BIOLOGICAL ESCAPEMENT GOAL

FOR

KING SALMON RIVER CHINOOK SALMON

By

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and
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ABSTRACT

Available data consisting of escapements, age composition and harvests of chinook salmon *Oncorhynchus tshawytscha* returning to the King Salmon River, a small river system located on Admiralty Island in Southeast Alaska, during the years 1971-1997 was analyzed. Ten years of weir operations (1983-1992) provided the basis for estimating total escapement and age composition in other years. From 1971-1997, annual foot or aerial surveys were conducted to count peak numbers of large spawners (age-.3 and older) in the King Salmon River. We estimated large spawners from 1971-1982 and 1993-1997 by using the average fraction counted during 1983-1992 (67.5%) and the observed variation around that mean. We calculated the inriver return of large fish for each brood year from the estimated number of large spawners each year and age composition data. We estimated the number of jacks (age-1.2 fish) from 1971-1982 and 1993-1995 by using the average percent of jacks (22%) for the 1979-1986 broods (known from weir counts). Harvests were estimated from exploitation rates from Crystal Lake Hatchery, applied to the estimated inriver returns of wild chinook salmon estimated for King Salmon River. From these data, total returns were calculated for 21 brood years, 1971-1991. Spawner-recruit parameters were estimated for a Ricker model and precision of parameters was estimated using two separate bootstrap methods, one which utilized residuals of returns with fixed variation in spawners and another which utilized the estimated variance for both returns and spawners. A biological escapement goal range of 120 to 240 total escapement of large spawners (age-.3 and older) is indicated for the King Salmon River chinook salmon stock. We also recommend annual collection of age/sex/size data from this stock and continuation of the annual surveys to count large spawners.

A draft of this analysis was prepared in 1997 and underwent review by an inter-divisional Alaska Department of Fish and Game escapement goal review team. We had recommended that the Alaska Department of Fish and Game formally adopt a biological escapement goal range of 120 to 240 total escapement of large spawners for the King Salmon River and a survey range of 80 to 160 large spawners. Based on the inter-divisional review team's recommendation, the suggested biological escapement goal was formally adopted by the Alaska Department of Fish and Game. The same draft was reviewed by the Chinook Technical Committee of the Pacific Salmon Commission in 1997 and following that review, the recommended biological escapement goal was fully accepted as a Pacific Salmon Commission chinook salmon escapement goal. As a result, both the Alaska Department of Fish and Game and the Pacific Salmon Commission use 120 to 240 total escapement of large spawners or a survey range of 80 to 160 large spawners as the escapement goal for the King Salmon River stock of chinook salmon. Review comments and suggestions as well as additional improvements were incorporated into the 1997 draft to develop this final technical report.

KEY-WORDS: chinook salmon, *Oncorhynchus tshawytscha*, King Salmon River, brood table, spawner-recruit, escapement goal, bootstrap

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* are known to spawn in 34 streams in Southeast Alaska (SEAK), including rivers that originate in Canada (transboundary rivers) and flow into coastal waters of SEAK. In the mid-1970s, the Alaska Department of Fish and Game (ADF&G) became concerned with stock status of chinook salmon in SEAK. At that time is was apparent that some chinook salmon stocks in Southeast Alaska, particularly the Taku and Stikine River stocks, were depressed relative to historical numbers of fish (Kissner 1974).

In order to increase escapements, initial fishery management measures included closing fisheries in terminal and near-terminal areas during the spring migration period. By the early 1980s, fishery management measures included establishment of catch ceilings and implementation of a 15-year chinook salmon rebuilding program which was started in 1981 (ADF&G 1981). In the mid-1980s, the Alaskan chinook salmon rebuilding program was incorporated into a comprehensive coast-wide rebuilding program as part of the Pacific Salmon Treaty with the objective of increasing escapement levels of wild stocks of chinook salmon returning to Oregon, Washington, British Columbia, and SEAK. In order to quantitatively track the rebuilding of chinook salmon escapements in SEAK, a group of streams was selected to perform annual escapement surveys aimed at enumerating or indexing wild chinook salmon spawner abundance. One of the streams selected was the King Salmon River (Figure 1).

At the time the rebuilding program was initiated, stock status data for SEAK chinook salmon was very limited. However, it was believed that escapement goals for key rivers were needed to assess rebuilding. Therefore, faced with very limited data, a simple approach to definition and calculation of escapement goals was used. Specifically, ADF&G set escapement goals for most SEAK chinook salmon stocks at the highest levels documented in historic stock assessment data sets prior to 1981. In 1981, ADF&G set the escapement goal for the King Salmon River at 200 chinook salmon based upon the highest counts up to that time (aerial counts of 200 in 1957 and 211 in 1973). In the mid-1980s, the King Salmon River escapement goal for chinook salmon was increased to 250 fish (total escapement) because by then, a weir was used to enumerate escapement and the increase accounted for improved counting efficiency. This goal of 250 fish for the annual King Salmon River chinook salmon escapement refers to "large" chinook salmon, not to jacks, because: 1) only large fish can be accurately counted during aerial surveys which is the predominant stock assessment methodology in SEAK, and 2) large fish include almost all females in a given chinook salmon stock and are a more stable numeric representation of the parent spawning stock. The escapement goal for survey counts was calculated at approximately 160 large spawners at that time, assuming that about 65% of the total escapement was counted in a survey in a single day, either from helicopter or by foot.

This report is written to document stock assessment data available for the chinook salmon stock that spawns in the King Salmon River and to analyze these data and formulate a recommendation concerning an appropriate biological escapement goal range. Available inriver abundance and age composition data is coupled with estimates of marine exploitation of a nearby coded-wire-tagged hatchery stock, in order to develop an estimated brood table. These data are then analyzed to develop a spawner-recruit relationship. This estimated relationship is then analyzed to predict the range of escapements expected to provide for maximum sustained yield, forming a basis for a recommendation to ADF&G concerning revision of the biological escapement goal for the King Salmon River stock of chinook salmon. Note that total run refers to abundance in a calendar year and that total return refers to abundance returning in subsequent years from a particular brood year.

DESCRIPTION OF KING SALMON RIVER STOCK

The King Salmon River drains an area of about 100 square kilometers on Admiralty Island (Figure 1). The entire drainage is within the U.S. Forest Service Admiralty Island National Monument. The river flows into King Salmon Bay in the eastern portion of Seymour Canal approximately 25 kilometers southeast of Juneau, Alaska. Seymour Canal empties into Stephens Passage approximately 90 kilometers southeast of Juneau on the southern half of Admiralty Island. The King Salmon River is one of only two island stream systems in SEAK known to support spawning populations of chinook salmon, both of which are small populations. ADF&G included the King Salmon River as one the escapement indicator stocks in 1981 to monitor trends in small chinook salmon stocks. ADF&G operated a weir on the King Salmon River from 1983–1992 to enumerate chinook salmon and to facilitate collection of spawners for egg takes used to initiate hatchery populations of chinook salmon elsewhere in SEAK. Prior to and since 1983, annual aerial (helicopter) and/or foot counts of chinook salmon have been made to index spawner abundance, whereby the highest count in a single day from either survey type is the survey count for a given calendar year.

The King Salmon River run of chinook salmon is a "spring" run. Maturing adults enter the river primarily in July, beginning about 1 July (Kissner 1977), and are present as mature fish in near-terminal marine waters in May and June. Kissner noted that chinook salmon entering the King Salmon River are in a more advanced maturation condition, compared to other chinook salmon populations in SEAK. Peak spawning occurs in late July (approximately 22–24 July; Kissner 1977), making it one of the earlier spawning chinook salmon stocks in the Southeast Alaska region (Pahlke 1996). The duration of immigration into the river and subsequent spawning is relatively short (Josephson et al. 1993). Alevins emerge the following spring and almost all rear inriver for one year before leaving freshwater as yearling smolt (age 1.0 in European aging notation).

Age composition data shows that males return over several age and year classes and females are more confined, but not limited, to a single age class (Appendix A1). Annual runs of males average 22% age-1.2 (total age is 4 years), 42% age-1.3, and 34% age-1.4, with minor returns of age classes 2.3 and 1.5. Annual runs of females average 12% age-1.3 fish, 79% age-1.4 fish (total age is 6 years), and 7% age-1.5 fish, with minor contributions of age-1.2 and age-2.5 fish. Within each principal age class, males are predominate in age-1.2 fish (96%) and age-1.3 fish (80%), while females are predominate in age-1.4 fish (69%) and age-1.5 fish (86%). Age-1.1 fish have not been observed in spawning grounds escapements for this stock. Individual age classes are reported in European aging notation where the integer to the left of the decimal is the number of years spent as fry in freshwater, the integer to the right of the decimal is the number of years spent in marine water and total age is the sum of the two integers plus one. An age-1.3 fish in European aging notation is equivalent to an age-5_2 fish in Gilbert-Rich aging notation.

Returns of coded wire tags (CWTs) from this stock, released from hatcheries in the region, indicate that chinook salmon from the King Salmon River are found principally in U.S. waters of SEAK during most of their marine life history stage. Stocks in SEAK with this ocean distribution pattern are categorized as "inside-rearing" stocks (CTC 1996). Fish from this stock are harvested as both immature (feeder) chinook salmon as well as maturing adults in their final year prior to spawning.

METHODS

Estimation of Annual Spawning Populations

Chinook salmon spawning in the King Salmon River were enumerated by biologists walking the banks of the river in 1957, 1960, and 1961 with subsequent counts of 200, 20, and 117 fish, respectively. This population was not assessed between 1962 and 1970. The chinook salmon population in the King Salmon River has been surveyed annually each year since 1971, using standardized methods. The entire river is surveyed with multiple annual surveys by helicopter and one or more surveys made by foot (walking the stream bank). King Salmon River chinook salmon mature and return at various ages; fish that return after spending less than three years at sea (jacks at age-1.2 or four years total age) are smaller, different in coloration, and are difficult to see and discern from other species during these surveys, particularly from the air. Most of the early returning fish are males (jacks) and therefore contribute little to the annual egg deposition, but are certainly important in contributing genetic material to each generation. Staff making surveys count large chinook salmon, those that have spent three or more years at sea. Hereafter, the term large refers to chinook salmon that are 3-ocean (age-1.3 or 5 total years for King Salmon River) and older fish; the term jack refers to 2-ocean-age fish (age class 1.2).

As the chinook salmon hatchery program in SEAK developed during the late 1970s to the mid-1980s, the King Salmon River population of spawning chinook salmon was used to provide brood stock for ADF&G's Snettisham Hatchery. A weir was constructed across the lower portion of the King Salmon River and was operated annually by ADF&G staff from 1983 to 1992 to enumerate the chinook salmon spawning population and to collect brood stock for hatchery use (Josephson et al. 1993). ADF&G staff counted jack and large chinook salmon as they passed upstream above the weir, kept track of fish removed for brood stock, and made counts of chinook salmon below the weir at the time the weir was removed. Removal of brood stock was dependent upon abundance of spawners, a sliding scale that allowed increased proportions of fish to be removed as abundance increased. The 10 annual paired data points consisting of peak surveys and weir counts available from 1983–1992 provides a basis for expanding peak counts of chinook salmon in the King Salmon River into estimates of the total spawning population for the years when only peak survey data is available. The weir data also provides a basis for estimating annual returns of jacks that are not accurately enumerated during surveys. During the 10 years of operation, the King Salmon River weir was never breached due to high water; and due to the relatively low and clear water at this site, it is believed that weir counts included all passing fish.

During the years that the weir was operated (1983–1992), annual spawning escapements of large chinook salmon were estimated by subtracting the number of large fish used for brood stock from the weir count of large fish and then adding the count of large fish downstream (usually minor) at the time the weir was removed (Table 1). Estimates of annual spawning escapements of large chinook salmon in the King Salmon River during other years from 1971–1997 were estimated by dividing the annual peak survey by an average expansion factor of 0.675 (Table 1), as detailed below. This factor was the average proportion of the estimated total large chinook salmon escapement observed during annual peak surveys from 1983 to 1992 (Table 1). The number of fish below the weir were not included in the calculation because these fish were held unnaturally in this small non-spawning area as ADF&G staff were concluding annual egg takes. Inclusion of these fish would bias the expansion factor during the non-weir years. An exception to this methodology was used in 1992, when the weir was removed early. The expansion factor was calculated with inclusion of the fish count below the weir because the survey occurred after the weir was removed and these fish were able to freely migrate to spawning areas. A second slight exception to the general expansion factor methodology occurred in 1988, when six large chinook salmon died after upstream passage and were removed by ADF&G before the survey took place. They were included in the estimate of escapement of large chinook salmon but not in the calculation of the expansion factor for large chinook salmon.

