# BIOLOGICAL ESCAPEMENT GOAL FOR

# KLUKSHU RIVER SYSTEM SOCKEYE SALMON

By

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and
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Regional Information Report1 No. 1J00-24

Alaska Department of Fish and Game
Division of Commercial Fisheries
Juneau, Alaska

May 2000

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## ACKNOWLEDGEMENTS

The authors thank the many field staff of ADF&G and CDF&O who have persevered through hardships with weather, bears, and people in the collection of the baseline data which formed the foundation for this paper. We thank Glen T. Oliver and Craig Farrington of ADF&G for providing recent age composition data. Scott A. McPherson and Edgar Jones are thanked for running the bootstrap analysis included in this report. Thanks to the Transboundary Technical Committee of the Pacific Salmon Commission for reviewing a draft of the report.

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## ABSTRACT

Available information on age compositions, escapements, and harvests of sockeye salmon *Oncorhynchus nerka* returning to the Klukshu River, a tributary system in the Alsek River drainage east of Yakutat, Alaska, during the years 1976-1997 was used to develop a brood table consisting of estimated escapements and estimated resultant age-specific recruits from these escapements. These data were subsequently used to estimate a spawner-recruit relationship based upon the estimated escapements of Klukshu sockeye salmon during the years 1976-1992 and recruits resulting from these escapements 3, 4, 5, and 6 years later. This spawner-recruit relationship was used to estimate the number of spawners that would, on average, provide for maximum sustained yield of this stock of sockeye salmon in fisheries in Canada and the U. S. that are believed to harvest this stock. Based upon the spawner-recruit relationship developed in this report, it is recommended that the following biological escapement goal be formally adopted by the Alaska Department of Fish and Game, the Canadian Department of Fisheries and Oceans, and the Transboundary Technical Committee of the Pacific Salmon Commission: Klukshu Sockeye Salmon: 7,500 to 15,000 spawners per year.



**KEY WORDS**: sockeye salmon, *Oncorhynchus nerka*, Klukshu River, Alsek River, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship

## INTRODUCTION

The Klukshu River is a tributary of the Tatshenshini River which in turn is a tributary of the Alsek River. The Alsek River originates in Canada and flows through the United States terminating in the Gulf of Alaska, east of Yakutat (Figure 1). Alsek River salmon stocks contribute to U.S. commercial and subsistence fisheries located near Dry Bay. No commercial fishery exists in the Canadian portion of the Alsek River drainage, although both aboriginal (Indian food) and recreational (sport) fisheries occur in the Tatshenshini River and some of its headwater tributaries. Management of salmon returning to the Alsek River drainage has been under the auspices of the Pacific Salmon Commission (PSC) since the signing of the U.S.-Canada Pacific Salmon Treaty in 1985.

Sockeye salmon *Oncorhynchus nerka* have been enumerated with the aid of a weir located on the Klukshu River just upstream of its confluence with the Tatshenshini River each year since 1976 by personnel of the Canadian Department of Fisheries and Oceans (CDF&O). This is the only sockeye salmon escapement enumeration program in the Alsek River drainage with a consistent and long-term escapement enumeration program.

An escapement goal for management of sockeye salmon accepted and adopted by both the U.S. and Canada for the Alsek River drainage has yet to be defined. In the mid-1980s, the U. S. set an interim escapement goal of 33,000 sockeye salmon for the Alsek River drainage and at the time assumed the portion of the overall escapement that spawned in the Klukshu River system was 37% based upon an Alaska Department of Fish and Game (ADF&G) mark-recapture study (McBride and Bernard 1984). Thus the intent was an escapement goal of about 12,000 sockeye salmon in the Klukshu River. At about the same time, the CDF&O set an interim escapement goal for the Alsek River drainage of 58,000 sockeye salmon. Professional judgements by staff of CDF&O were that about 60% of the overall Alsek River drainage sockeye salmon population spawned in the Klukshu River system and hence intent was an escapement goal of about 35,000 sockeye salmon in the Klukshu River. Because neither country has yet to define an escapement goal for sockeye salmon returning specifically to the Klukshu River system (the only consistent enumeration program in place) and because the two countries have yet to reach agreement on the portion of Alsek River system sockeye salmon population that returns to the Klukshu, the Transboundary Technical Committee (TTC) of the PSC has used the annual Klukshu escapement counts coupled with a goal range of 33,000 to 58,000 sockeye returning to the Alsek River drainage to evaluate management (range of 37% to 60% for a measure of the proportion of Klukshu River system sockeye salmon in the overall Alsek River system run). Other than continuing the collection of data, little technical progress has been made since the signing of the U.S.-Canada Pacific Salmon Treaty to assist in defining an escapement goal for Klukshu River system sockeye salmon that is acceptable to both countries. However, technical progress is needed at this time to address specific requirements included in Annex IV of the Pacific Salmon Treaty Fishing Annexes and Related Agreements agreed to by the United States and Canada in June 1999. Specifically, that June 1999 agreement states:

> *"c the Alsek River:*
>
> *(i) Consistent with paragraph 2 above, the Parties will develop and implement cooperative abundance-based management programs for Alsek River chinook, sockeye and coho salmon, including MSY escapement and management goals for chinook and sockeye salmon."*

This report is written to coalesce and document available data concerning abundance and age composition of Klukshu origin sockeye salmon in U. S. and Canadian fishery catches and escapements. Further, the intent of this report is to use available data from both countries to provide a technical estimate of the annual average escapement levels that are most likely to produce maximum sustained

yields in fisheries of both countries. Intent of this report is to thereby provide a technical recommendation concerning an appropriate biological escapement goal for this stock of sockeye salmon in the hope that both countries will reach a consensus agreement on an appropriate management target that can be used by the Pacific Salmon Commission and its technical committees in annual evaluations of fishery management.

## KLUKSHU SOCKEYE ESCAPEMENTS, HARVESTS, RETURNS, AND THE SPAWNER-RECRUIT RELATIONSHIP

### *Klukshu Sockeye Salmon Escapements and Canadian Harvests*

Numeric escapement information for sockeye salmon spawning in the Klukshu River is annually obtained by staff of the CDF&O with the aid of a weir constructed across the lower portion of the Klukshu River. Counts of sockeye salmon as they pass the Klukshu River weir have been made each year since 1976. Some fishing occurs upstream of the weir; staff of CDF&O annually estimate these catches. Further, some sockeye salmon are removed as brood stock and subsequently used for small scale enhancement activities; staff of CDF&O enumerate these removals. The CDF&O provides estimates of the number of sockeye salmon that spawn each year by subtracting from the weir counts, the estimated upstream catches and brood stock removals. These annual estimates provide a continuous data base of monitored annual escapements that represent reliable estimates of the number of sockeye salmon spawning in the Klukshu River system. The annual escapement estimates do not represent a complete census because of the estimated fishery catches that are subtracted. However, in most years (particularly since 1980), removals are relatively small in comparison to weir counts so the escapement estimates, in many cases, nearly represent a complete census and sampling error is relatively low. CDF&O also keeps track of the weir counts of sockeye salmon through August 15$^{th}$ and thereafter each year in an effort to monitor early segments of the escapement versus later segments of the escapement. During the 22 years between 1976 and 1997, the estimated annual escapements of sockeye salmon that spawned in the Klukshu River system ranged from 7,051 fish in 1979 to 28,899 fish in 1982, a 4.1 fold level of variation (Table 1).

Sockeye salmon of Klukshu River system origin are harvested in Canadian aboriginal and sport fisheries. The sport fishery takes place in the Klukshu River below the weir and in portions of the Tatshenshini River near its confluence with the Klukshu River. Because of the location of the sport fishery, staff of the CDF&O estimate that 90% of the sockeye salmon annually harvested in the Alsek drainage sport fishery are of Klukshu origin. During the 22 years between 1976 and 1997, the sport fishery is estimated to have harvested from 32 to 727 sockeye salmon of Klukshu River origin (Table 2). The Canadian aboriginal fishery historically took place above the Klukshu River weir, but starting in 1989, a portion of the harvest took place in the Klukshu River below the weir. These harvests are monitored by staff of CDF&O and the harvests both above and below the weir are estimated on an annual basis and assumed to be completely of Klukshu River system origin. Canadian aboriginal harvests annually taking place above the weir during the 22 years of 1976 to 1997 have ranged from 484 sockeye salmon in 1997 to 10,000 sockeye salmon in 1977 (Table 2). Canadian aboriginal harvests of Klukshu River system origin sockeye salmon below the weir have ranged from 150 fish in 1989 to 780 fish in 1995 during the nine years between 1989 and 1997 (Table 2).

CDF&O has monitored the age composition of sockeye salmon in the terminal return to the Klukshu River system each year since 1976. From 1976 to 1982, sockeye salmon harvested in the aboriginal

fishery were sampled to annually estimate age composition of the terminal return. From 1983 to 1997, sockeye salmon were annually captured in a trap located within the counting chamber of the weir and subsequently sampled to monitor age composition of the terminal return. Annual sample sizes of aged sockeye salmon in the terminal returns have ranged from a low of 72 fish in 1980 to a high of 989 fish in 1997 (Table 3). In most years (14 of 22 of the years, 64% of the annual cases), sample sizes of aged sockeye salmon exceeded 300 fish and thus these samples provided information needed to develop relatively precise age composition estimates. These estimated annual age compositions (Table 3) when multiplied by the number of sockeye salmon that were estimated to annually spawn or were removed in Canadian fisheries or for brood stock, result in age specific Canadian terminal returns of Klukshu origin sockeye salmon (Table 4). Because the majority of these sockeye salmon, whether escaping to spawn or being caught in the Canadian aboriginal fishery above the weir, were directly enumerated and because sample sizes used to estimate annual age composition of terminal returns was usually large, the age specific terminal return estimates are relatively precise. Conversely, annual measurement error of the age specific Canadian returns of Klukshu sockeye are relatively low.

