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YUKON RIVER SONAR ESCAPEMENT ESTIMATE

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by

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ABSTRACT

The Yukon River sonar project was designed to provide estimates of daily escapement past lower-river commercial and subsistence fisheries for chinook, summer and fall chum, and coho salmon. The sampling site, located at river km 197, has been used for this purpose since 1985. Fish passage was estimated through temporal and spatial expansion of fish counts obtained through hydroacoustic gear deployed on both banks of the river between 8 June and 11 September 1989. A gill net test fishery sampled the migrant fish population to provide information on which to base apportionment of sonar counts to species. Six gill nets ranging from 101.6 to 215.9 mm stretched mesh were used to capture fish. Catches were adjusted for gill net selectivity and effort, and were used to estimate species proportions. A total of 2,794,328 fish passed the sampling site; 71 percent traveled along the left bank while 29 percent traveled along the right bank. The program estimated passage of 79,362 chinook salmon, 1,622,331 summer chum salmon, 684,840 fall chum salmon, and 174,631 coho salmon during the time period sampled. Peak passage occurred on 18 June, 20 June, 08 August, and 21 August for chinook, summer chum, fall chum, and coho salmon.

KEY WORDS: salmon, hydroacoustic, Yukon River, species apportionment, escapement

INTRODUCTION

Yukon River salmon stocks are harvested for both commercial and subsistence use. Although the most intense fishery occurs within 240 km of the river mouth, salmon stocks are exploited over more than 1,600 km of river in Alaska and Canada. Management of the fisheries resource requires timely knowledge of run strength and escapement levels. Such information, however, is difficult to obtain in the Yukon River due to its large size, multiple channels, and highly turbid water. Fishery managers therefore base their decisions on information obtained from several sources, each of which has unique strengths and weaknesses.

Visual surveys of distant clear-water spawning tributaries provide stock specific indices of escapement. These indices, however, are highly dependent upon survey timing and spawner stream life, may not be representative of system escapement levels, and are not available for in-season management use. Similarly, sonar estimates of salmon escapement in spawning tributaries are not timely enough to provide a basis for decision making, and only provide information for a single fish stock. Test fishery gill net indices obtained near the river mouth provide in-season information, but interpretation of this information is confounded by gill net selectivity, changes in net site characteristics, and inter-annual variability in fish migration paths through the three river mouth channels.

Estimation of fish passage in the mainstem Yukon River attempts to solve the problems associated with other abundance indexing and estimating methods. Location of the sonar sampling site at River km 197 limits the delay between the lowermost commercial fishery and the point of estimation to approximately three days migration time. Additionally, there is only one important spawning tributary (Andreafsky River) downstream from the sonar sampling site, making it possible to estimate the number of salmon returning to most of the Yukon River drainage.

The Yukon River sonar project has provided management with timely in-season run strength estimates since 1986. The 1989 field season focused on the following Pacific salmon species; chinook salmon *(Oncorhynchus tshawytscha)*, chum salmon *(O. keta)*, and coho salmon *(O. kisutch)*. Specific objectives of the project were as follows:

1. Estimate, by time period, the number of fish migrating past river km 197 through:
   a. estimation of the number of fish passing river km 197 between 8 June and 11 September and,
   b. estimation of the species composition of the fish using drift gill nets of several different mesh sizes.
2. Monitor migratory run timing of salmon.

Study Area Description

The Yukon River flows approximately 2415 km from its source in the Canadian Yukon Territory to its mouth in Norton Sound along Alaska's northwest coast. The lower 193 km consists of an extensive delta area with multiple channels and unstable banks. Near the village of Pilot Station (river km 196) the river narrows to a single channel with relatively stable banks. At river km 197 the river is approximately 670 m wide and reaches a maximum depth of 27 m. The combination of physical conditions including a single channel, stable river banks, relatively narrow channel width, high water velocity, and proximity to lower river fisheries resulted in the choice of this location for deployment and operation of hydroacoustic equipment in 1983 (Mesiar et al., 1986), and continued use through 1989.

Two sites, one on the left bank and one on the right bank, were used in 1989 (Figure 1). The left bank bottom is comprised of silt and sand. Bottom contour and stability vary with hydrologic conditions; high flow rates cause dramatic changes in bottom profile over short periods of time. The right bank bottom is comprised of gravel and cobble and remains extremely stable throughout the season.

METHODS

There are two fundamental components of fish passage estimation in locations of temporally mixed species. First is estimation of the total number of fish passing the sampling site. Second is determination of species composition of the fish.

Hydroacoustic Counting

Sampling Design

The sampling design used in 1989 followed that used in previous years and documented by Mesiar et al. (1986). Experience at the sonar site has demonstrated that fish travel within 100 m of shore on the left bank and within 50 m of shore on the right bank (Nickerson and Gaudet 1985; Mesiar et al. 1986). Spatial stratification for hydroacoustic sampling was based on this knowledge as well as on knowledge of river bottom characteristics on each bank.