Escapements of large chinook salmon from 1971–1982 and 1993–1997 were estimated by dividing the peak survey count by the average counted in the survey from 1983–1992 as:

$$\hat{S}_i = \frac{\hat{E}_i}{\overline{P}_L} \tag{1}$$

where $\hat{S}_i$ is the estimated total escapement of large fish in year i, $\hat{E}_i$ is the peak survey count in year i, and $\overline{P}_L$ is the average proportion of total large escapement counted from 1983–1992 (0.675).

Expansion factor methodology was used to estimate the variance of the number of large spawners in the King Salmon River in years for which survey counts were available, and weir counts were not. An expansion factor ($\hat{\pi}_t$) for large chinook salmon spawners in the King Salmon River in a calendar year is:

$$\hat{\pi}_i = \hat{S}_i / C_i \tag{2}$$

$$v(\hat{\pi}_i) = v(\hat{S}_i) / C_i^2 \tag{3}$$

where i is the year with a weir count of large spawners $\hat{N}_i$ and C_i is the peak survey count of large spawners.

The mean or long-term expansion factor (π) is:

$$\pi = \sum_{i=1}^{k} \hat{\pi}_i \;/\; k \tag{4}$$

$$v(\pi) = \sum_{i=1}^{k} (\hat{\pi}_i - \pi)^2 \;/\; (k-1) \tag{5}$$

where k is the number of years with weir counts (10 for the King Salmon River, from 1983–1992).

The estimator for expanding peak survey counts into estimates of spawning abundance is:

$$\hat{S}_t = \pi \; C_t \tag{6}$$

$$v(\hat{S}_t) = C_t^2 \; v(\pi). \tag{7}$$

Equation 7 was used to estimate the variance for the number of large spawners from 1971–1982 and 1993–1997.

Estimation of Age Composition of Annual Inriver Runs

Estimation of the numbers of fish by age class in each annual run involved several steps. First, the numbers of large fish by age was calculated by multiplying the estimated annual proportions for each large age class by the annual inriver run abundance of large fish for 1983–1992. Second the average proportions by large age class for 1983–1992 was used to estimate the numbers of large fish by age for 1971–1982 and 1993–1997. Third, inriver brood year returns were calculated for large fish. Fourth, the average proportion of jacks in 10 brood years (the 1979–1988 broods) was calculated from the weir counts of jacks in 1983-1990 and the above-mentioned 1979–1988 inriver returns of large fish. Fifth, the average jack proportion for the 1979–1988 broods was used to estimate jacks in the remaining years. Sixth, all jacks aged in the historical collection (69 aged jacks) were age-1.2 fish; thereby all jacks were assumed to be age-1.2 fish. These six steps resulted in estimates of numbers of fish by age class for 1971–1997, which formed the basis for calculation of inriver brood year returns.

Age Composition of Large Fish

Chinook salmon were sampled for age (scales), sex, and size during weir and egg take operations from 1983 to 1992. Because chinook salmon carcasses from egg/milt takes were sampled, sex determination had no error. Fish taken for brood stock were taken on a sliding-scale dependent on the magnitude of the escapement and males and females were selected systematically, and were not selected differentially for physical traits. Large fish and jacks, however, were sampled differentially. Of the fish sampled, between 14 and 94 total chinook (including jacks) and between 14 and 81 large chinook salmon returning to the King Salmon River were annually sampled and their age determined during the 11-year period of 1982–1992 (Table 2). A sampling trip in 1982 resulted in 24 large chinook salmon being aged; these fish were not selected systematically. All of the scales taken from chinook salmon from the King Salmon River were re-aged as part of this study, from the original acetate impressions.

The proportion of the inriver population composed of a given age (annually) within the large fish category for 1983–1992 was estimated as a binomial variable from the weir sample:

$$\hat{p}_{Lij} = \frac{n_{Lij}}{n_{Li}} \qquad (8)$$

where $\hat{p}_{Lij}$ is the estimated proportion of the population of large chinook salmon of age *j* in year *i*, n_{Lij} is the number of large chinook salmon of age *j* in year *i*, and n_{Li} is the number of large chinook salmon in the sample *n* in year *i* taken at the weir. Note $\sum_j \hat{p}_{Lij} = 1$.

Sample variance was calculated as:

$$v(\hat{p}_{Lij}) = \frac{\hat{p}_{Lij}(1-\hat{p}_{Lij})}{n_{Li}-1} * 1 - \frac{n_{Li}}{N_{Li}} \tag{9}$$

where N_{Li} is the number of large fish counted inriver. N_{Li} is slightly higher than S_i because of fish taken for brood stock.

The proportion of the inriver population composed of a given age (annually) within large fish for 1971–1982 and 1993–1997 was estimated from the average proportion by age within large fish for 1983–1992 ($\overline{p}_{Lj}$) and the variance as $v(\overline{p}_{Lj})$. Finite population correction was not used for 1971–1982 and 1993–1997. Note that N_{Li} was the same number as S_i in these years except 1979, 1981, and 1982, when brood stock was taken.

Numbers of large fish inriver by age were estimated as the summation of products of estimated age composition and estimated abundance of large fish:

$$\hat{N}_{Lij} = \hat{p}_{Lij}\hat{N}_{Li} \tag{10}$$

with a sample variance calculated according to procedures in Goodman (1960):

$$v(\hat{N}_{Lij}) = \sum_{i}\left(v(\hat{p}_{Lij})\hat{N}_{Li}^{\,2} + v(\hat{N}_{Li})\hat{p}_{Lij}^{2} - v(\hat{p}_{Lij})v(\hat{N}_{Li})\right) \tag{11}$$

Estimation of Jacks for 1971–1982 and 1993–1997

Jack chinook salmon passing the King Salmon River weir were directly enumerated from 1983–1992 (Table 3). The proportion of jacks in total inriver cohort returns of chinook salmon for brood years 1979–1986 ($\hat{N}_i$) was estimated by dividing the number of jacks returning from the brood year four years later by the summation of: (1) the number of jacks returning four years later, (2) the number of large age-5 fish returning five years later, (3) the number of large age-6 fish returning six years later, (4) the number of large age-7 fish returning seven years later, and (5) the number of large age-8 fish returning eight years later. These brood year returns were based almost entirely on weir counts and annual estimates of age distribution and were deemed the most accurate for estimating the number of jacks in other years. The estimated percent jack composition for inriver returns of chinook salmon to the King Salmon River for brood years 1979–1986 ranged from 12.1% jacks returning from brood year 1979 to 39.4% jacks returning from brood year 1986; the 10-year average was 22.2% ($\overline{P}_J$) and the SD ($\overline{P}_J$) was 7.9%.

The 10-year average value of 22.2% jacks in inriver total returns from brood years 1979–1986 was used to estimate jacks from 1971–1982 and 1993–1995, when jacks were not directly counted, as:

$$\hat{N}_{Ji} = \frac{\hat{N}_{Li}}{\left(1-\overline{P}_J\right)} - \hat{N}_{Li} \tag{12}$$

where $\hat{N}_{Ji}$ is the estimated inriver return of jacks in brood year i, $\hat{N}_{Li}$ is the estimated inriver return of large chinook salmon in brood year i, and $\overline{P}_J$ is the average proportion of jacks in brood years returns from 1979–1986, which was 0.222.

Estimation of Total Inriver Returns

Total inriver returns of chinook salmon to the King Salmon River for brood years 1971–1991 were estimated by:

$$\hat{N}_i = \hat{N}_{J(i+4)} + \sum_{i=5}^{i=8} \hat{N}_{Li} \tag{13}$$

Estimation of Marine Exploitation Rates and Total Recruitment

Wild chinook salmon returning to the King Salmon River have not been tagged or otherwise marked such that they can be distinguished from chinook salmon returning elsewhere when they are caught in mixed stock fisheries. Nor is there a directed fishery for this small stock of chinook salmon. Crystal Lake Hatchery (located nearby) releases coded-wire-tagged chinook salmon from Andrew Creek brood source. We believe that chinook salmon from Andrew Creek have a similar marine life history to those from the King Salmon River and this hatchery stock was used as an indicator stock to estimate marine exploitation of the King Salmon River stock. Estimated exploitation rates from Crystal Lake Hatchery were available for the 1979–1989 broods.

Landed catch and incidental fishing mortality were estimated with methodology used by the Pacific Salmon Commission, Chinook Technical Committee (CTC) in their exploitation rate analysis (CTC 1996, Chapter 3). The CTC exploitation rate analysis estimates total fishing mortality for a particular coded wire tag (CWT) indicator stock (Crystal Lake Hatchery in this case) by:

$$F\hat{M}_i = \sum_{j=1} \hat{C}_{ij}(AEQ_{ij}) + \sum_{j=1} I\hat{M}_{ij}(AEQ_{ij});\ and\ \hat{C}_i = \sum_{j=1} \hat{C}_{ij}(AEQ_{ij}); I\hat{M}_i = \sum_{j=1} I\hat{M}_{ij}(AEQ_{ij});$$
$$F\hat{M}_i = \hat{C}_i + I\hat{M}_i \tag{14}$$

where: $\hat{FM}_i$ = estimated total fishing mortality for brood i in adult equivalents (AEQs);

$\hat{C}_{ij}$ = estimated landed catch for brood i of age j;

$\hat{IM}_{ij}$ = estimated incidental mortality for brood i of age j; and

AEQ_{ij} = adult equivalent factor for brood i and age j.

Returns in landed catch and incidental fishing mortality were calculated in adult equivalents (AEQs) because a significant portion of both escapements and fishing mortality occurs at younger ages (total age 3 and 4) for inside-rearing SEAK chinook salmon stocks, including King Salmon River, Andrew Creek, and Behm Canal stocks (Pahlke 1995; McPherson and Carlile 1997). In short, AEQ factors discount the chinook salmon harvested at younger ages because of the additional natural mortality that would have occurred prior to the time these fish reached maturity. These values were estimated from the Crystal Lake Hatchery stock; AEQ factors averaged 0.56 for age-3 fish, 0.78 for age-4 fish, and 0.95 for age-5 fish (i.e., 100 age-3 fish caught were calculated as 56 fish in AEQs).

Landed catch is estimated directly from recoveries of CWTs from the stock of interest over several ocean ages (age .2 to age .6) in all fisheries. Incidental fishing mortality is calculated based on the assumption that a portion of chinook salmon caught and released die due to handling. Incidental fishing mortality in SEAK occurs from encounters of legal-size ($\geq$ 28 in total length) chinook salmon during periods of non-retention in sport and commercial fisheries as well as from the capture and release of fish in the sport fishery during periods when chinook salmon can be retained. Chinook salmon < 28 in (shakers) are all caught and released both during periods of retention and non-retention in sport and commercial fisheries. When the Crystal Lake Hatchery exploitation rates were run for this report (August 1997), the CTC analysis assumed that 30% of chinook salmon caught and released in commercial troll and sport fisheries die after release, and that 90% of chinook salmon caught and released in commercial net fisheries die after release. These assumptions likely overestimated incidental fishing mortality because the mortality rates we used are higher than those in the contemporary literature (Wertheimer et al. 1989; NRC 1994).

Because of changes in management of the SEAK fisheries since the late 1970s, the exploitation rate of chinook salmon for earlier brood years is best approximated by using the average landed catch rate for brood years 1979–1982 coupled with the incidental mortality rate estimated for brood year 1979; resulting in an estimated exploitation rate for pre-1979 brood years of 43.6%. This was done because the commercial troll fishery was open virtually year-round prior to 1982 and incidental mortality was low.

We then calculated the total fishing mortality rates for the Crystal Lake Hatchery stock by:

$$\hat{FMR}_{ih} = \frac{\hat{C}_{ih} + \hat{IM}_{ih}}{\hat{C}_{ih} + \hat{IM}_{ih} + \hat{E}_{ih}} \qquad (15)$$

where: $\hat{FMR}_{ih}$ = estimated total fishing mortality for brood i in adult equivalents;

$\hat{C}_{ih}$ = estimated landed catch for brood i for hatchery stock h;

$\hat{IM}_{ih}$ = estimated incidental mortality for brood i for hatchery stock h; and

$\hat{E}_{ih}$ = estimated return in escapement for brood i for hatchery stock h.