### *Harvest of Klukshu Origin Sockeye Salmon in U.S. Fisheries*

Sockeye salmon are harvested in set gillnet fisheries below the border in the U.S. portion of the Alsek River (fishing district 182-30) and in U.S. surf waters near the terminus of the Alsek River (fishing district 182-31). We conjecture that Alsek origin sockeye salmon may be harvested in other marine fisheries, however, no factual data exists to support this conjecture. Two types of fisheries have occurred; commercial set gillnet fishing and subsistence set gillnet fishing. Harvests in the commercial fishery are enumerated from fish tickets (sales receipts issued to fishers from processors when their catches are sold). Commercial harvests are considered a census with no sampling error. Harvests in the subsistence fishery are enumerated from catch reports returned to ADF&G for permits issued to fishery participants and are assumed to have only moderate precision (coefficient of variation is believed to be less than 30%, but more than 10%). However, because the annual harvests in the subsistence fishery are tiny in comparison to the commercial harvests (Table 5), overall catch of sockeye salmon in the U.S. Alsek fishery is known precisely on an annual basis. During the 22 years from 1976 to 1997, the U.S. Alsek fishery catches of sockeye salmon were estimated to have ranged from a low of 6,035 fish in 1985 to a high of 50,580 in 1978.

What is not known is the proportion of the U.S. Alsek fishery comprised of Klukshu origin sockeye salmon on an annual basis. This proportion has only been estimated based on a sampling program in one of the twenty-two years since 1976. An ADF&G mark-recapture experiment conducted in 1983 estimated that Klukshu weir counts of sockeye salmon represented 37% of the total Alsek River system escapement (McBride and Bernard, 1984). It should be noted that the McBride and Bernard study was a feasibility study that resulted in an incomplete cross-section of the 1983 Alsek sockeye return. Tag recoveries only occurred from the Klukshu weir site; not drainage wide. Consequently, the results of the McBride and Bernard study may be somewhat misleading. Professional judgement by staff of CDF&O in the early 1980s placed the proportion at 60% (TBR 1994). Knowing the annual U.S. Alsek fishery harvest of sockeye salmon on an annual basis with high precision but not knowing what proportions of those annual harvests were of Klukshu River origin forces us to consider three alternative assumptions in an effort to estimate total annual returns of Klukshu River system sockeye salmon.

> **Alternative one** relies on the 1983 ADF&G mark-recapture study. This study provides the best available technical estimate because it is the only information available which has its basis grounded upon a field sampling program. Hence, this alternative, hereafter referred to as <u>model</u>

one allocates 37% of the annual U.S. harvests of sockeye salmon in the Alsek fishery to the Klukshu River system stock with the remaining 63% being allocated to an undefined and unknown mix of other sockeye salmon stocks**. We believe this approach to be the only approach of the three attempted that is based upon available technical data for this stock of sockeye salmon. This alternative is based upon best available fishery science concerning estimating the annual total returns of Klukshu origin sockeye salmon.** The advantage of this approach is that it is based upon a sampling program that took place in one of the years in question. The disadvantage is that in all likelihood, the proportion varies each year and whether or not the value of 37% is appropriate for the other 21 years is unknown. Use of the value of 37% for all years may be biased; that is, it might be too low or alternatively it might be too high. The only certainty is that the annual proportions of Klukshu River system sockeye salmon in the annual U.S. Alsek River fishery are somewhere between 0% and 100% each year. This certainty leads to the next two alternatives.

**Alternative two** assumes that none of the sockeye salmon annually caught in the U.S. Alsek fishery are of Klukshu River origin. This alternative, hereafter referred to as model two allocates none of the annual U.S. harvests of sockeye salmon in the Alsek fishery to the Klukshu River system stock, while 100% are allocated to an undefined and unknown mix of other sockeye salmon stocks. Thus the annual terminal runs to Canada as estimated in Table 4 represent the entire annual total return. We know for certain that this is an absolute minimum estimate of the annual total return of Klukshu origin sockeye salmon. The advantage of this approach is that we do not have to apply the 1985 ADF&G study results to any of the years in the data set in order to estimate annual Klukshu origin sockeye salmon returns. The disadvantage is that we are certain that estimated annual returns of Klukshu origin sockeye salmon with this approach are biased low. Further, the professional judgement of some CDF&O staff is that the appropriate proportion is 60%. In addition to the certainty that at least some of the U.S. Alsek sockeye salmon catches are of Klukshu origin is the plausible case that some Klukshu River system sockeye salmon are caught in other U.S. fisheries, even if no technical data is available to support this supposition. **Estimates of the annual total returns of Klukshu origin sockeye salmon provided with model two are not based on best available fishery science but were developed to assist in bracketing the Klukshu River system escapement level expected to provide for maximum sustained yield fisheries**.

**Alternative three** assumes that all of the sockeye salmon annually caught in the U.S. Alsek fishery are of Klukshu River origin. This alternative, hereafter referred to as model three allocates all of the annual U.S. harvests of sockeye salmon in the Alsek fishery to the Klukshu River system stock, while none are allocated to an undefined and unknown mix of other sockeye salmon stocks. We believe this to be a maximum estimate of the annual total return. Reproducing stocks of sockeye salmon other than the Klukshu River origin stock spawn above the U.S. Alsek fishery, and it is unreasonable to conclude that the U.S. fishery is not composed of a mix of sockeye salmon stocks. Thus the known existence of these other stocks and the fact that this supposition is not compatible with either the 1985 ADF&G study nor with professional judgements of CDF&O staff make this approach incompatible with best available fishery science. On the other hand, even if not all U.S. Alsek sockeye salmon fishery catches are of Klukshu origin, this approach allows Klukshu origin returns to exceed what is deemed reasonable with respect to the U.S. Alsek fishery and the difference might be explained as Klukshu origin sockeye salmon not caught in the U.S. Alsek fishery, but in other U.S. fisheries. Although it is plausible that Klukshu origin sockeye salmon are caught in U.S. fisheries other than the Alsek, there is no available data supporting such a supposition nor is there any technical

information available to estimate annual harvests. **Estimates of the annual total returns of Klukshu origin sockeye salmon provided with model three are not based on best available fishery science but were developed to assist in bracketing the Klukshu River system escapement level expected to provide for maximum sustained yield fisheries.**

Sockeye salmon caught in the U.S. Alsek fishery have been sampled to estimate age composition on an annual basis since 1982 (Table 6). Annual sample sizes have been relatively large (ranging from 455 aged samples in 1994 to 2,011 aged samples in 1983). Hence precision of age compositions estimated on an annual basis is likewise relatively high. These relatively precise age compositions when coupled with the precise harvest numbers provide relatively precise estimates of the number of sockeye salmon harvested by age. Because direct sampling of the sockeye salmon harvest in the U.S. Alsek River did not start until 1982, we have used the average age composition during the years 1982-1997 as a proxy value for the years 1976-1981. However, these assumed age compositions and resultant estimates of age specific harvests have little effect on subsequent analysis because only the age-3, 4, and 5 fish in 1976, the age-3 and 4 fish in 1977, and the age-3 fish in 1978 are included in the stock-recruit relationship discussed later in this report (6 of 68, or 9% of the age/brood year cohorts used in the analysis).

### *Estimated Total Returns of Klukshu River System Origin Sockeye Salmon*

As described above, a basic premise of this analysis is that 37% of the sockeye salmon harvested in the U.S. Alsek fishery are of Klukshu River system origin. Thus, on an annual basis, the addition of these fish caught in U.S. waters with those counted at the Klukshu River weir and those sockeye of Klukshu origin caught below the weir in Canadian waters provides annual estimates of the total return of Klukshu River system origin sockeye salmon. Total returns of Klukshu River system origin sockeye salmon are estimated to have ranged from a low of 12,012 fish in 1988 to a high of 46,032 fish in 1978 during the 22 year period of 1976-1997 (Table 7). Table 8 provides age specific estimates for each of these 22 annual returns.

### *Estimated Recruits Resulting From 1976-1992 Brood Year Escapements*

The number of Klukshu River system origin sockeye salmon recruits resulting from individual brood year escapements *(i)* in the data set was estimated as the summation of estimated total returns of age-3 fish in year $i+3$, age-4 fish in year $i+4$, age-5 fish in year $i+5$, and age-6 fish in year $i+6$. The data used for this summation process is that of Table 8 and the results are provided in Table 9. Brood years 1976-1992 were included. The age-6 recruits in 1998 for the 1992 brood year (699 fish) were estimated as the average age-6 recruitment (Table 7). Because very few fish return at age 6, this estimation procedure has little effect on the spawner-recruit relationship discussed later in this report. As discussed earlier, the age-3 recruits for brood years 1976, 1977, and 1979, the age-4 recruits for brood years 1976 and 1977, and the age-5 recruits for the 1976 brood year are partially based on an assumed age composition (the U.S. Alsek fishery component) rather than a directly sampled age composition. Total recruits of Klukshu River system sockeye salmon resulting from the 1976-1992 brood years were estimated to have ranged from a low of 12,503 fish from the 1983 brood year to a high of 46,353 fish from the 1977 brood year (Table 9).

These calculations laid the basis for developing an estimated paired data set with a sample size of 17 consisting of: (1) estimated escapements during the years 1976-1992 and, (2) estimated recruitment resulting from these escapements. This paired data set was used in model 1 calculations. As described

earlier, the model 1 data set (Table 10) was developed to provide the best available scientific information upon which a technical analysis of the maximum sustained yield escapement level could be estimated.

