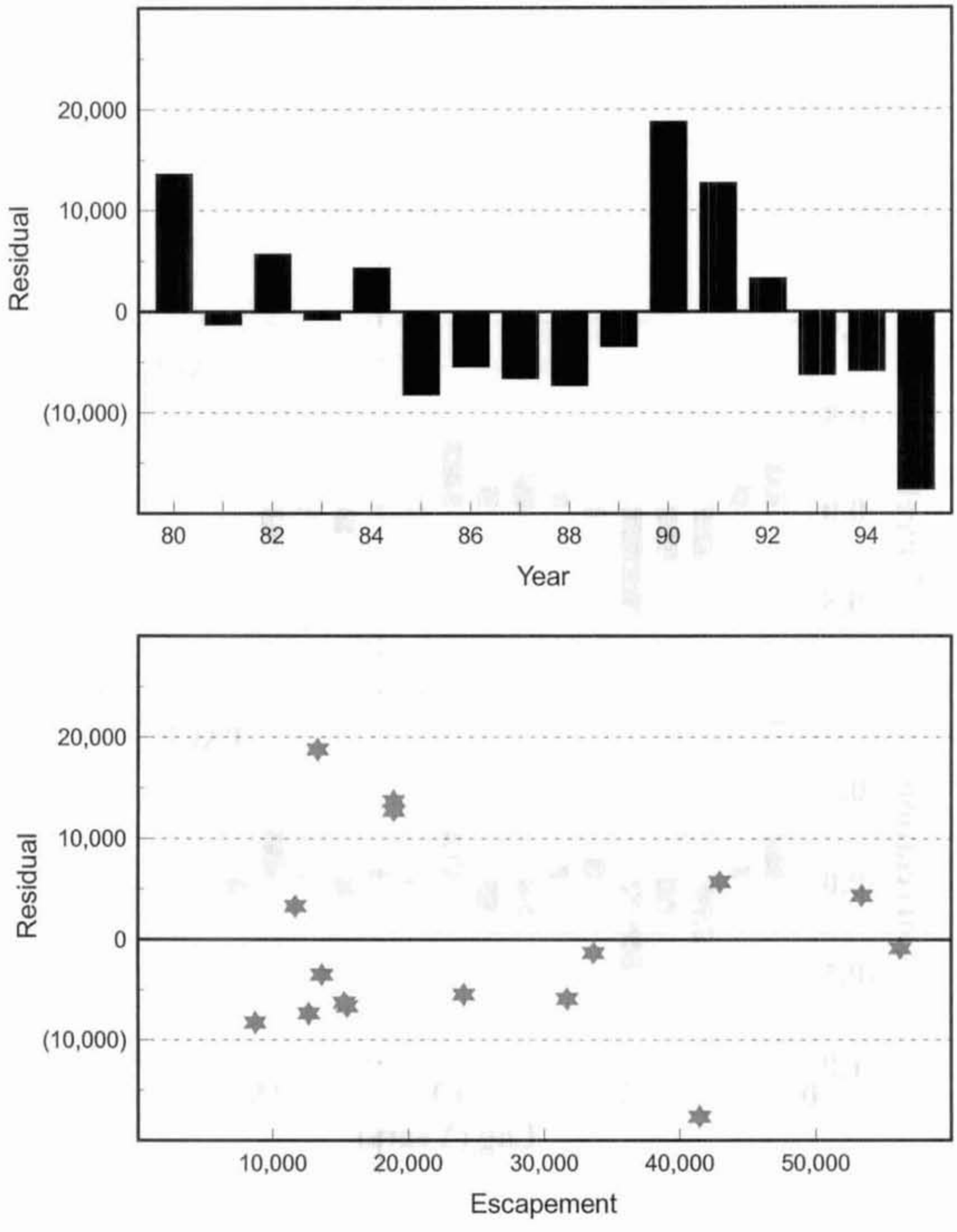


Figure 6. Residuals in the brood year 1980-1995 stock-recruit relationship developed for the Kwiniuk River stock of chum salmon. Residuals versus year in upper panel and residuals versus escapement in the lower panel.