Total returns ($\hat{R}_i$) for the King Salmon River stock from a given brood were calculated by:

$$\hat{R}_i = \frac{\hat{N}_i}{\left(1 - FM\hat{R}_{ih}\right)} \quad (16)$$

Estimation of Spawner-Recruit Parameters

The Ricker stock recruitment curve (Ricker 1954) has been widely used in population dynamics. Many studies have fit the Ricker curve to spawner-recruit data and then calculated optimum escapement (Hilborn 1985). The Ricker (1975, Appendix III, Curve 1) spawner-recruit model is:

$$R_i = S_i \, \alpha \, e^{-\beta S_i} \quad (17)$$

where: R_i = total return of all ages for brood i; S_i = number of large spawners in year i; and, α and β = parameters to be estimated. A variation of this model (see below) was used to estimate spawning requirements and other population parameters.

Parameter α is an estimate of the number of returning adults, from a given spawning adult, in the absence of density dependence, and is a measure of the productivity rate of a stock. The parameter β is a measure of capacity and the inverse of β is the number of spawners that produces the theoretical average maximum return (S_{max}) for the stock of interest. When estimated, these two parameters are used to calculate expected total return from a given level of spawners.

Several other parameters of interest to fishery managers can be derived from α and β (see Appendix III, Curve No. 1 in Ricker 1975). Optimal escapement (S_{MSY}), is estimated by an iterative solution of,

$$1 = (1 - \beta S_{MSY}) \, \alpha \quad \exp(-\beta S_{MSY}) \quad (18)$$

This level of spawners (S_{MSY}) producing MSY is defined as the biological escapement goal (BEG) by ADF&G in the salmon escapement goal policy adopted in 1992 and revised in 1997.

Parameters were estimated in EXCEL SOLVER using a modification (natural log transformation) of equation (11),

$$\ln(\hat{R}_i) = \ln(\hat{\alpha}) + \ln(\hat{S}_i) - \hat{\beta}\hat{S}_i + \varepsilon_i \quad (19)$$

where; $\ln(\hat{R}_i)$ = the natural log of estimated total returns for brood i; $\ln(\hat{S}_i)$ = the natural log of estimated large spawners in brood year i and ε_i are residuals (natural log) used in the bootstrap section following.

The paired data set consisting of the estimated escapements of large spawners and the total returns produced from these escapements for brood years 1971–1991 (n = 21) was used to develop a spawner-recruit relationship by fitting the paired data set with the above model.

Once spawner-recruit relationships were calculated, a series of parameters were estimated including: (1) carrying capacity, or the point on the modeled spawner-recruit line where it intersects the replacement line; (2) the estimated escapement that produces the maximum recruits, or highest point on the curve (estimated maximum recruitment escapement); and, (3) the optimum escapement, or the point on the modeled spawner-recruit line where harvestable surplus is at a maximum (estimated MSY escapement).

Bootstrap Analysis of the Spawner Recruit Relationship

Both the variance (mean square error) and confidence intervals for $\hat{\alpha}, \hat{\beta}$, and $\hat{S}_{MSY}$ for the King Salmon River stock were estimated with modifications of bootstrap procedures in McPherson (1990). Error structure for Y (returns) was assumed to be multiplicative-lognormal and error structure of X (large spawners) was assumed to be multiplicative (Walters and Ludwig 1981). Parameters were estimated in EXCEL SOLVER using:

$$\ln(\hat{R}_i) = \ln(\hat{\alpha}) + \ln(\hat{S}_i) - \hat{\beta}\hat{S}_i + \varepsilon_i \qquad (20)$$

where; $\ln(\hat{R}_i)$ = the natural log of estimated total returns for brood i; $\ln(\hat{S}_i)$ = the natural log of estimated large spawners in brood year i;

$$\varepsilon_i = \frac{\ln(\hat{R}_i) - \ln(R^+)}{\sqrt{\left(1-\frac{z}{n}\right)}} \qquad (21)$$

and where: R^+ is the predicted return for a given stock, using the estimated α and β for that stock and data set; z is the number of parameters estimated (two); and, n is the number of brood years in the data set (21). The denominator for estimating ε is a correction factor for bias of residuals (Wu 1986).

For each bootstrap run, the original data set was fit using Equation 20 and bias corrected residuals (ε_i) were stored. For each replicate, the same number of X and Y observations in the original data set were calculated. Each Y observation in a replicate was calculated as $R_i^* = R_i^+ + \varepsilon$ (selected at random with replacement). Each X observation was calculated as $S_i^* = S_i\ p^*$, where p^* was a random number with a mean of 1.0 and a SD of 0.15. A new set of statistics $\{S_i^*, R_i^*\}$ along with new estimates for $\hat{S}^*_{MSY}, \hat{\alpha}^*$,and $\hat{\beta}^*$ were generated from each bootstrap sample, and 1,000 such bootstrap samples were drawn creating the empirical distributions $\hat{F}\left(\hat{S}^*_{MSY}\right)$, $\hat{F}(\hat{\alpha})$, and $\hat{F}\left(\hat{\beta}\right)$ which are estimates of $\mathrm{F}\left(S^*_{MSY}\right)$, $\mathrm{F}(\hat{\alpha})$, and $\mathrm{F}\left(\hat{\beta}\right)$. Confidence intervals were estimated from $\hat{F}\left(\hat{S}^*_{MSY}\right)$, $\hat{F}(\hat{\alpha})$, and $\hat{F}\left(\hat{\beta}\right)$ with the percentile method (Efron and Tibshirani 1993, Section 13.3). Variance was estimated as $v\left(\hat{S}^*_{MSY}\right) = (B-1)^{-1}\sum_{b=1}^{B}\left(\hat{S}^*_{MSY(b)} - \bar{\hat{S}}^*_{MSY}\right)^2$ where B is the number of bootstrap samples (1,000). The variance of $\hat{\alpha}^*$ and $\hat{\beta}^*$ was estimated similarly. Management ranges for $\hat{S}_{MSY}$ were estimated using the interval 0.8($\overline{\hat{S}}^*_{MSY}$), to 1.6($\overline{\hat{S}}^*_{MSY}$), based on recommendations in (Eggers 1993), where he estimated optimal harvests over a wide range of management scenarios and found this range to produce harvests within ± 10% of maximum, on average.

RESULTS

Annual Spawning Abundance

Estimated escapements of large spawners ($\hat{S}_i$) averaged 190 fish (1971–1997) and ranged from a low of 62 fish in 1975 to a high of 354 chinook salmon in 1982, representing a six-fold range in escapements (Table 1). Peak survey counts between 1983 and 1992 averaged 67.5% (SD = 11.0%; CV = 16%) of the total number of large spawners, when the weir was operated. The expansion factor, estimated from survey and weir counts from 1983–1992, was 1.52 (SE = 0.26; CV = 17%). During the 10 years of weir operations (1983–1992), escapements of large chinook salmon averaged 200 fish with a range from 99 in 1992 to 265 in 1984 (Table 3). Decade averages for large-fish escapements were 144 during the 1970s, 218 during the 1980s, and 207 during the 1990s (1990–1997). Coefficients of variation (CVs) for estimates of large spawners in years without the weir (1971–1982 and 1993–1997), averaged 18.0%, estimated from the bootstrap procedure for large spawners.

Estimated escapements of jack spawners (age-1.2 fish) averaged 54 fish for 1971–1991 and about the same (53 fish) from 1983 to 1992, when the weir was operated (Table 3). Jacks averaged an estimated 40 fish during the 1970s and 60 or more during the 1980s and 1990s.

Estimated total spawners averaged 234 fish from 1971 to 1995 and ranged from 108 in 1975 to 442 in 1982 (Table 3). Note that jack spawners were not included as spawners in the spawner-recruit analysis.

Age Composition and Inriver Runs

The estimated age composition of inriver runs of large chinook salmon averaged 32.5% (SE=21.3%) age-1.3 fish, 62.6% (SE=20.8%) age-1.4 fish, 3.9% (SE=5.0%) age-1.5 fish, with less than 1% contributions from age-2.3 and age-2.5 fish (Table 2). These were the average proportions ($\overline{p}_{Lj}$) used to estimate the age composition of large fish in years without the weir. On average, 17.3% of the inriver run from 1983 to 1992 was aged. From 1983 to 1992, age-1.4 fish were the most abundant age class inriver except in 1985 and 1992, when age-1.3 fish were most abundant (Table 2).

Estimated inriver runs (large fish and jacks = $\hat{N}_i$) showed the same trends as seen in the escapements mentioned above, with a low of 108 fish in 1975 and a high of 472 fish in 1982 (Table 4). Inriver runs averaged 287 fish from 1983–1992 and 256 for all years. Jacks (age-1.2 fish) averaged 19.8% of the inriver runs from 1983–1992, age-1.4 fish 49.6%, and age-1.3 fish 26.5% (Table 5). Estimated average age compositions for the period 1971–1995 were approximately the same for all age classes as those estimates for the 1983–1992 time period.

Total Returns By Brood Year

Inriver Brood Year Returns

The estimated total inriver brood year returns ($\hat{N}_i$) averaged 273 chinook salmon for the 1971–1991 broods, ranging from 89 fish for the 1986 brood to about 430 fish for the 1976 and 1980 broods (Table 6). Inriver returns were lowest for the early 1970s, similar to observed inriver trends for other SEAK chinook stocks which were enumerated at that time (Pahlke 1996). The return/large spawner rate averaged 1.9 for the 21 broods. The proportion of jacks in the 1979–1986 broods averaged 0.222 ($\overline{P}_J$), with an associated SE = 0.079.

The highest six inriver returns were estimated for the 1976, 1980, 1991, 1977, 1978, and 1982 broods, with estimated inriver returns ranging from 391 fish to 431 fish for those six broods (Table 6; Figure 2). Of these six inriver returns, five came from escapements between 84 and 199 large spawners, while the 1982 inriver return came from the largest escapement in the database (354 large spawners).

The estimated precision of large spawners ($\hat{S}_i$) in the 1971–1991 database averaged 11% CV (Table 7), which is comparatively low. Relative precision of estimates of escapements and inriver brood year returns is visually presented in Figure 3.

Total Returns

The estimated fishing mortality rates, calculated from the 1979–1989 Crystal Lake Hatchery brood data, averaged 51% total fishing mortality (Table 8). Estimated landed catch mortality from all gear types, averaged 35% for all broods and 41% for the 1979–1982 broods. Incidental mortality, which is probably overestimated, averaged 16%.

Estimated total returns ($\hat{R}_i$) averaged 545 for the 1971–1991 broods, ranging from 212 for the 1986 brood to 1,285 for the 1982 brood (Table 9). Estimated total return/large spawner rates averaged 3.6 and ranged from 0.8 for the 1973 and 1986 broods to 8.5 for the 1980 brood. Fishing mortality averaged 271 fish, or about 50% of total returns. The highest total returns were estimated for the 1982, 1980, 1985, 1976, 1991, 1977, and 1978 broods (Table 9; Figure 2), similar to estimates of inriver returns, except that the 1982 brood estimate was far above the rest.

Spawner-Recruit Parameters

The point estimate of optimal escapement ($\hat{S}_{MSY}$) was 137 large spawners from the original data set (Table 10). However, that estimate does not take into account measurement error. Although we attempted to estimate measurement errors associated with estimates of escapement and total returns, we were only partially successful with this endeavor. We were successful in estimating measurement errors associated with escapements and inriver returns (Figure 3). However, we had to use estimated exploitation rates for a nearby hatchery chinook salmon stock to expand inriver return estimates into total return estimates and there was no scientific approach that we could identify to estimate the level of additional measurement error introduced into the analysis due to this assumption.

Hilborn and Walters (1992:271-2) published the following empirical approximation of the estimated spawning size that produces maximum sustained yield or MSY as a function of estimated parameters:

$$\hat{S}_{MSY} \cong \frac{\ln\hat{\alpha} + \hat{\sigma}_{\varepsilon}^2/2}{\hat{\beta}}[0.5 - 0.07(\ln\hat{\alpha} + \hat{\sigma}_{\varepsilon}^2/2)] \qquad (22)$$

where: $\hat{\sigma}_{\varepsilon}^2$ = the mean square error from the regression. Use of the Hilborn and Walters (1992) formulation results in a point estimate of optimal escapement ($\hat{S}_{MSY}$) of 141 large spawners from the original data set.