A second and a third data set were also developed, each consisting of the same observations concerning escapement but with differing estimates of recruits. Recruit estimates associated with model-2 calculations (Table 10) were developed from the data provided in Table 4, the estimated age specific terminal runs to Canada. In this case, the terminal returns to Canada were treated as being equal to the total annual returns and the resultant total recruitments estimated as the summation of: age-3 fish three years later, age-4 fish four years later, age-5 fish 5 years later, and age-6 fish six years later from data provided in Table 4. This data set includes the inherent assumption that the U.S. fishery harvests no Klukshu origin sockeye salmon. This model, as discussed above, was developed along with model 3 to bracket the escapement level predicted to provide for maximum sustained yield fisheries. The model 3 data set, on the other hand, is derived from the assumption that all sockeye salmon harvested in the U.S. Alsek fishery are of Klukshu origin. Table 11 provides the annual age specific total returns associated with such an assumption. The recruits associated with the model 3 data set (Table 10) were estimated as the summation of: age-3 fish three years later, age 4 fish four years later, age-5 fish 5 years later, and age-6 fish six years later with data taken from Table 11.

### *Spawner-Recruit Relationship for Klukshu Origin Sockeye Salmon*

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

$$R = S\ exp[a(1-S/P_m)] \qquad (1)$$

where: R = estimated total recruitment;
S = spawning escapement;
*exp* = base of the natural system of logarithms;
a = intrinsic rate of population increase in the absence of density-dependent limitations;
$P_m$ = carrying capacity.

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

$$Ln(R/S) = a - a/P_m(S) + \text{error}. \qquad (2)$$

Linear regression procedures provided estimates of the intercept (a) and the slope ($a/P_m$) of the equation. The estimated number of spawners that produce the maximum number of recruits is:

$$S_{max} = P_m/a; \qquad (3)$$

and, the estimated number of spawners that produce the maximum harvestable surplus (MSY escapement) is estimated by iteratively solving the equation:

$$S_{msy} = P_m/a\ \{1-exp[-a(1-S_{msy}/P_m)]\}. \qquad (4)$$

Once the spawner-recruit relationships were calculated, a series of parameters were estimated including the estimated MSY escapement, or the point on the modeled spawner-recruit line where harvestable surplus is at a maximum, or $S_{msy}$.

Analysis of the spawner-recruit relationship for the model 1 data set resulted in an estimate of 9,505 spawners as the MSY escapement level for the Klukshu River stock of sockeye salmon (Table 12). The spawner-recruit relationship developed estimated that maximum surplus yield from the Klukshu River stock of sockeye salmon is 14,371 fish, on average. If the Klukshu River stock of sockeye salmon were managed at the indicated MSY escapement level of 9,505 spawners per year, a fishery yield of 14,371 fish is estimated to be provided, on average, indefinitely. Replacement escapement, or the point on the spawner-recruit relationship where harvestable surplus falls to zero is estimated at about 24,000 spawning sockeye salmon (Figure 2). The maximum stock size is estimated to occur with an escapement level of about 16,000 sockeye salmon in the Klukshu River escapement; estimated total annual average stock size at this level of escapement is about 27,000 sockeye salmon (Figure 2). The residual pattern in the model 1 spawner-recruit relationship when plotted through time and against brood year escapements appear random (upper and middle panels of Figure 3). Residuals in the model-1 spawner-recruit relationship were also plotted against the proportion of total annual escapement that was counted at the Klukshu River weir prior to August 16 of each year[2] to determine if the early, or alternatively, the late component of the escapement was inherently more productive (Figure 3, lower panel). The pattern of residuals in this plot is also random and there is no relationship between residuals in the spawner-recruit relationship and the proportion of escapement that passed the weir during the early segment of the run.

Analysis of the spawner-recruit relationship for the model 2 data set (no Klukshu sockeye harvested in U.S. fisheries) resulted in an estimate of 7,806 spawners as the MSY escapement level for the Klukshu River stock of sockeye salmon (Table 12). This estimate of the MSY escapement level is about 1,700 fewer spawners or 17% less than the estimate based upon best available scientific information. Analysis of the spawner-recruit relationship for the model-3 data set (all sockeye harvested in the U.S. Alsek fishery are of Klukshu origin) resulted in an estimate of 11,313 spawners as the MSY escapement level for the Klukshu River stock of sockeye salmon (Table 12). This estimate of the MSY escapement level is about 1,800 more spawners or 19% more than the estimate based upon best available scientific information. Thus the range of possible choices with regard to the proportion of Klukshu origin sockeye salmon in the U.S. Alsek fishery during the years used in this analysis has the potential to alter the indicated estimate of MSY escapement level by about $\pm$ 20%.

### *Bootstrap Analysis of the Spawner-Recruit Relationship for Klukshu Origin Sockeye Salmon*

The variances (mean square errors) for alpha, beta, and the MSY escapement level ($S_{msy}$) were estimated with modifications of bootstrap procedures in McPherson (1990). Error structure for Y (estimated total recruits) was assumed to be multiplicative-lognormal and error structure of X (estimated escapements of sockeye) was assumed to be multiplicative. Walters and Ludwig (1981) showed that multiplicative error structure for escapements, either normally or uniformly distributed, produced essentially the same results.

In the bootstrap run, the original data set associated with model 1 (estimated escapements of sockeye from Table 10, column 2 and estimated total cohort recruitment from Table 10, column 3) was fit using equation [1] and bias corrected residuals ($\varepsilon_i$) were stored. For each replicate, the same number of X and Y observations as in the original data set (n = 17) were used. Each Y observation in a replicate was selected

[2] Data for calculating the proportion of escapement prior to August 16th is provided in Table 1; mean migratory timing of the Klukshu sockeye salmon stock is shown in Figure 4.

from the17 possible values calculated as: $R_i^* = R_i^+ + \varepsilon$ (selected at random with replacement). Each X observation $\{S_i^*\}$ was selected at random (with replacement) from the original 17 observations. A new set of statistics $\{S_i^*, R_i^*\}$ along with new estimates for alpha, beta, and $S_{msy}$ escapement $(P_s^*)$ were generated from each bootstrap sample, and 2,000 such bootstrap samples were drawn creating the empirical distributions $\hat{F}(\hat{P}_s^*), \hat{F}(\hat{\alpha}), \hat{F}(\hat{\beta})$ , which are estimates of $F(P_s^*)$ , $F(\hat{\alpha})$, and $F(\hat{\beta})$ . The difference between the average of bootstrap estimates and the original estimate is an estimate of statistical bias in the latter statistic (Efron and Tibshirani 1993, Section 10.2). Confidence intervals were estimated from $\hat{F}(\hat{P}_s^*), \hat{F}(\hat{\alpha}), \hat{F}(\hat{\beta})$ with the percentile method (Efron and Tibshirani 1993, Section 13.3). Variance was estimated as $v(\hat{P}_s^*) = (B-1)^{-1} \sum_{b=1}^{B} (\hat{P}_{s(b)}^* - \overline{\hat{P}}_s^*)^2$ where B is the number of bootstrap samples (2,000). The variances for alpha and beta were estimated similarly.

A maximum sustained yield escapement goal range was estimated using the 0.8 ($\overline{\hat{P}}_s^*$), to 1.6 ($\overline{\hat{P}}_s^*$) procedure of Eggers (1993). This method examined optimizing harvests over a wide range of management scenarios. The bootstrap mean for $P_s$ 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 Klukshu River stock of sockeye salmon is 9,361 spawners and the coefficient of variation for this mean statistic is 13.1% (Table 13). The 90% confidence interval for the estimated MSY escapement level for the Klukshu River sockeye salmon stock is estimated at 7,749 to 11,672 spawners (Table 13), and this 90% confidence interval encapsulates the point estimate values for MSY escapement level predicted with all three models which differentially account for the proportion of Klukshu origin sockeye salmon harvested in the U.S. Alsek fishery. The bootstrap mean estimate of the MSY escapement level is lower than the model 1 regression estimate of 9,505 spawners, but differs by only 144 fish, indicating bias is minor at 1.5%.

***Biological Escapement Goal for Klukshu Origin Sockeye Salmon***

We believe that the best available scientific estimate of the MSY escapement point value for the Klukshu River stock of sockeye salmon is about **9,400** spawners. We believe that the biological escapement goal for the Klukshu River stock of sockeye salmon should be set at **7,500 to 15,000** spawners per year. This range is based upon our best estimate of the point value and the methodology of Eggers (1993). This range encompasses the 90% confidence interval of MSY escapement based on the bootstrap analysis (Table 13) as well as encapsulating the point values derived from the model 1, 2, and 3 analyses used to bracket the MSY level depending upon assumptions regarding the U.S. Alsek fishery stock composition (Table 12).

The CDF&O has expressed concerns over the status of the early component of the Klukshu River system sockeye salmon run. Further, the U.S. Pacific Salmon Treaty has called for a cooperative attempt to rebuild early-run sockeye stocks of the Alsek River system. For those reasons, we believe it appropriate to initiate a discussion of management targets for the early run (and late run).

Mean migratory timing of the sockeye salmon run at the Klukshu River weir during the years 1976-1997 was calculated (Figure 4). Over this 22 year period, 15% of the run passed the weir on or before August 15th, the date used by CDF&O to designate sockeye as being of either the early run or, alternatively, the

late run. One approach to designating early and late run escapement objectives would be to apply 15% to the overall goal, thereby defining an early (and late) run management objective. A potential down-side to this approach is that productivity of the early and late run components may not be the same. However, a comparison of the residuals of the model developed with the proportion of run escaping on or before August 15th does not hint at substantially different productivity of early and late run segments (see Figure 3, bottom panel).