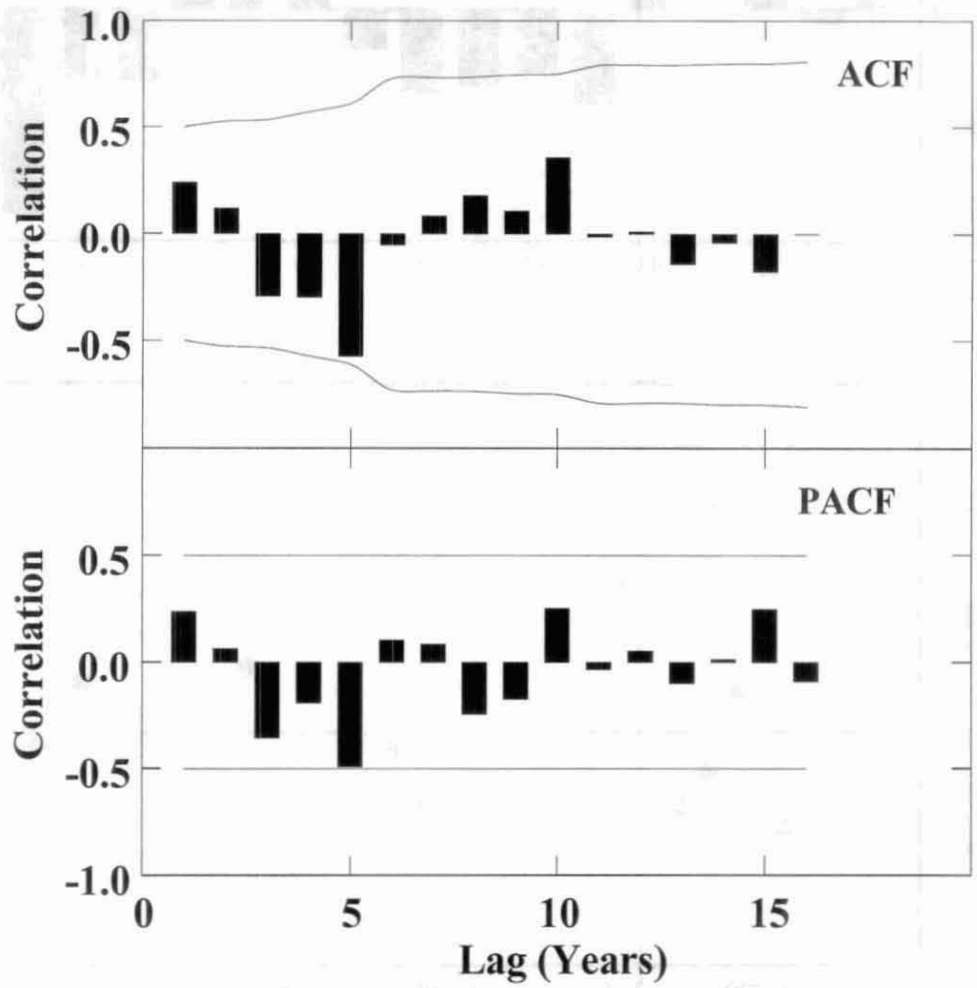


Figure 7. Auto-correlation functions (ACF) and partial auto-correlation functions (PACF) of residuals in the spawner-recruit relationship for Kwiniuk River chum salmon, brood years 1980-1995