The mean of the bootstrap method, using fixed spawner variation of 0.15 (i.e., uncertainty in estimates of spawners) and residuals ($R_i^* = R_i^+ + \varepsilon$) for returns, for ($\bar{\hat{S}}_{MSY}^*$) was 151 with a 95% confidence interval of 97 to 271 large spawners, using the percentile method. The estimate of α from the total return data was 7.8, with a bootstrap mean of 7.9 (Table 10). Use of the Hilborn and Walters (1992) approach provides an estimate of α from the total return data as 9.0, within the 95% confidence interval derived from bootstrapping. The estimate of β from the total return data was 0.0054, similar to the bootstrap mean (0.0052). We believe the bootstrap mean estimate of the escapement level of large spawners that produces MSY is likely the best estimate of that parameter (151 large spawners). Residuals associated with the relationship appear random (Figure 4). Tests for auto-correlation and partial auto-correlation demonstrated no significant relationships, indicating a lack of time series bias in the data (Figure 5). Using the methodology of Eggers (1993), the interval 0.8($\bar{\hat{S}}_{MSY}^*$), to 1.6($\bar{\hat{S}}_{MSY}^*$) was 121 to 242 large spawners for this estimate.

We also used the inriver return data to estimate optimal spawners for comparative purposes; the estimated $\hat{S}_{MSY}$ was 95 large spawners, which was less than the lower end of the 95% confidence interval for the bootstrap intervals from the total return data sets. This estimate was not used as a recommendation because no estimates of harvest are included.

In recommending a biological escapement goal range, we recommend using the bootstrap mean where $\bar{\hat{S}}_{MSY}^*$ = 150 because that method will account for time series changes, i.e., variation in survival over time. Therefore, from this analysis a biological escapement goal (BEG) range of 120 to 240 large spawners is recommended.

DISCUSSION

Since the mid-1980s, the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC) has used algorithms to analyze annual stock assessment escapement data and has compared trends in these data with existing escapement goals for various stocks to assess progress toward rebuilding. These analyses provide useful information on specific stocks as well as on a regional and/or coastal basis. The CTC in 1994 and again in 1996 used such information in the existing algorithm to conclude that the King Salmon River stock of chinook salmon was "not rebuilding" (CTC 1994, 1996). If the stock is "not rebuilding," or in other words, is presently below the stock status anticipated at the end of the rebuilding period, then some factor must be responsible for the failure of the stock to perform as expected. Two alternative explanations are readily available: (1) the escapement goal, or yardstick by which rebuilding is measured may be inappropriate; or, (2) harvest rates might be excessive, depressing the stock, and preventing it from reaching an appropriate level of spawning escapement.

An inherent assumption of the ADF&G chinook salmon rebuilding program, and later the PSC chinook salmon rebuilding program, was that chinook salmon stocks coast-wide were declining and/or depressed before rebuilding was implemented. However, as the CTC states (1994) "*not all chinook stocks were declining*" and further, as is becoming more and more obvious, not all chinook stocks were depressed. When the rebuilding program began there was very little information available for most chinook salmon stocks in SEAK, including the King Salmon River. ADF&G assumed the King Salmon River stock of chinook salmon and all other SEAK wild stocks of chinook salmon were depressed and consequently ADF&G adopted very conservative escapement goal policies. Most of the SEAK escapement goals were defined at the very upper limits of the available observations concerning prior escapement levels. Coupled with SEAK and international fishery restrictions, these very conservative escapement goal policies were thought to ensure greatly increased annual escapements in future years. However, this result would only occur if the specific stock was depressed and if the escapement goal defined was less than or equal to a reasonable approximation of the maximum sustainable yield escapement level.

Many ADF&G technical staff and PSC technical committee members have long recognized the escapement goals developed at the time of the implementation of the ADF&G and PST chinook salmon rebuilding programs were not necessarily good estimates or even estimates of the maximum sustainable yield escapement level (MSY escapement). Further, it has long been recognized by many technical staff associated with these rebuilding programs that scientific analysis of spawner-recruit relationships is required to develop estimates of MSY escapement for these chinook salmon stocks. For instance, in 1991, the escapement goal for the Situk River stock of chinook salmon was lowered to 600 large fish based upon a scientific analysis of the spawner-recruit relationship (McPherson 1991). The escapement goal for this stock of chinook salmon developed at the initiation of the ADF&G rebuilding program was 5,100 fish; thus the scientific analysis, when it was conducted, identified an appropriate MSY escapement goal that was about 12% of the initial goal set in 1981 by simplistic methodology. In 1997, ADF&G revised the biological escapement goal for the Situk River chinook salmon stock to a range from 500 to 1,000 large spawners in recognition of uncertainty associated with the point goal of 600, that an escapement goal range is more appropriate for fishery management, and that recruitment magnitude is similar over a range of escapements.

Similarly, index escapement goals established at the start of the rebuilding program for Behm Canal stocks of chinook salmon have also been lowered, based upon scientific analysis of spawner-recruit relationships (McPherson and Carlile 1997). Specifically, the Unuk River chinook salmon goal was decreased from 1,800 to 875 large index spawners, about 50% of the initial 1981 goal; the Chickamin River goal was decreased from 900 to 525 large index spawners, about 60% of the initial 1981 goal; the

Blossum River goal was decreased from 800 to 300 large index spawners, about 38% of the initial 1981 goal; and, the Keta River goal was decreased from 500 to 300 large index spawners, about 60% of the initial 1981 goal. In 1997, these point goals were changed to biological escapement goal ranges as follows: (1) Unuk River: 650–1,400 large index spawners; (2) Chickamin River: 450–900 large index spawners; (3) Blossum River: 250–500 large index spawners; and, (4) Keta River: 250–500 large index spawners. This most recent change was made due to inherent uncertainty in estimates of MSY escapement levels and in recognition that escapement goal ranges are more appropriate to fishery management than are point goals.

A technical report summarizing development and analysis of a spawner-recruit relationship for the Klukshu River stock of chinook salmon shows a similar pattern. The pre-1998 Klukshu River escapement goal for chinook salmon was 4,700 spawners. The new analysis indicates that the appropriate escapement goal range is 1,100 to 2,300 spawners; about 25% to 50% of the existing goal established by simplistic methodology (McPherson, Etherton, and Clark, 1998).

Thus, each of these six scientific analyses of the spawner-recruit relationships for SEAK chinook salmon stocks indicated that the escapement goals developed in the early 1980s, based on historic high counts, were set too high. This history leads credence to the hypothesis that the 1981 King Salmon River escapement goal for chinook salmon was likely too high and provides a potential explanation for the failure of this stock to reach the ADF&G and PSC chinook salmon rebuilding program expectations.

The 1971–1991 spawner-recruit database for the King Salmon River chinook salmon stock contains 21 estimates of escapement (large spawners). Nine of these are a total census from weir counts. During the ten years of weir operation, aerial and foot surveys were conducted in the same manner as surveys conducted from 1971–1982 and 1993–1997 (Pahlke 1996). It was found that, on average, 67.5% of large spawners are counted in the annual surveys, with a relatively low degree of variation in this percentage (range = 49 to 85%; Table 1). Because such a large fraction of total spawners is counted, the estimates of total large spawners from 1971–1982 and 1993–1997 were relatively precise as the CV averaged approximately 18% for those years (Table 3). The high fraction counted is undoubtedly a function of a short run duration inriver, a small system (< 15 km long) with clear water, and standardized surveys and surveyors. This is the highest fraction of total escapement counted during aerial/foot surveys for any chinook system in SEAK regularly and systematically enumerated with such techniques (Pahlke 1996).

Age composition and numbers of jacks were available directly for 10 years (1983–1992). An average of 17% of the large fish were successfully aged during those years (Table 2). Age composition of large fish was representative; we stratified the age composition estimates by sex and weir counts by sex (see Appendix A1), in an exploratory exercise, and estimates of optimal spawners ($\hat{S}_{MSY}$) was virtually the same, within 2%, of that using the unstratified estimates used in the body of this paper.

Estimating harvest for this population was likely the greatest source of measurement error in calculating spawner-recruit parameters for this stock because direct estimates for this wild stock were not available. The estimates we used from nearby Crystal Lake Hatchery, which used Andrew Creek brood stock, may or may not be reflective of King Salmon River exploitation rates. However, other hatchery releases of both stocks have shown them to both be "inside-rearing" stocks, which rear primarily in central and northern waters of SEAK. Additionally, exploitation rates from releases of southern SEAK inside-rearing stocks (Unuk and Chickamin Rivers), show similar trends in individual brood year exploitation rates and, to some extent, marine survival (McPherson and Carlile 1997). We may or may not have overestimated $\hat{S}_{MSY}$ (used higher value) in using the Crystal Lake exploitation rates for individual brood years. The exploitation rate for the 1982 brood was high (70%), which gave this point from the highest escapement a significant effect on the estimate of $\hat{S}_{MSY}$. Had we used an average exploitation rate of 52% for all brood years, the point estimate of $\bar{\hat{S}}^*_{MSY}$ would have been 126 versus 151, and the recommended range would have been 100 to 200 large spawners versus 120 to 240 large spawners. Similarly, the estimate of $\bar{\hat{S}}^*_{MSY}$ for inriver returns (with no exploitation) was much lower at about 100 large spawners.

There is not a clear evidence of time series bias in this database (see Figures 2–5). Relatively low production from the relatively low numbers of spawners for the 1971, 1972, 1974, and 1979 broods is balanced by the relatively high production from the 1976, 1978, 1980, and 1991 broods with similar escapement strengths. Additionally, the estimated total return for the 1982 brood was the highest in the database, but the next six largest returns (the 1976–1978, 1980, 1985, and 1991 broods) all came from escapements of less than 200 large spawners.

RECOMMENDATIONS

We believe that preserving long-term stock assessment and overall stock health should continue to be one of the highest priorities for ADF&G and the Pacific Salmon Commission. Stock assessment programs such as the King Salmon River program in place since the early 1970s provide information on the basic biology of the resource which is often poorly understood due to the lack of long-term programs coast-wide. These programs also provide a continuing time series of data which can be used to understand the causes of abundance fluctuations, allow for year-to-year comparisons, provide a basis for evaluating status of the resource, and help improve management. Based on these considerations and the above analysis we have the following recommendations for the King Salmon River chinook salmon stock at this time.

- Set the biological escapement goal as a range of 120 to 240 large spawners (total escapement) and/or a survey count of 80 to 160 large spawners.[2]
- Improve annual stock monitoring by collecting annual age composition data from spawners within the King Salmon River drainage with an annual targeted sample size of 50 aged fish.[3]
- Continue the annual helicopter and foot surveys to enumerate large chinook.[4]

[2] This recommendation was fully implemented in 1998. A draft report of this analysis was reviewed by an interdivisional ADF&G escapement goal review team and based on their support of this recommendation, ADF&G formally adopted the suggested biological escapement goal in 1998. Further, the Chinook Technical Committee of the Pacific Salmon Commission reviewed the draft report, supported the recommendation, and fully adopted the suggested escapement goal as an agreed-upon PSC chinook salmon escapement goal in 1998.

[3] This recommendation has been acted upon since 1998. Funding provided by the Pacific Salmon Commission as recommended by the Chinook Technical Committee has been allocated to ADF&G to sample the King Salmon River escapements in 1998-2002 to obtain statistically valid age and sex composition estimates.

[4] This recommendation has been acted upon each year with ADF&G funding and carrying out the successful implementation of surveys of the King Salmon River wherein escapements are indexed through the counting of large chinook.

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Table 1. Peak annual survey counts and weir counts of large chinook salmon (age-.3 and older) in the King Salmon River, estimated proportion of the total counted during peak surveys, fish taken for brood stock and estimated total escapement, 1971–1997.