Another approach would be to attempt to reconstruct the early and late runs and conduct independent stock-recruit analyses. At the present time, this approach has a myriad of technical problems. First, it is unlikely that all early run fish migrate past the weir on or before August 15th; such a date may represent a long-term average when more early run fish migrate than late run fish, but the appropriate date in any given year likely varies. This technical problem potentially creates serious errors when trying to determine run strength for the two run components, particularly for the weaker of the two runs. Some error in assigning early run fish to the late component creates minor problems because the late component is much larger. However, some error in assigning late run fish to the early component can have large effects. It is likely that this is why the early run component has an apparent variation of 63 fold from 1976-1997 (from 181 in 1976 to 11,339 in 1992), while variation in the late run is much less at only 5 fold for the same time period (4,931 in 1997 to 25,941 in 1982); see Table 1. An even more serious technical problem has to do with allocation of U.S. caught fish in downstream waters. The 111 sockeye salmon tagged at Dry Bay and recovered at Klukshu weir in the McBride and Bernard (1984) study took from 37 to 90 days to reach Klukshu weir. Attempting to label sockeye in the Dry Bay area as early or late run based upon a specific calendar date would lead to large errors, given the large variation in the 111 individual sockeye salmon migrations measured to date. Some other run designation tool is needed to classify fish as to whether or not they originated in the Klukshu and from which run segment (early versus late) in order to minimize stock and run classification errors.

We recommend that the issue of technically identifying appropriate escapement objectives for the early and late run components of the Klukshu sockeye salmon stock be further researched. Current thinking is that the early run sockeye salmon likely spawn in the outlet of Klukshu Lake (Klukshu River) while the late run fish likely spawn in the lake itself[3]. If so and if early run fish rear in Klukshu Lake, then they would have to be pre-programmed to migrate upstream after hatching, implying a genetic difference between the run components. If they are not pre-programmed, they likely rear downstream of Klukshu Lake under different rearing conditions. If these stocks are genetically different or if they rear in different locations, some type of stock identification tool might be identified with further research (genetic stock identification or scale patterns). Such a tool, if identified and applied to samples from the Klukshu escapement and Dry Bay catch, may address technical problems identified above and may potentially lead to a technical basis for development of early and late run segment escapement goals.

Other than recommending further study, we make no specific recommendations for early or late run escapement objectives at this time. However, we believe it prudent for fishery managers to make every effort to spread the recommended escapement objective of 7,500 to 15,000 sockeye salmon into the Klukshu River and Lake system across the entire historic time period. Thus, on average, we would expect managers to continue to achieve about 15% of the escapement on or before August 15th. This recommended management approach is anticipated to produce maximum sustained yield fisheries in the

[3] Of 15 radio transmitters applied to early run Klukshu sockeye salmon in 1999, 13 were located in the river downstream approximately 10 km from lake outlet, and 2 were located in the lake. Of 20 radio transmitters applied to late run fish, 16 were located in the lake and 4 were located in the Klukshu River. Liz Fillatre, University of Northern B. C. student, has found genetic separation in early and late run fish that returned in 1999. She also found genetic separation, based on scale sample DNA, in the 1997 return. She proposes to investigate DNA of juveniles in the lake and stream habitats to determine if river hatched sockeye are migrating into and rearing in Klukshu Lake.

U.S. and in Canada while achieving the same distribution of early and late run components that existed during the base line years used to estimate the overall MSY escapement range.

## STOCK STATUS OF KLUKSHU SOCKEYE SALMON GIVEN MSY ESCAPEMENT GOAL

Since 1976, only one of the twenty-two (5%) annual Klukshu River sockeye salmon escapements were below the range of escapements that we have estimated will produce maximum sustained yield and that occurred in 1979 when the escapement totaled 7,051 spawners (Table 14). Of the twenty-one other annual escapements, 9 (40%) were within the range of escapements estimated to produce maximum sustained yield while 12 (55%) were above that range. This pattern of escapements indicates that the Klukshu River stock of sockeye salmon is healthy, but has been underutilized, particularly the latter portions of the annual runs.

The escapement patterns since 1976 indicate that a surplus of Klukshu River system sockeye salmon have been available in most years beyond the harvests that have occurred in Canadian and U.S. fisheries. Assuming fishery managers can successfully control escapements within our recommended range of 7,500 to 15,000 sockeye salmon spawners into the Klukshu system, a potential increase in sustainable harvest is anticipated.

## RECOMMENDATIONS

We recommend that the following biological escapement goal for the Klukshu River system stock of sockeye salmon be formally adopted by the Canadian Department of Fisheries and Oceans, by the Alaska Department of Fish and Game, and by the Transboundary Technical Committee of the Pacific Salmon Commission: **Klukshu Sockeye Salmon: 7,500 to 15,000 spawners per year.**

We also recommend that this biological escapement goal analysis be updated in the year 2004 because at that time, significantly more information will be available for further development and refinement of the overall spawner-recruit relationship. Further, it may be that early and late run objectives can be identified within such a time frame. Refinement and further development of these relationships may lead to improved escapement goals that will better result in MSY fisheries.

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

1. Further research of the proportion of Klukshu sockeye salmon caught in the Dry Bay fishery. This work should advance knowledge gained from the McBride and Bernard (1984) work by the thorough application of tags across a several year period. It will be important to determine annual variation in this proportion as well as within-season variation (early versus late proportions across several years).
2. Further investigation of the potential life history differences between early and late run segments of the Klukshu sockeye stock. These investigations should be focused to discern whether or not these segments spawn and rear in the same locations as well as determine potential stock identification tools that can be applied to fish caught in fisheries and passing upstream of the weir.

3. Consider marking sockeye salmon smolts migrating from Klukshu Lake with coded wire tags and monitor downstream fisheries in the U.S. for eventual tag recovery.

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Table 1. Klukshu River weir counts of sockeye salmon and estimated annual escapements.

| Year | Annual Klukshu River Weir Count of Sockeye Salmon | Klukshu River Weir Count of Sockeye Salmon Through August 15th | Klukshu River Weir Count of Sockeye Salmon After August 15th | Annual Estimated Number of Sockeye Salmon Removed | Estimated Annual Escapement of Sockeye Salmon |
|---|---|---|---|---|---|
| 1976 | 11,691 | 181 | 11,510 | 3,750 | 7,941 |
| 1977 | 26,791 | 8,931 | 17,860 | 11,350 | 15,441 |
| 1978 | 26,867 | 2,508 | 24,359 | 7,850 | 19,017 |
| 1979 | 12,311 | 977 | 11,334 | 5,260 | 7,051 |
| 1980 | 11,750 | 1,008 | 10,742 | 900 | 10,850 |
| 1981 | 20,348 | 997 | 19,351 | 1,900 | 18,448 |
| 1982 | 33,699 | 7,758 | 25,941 | 4,800 | 28,899 |
| 1983 | 20,492 | 6,047 | 14,445 | 2,475 | 18,017 |
| 1984 | 12,727 | 2,769 | 9,958 | 2,500 | 10,227 |
| 1985 | 18,620 | 539 | 18,081 | 1,361 | 17,259 |
| 1986 | 24,850 | 416 | 24,434 | 1,914 | 22,936 |
| 1987 | 10,504 | 3,269 | 7,235 | 1,158 | 9,346 |
| 1988 | 9,341 | 585 | 8,756 | 1,604 | 7,737 |
| 1989 | 23,542 | 3,400 | 20,142 | 1,906 | 21,636 |
| 1990 | 25,995 | 1,316 | 24,679 | 1,388 | 24,607 |
| 1991 | 18,977 | 1,924 | 17,053 | 1,332 | 17,645 |
| 1992 | 19,767 | 11,339 | 8,428 | 1,498 | 18,269 |
| 1993 | 16,740 | 5,369 | 11,371 | 1,819 | 14,921 |
| 1994 | 15,038 | 3,247 | 11,791 | 1,146 | 13,892 |
| 1995 | 20,696 | 2,289 | 18,407 | 879 | 19,817 |
| 1996 | 8,320 | 1,502 | 6,818 | 429 | 7,891 |
| 1997 | 11,496 | 6,565 | 4,931 | 193 | 11,303 |
| Average | 18,207 | 3,315 | 14,892 | 2,610 | 15,598 |
| Minimum | 8,320 | 181 | 4,931 | 193 | 7,051 |
| Maximum | 33,699 | 11,339 | 25,941 | 11,350 | 28,899 |

**Data Source:**

Klukshu River weir counts and annual escapement estimates data taken from TBR (1998). Annual numbers of sockeye salmon removed represents the combination of fishery harvests above the weir and fish removed for brood stock.

Table 2. Harvests of sockeye salmon in Canadian Alsek drainage fisheries, 1976-1997.

| Year | Indian Food Fishery Harvests | Indian Food Fishery Harvests Below Klukshu Weir | Sport Fishery Harvests | Sport Fishery Harvests Estimated to be of Klukshu Origin |
|---|---|---|---|---|
| 1976 | 4,000 | 0 | 600 | 540 |
| 1977 | 10,000 | 0 | 500 | 450 |
| 1978 | 8,000 | 0 | 500 | 450 |
| 1979 | 7,000 | 0 | 750 | 675 |
| 1980 | 800 | 0 | 600 | 540 |
| 1981 | 2,000 | 0 | 808 | 727 |
| 1982 | 5,000 | 0 | 755 | 680 |
| 1983 | 2,550 | 0 | 732 | 659 |
| 1984 | 2,600 | 0 | 289 | 260 |
| 1985 | 1,361 | 0 | 100 | 90 |
| 1986 | 1,914 | 0 | 307 | 276 |
| 1987 | 1,158 | 0 | 383 | 345 |
| 1988 | 1,604 | 0 | 322 | 290 |
| 1989 | 1,851 | 150 | 319 | 287 |
| 1990 | 2,314 | 302 | 392 | 353 |
| 1991 | 2,111 | 602 | 303 | 273 |
| 1992 | 2,592 | 183 | 582 | 524 |
| 1993 | 2,361 | 168 | 329 | 296 |
| 1994 | 1,745 | 526 | 261 | 235 |
| 1995 | 1,745 | 780 | 682 | 614 |
| 1996 | 1,204 | 614 | 157 | 141 |
| 1997 | 484 | 284 | 36 | 32 |
| Average | 2,927 | 164 | 441 | 397 |
| Minimum | 484 | 0 | 36 | 32 |
| Maximum | 10,000 | 780 | 808 | 727 |

**Data Source:**

Overall Indian food fishery and sport fishery harvest data taken from TBR (1998). Sockeye salmon sport fishery harvests are assumed to be 90% Klukshu origin based upon location and timing of fishery. Estimates of the Indian food fishery harvests below the Klukshu weir are from data files of the Canadian Department of Fisheries and Oceans, Whitehorse, Yukon Territory, Canada.