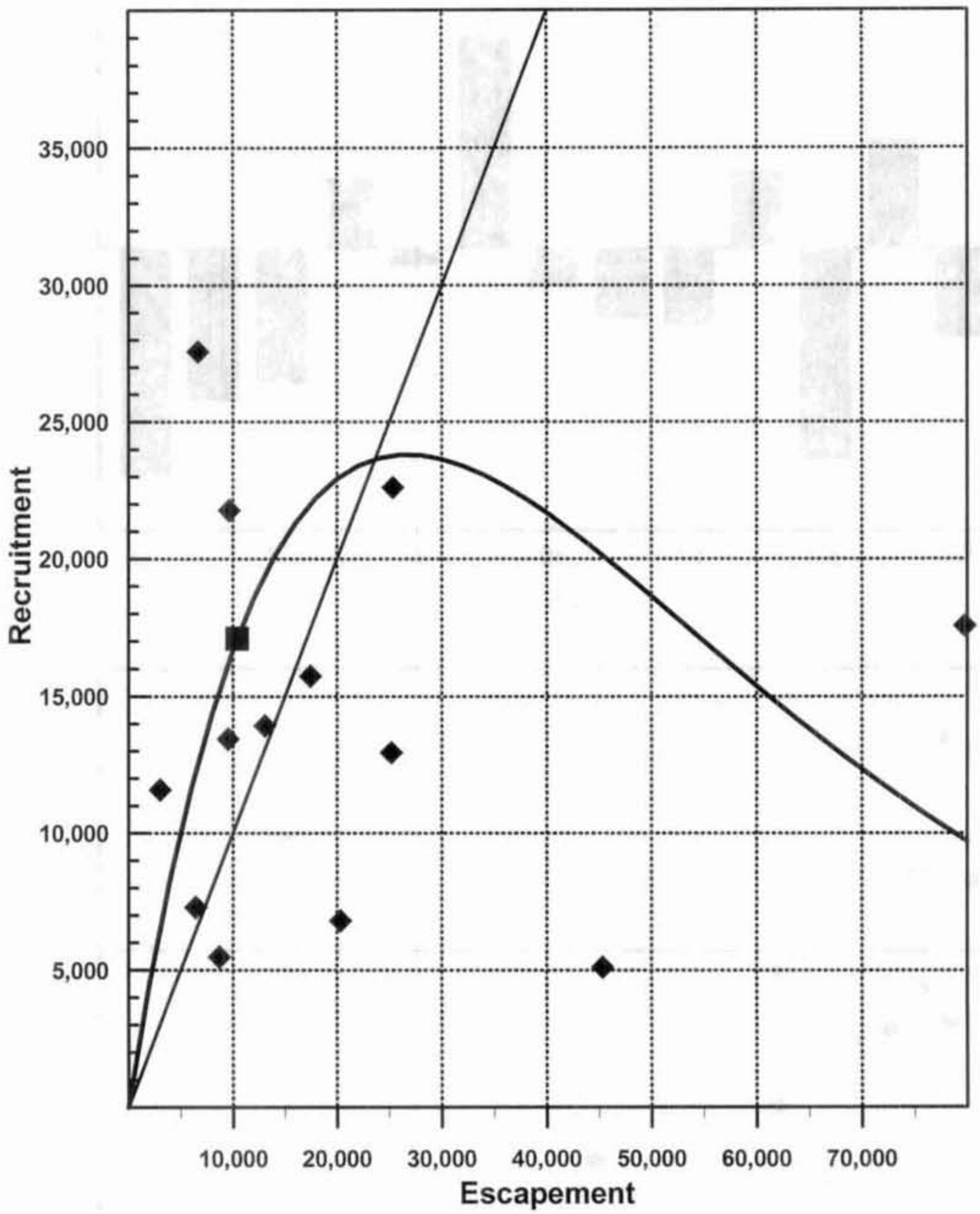


Figure 8. Stock-recruit relationship for Tubutulik River chum salmon, brood years 1983-1995.