Year	Peak Survey Count of Chinook Salmon	Weir Count of Large Fish	Foot Count of Chinook Below Weir	Number of Fish Removed for Egg Take	Weir Count Minus Chinook Removed for Egg Take	Estimated Proportion of Escapement Observed During Survey	Peak Survey Divided by Average Proportion (0.675)	Estimated Escapement (large fish)
1971	94						139	139
1972	90						133	133
1973	211						313	313
1974	104						154	154
1975	42						62	62
1976	65						96	96
1977	134						199	199
1978	57						84	84
1979	88			17			130	113
1980	70						104	104
1981	101			11			150	139
1982	259			30			384	354
1983	183	252	30	37	215	0.851	271	245
1984	184	298	13	46	252	0.730	273	265
1985	105	194	10	29	165	0.636	156	175
1986	190	264	17	26	238	0.798	282	255
1987	128	207	20	31	176	0.727	190	196
1988	94	231	12	35	196	0.495	139	208
1989	133	249	29	38	211	0.630	197	240
1990	98	200	8	29	171	0.573	145	179
1991	91	146	8	20	126	0.722	135	134
1992	58	47	70	18	29	0.586	86	99
1993	175						259	259
1994	140						207	207
1995	97						144	144
1996	192						284	284
1997	238						353	353
Avg.	127	209	22	28	178	67.5%	188	190

Notes: In 1992, the King Salmon Weir was terminated early; therefore, the annual escapement of large chinook salmon was estimated as the weir count minus the egg take plus the number of large chinook salmon observed below the weir (47-29+70 = 99); and, the expansion proportion was calculated as 59/99 = 0.586. In 1988, six large chinook salmon died of handling mortality; therefore the expansion proportion was calculated as the peak survey count divided by the calculation of the weir count minus the egg take minus the six dead fish (94/(231-35-6) = 0.495); and, the escapement was calculated as the weir count minus the egg take plus the foot count below the weir (231-35+12 = 208). In the other years between 1983–1992, the annual expansion proportions were calculated by dividing the peak surveys by the weir counts minus the chinook salmon egg takes; and, the annual escapements were estimated by adding the weir counts to the foot counts below the weir minus the egg takes. In all other years, the annual escapements of large chinook salmon were estimated by dividing the peak survey counts by the average expansion proportion (0.675; i.e., an expansion factor of 1.48 [SE=0.26]).

Table 2. Number of chinook salmon aged from annual inriver runs of chinook salmon and percentages by age class from the King Salmon River, 1982–1992.

Panel A. Number of Chinook Salmon Aged

Calendar Year	Jacks Age-1.2	Large Chinook Age-1.3	Large Chinook Age-2.3	Large Chinook Age-1.4	Large Chinook Age-1.5	Large Chinook Age-2.5	Total Aged	Total Large Fish Aged	Observed Inriver Run Large Fish	Percent of Large Fish Aged
1982	1	3	0	21	0	0	25	24		
1983	13	21	0	47	13	0	94	81	282	28.7%
1984	16	8	0	34	3	0	61	45	311	14.5%
1985	5	15	0	12	0	0	32	27	204	13.2%
1986	13	7	0	28	0	0	48	35	281	12.5%
1987	2	10	1	13	1	0	27	25	227	11.0%
1988	2	3	0	25	1	0	31	29	243	11.9%
1989	2	9	0	21	2	2	36	34	278	12.2%
1990	2	15	0	15	1	0	33	31	208	14.9%
1991	0	1	0	13	0	0	14	14	154	9.1%
1992	13	38	0	14	0	0	65	52	117	44.4%
Total 1983-1992	68	127	1	222	21	2	441	373	2,305	
Avg 1983-1992	7	13	0	22	2	0	44	37	231	17.3%

Panel B. Percent by Age for Large Chinook Salmon

Calendar Year	Age Class Age-1.3	Age Class Age-2.3	Age Class Age-1.4	Age Class Age-1.5	Age Class Age-2.5	Total
1982						
1983	25.9%	0.0%	58.0%	16.0%	0.0%	100.0%
1984	17.8%	0.0%	75.6%	6.7%	0.0%	100.0%
1985	55.6%	0.0%	44.4%	0.0%	0.0%	100.0%
1986	20.0%	0.0%	80.0%	0.0%	0.0%	100.0%
1987	40.0%	4.0%	52.0%	4.0%	0.0%	100.0%
1988	10.3%	0.0%	86.2%	3.4%	0.0%	100.0%
1989	26.5%	0.0%	61.8%	5.9%	5.9%	100.0%
1990	48.4%	0.0%	48.4%	3.2%	0.0%	100.0%
1991	7.1%	0.0%	92.9%	0.0%	0.0%	100.0%
1992	73.1%	0.0%	26.9%	0.0%	0.0%	100.0%
Avg 1983-92 [a]	**32.5%**	**0.4%**	**62.6%**	**3.9%**	**0.6%**	**100.0%**

[a] Average used for estimating age composition of large chinook salmon in 1971–1982 and 1993–1997.

Table 3. Estimated spawning escapements of large and jack chinook salmon in the King Salmon River, 1971–1997. Estimates in bold are from years of weir operations.

Calendar Year	Estimated Large Spawners	Estimated SE of Large Spawners	Estimated CV of Large Spawners	Estimated Jack Spawners	Estimated SE of Jack Spawners	Estimated CV of Jack Spawners	Estimated Lg + Jack (Total) Spawners	Estimated SE of Total Spawners	Estimated CV of Total Spawners
1971	139	24	17.4%	66	30	45.5%	205	39	18.8%
1972	133	23	17.4%	54	24	44.4%	187	33	17.8%
1973	313	54	17.4%	26	12	46.2%	339	56	16.4%
1974	154	27	17.4%	24	11	45.8%	178	29	16.3%
1975	62	11	17.4%	46	22	48.3%	108	25	22.8%
1976	96	17	17.4%	35	17	48.6%	132	24	18.2%
1977	199	34	17.4%	33	16	47.5%	231	38	16.4%
1978	84	15	17.4%	33	16	47.3%	118	21	18.2%
1979	113	23	20.0%	41	20	48.0%	154	30	19.4%
1980	104	18	17.4%	96	46	48.1%	200	49	24.8%
1981	139	26	18.8%	88	43	48.6%	227	50	22.1%
1982	354	67	18.8%	88	44	49.7%	442	80	18.1%
1983	**245**	**0**	**0.0%**	**20**	**0**	**0.0%**	**265**	**0**	**0.0%**
1984	**265**	**0**	**0.0%**	**67**	**0**	**0.0%**	**332**	**0**	**0.0%**
1985	**175**	**0**	**0.0%**	**43**	**0**	**0.0%**	**218**	**0**	**0.0%**
1986	**255**	**0**	**0.0%**	**64**	**0**	**0.0%**	**319**	**0**	**0.0%**
1987	**196**	**0**	**0.0%**	**59**	**0**	**0.0%**	**255**	**0**	**0.0%**
1988	**208**	**0**	**0.0%**	**52**	**0**	**0.0%**	**260**	**0**	**0.0%**
1989	**240**	**0**	**0.0%**	**70**	**0**	**0.0%**	**310**	**0**	**0.0%**
1990	**179**	**0**	**0.0%**	**34**	**0**	**0.0%**	**213**	**0**	**0.0%**
1991	**134**	**0**	**0.0%**	**90**	**0**	**0.0%**	**224**	**0**	**0.0%**
1992	**99**	**0**	**0.0%**	**28**	**0**	**0.0%**	**127**	**0**	**0.0%**
1993	259	45	17.4%	49	23	47.7%	308	51	16.5%
1994	207	36	17.4%	68	33	47.9%	276	49	17.7%
1995	144	25	17.4%	90	42	46.5%	234	49	20.8%
1996	284	49	17.4%	NE	NE		NE	NE	
1997	353	61	17.4%	NE	NE		NE	NE	
Averages									
1971-1997	190	21	11.1%						
1971-1991	180	16	10.2%	54	14	27.0%	234	23	10.9%
1971-1995	180	18	10.6%	55	16	28.4%	234	25	11.4%
1983-1992	**200**	**0**	**0.0%**	**53**	**0**	**0.0%**	**252**	**0**	**0.0%**
1971-1979	144	25	17.7%	40	19	46.8%	184	33	18.3%
1980-1989	218	11	5.5%	65	13	14.6%	283	18	6.5%
1990-1997	207	27	10.9%						
1990-1995	170	18	8.7%	60	16	23.7%	230	25	9.2%

Table 4. Estimated annual inriver runs of chinook salmon in the King Salmon River by calendar year and age class, 1971–1997. Estimated standard errors are in parentheses. Total run includes age-1.2 jacks.

	Total age and age class in European age notation							
Calendar	4-year	5-year	6-year	6-year	7-year	8-year		
Year	1.2	1.3	2.3	1.4	1.5	2.5	Large Total	Total Run
1971	66 (30)	45 (21)	1 (1)	87 (25)	5 (5)	1 (2)	139 (24)	205 (41)
1972	54 (24)	43 (20)	1 (1)	83 (24)	5 (4)	1 (2)	133 (23)	187 (35)
1973	26 (12)	101 (47)	1 (3)	196 (55)	12 (10)	2 (4)	313 (54)	339 (56)
1974	24 (11)	50 (23)	1 (1)	96 (27)	6 (5)	1 (2)	154 (27)	178 (31)
1975	46 (22)	20 (9)	0 (1)	39 (11)	2 (2)	0 (1)	62 (11)	108 (25)
1976	35 (17)	31 (14)	0 (1)	60 (17)	4 (3)	1 (1)	96 (17)	132 (24)
1977	33 (16)	64 (30)	1 (2)	124 (35)	8 (7)	1 (2)	199 (34)	231 (40)
1978	33 (16)	27 (13)	0 (1)	53 (15)	3 (3)	0 (1)	84 (15)	118 (22)
1979	41 (20)	42 (20)	1 (1)	82 (23)	5 (4)	1 (2)	130 (23)	171 (31)
1980	96 (46)	34 (16)	0 (1)	65 (18)	4 (3)	1 (1)	104 (18)	200 (50)
1981	88 (43)	49 (23)	1 (1)	94 (27)	6 (5)	1 (2)	150 (26)	238 (51)
1982	88 (44)	125 (54)	2 (3)	240 (82)	15 (12)	2 (5)	384 (67)	472 (86)
1983	20 (0)	73 (12)	0 (0)	164 (13)	45 (10)	0 (0)	282 (0)	302 (0)
1984	82 (0)	55 (17)	0 (0)	235 (19)	21 (11)	0 (0)	311 (0)	393 (0)
1985	47 (0)	113 (19)	0 (0)	91 (19)	0 (0)	0 (0)	204 (0)	251 (0)
1986	74 (0)	56 (18)	0 (0)	225 (18)	0 (0)	0 (0)	281 (0)	355 (0)
1987	62 (0)	91 (21)	9 (9)	118 (22)	9 (9)	0 (0)	227 (0)	289 (0)
1988	54 (0)	25 (13)	0 (0)	209 (15)	8 (8)	0 (0)	243 (0)	297 (0)
1989	72 (0)	74 (20)	0 (0)	172 (22)	16 (11)	16 (11)	278 (0)	350 (0)
1990	35 (0)	101 (18)	0 (0)	101 (18)	7 (6)	0 (0)	208 (0)	243 (0)
1991	90 (0)	11 (10)	0 (0)	143 (10)	0 (0)	0 (0)	154 (0)	244 (0)
1992	28 (0)	86 (5)	0 (0)	32 (5)	0 (0)	0 (0)	117 (0)	145 (0)
1993	49 (23)	84 (39)	1 (2)	162 (46)	10 (9)	2 (3)	259 (45)	308 (52)
1994	68 (33)	67 (31)	1 (2)	130 (37)	8 (7)	1 (3)	207 (36)	276 (51)
1995	90 (42)	47 (22)	1 (1)	90 (25)	6 (5)	1 (2)	144 (25)	234 (49)
1996		92 (41)	1 (2)	178 (40)	11 (10)	2 (4)	284 (49)	284 (52)
1997		114 (51)	1 (3)	221 (49)	14 (12)	2 (4)	353 (61)	353 (66)
Averages								
1983-1992	56	68	1	149	11	2	231	287
1971-1997	56	64	1	129	9	1	204	256

Table 5. Estimated percentage age composition of annual inriver runs of chinook salmon in the King Salmon River, 1971–1997.