Table 3. Age composition of sockeye salmon sampled from the Canadian fishery or at the Klukshu River weir.

| | Age Composition of Canadian Sockeye Harvests and Escapement: | | | | | Sample | Sample |
|---|---|---|---|---|---|---|---|
| Year | Age 3 | Age 4 | Age 5 | Age 6 | Total | Size | Source |
| 1976 | 5% | 86% | 9% | 0% | 100% | 446 | IFF |
| 1977 | 1% | 52% | 45% | 2% | 100% | 178 | IFF |
| 1978 | 0% | 20% | 77% | 3% | 100% | 90 | IFF |
| 1979 | 0% | 22% | 69% | 9% | 100% | 174 | IFF |
| 1980 | 0% | 26% | 74% | 0% | 100% | 72 | IFF |
| 1981 | 1% | 43% | 56% | 0% | 100% | 233 | IFF |
| 1982 | 0% | 17% | 82% | 1% | 100% | 166 | IFF |
| 1983 | 0% | 5% | 95% | 0% | 100% | 445 | Weir |
| 1984 | 0% | 2% | 96% | 2% | 100% | 154 | Weir |
| 1985 | 0% | 14% | 84% | 2% | 100% | 204 | Weir |
| 1986 | 0% | 18% | 81% | 1% | 100% | 528 | Weir |
| 1987 | 0% | 20% | 79% | 1% | 100% | 407 | Weir |
| 1988 | 0% | 16% | 77% | 7% | 100% | 485 | Weir |
| 1989 | 0% | 30% | 70% | 0% | 100% | 699 | Weir |
| 1990 | 0% | 6% | 94% | 0% | 100% | 688 | Weir |
| 1991 | 0% | 17% | 82% | 1% | 100% | 494 | Weir |
| 1992 | 0% | 8% | 91% | 1% | 100% | 700 | Weir |
| 1993 | 0% | 17% | 81% | 2% | 100% | 753 | Weir |
| 1994 | 0% | 35% | 64% | 1% | 100% | 431 | Weir |
| 1995 | 0% | 4% | 96% | 0% | 100% | 677 | Weir |
| 1996 | 2% | 13% | 82% | 3% | 100% | 354 | Weir |
| 1997 | 0% | 4% | 91% | 5% | 100% | 989 | Weir |
| Average | 0% | 22% | 76% | 2% | - | 426 | - |
| Minimum | 0% | 2% | 9% | 0% | - | 72 | - |
| Maximum | 5% | 86% | 96% | 9% | - | 989 | - |

**Note:**

Under the column labeled sample source, IFF means sockeye were sampled for age composition from the Canadian Indian food fishery (Canadian aboriginal fishery), and Weir means sockeye were sampled for age composition at the Klukshu River weir.

Table 4. Estimated age specific Klukshu River system origin sockeye salmon in the annual terminal returns to Canada.

| Year | Age 3 | Age 4 | Age 5 | Age 6 |
|---|---|---|---|---|
| 1976 | 612 | 10,519 | 1,101 | 0 |
| 1977 | 272 | 14,165 | 12,258 | 545 |
| 1978 | 0 | 5,463 | 21,034 | 820 |
| 1979 | 0 | 2,857 | 8,960 | 1,169 |
| 1980 | 0 | 3,195 | 9,095 | 0 |
| 1981 | 211 | 9,062 | 11,802 | 0 |
| 1982 | 0 | 5,844 | 28,191 | 344 |
| 1983 | 0 | 1,058 | 20,093 | 0 |
| 1984 | 0 | 260 | 12,468 | 260 |
| 1985 | 0 | 2,619 | 15,716 | 374 |
| 1986 | 0 | 4,523 | 20,352 | 251 |
| 1987 | 0 | 2,170 | 8,571 | 108 |
| 1988 | 0 | 1,541 | 7,416 | 674 |
| 1989 | 0 | 7,194 | 16,785 | 0 |
| 1990 | 0 | 1,599 | 25,051 | 0 |
| 1991 | 0 | 3,375 | 16,279 | 199 |
| 1992 | 0 | 1,638 | 18,631 | 205 |
| 1993 | 0 | 2,925 | 13,935 | 344 |
| 1994 | 0 | 5,530 | 10,111 | 158 |
| 1995 | 0 | 884 | 21,206 | 0 |
| 1996 | 182 | 1,180 | 7,442 | 272 |
| 1997 | 0 | 472 | 10,749 | 591 |
| Average | 58 | 4,003 | 14,420 | 287 |
| Minimum | 0 | 260 | 1,101 | 0 |
| Maximum | 612 | 14,165 | 28,191 | 1,169 |

Table 5. Harvests of sockeye salmon in U.S. Alsek fisheries, 1976-1997.

| Year | Commercial River Fishery | Commercial Surf Fishery | Subsistence Fishery | Total Harvest |
|---|---|---|---|---|
| 1976 | 19,741 | 0 | 51 | 19,792 |
| 1977 | 40,780 | 0 | 113 | 40,893 |
| 1978 | 50,580 | 0 | 0 | 50,580 |
| 1979 | 41,449 | 0 | 35 | 41,484 |
| 1980 | 25,522 | 0 | 41 | 25,563 |
| 1981 | 23,641 | 0 | 50 | 23,691 |
| 1982 | 27,423 | 0 | 75 | 27,498 |
| 1983 | 17,637 | 656 | 25 | 18,318 |
| 1984 | 12,751 | 1,575 | 0 | 14,326 |
| 1985 | 5,940 | 0 | 95 | 6,035 |
| 1986 | 24,791 | 0 | 241 | 25,032 |
| 1987 | 11,393 | 0 | 173 | 11,566 |
| 1988 | 6,194 | 92 | 148 | 6,434 |
| 1989 | 12,268 | 1,245 | 131 | 13,644 |
| 1990 | 17,013 | 0 | 144 | 17,157 |
| 1991 | 17,542 | 0 | 104 | 17,646 |
| 1992 | 18,832 | 478 | 37 | 19,347 |
| 1993 | 19,295 | 748 | 80 | 20,123 |
| 1994 | 17,998 | 1,641 | 45 | 19,684 |
| 1995 | 30,595 | 2,517 | 167 | 33,279 |
| 1996 | 13,755 | 1,427 | 67 | 15,249 |
| 1997 | 23,056 | 2,823 | 273 | 26,152 |
| Avg | 21,736 | 600 | 95 | 22,432 |
| Min | 5,940 | 0 | 0 | 6,035 |
| Max | 50,580 | 2,823 | 273 | 50,580 |

**Data Source:**

Harvest data for the years 1976-1994 taken from Clark, Burkholder, and Clark (1995). Commercial harvest and subsistence/personal use harvest data for the years 1995-1997 taken from an ALEX computer run dated 9/21/98.

Table 6. Age composition of sockeye salmon sampled from the U.S. Alsek fishery, 1982-1997.

| | Age Composition of U.S. Alsek Sockeye Salmon Harvests: | | | | | |
|---|---|---|---|---|---|---|
| Year | Age 3 | Age 4 | Age 5 | Age 6 | Total | Sample Size |
| 1982 | 1% | 19% | 73% | 7% | 100% | 1,556 |
| 1983 | 1% | 11% | 88% | 0% | 100% | 2,011 |
| 1984 | 1% | 11% | 86% | 2% | 100% | 1,892 |
| 1985 | 1% | 32% | 64% | 3% | 100% | 1,521 |
| 1986 | 2% | 22% | 69% | 7% | 100% | 1,647 |
| 1987 | 0% | 14% | 83% | 3% | 100% | 1,653 |
| 1988 | 1% | 17% | 79% | 3% | 100% | 1,338 |
| 1989 | 1% | 19% | 75% | 5% | 100% | 746 |
| 1990 | 1% | 31% | 62% | 6% | 100% | 614 |
| 1991 | 0% | 21% | 71% | 8% | 100% | 483 |
| 1992 | 1% | 15% | 79% | 5% | 100% | 523 |
| 1993 | 0% | 16% | 72% | 12% | 100% | 496 |
| 1994 | 0% | 21% | 74% | 5% | 100% | 455 |
| 1995 | 0% | 13% | 84% | 3% | 100% | 622 |
| 1996 | 0% | 10% | 87% | 3% | 100% | 516 |
| 1997 | 1% | 18% | 78% | 3% | 100% | 541 |
| Average | 1% | 18% | 76% | 5% | 100% | 1,038 |
| Minimum | 0% | 10% | 62% | 0% | - | 455 |
| Maximum | 32% | 32% | 88% | 12% | - | 2,011 |

**Data Source:**

Age composition for the years 1982-1994 taken from Clark, Burkholder, and Clark (1995); age composition for the years 1995-1997 provided by Glen T. Oliver (personal communication).