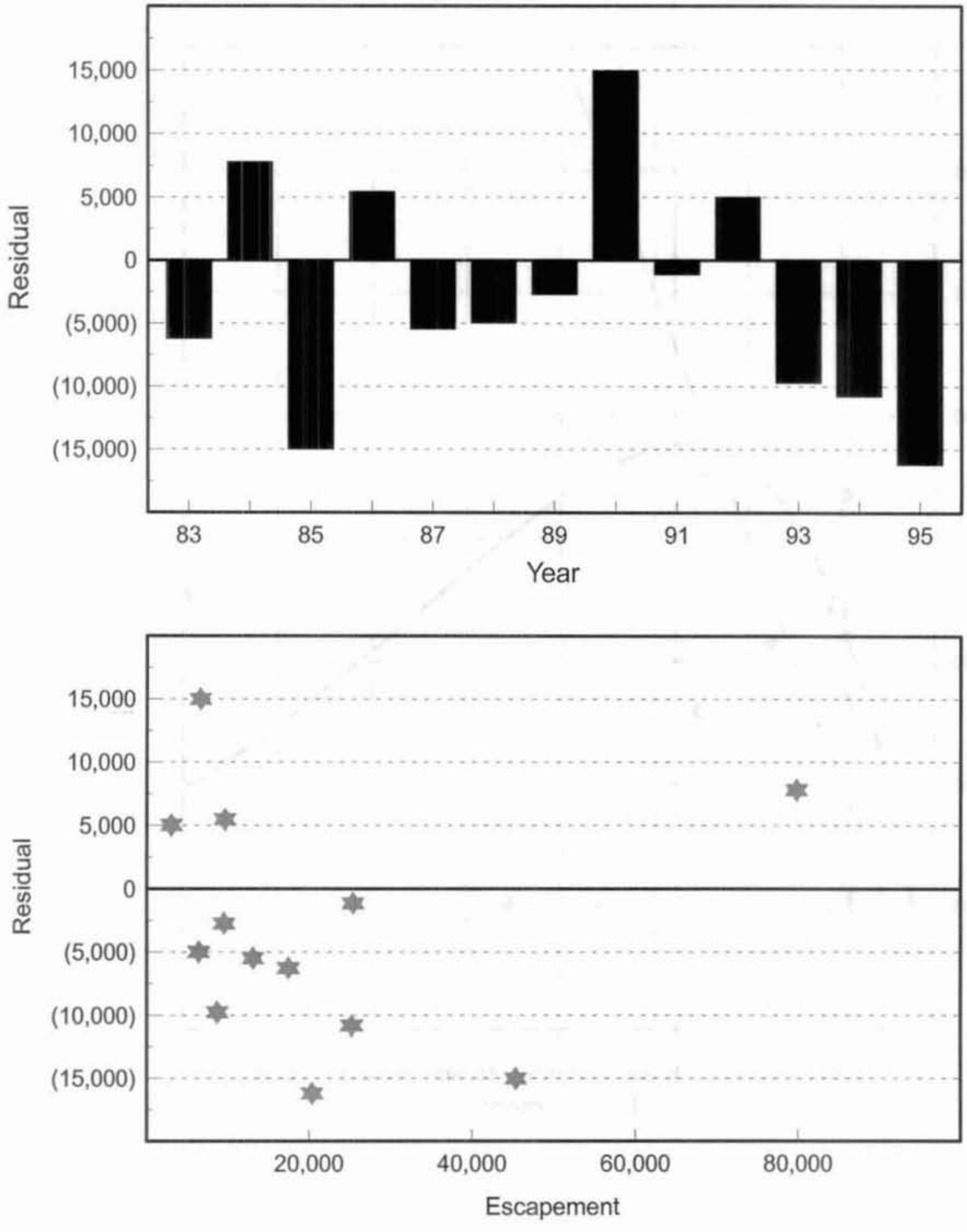


Figure 9. Residuals in the brood year 1983-1995 stock-recruit relationship developed for the Tubutulik River stock of chum salmon. Residuals versus year in upper panel and residuals versus escapement in the lower panel.

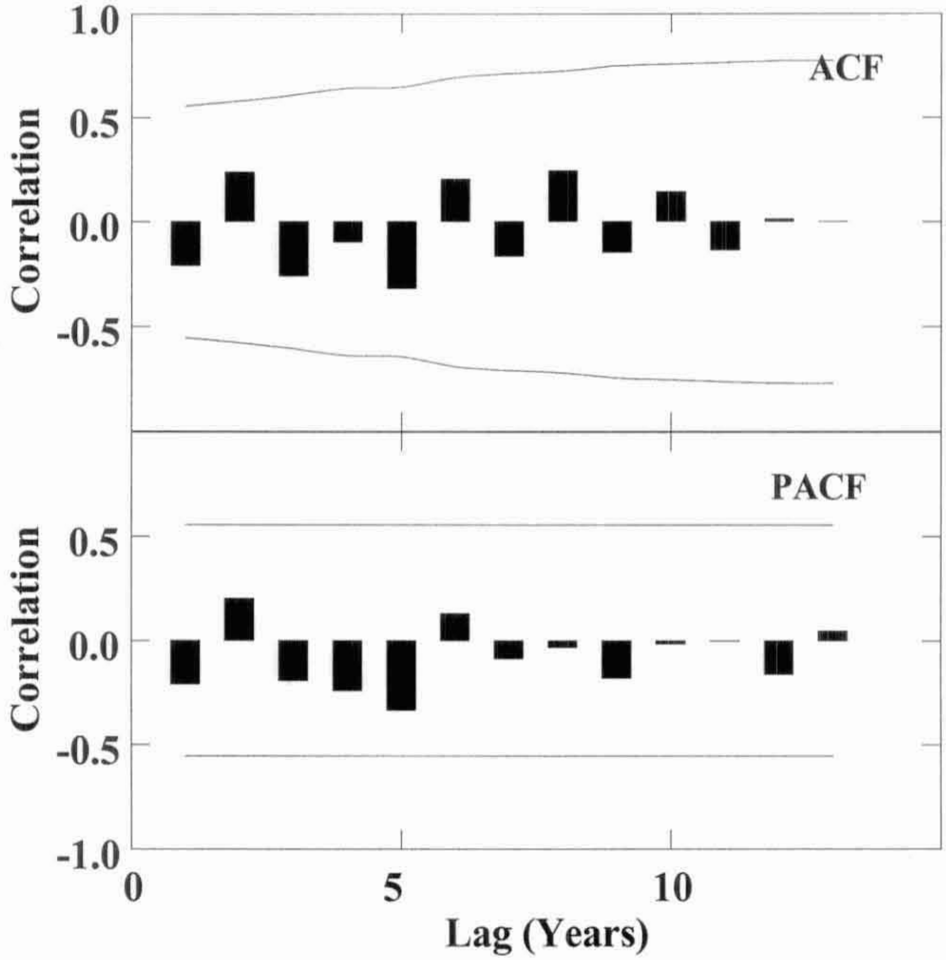


Figure 10. Auto-correlation functions (ACF) and partial auto-correlation functions (PACF) of residuals in the spawner-recruit relationship for Tubutulik River chum salmon, brood years 1983-1995