Calendar	Age Class						
Year	1.2	1.3	2.3	1.4	1.5	2.5	Total
1971	32.2%	22.0%	0.3%	42.5%	2.7%	0.4%	100.0%
1972	28.8%	23.1%	0.3%	44.6%	2.8%	0.4%	100.0%
1973	7.7%	30.0%	0.4%	57.8%	3.6%	0.5%	100.0%
1974	13.5%	28.1%	0.3%	54.2%	3.4%	0.5%	100.0%
1975	42.4%	18.7%	0.2%	36.1%	2.3%	0.3%	100.0%
1976	26.8%	23.8%	0.3%	45.8%	2.9%	0.4%	100.0%
1977	14.1%	27.9%	0.3%	53.8%	3.4%	0.5%	100.0%
1978	28.1%	23.3%	0.3%	45.0%	2.8%	0.4%	100.0%
1979	23.9%	24.7%	0.3%	47.7%	3.0%	0.4%	100.0%
1980	48.0%	16.9%	0.2%	32.5%	2.0%	0.3%	100.0%
1981	37.1%	20.4%	0.3%	39.4%	2.5%	0.4%	100.0%
1982	18.6%	26.4%	0.3%	50.9%	3.2%	0.5%	100.0%
1983	6.7%	24.2%	0.0%	54.2%	15.0%	0.0%	100.0%
1984	20.9%	14.1%	0.0%	59.8%	5.3%	0.0%	100.0%
1985	18.7%	45.2%	0.0%	36.1%	0.0%	0.0%	100.0%
1986	20.8%	15.8%	0.0%	63.3%	0.0%	0.0%	100.0%
1987	21.5%	31.4%	3.1%	40.8%	3.1%	0.0%	100.0%
1988	18.2%	8.5%	0.0%	70.5%	2.8%	0.0%	100.0%
1989	20.6%	21.0%	0.0%	49.1%	4.7%	4.7%	100.0%
1990	14.4%	41.4%	0.0%	41.4%	2.8%	0.0%	100.0%
1991	36.9%	4.5%	0.0%	58.6%	0.0%	0.0%	100.0%
1992	19.6%	58.8%	0.0%	21.7%	0.0%	0.0%	100.0%
1993	15.9%	27.3%	0.3%	52.7%	3.3%	0.5%	100.0%
1994	24.8%	24.4%	0.3%	47.1%	3.0%	0.4%	100.0%
1995	38.5%	20.0%	0.2%	38.5%	2.4%	0.4%	100.0%
Statistics							
1983-1992 Avg	19.8%	26.5%	0.3%	49.6%	3.4%	0.5%	100.0%
1971-1995 Avg	23.9%	24.9%	0.3%	47.4%	3.1%	0.4%	100.0%

Table 6. Estimated inriver brood year returns of chinook salmon from the King Salmon River, for brood years 1971–1991. Estimates in bold are from years of weir operation.

Brood Year	Parent Year Large Escapement	Inriver Brood Year Returns Age and Year Class 4-Yr 1.2	5-Yr 1.3	6-Yr 2.3	6-Yr 1.4	7-Yr 1.5	8-Yr 2.5	Estimated Inriver Return of Large Fish	Total Estimated Inriver Return	Return/ Large Spawner	Brood Year Percent Jacks
1971	139	46	31	1	124	3	1	160	206	1.5	
1972	133	35	64	0	53	5	1	123	159	1.2	
1973	313	33	27	1	82	4	1	115	147	0.5	
1974	154	33	42	0	65	6	2	116	149	1.0	
1975	62	41	34	1	94	15	**0**	143	184	3.0	
1976	96	96	49	2	240	**45**	**0**	336	431	4.5	
1977	199	88	125	**0**	**164**	**21**	**0**	309	397	2.0	
1978	84	88	**73**	**0**	**235**	**0**	**0**	308	396	4.7	
1979	113	**20**	**55**	**0**	**91**	**0**	**0**	**146**	**166**	1.5	12.1%
1980	104	**82**	**113**	**0**	**225**	**9**	**0**	**347**	**429**	4.1	19.1%
1981	139	**47**	**56**	**9**	**118**	**8**	**16**	**208**	**255**	1.8	18.4%
1982	354	**74**	**91**	**0**	**209**	**16**	**0**	**317**	**391**	1.1	18.9%
1983	**245**	**62**	**25**	**0**	**172**	**7**	**0**	**204**	**266**	1.1	23.3%
1984	**265**	**54**	**74**	**0**	**101**	**0**	**0**	**174**	**228**	0.9	23.7%
1985	**175**	**72**	**101**	**0**	**143**	**0**	2	**245**	**317**	1.8	22.7%
1986	**255**	**35**	**11**	**0**	**32**	10	1	**54**	**89**	0.3	39.4%
1987	**196**	**90**	**86**	1	162	8	1	258	348	1.8	
1988	**208**	**28**	84	1	130	6	2	222	251	1.2	
1989	**240**	49	67	1	90	11	2	171	220	0.9	
1990	**179**	68	47	1	178	14		240	308	1.7	
1991	**134**	90	92	1	221			315	404	3.0	
1992	**99**		114								
Averages											
1979-1986	206	56	66	1	136	6	2		268	1.6	**22.2%**
1971-1991	180	59	64	1	139	9	1		273	1.9	

Table 7. Estimated standard errors of parent year escapements and inriver brood year returns of King Salmon River chinook salmon used in the spawner-recruit analysis for the 1971–1991 brood years. Estimates in bold are from years of weir operation.

Brood Year	SE Large Esc.	CV Large Esc.	Age and Year Class 4-Yr 1.2	5-Yr 1.3	6-Yr 2.3	6-Yr 1.4	7-Yr 1.5	8-Yr 2.5	SE Inriver Return	CV Inriver Return	Estimated Inriver Return
1971	28	19.9%	22	14	2	35	3	2	44	21.4%	206
1972	26	19.3%	17	30	1	15	4	1	38	23.8%	159
1973	55	17.6%	16	13	1	23	3	2	31	20.9%	147
1974	29	18.6%	16	20	1	18	5	5	32	21.4%	149
1975	13	20.1%	20	16	1	27	12	**0**	39	21.0%	184
1976	17	17.6%	46	23	3	82	**10**	**0**	98	22.6%	431
1977	37	18.5%	43	54	**0**	**13**	**11**	**0**	71	17.8%	397
1978	15	18.0%	44	**12**	**0**	**19**	**0**	**0**	49	12.4%	396
1979	24	21.0%	**0**	**17**	**0**	**19**	**0**	**0**	**25**	**15.0%**	**166**
1980	19	18.5%	**0**	**19**	**0**	**18**	**9**	**0**	**27**	**6.3%**	**429**
1981	27	19.8%	**0**	**18**	**9**	**22**	**8**	**11**	**32**	**12.7%**	**255**
1982	74	20.8%	**0**	**21**	**0**	**15**	11	**0**	**28**	**7.2%**	**391**
1983	**0**	**0.0%**	**0**	**13**	**0**	**22**	6	**0**	**26**	**9.9%**	**266**
1984	**0**	**0.0%**	**0**	**20**	**0**	**18**	**0**	**0**	**27**	**11.6%**	**228**
1985	**0**	**0.0%**	**0**	**18**	**0**	**10**	**0**	3	**21**	**6.5%**	**317**
1986	**0**	**0.0%**	**0**	**10**	**0**	**5**	9	3	**15**	**16.6%**	**89**
1987	**0**	**0.0%**	**0**	**5**	2	46	7	2	47	13.4%	348
1988	**0**	**0.0%**	**0**	39	2	37	5	4	54	21.6%	251
1989	**0**	**0.0%**	23	31	1	25	10	4	48	21.7%	220
1990	**0**	**0.0%**	33	22	2	40	12		57	18.6%	308
1991	**0**	**0.0%**	42	41	3	49			77	18.9%	404
Averages											
1979-1986	18	10.0%	0	17	1	16	5	2	25	10.7%	268
1971-1991	17	10.9%	15	22	1	27	6	2	42	16.3%	273

Table 8. Estimated marine fishery related mortality of coded-wire-tagged chinook salmon released from Crystal Lake Hatchery for brood years 1979–1989.

Brood Year	Number of Chinook Salmon Released	Estimated Exploitation Rates: Landed Catch	Incidental Mortality	Total Mortality	Marine Survival
1979	39,117	32.7%	2.3%	35.0%	7.8%
1980	56,660	45.0%	6.6%	51.6%	4.4%
1981	58,156	40.2%	12.5%	52.7%	4.6%
1982	93,465	47.4%	22.2%	69.6%	5.3%
1983	28,285	38.5%	18.1%	56.6%	2.5%
1984	41,825	36.6%	21.4%	58.0%	3.4%
1985	42,165	45.3%	16.0%	61.3%	1.7%
1986	31,107	42.1%	15.9%	58.0%	4.0%
1987	50,096	22.4%	18.8%	41.2%	2.7%
1988	44,765	20.5%	22.2%	42.7%	0.6%
1989	89,216	17.1%	15.4%	32.5%	1.2%
Avg 1979-1989	52,260	35.3%	15.6%	50.8%	3.5%
Avg 1979-1982	61,850	41.3%	10.9%	52.2%	5.5%

Note: Fishery related mortality for brood years 1971–1978 estimated as the average landed catch mortality for brood years 1979–1982 (41.3%) plus the incidental mortality estimated for brood year 1979 (2.3%) or a total estimated fishing related mortality of 43.6%.

Table 9. Estimated total brood year returns of chinook salmon from the King Salmon River, 1971–1991. Estimates in bold are from years of weir operation.

Brood Year	Large Esc.	Age and Year Class 4-Yr 1.2	5-Yr 1.3	6-Yr 2.3	6-Yr 1.4	7-Yr 1.5	8-Yr 2.5	Total Inriver Return	Inriver Return/ Large Spawner	Estimated Exploitation Rate	Estimated Total Return	Total Return/ Large Spawner	Estimated Total Fishing Mortality
1971	139	46	31	1	124	3	1	206	1.48	*0.436*	366	2.63	159
1972	133	35	64	0	53	5	1	159	1.19	*0.436*	281	2.11	123
1973	313	33	27	1	82	4	1	147	0.47	*0.436*	261	0.83	114
1974	154	33	42	0	65	6	2	149	0.97	*0.436*	264	1.71	115
1975	62	41	34	1	94	15	**0**	184	2.95	*0.436*	326	5.24	142
1976	96	96	49	2	240	**45**	**0**	431	4.48	*0.436*	765	7.94	334
1977	199	88	125	**0**	**164**	**21**	**0**	397	2.00	*0.436*	704	3.55	307
1978	84	88	**73**	**0**	**235**	**0**	**0**	396	4.69	*0.436*	702	8.32	306
1979	113	**20**	**55**	**0**	**91**	**0**	**0**	**166**	**1.46**	0.350	256	2.25	89
1980	104	**82**	**113**	**0**	**225**	**9**	**0**	**429**	**4.14**	0.515	885	8.53	456
1981	139	**47**	**56**	**9**	**118**	**8**	**16**	**255**	**1.84**	0.527	539	3.89	284
1982	354	**74**	**91**	**0**	**209**	**16**	**0**	**391**	**1.10**	0.696	1,285	3.63	894
1983	**245**	**62**	**25**	**0**	**172**	**7**	**0**	**266**	**1.08**	0.566	612	2.50	346
1984	**265**	**54**	**74**	**0**	**101**	**0**	**0**	**228**	**0.86**	0.580	543	2.05	315
1985	**175**	**72**	**101**	**0**	**143**	**0**	2	**317**	**1.81**	0.613	820	4.68	502
1986	**255**	**35**	**11**	**0**	**32**	10	1	**89**	**0.35**	0.580	212	0.83	123
1987	**196**	**90**	**86**	1	162	8	1	348	1.77	0.413	593	3.02	245
1988	**208**	**28**	84	1	130	6	2	251	1.21	0.427	437	2.10	187
1989	**240**	49	67	1	90	11	2	220	0.92	0.326	326	1.36	106
1990	**179**	68	47	1	178	14		308	1.72	*0.436*	546	3.05	238
1991	**134**	90	92	1	221			404	3.02	*0.436*	717	5.35	313
1992	**99**		114										
Averages													
1979-1986	206	56	66	1	136	6	2	268	1.6	0.553	644	3.5	376
1971-1991	180	59	64	1	139	9	1	273	1.9	0.474	545	3.6	271

Table 10. Estimated spawner-recruit parameters for the King Salmon River chinook salmon stock.

Parameter	Original Point Estimate	Bootstrap Estimates				
					95% Confidence Interval	
		Mean	SD	Median	Lower	Upper
α	7.8	7.9	2.7	7.4	4.1	14.7
β	0.0054	0.0052	0.0016	0.0052	0.0022	0.0084
S_{MSY}	137	151	57	138	97	271

Note: Use of Walters and Hilborn (1992) formulation results in an estimate of S_{MSY} of 141 large spawners and the associated α estimate is 9.0.