**Note:**

Because sampling for age composition of sockeye salmon harvested in the U.S. Alsek fishery in the years 1976-1981 did not occur, average age composition from sampled years was used as a proxy for each of these years (i.e., age 3 - 1%, age 4 - 18%, age 5 - 76%, and age 6 - 5%). This assumption has little effect on the analysis because few of these cohort returns were used in the spawner-recruit analysis (cohorts used in spawner-recruit analysis with assumed average age composition: age 3s from the years 1979, 1980, and 1981, age 4s from the years 1980 and 1981, and age 6s from the year 1981).

Table 7. Estimated annual total returns of Klukshu River origin sockeye salmon, 1976-1997.

| Year | Annual Klukshu River Weir Count of Sockeye Salmon | Estimated Indian Food Fishery Harvests Below Klukshu Weir | Canadian Sport Fishery Harvests Assumed to be of Klukshu Origin | U.S. Alsek Fishery Harvests Assumed to be of Klukshu Origin (37%) | Estimated Total Annual Return of Klukshu River Origin Sockeye Salmon |
|---|---|---|---|---|---|
| 1976 | 11,691 | 0 | 540 | 7,323 | 19,554 |
| 1977 | 26,791 | 0 | 450 | 15,130 | 42,371 |
| 1978 | 26,867 | 0 | 450 | 18,715 | 46,032 |
| 1979 | 12,311 | 0 | 675 | 15,349 | 28,335 |
| 1980 | 11,750 | 0 | 540 | 9,458 | 21,748 |
| 1981 | 20,348 | 0 | 727 | 8,766 | 29,841 |
| 1982 | 33,699 | 0 | 680 | 10,174 | 44,553 |
| 1983 | 20,492 | 0 | 659 | 6,778 | 27,929 |
| 1984 | 12,727 | 0 | 260 | 5,301 | 18,288 |
| 1985 | 18,620 | 0 | 90 | 2,233 | 20,943 |
| 1986 | 24,850 | 0 | 276 | 9,262 | 34,388 |
| 1987 | 10,504 | 0 | 345 | 4,279 | 15,128 |
| 1988 | 9,341 | 0 | 290 | 2,381 | 12,012 |
| 1989 | 23,542 | 150 | 287 | 5,048 | 29,027 |
| 1990 | 25,995 | 302 | 353 | 6,348 | 32,998 |
| 1991 | 18,977 | 602 | 273 | 6,529 | 26,381 |
| 1992 | 19,767 | 183 | 524 | 7,158 | 27,632 |
| 1993 | 16,740 | 168 | 296 | 7,446 | 24,650 |
| 1994 | 15,038 | 526 | 235 | 7,283 | 23,082 |
| 1995 | 20,696 | 780 | 614 | 12,313 | 34,403 |
| 1996 | 8,320 | 614 | 141 | 5,642 | 14,717 |
| 1997 | 11,496 | 284 | 32 | 9,676 | 21,488 |
| Average | 18,207 | 164 | 397 | 8,300 | 27,068 |
| Minimum | 8,320 | 0 | 32 | 2,233 | 12,012 |
| Maximum | 33,699 | 780 | 727 | 18,715 | 46,032 |

**Data Source:**

Klukshu River weir counts from Table 1, column 2; Canadian harvest estimates from Table 2, columns 3 and 5; and the total U.S. Alsek fishery harvest estimates from Table 5, column 5 multiplied by 0.37.

Table 8. Estimated age specific Klukshu River system origin sockeye salmon in annual returns.

| Year | Age 3 | Age 4 | Age 5 | Age 6 |
|---|---|---|---|---|
| 1976 | 685 | 11,837 | 6,666 | 366 |
| 1977 | 424 | 16,889 | 23,758 | 1,301 |
| 1978 | 187 | 8,832 | 35,257 | 1,755 |
| 1979 | 153 | 5,620 | 20,626 | 1,936 |
| 1980 | 95 | 4,898 | 16,283 | 473 |
| 1981 | 298 | 10,640 | 18,464 | 438 |
| 1982 | 102 | 7,778 | 35,618 | 1,056 |
| 1983 | 68 | 1,803 | 26,058 | 0 |
| 1984 | 53 | 843 | 17,026 | 366 |
| 1985 | 22 | 3,334 | 17,145 | 441 |
| 1986 | 185 | 6,560 | 26,743 | 900 |
| 1987 | 0 | 2,769 | 12,123 | 237 |
| 1988 | 24 | 1,946 | 9,297 | 746 |
| 1989 | 50 | 8,153 | 20,572 | 252 |
| 1990 | 63 | 3,567 | 28,987 | 381 |
| 1991 | 0 | 4,746 | 20,914 | 721 |
| 1992 | 72 | 2,712 | 24,286 | 563 |
| 1993 | 0 | 4,116 | 19,296 | 1,238 |
| 1994 | 0 | 7,059 | 15,501 | 522 |
| 1995 | 0 | 2,484 | 31,550 | 369 |
| 1996 | 182 | 1,744 | 12,350 | 442 |
| 1997 | 97 | 2,214 | 18,296 | 881 |
| Average | 125 | 5,479 | 20,764 | 699 |
| Minimum | 0 | 843 | 6,666 | 0 |
| Maximum | 685 | 16,889 | 35,618 | 1,936 |

Table 9. Estimated recruits by age from escapements of Klukshu River sockeye salmon, 1976-1992.

| Brood Year | Estimated Age 3 Recruits | Estimated Age 4 Recruits | Estimated Age 5 Recruits | Estimated Age 6 Recruits | Estimated Total Recruits |
|---|---|---|---|---|---|
| 1976 | 153 | 4,898 | 18,464 | 1,056 | 24,571 |
| 1977 | 95 | 10,640 | 35,618 | 0 | 46,353 |
| 1978 | 298 | 7,778 | 26,058 | 366 | 34,499 |
| 1979 | 102 | 1,803 | 17,026 | 441 | 19,372 |
| 1980 | 68 | 843 | 17,145 | 900 | 18,956 |
| 1981 | 53 | 3,334 | 26,743 | 237 | 30,367 |
| 1982 | 22 | 6,560 | 12,123 | 746 | 19,451 |
| 1983 | 185 | 2,769 | 9,297 | 252 | 12,503 |
| 1984 | 0 | 1,946 | 20,572 | 381 | 22,898 |
| 1985 | 24 | 8,153 | 28,987 | 721 | 37,884 |
| 1986 | 50 | 3,567 | 20,914 | 563 | 25,094 |
| 1987 | 63 | 4,746 | 24,286 | 1,238 | 30,333 |
| 1988 | 0 | 2,712 | 19,296 | 522 | 22,530 |
| 1989 | 72 | 4,116 | 15,501 | 369 | 20,058 |
| 1990 | 0 | 7,059 | 31,550 | 442 | 39,050 |
| 1991 | 0 | 2,484 | 12,350 | 881 | 15,715 |
| 1992 | 0 | 1,744 | 18,296 | 699 | 20,740 |
| Average | 70 | 4,421 | 20,837 | 577 | 25,904 |
| Minimum | 0 | 843 | 9,297 | 0 | 12,503 |
| Maximum | 298 | 10,640 | 35,618 | 1,238 | 46,353 |

**Note:**

The age-6 component of the brood year 1992 recruitment is based upon average age-6 recruitment. All age specific estimates listed above are also provided on a return year basis in Appendix Table 1.

Table 10. Estimated brood year escapements of sockeye salmon into the Klukshu River and estimated resultant recruitment from these escapements under three alternate assumptions concerning the origin of sockeye salmon harvested in the U.S. Alsek fishery.

| Brood Year | Estimated Escapement | Estimated Recruits Assuming U.S. Harvest is 37% Klukshu Origin Sockeye Salmon (Model 1) | Estimated Recruits Assuming U.S. Harvests No Klukshu Origin Sockeye Salmon (Model 2) | Estimated Recruits Assuming 100% of U.S. Harvest is Klukshu Origin Sockeye Salmon (Model 3) |
|---|---|---|---|---|
| 1976 | 7,941 | 24,571 | 15,341 | 40,287 |
| 1977 | 15,441 | 46,353 | 37,253 | 61,847 |
| 1978 | 19,017 | 34,499 | 26,408 | 48,276 |
| 1979 | 7,051 | 19,372 | 13,899 | 28,691 |
| 1980 | 10,850 | 18,956 | 16,227 | 23,601 |
| 1981 | 18,448 | 30,367 | 23,080 | 42,773 |
| 1982 | 28,899 | 19,451 | 13,768 | 29,128 |
| 1983 | 18,017 | 12,503 | 9,586 | 17,471 |
| 1984 | 10,227 | 22,898 | 18,326 | 30,682 |
| 1985 | 17,259 | 37,884 | 32,443 | 47,149 |
| 1986 | 22,936 | 25,094 | 18,082 | 37,034 |
| 1987 | 9,346 | 30,333 | 22,350 | 43,926 |
| 1988 | 7,737 | 22,530 | 15,731 | 34,106 |
| 1989 | 21,636 | 20,058 | 13,036 | 32,014 |
| 1990 | 24,607 | 39,050 | 27,008 | 59,554 |
| 1991 | 17,645 | 15,715 | 8,916 | 27,293 |
| 1992 | 18,269 | 20,740 | 12,216 | 35,253 |
| Average | 16,196 | 25,904 | 19,039 | 37,593 |
| Minimum | 7,051 | 12,503 | 8,916 | 17,471 |
| Maximum | 28,899 | 46,353 | 37,253 | 61,847 |

Table 11. Estimated age specific Klukshu River system origin sockeye salmon in annual returns assuming all sockeye harvested in the U.S. Alsek fishery are of Klukshu origin.