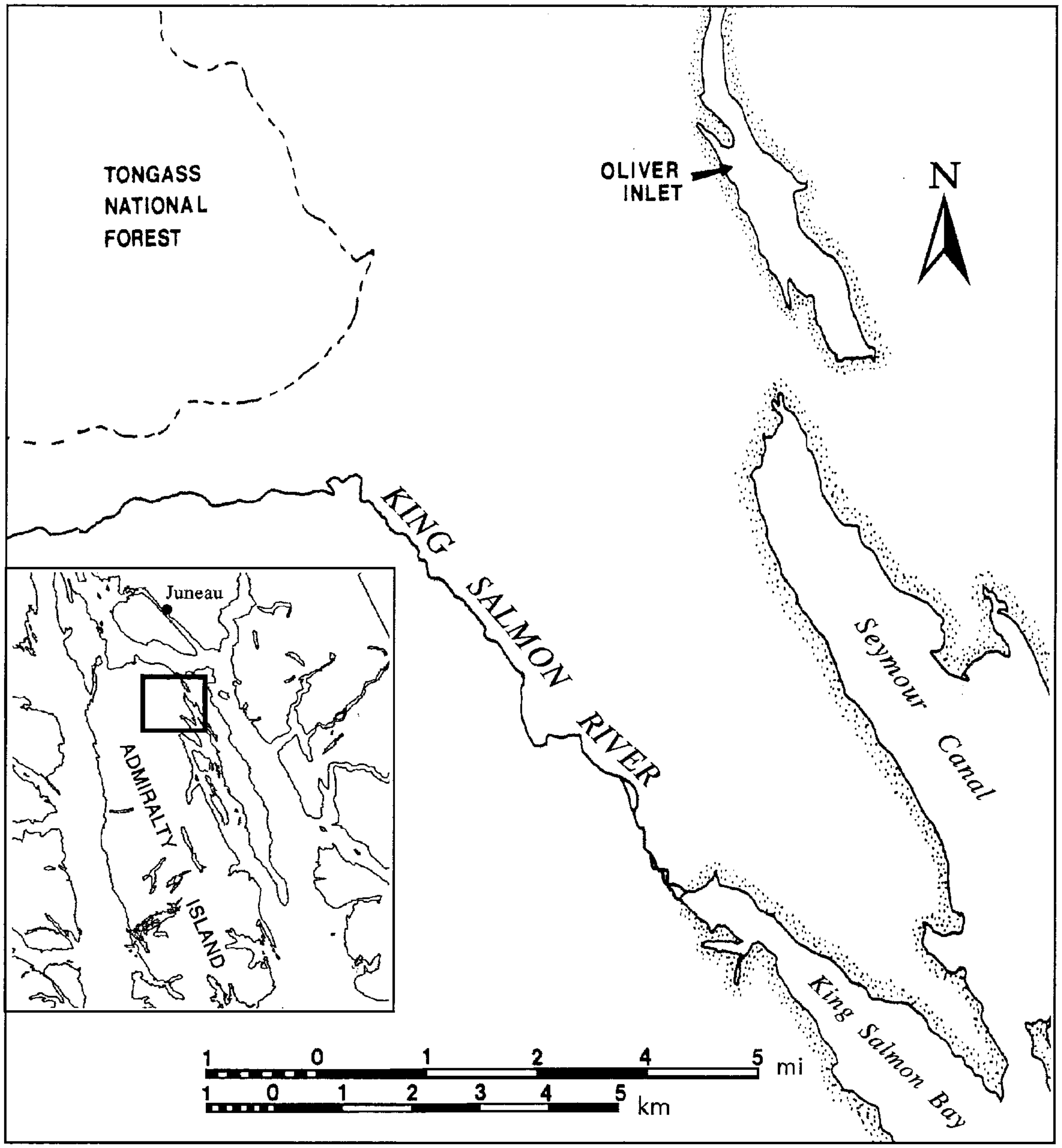
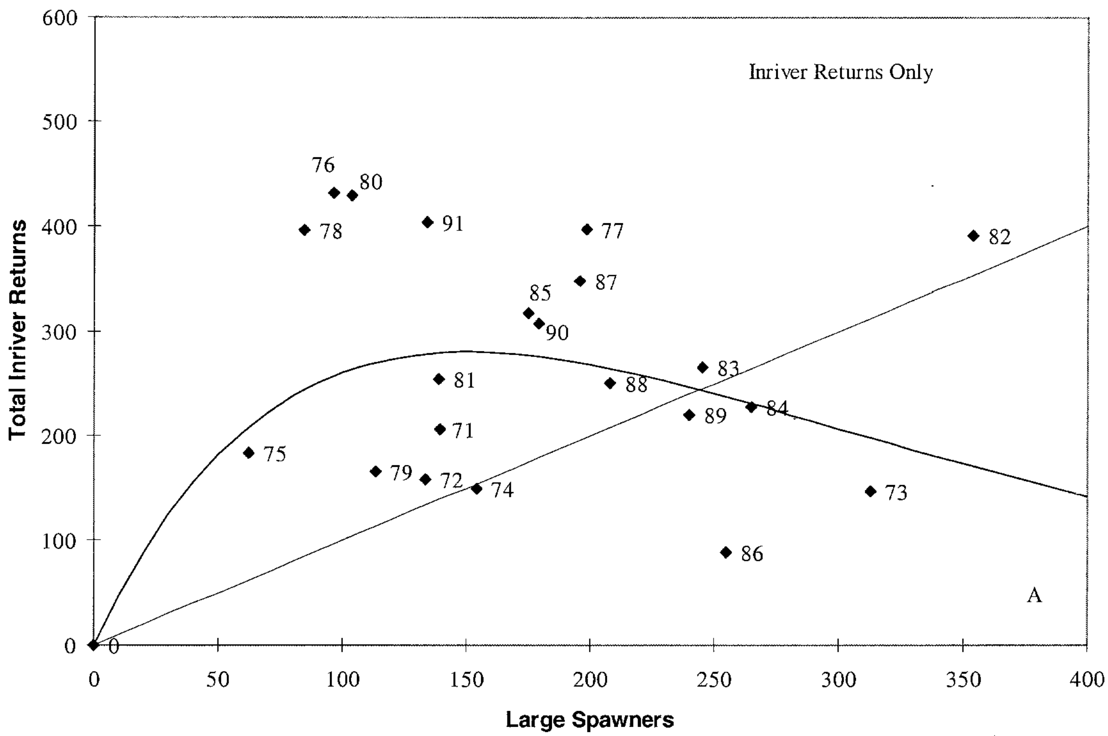


Figure 1. Map of the northeast portion of Southeast Alaska showing the King Salmon River.



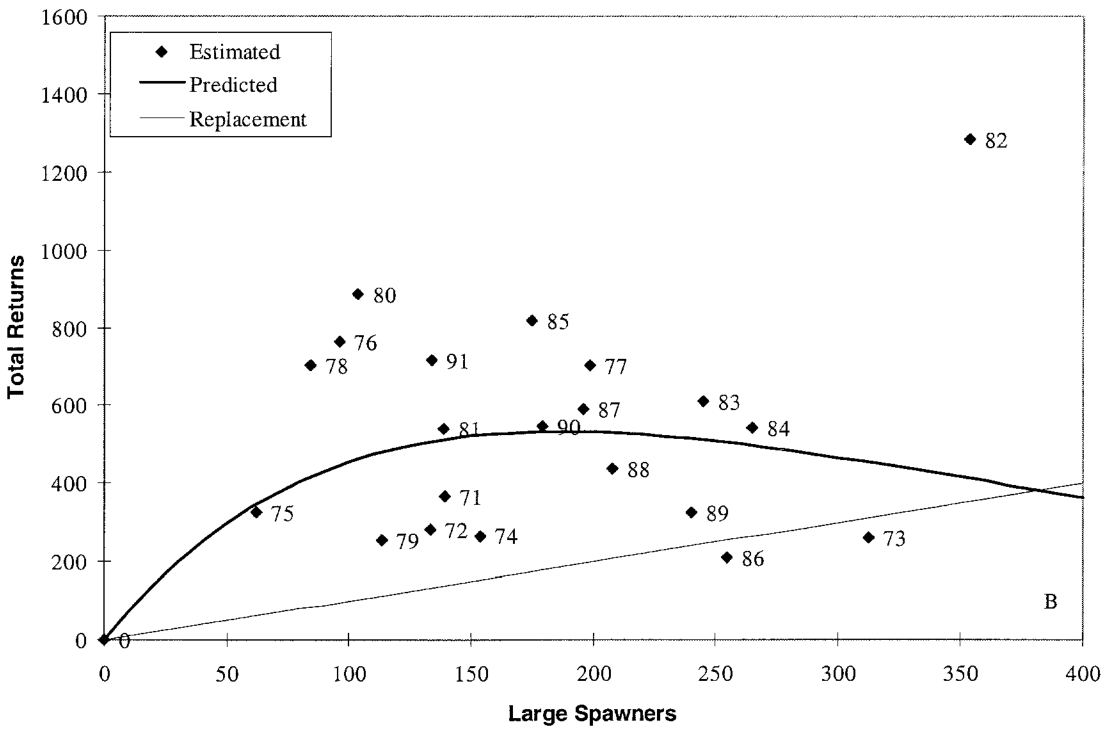


Figure 2. Estimated inriver brood year returns (panel A) and total brood year returns (panel B) for King Salmon River chinook salmon, 1971–1991 brood years.

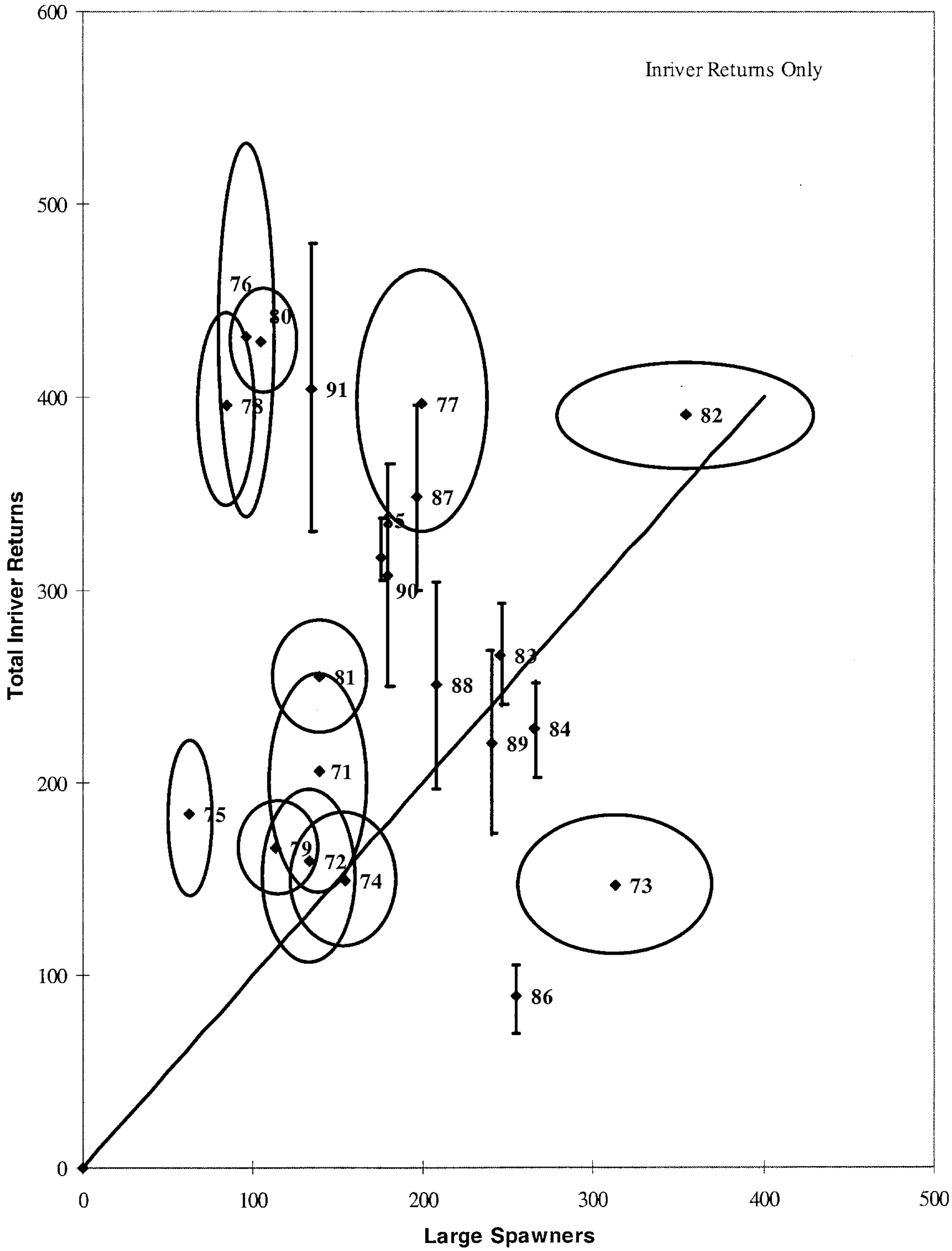


Figure 3. Precision of estimates of large spawners and inriver brood year returns of chinook salmon to the King Salmon River. The bars and ellipses show precision of estimates and are calculated based on point estimates for large spawners and inriver returns ± one standard error. Because spawners enumerated by weir for brood years 1983–1991 are considered a census, they have no variability associated with the X axis. Note that the scales for X (spawners) and Y (inriver returns) are approximately 1:1.

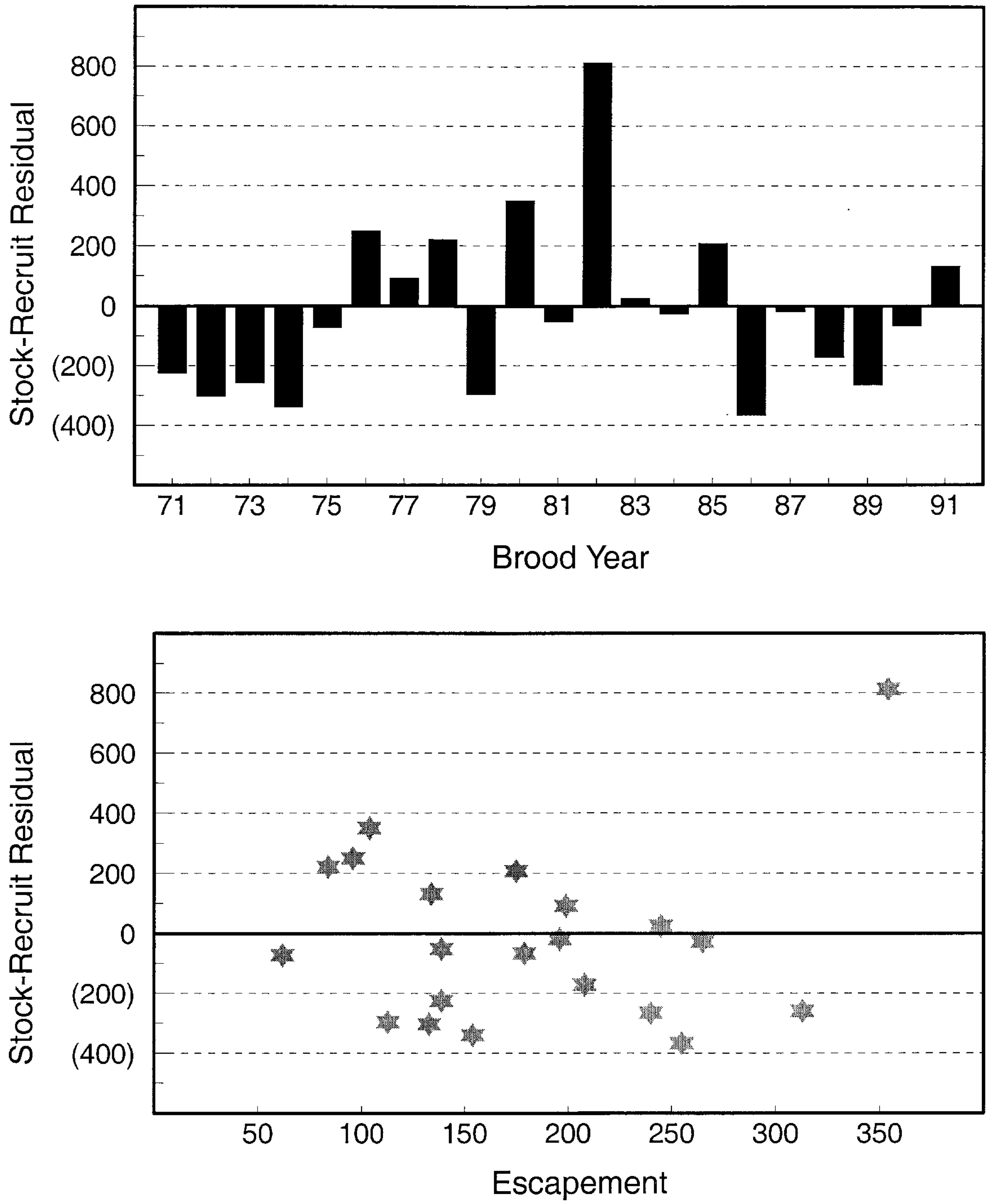


Figure 4. Residuals in the stock-recruit relationship plotted versus brood year (upper panel) and versus escapement (lower panel), King Salmon River chinook salmon, 1971–1991 brood years.

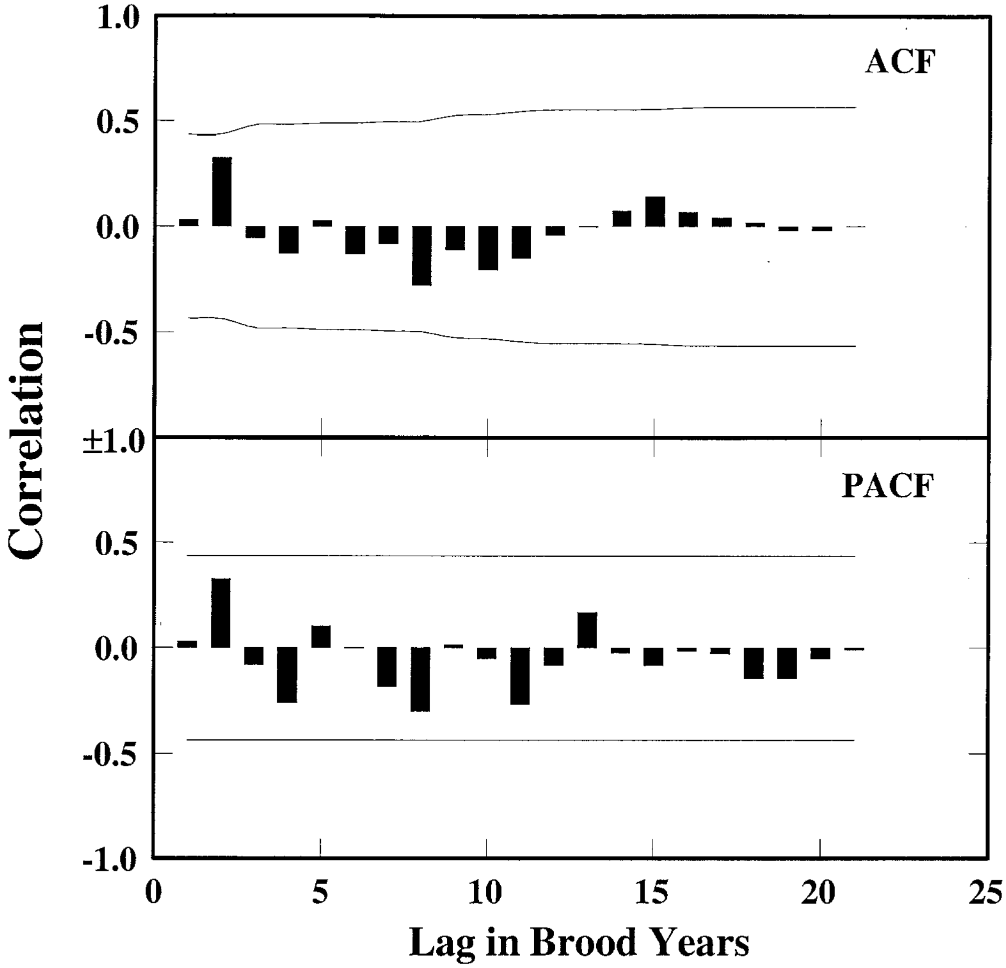


Figure 5. Tests for auto-correlation and partial auto-correlation of residuals in the stock-recruit relationship, King Salmon River chinook salmon, 1971–1991 brood years. The lines above and below the bars represent 95% critical values, indicating that auto-correlation and partial auto-correlation is insignificant with this data set.

Appendix A1. Age composition by sex and age of chinook salmon sampled from the King Salmon River, 1983–1992.

Panel A. Age Composition (Males, numbers aged)								Weir Count Males			Percent
Year	1.2	1.3	2.3	1.4	1.5	2.5	Total	Large	Jacks	Total	Aged
1983	11	20		14	2		47	144	20	164	28.7%
1984	16	7		13	1		37	130	82	212	17.5%
1985	5	12		1			18	119	47	166	10.8%
1986	13	6		6			25	133	74	207	12.1%
1987	2	9	1	3			15	115	62	177	8.5%
1988	2	3		10			15	137	54	191	7.9%
1989	2	7		12			21	118	72	190	11.1%
1990	2	14		1			17	88	35	123	13.8%
1991		1		4			5	71	90	161	3.1%
1992	12	22		6			40	58	28	86	46.5%
Average	7	10	0	7	0	0	24	111	56	168	16.0%

Panel B. Age Composition (Males, percents)							
Year	1.2	1.3	2.3	1.4	1.5	2.5	Total
1983	23.4%	42.6%	0.0%	29.8%	4.3%	0.0%	100.0%
1984	43.2%	18.9%	0.0%	35.1%	2.7%	0.0%	100.0%
1985	27.8%	66.7%	0.0%	5.6%	0.0%	0.0%	100.0%
1986	52.0%	24.0%	0.0%	24.0%	0.0%	0.0%	100.0%
1987	13.3%	60.0%	6.7%	20.0%	0.0%	0.0%	100.0%
1988	13.3%	20.0%	0.0%	66.7%	0.0%	0.0%	100.0%
1989	9.5%	33.3%	0.0%	57.1%	0.0%	0.0%	100.0%
1990	11.8%	82.4%	0.0%	5.9%	0.0%	0.0%	100.0%
1991	0.0%	20.0%	0.0%	80.0%	0.0%	0.0%	100.0%
1992	30.0%	55.0%	0.0%	15.0%	0.0%	0.0%	100.0%
Average	22.4%	42.3%	0.7%	33.9%	0.7%	0.0%	100.0%

Panel C. Age Composition(Females, numbers aged)								Weir Count	Percent	Weir Count
Year	1.2	1.3	2.3	1.4	1.5	2.5	Total	Females	Aged	% Females
1983	2	1		33	11		47	138	34.1%	45.7%
1984		1		21	2		24	181	13.3%	46.1%
1985		3		11			14	85	16.5%	33.9%
1986		1		22			23	148	15.5%	41.7%
1987		1		10	1		12	112	10.7%	38.8%
1988				15	1		16	106	15.1%	35.7%
1989		2		9	2	2	15	160	9.4%	45.7%
1990		1		14	1		16	120	13.3%	49.4%
1991				9			9	83	10.8%	34.0%
1992	1	16		8			25	59	42.4%	40.7%
Average	0	3	0	15	2	0	20	119	18.1%	41.2%

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Panel D. Age Composition (Males, percents)							
Year	1.2	1.3	2.3	1.4	1.5	2.5	Total
1983	4.3%	2.1%	0.0%	70.2%	23.4%	0.0%	100.0%
1984	0.0%	4.2%	0.0%	87.5%	8.3%	0.0%	100.0%
1985	0.0%	21.4%	0.0%	78.6%	0.0%	0.0%	100.0%
1986	0.0%	4.3%	0.0%	95.7%	0.0%	0.0%	100.0%
1987	0.0%	8.3%	0.0%	83.3%	8.3%	0.0%	100.0%
1988	0.0%	0.0%	0.0%	93.8%	6.3%	0.0%	100.0%
1989	0.0%	13.3%	0.0%	60.0%	13.3%	13.3%	100.0%
1990	0.0%	6.3%	0.0%	87.5%	6.3%	0.0%	100.0%
1991	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
1992	4.0%	64.0%	0.0%	32.0%	0.0%	0.0%	100.0%
Average	0.8%	12.4%	0.0%	78.9%	6.6%	1.3%	100.0%

Panel E. Average % of males and females within age class							
Sex	1.2	1.3	2.3	1.4	1.5	2.5	Total
Males	95.6%	79.5%	100.0%	31.5%	14.3%	0.0%	58.5%
Females	4.4%	20.5%	0.0%	68.5%	85.7%	100.0%	41.5%