| Year | Age 3 | Age 4 | Age 5 | Age 6 |
|---|---|---|---|---|
| 1976 | 809 | 14,081 | 16,143 | 990 |
| 1977 | 681 | 21,526 | 43,337 | 2,589 |
| 1978 | 506 | 14,568 | 59,475 | 3,349 |
| 1979 | 415 | 10,324 | 40,488 | 3,243 |
| 1980 | 256 | 7,797 | 28,522 | 1,278 |
| 1981 | 448 | 13,327 | 29,807 | 1,185 |
| 1982 | 275 | 11,069 | 48,264 | 2,269 |
| 1983 | 183 | 3,073 | 36,213 | 0 |
| 1984 | 143 | 1,836 | 24,788 | 546 |
| 1985 | 60 | 4,551 | 19,579 | 555 |
| 1986 | 501 | 10,030 | 37,624 | 2,004 |
| 1987 | 0 | 3,789 | 18,170 | 455 |
| 1988 | 64 | 2,635 | 12,499 | 867 |
| 1989 | 136 | 9,786 | 27,018 | 682 |
| 1990 | 172 | 6,918 | 35,688 | 1,029 |
| 1991 | 0 | 7,081 | 28,807 | 1,610 |
| 1992 | 193 | 4,540 | 33,915 | 1,172 |
| 1993 | 0 | 6,144 | 28,424 | 2,759 |
| 1994 | 0 | 9,663 | 24,678 | 1,142 |
| 1995 | 0 | 5,210 | 49,161 | 998 |
| 1996 | 182 | 2,705 | 20,708 | 730 |
| 1997 | 262 | 5,180 | 31,147 | 1,375 |
| Average | 240 | 7,992 | 31,566 | 1,401 |
| Minimum | 0 | 1,836 | 12,499 | 0 |
| Maximum | 809 | 21,526 | 59,475 | 3,349 |

Table 12. Stock-recruitment relationship statistics under three alternate assumptions concerning the origin of sockeye salmon harvested in the U.S. Alsek fishery.

| Stock-Recruitment Relationship Statistic | Statistics Assuming U.S. Harvest is 37% Klukshu Origin Sockeye Salmon (Model 1) | Statistics Assuming U.S. Harvests No Klukshu Origin Sockeye Salmon (Model 2) | Statistics Assuming U.S. Harvest is 100% Klukshu Origin Sockeye Salmon (Model 3) |
|---|---|---|---|
| Ricker Alpha | 4.5858 | 3.4309 | 6.4761 |
| Ricker Beta | -0.00006332 | -0.00006573 | -0.00006114 |
| Number of Data Pairs | 17 | 17 | 17 |
| MSY Escapement Level | 9,505 | 7,806 | 11,313 |
| Est. Maximum Yield | 14,371 | 8,226 | 25,373 |
| Est. MSY Exploit. Rate | 60% | 51% | 69% |

Table 13. Estimates of spawner-recruit parameters (alphas and betas; intercepts and slopes of regressions) and associated precision for the bootstrap data set (n = 2,000) used to estimate the escapement level that produces maximum sustained yield for sockeye salmon in the Klukshu River (Model 1 data set; i.e., the U.S. harvest is assumed to be comprised of 37% Klukshu origin sockeye salmon).

| Statistic | Maximum Sustained Yield Escapement Level | Ricker Alpha | Ricker Beta |
|---|---|---|---|
| Mean | 9,361 | 5.0532 | -0.0000675 |
| Standard Deviation | 1,222 | 1.3065 | -0.0000149 |
| Coefficient of Variation | 13.1% | 25.9% | 22.0% |
| Lower 90% C.I. | 7,749 | | |
| Upper 90% C.I. | 11,672 | | |

Table 14. Years when annual Klukshu River system sockeye salmon escapements were below, within or above the biological escapement goal range recommended in this report.

| Recommended Biological Escapement Goal | Years When Escapement Was Below Recommended Goal | **Years When Escapement Was Within Recommended Goal Range** | Years When Escapement Was Above Recommended Goal |
|---|---|---|---|
| **7,500-15,000 Spawners** | 1979 | 1976, 1980, 1984, 1987, 1988, 1993, 1994, 1996, 1997 | 1977, 1978, 1981, 1982, 1983, 1985, 1986, 1989, 1990, 1991, 1992, 1995 |

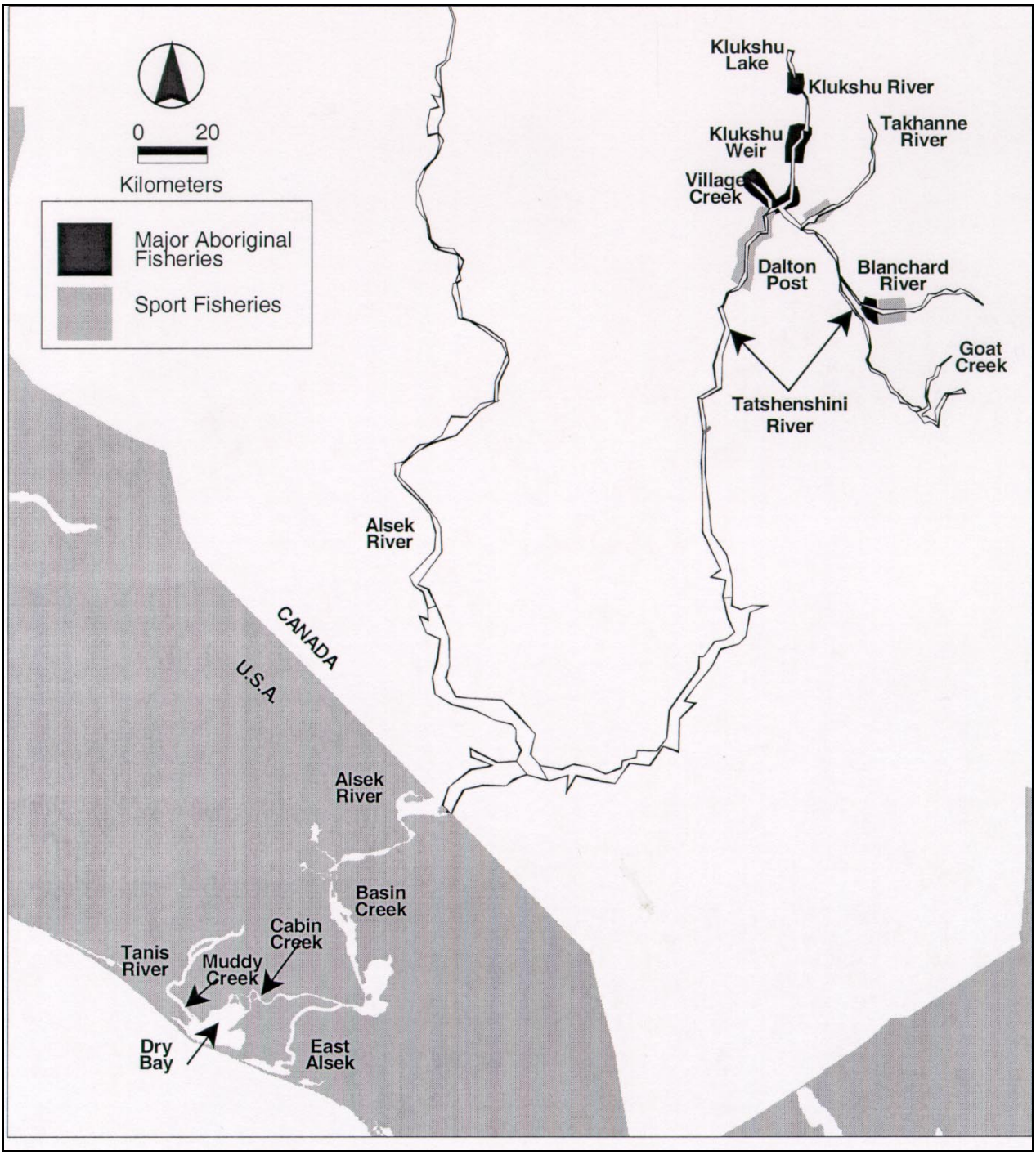


Figure 1. Map of the Alsek River and principal U.S. and Canadian fishing areas.

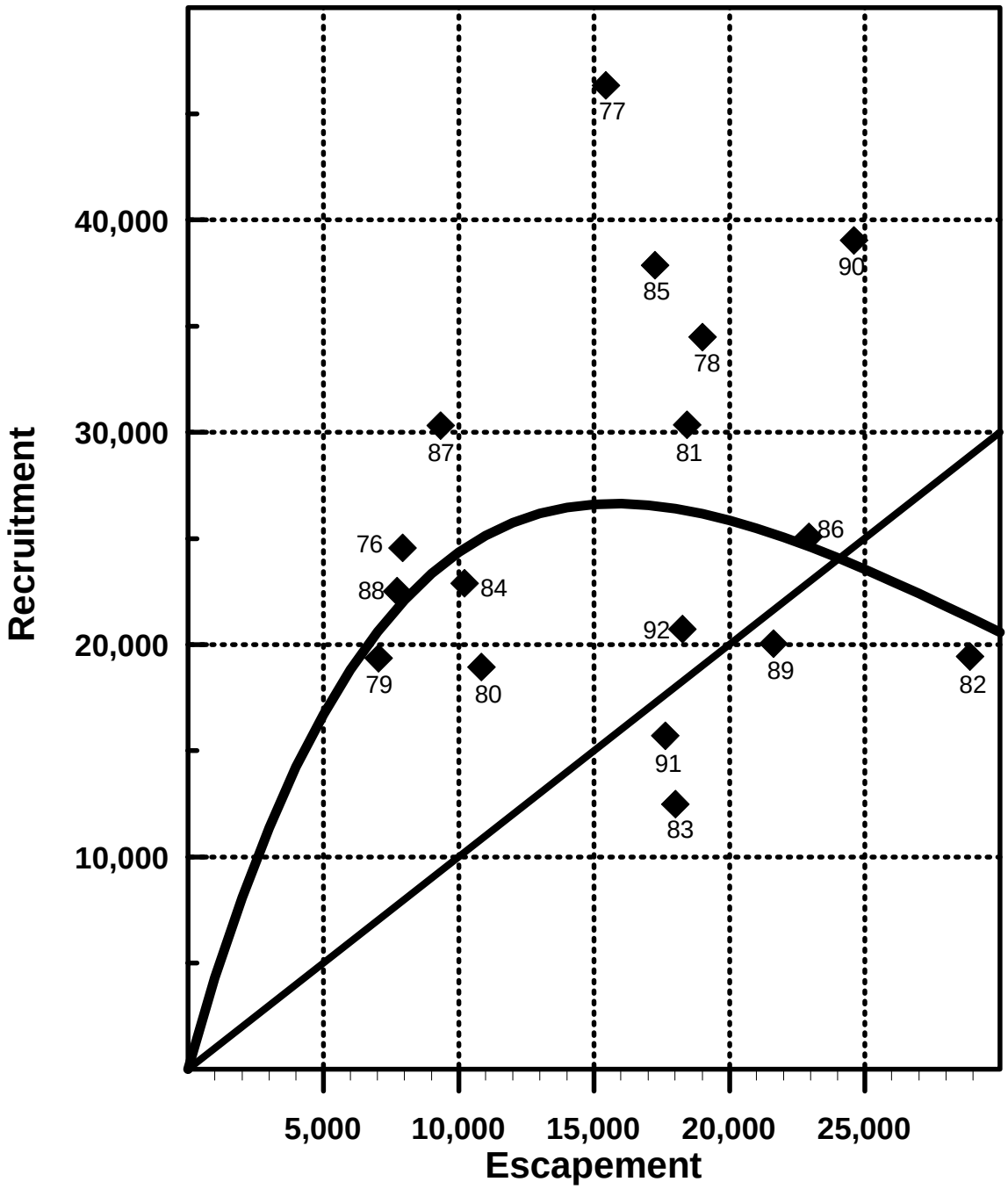


Figure 2. Spawner-recruit relationship for Klukshu River sockeye salmon (brood years 1976-1992). The recommended biological escapement goal is 7,500 to 15,000 spawners based upon the methodology of Eggers (1993) and the point escapement level predicted to provide for maximum sustained yield (9,505 spawners).

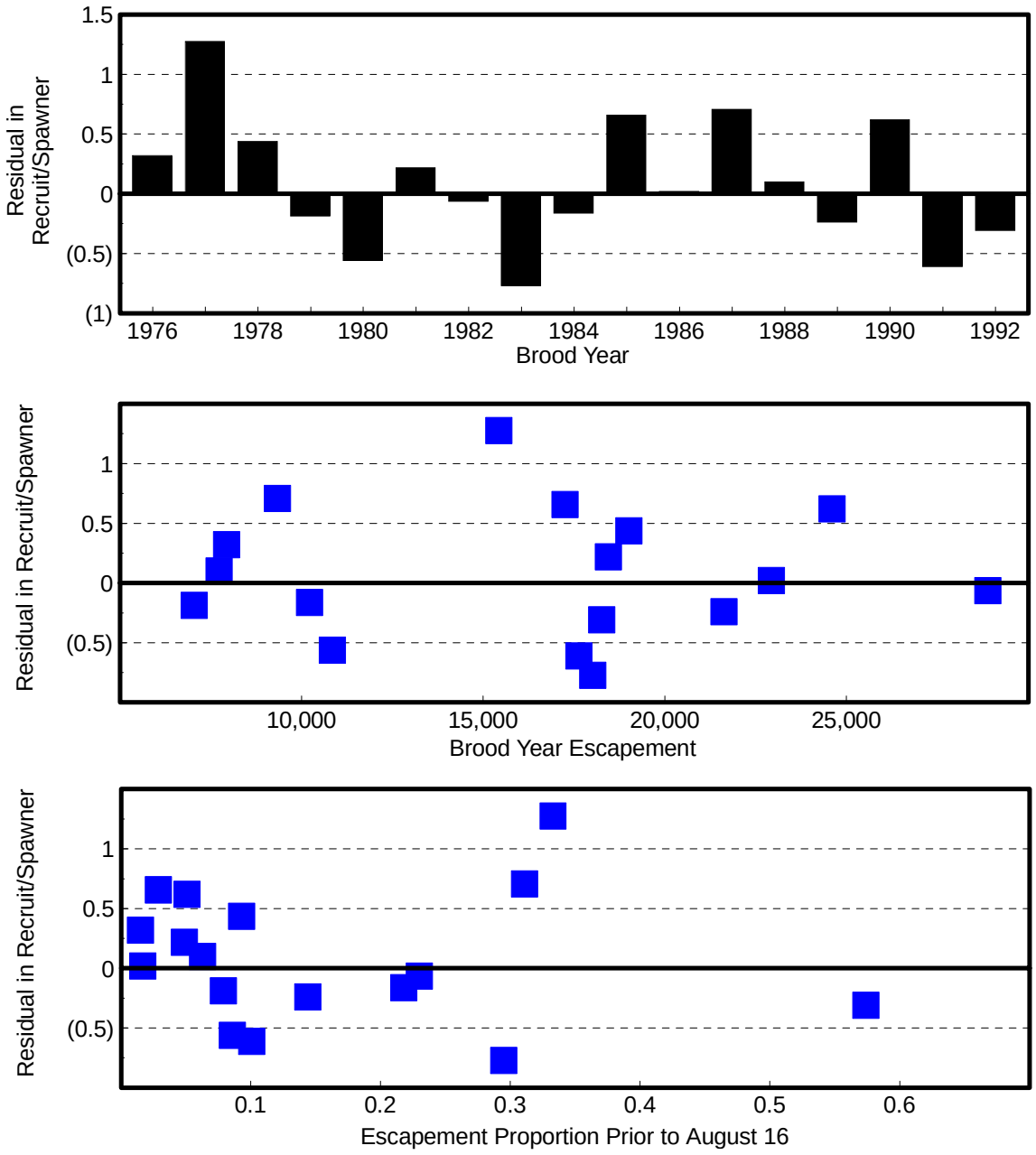


Figure 3. Residuals in the brood year 1976-1992 spawner-recruit relationship for Klukshu sockeye salmon; residuals versus brood year (upper panel), residuals versus brood year escapements (middle panel), and residuals versus the proportion of annual escapement that passed the Klukshu River weir before August 16th (lower panel).

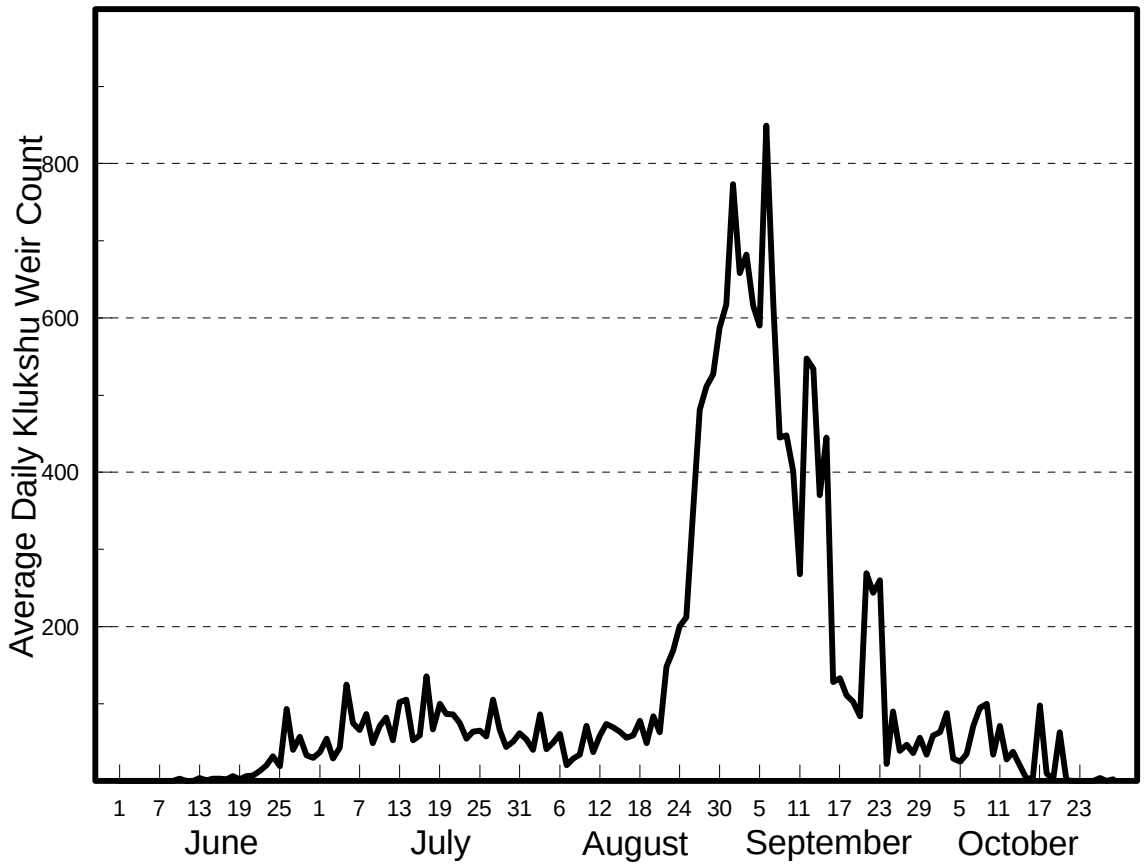


Figure 4. Average daily counts of sockeye salmon at the Klukshu River weir, 1976-1997. The average proportion of sockeye salmon counted at the weir prior to August 16th is 15%.

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