The left bank bottom varies within a season due to changing hydrologic conditions and silt/sand composition. As in the past, two strata, near-shore and off-shore, were ensonified due to offshore fish distribution and irregularities of the river bottom profile (Figure 2). The near-shore stratum encompassed the area from the shoreline to the break in the slope, and the off-shore stratum continued from that point to a distance of 95 m for a total range of approximately 130 m. The shallow bottom gradient, transducer beam dimensions, and fish orientation to the river bottom eliminated the need for sampling separate bottom and surface strata.

The right bank is characterized by a fairly even, stable bottom with a steep gradient (Figure 2). The lack of large bottom irregularities allows deployment of one system with two transducers to ensonify the horizontal distance necessary for detection of all migrant fish. The steep gradient requires separation of the water column into two discrete strata. The bottom stratum grazes the river bottom from shore to 86 m range and conforms to the dimensions of the acoustic beam. The surface stratum includes the remaining portion of the water column.

Based on prior analysis of the coefficient of variation of fish counts in sample intervals of five to 60 minutes (incremented by five minute steps) (Nickerson and Gaudet, 1985) a sample interval of 20 minutes was used in 1989. Sampling frequency was determined by the level of precision and accuracy deemed acceptable by fishery managers. A total of 12 sample intervals for each of the four strata are required to estimate fish passage p_i with accuracy d=0.1 and precision (α) of a one in ten chance of missing the interval $p_i \pm d$.

Each of the four strata was ensonified for four 20-minute intervals during each of three 4-hour time periods within each 24-hour day. The 4-hour time periods were 0600 to 1000 hours, 1300 to 1700 hours, and 2030 to 0030 hours.

Equipment and Procedures

Similar hydroacoustic equipment complements were used on each bank of the river. A 420 Khz Biosonics transceiver, one 4°x15° elliptical-beam transducer (nearshore) and one 6° circular-beam transducer (offshore) were used on the left bank. On the right bank, a 420 Khz Biosonics transceiver activated two 4°x15° elliptical-beam transducers (surface and bottom) with alternate pings through a Biosonics model 151 multiplexer. The transceiver emitted eight pings sec^{-1} for both right bank strata and for the left bank nearshore stratum. Four pings sec^{-1} were emitted during left bank offshore sampling. The pulse width on both left and right banks was 0.4 ms.

Transducers were attached to a tripod-mounted pan and tilt unit which allowed remote aiming, or to a stationary, manually positioned tripod used in shallow water conditions. All transducers were aimed approximately 15 degrees downstream to facilitate determination of target direction using change-in-range techniques (Appendix 1). Both sites included in-shore weirs downstream of the nearshore transducers. These were designed to deflect nearshore migrants through the acoustic beam. The right bank site also included a boom log positioned above the transducer to deflect debris.

Detected targets having voltage levels higher than a pre-set threshold level, (based on the smallest sized fish to be detected), were displayed on EPC model 3200 chart recorders. Targets appeared as dark traces within any of five range intervals on the chart recording paper. Technicians initiated sampling sequences and monitored chart recorder output.

Optimal positioning of transducers as well as spatial expansion of hydroacoustic data requires knowledge of river bottom contours. River bottom profiles (depth at distance from a reference stake) were obtained each day on the left bank, and once per week on the right bank. Both formal and informal bottom profiles were measured. Formal profiles, used for spatial expansion, were measured for each change of transducer position. One end of a 100 m fiberglass tape was held at the reference stake while the other end was carried out into the river in a boat. At three m range intervals a mark was made on a Lowrance X15 recording fathometer. The resultant depth/distance points comprised the bottom profile used for spatial expansion. Since spatial expansion of the data is dependant upon river cross sectional area, which varies with water depth, a reference depth was measured when the season's first bottom profiles were obtained, and water depth relative to that reference was measured and recorded each day.

Informal bottom profiles were also recorded with a Lowrance X15 fathometer, but distance from shore was not accurately measured as the recordings served only to give an impression of river bottom slope and irregularity for optimal transducer placement. A series of up to eight left bank bottom profiles obtained at 25 m intervals along a 200 m section of shoreline was evaluated each day to determine location of the bottom conditions most conducive to detection of fish with sonar. If the site in use at the time of bottom profile evaluation was not the most favorable, transducer repositioning to the best location was scheduled and completed within eight hours. Transducer movement at a particular site, which coincided with change in water level, was measured relative to the reference stake used for bottom profile measurement.

Analytical Methods

Technicians monitored chart recorder output during each 20 minute sample interval, classifying and counting detected targets in each of the five range intervals (sectors) in a stratum. Targets were categorized as one of the following: 1) upstream directed and assumed to be fish (u); 2) downstream directed and assumed to be debris (d); or 3) direction unknown (z). The number of upstream targets in each sector and sample interval was increased by a proportion of the targets of unknown direction resulting in the net number of upstream directed targets (n). The increase was determined from the ratio of upstream targets to all targets of known direction (u+d), or:

$$n_{i,j}=u_{i,j}+\left[\frac{u_{i,j}}{u_{i,j}+d_{i,j}}\,(z_{i,j})\right]$$

Each day the net number of upstream-directed targets in each beam sector and stratum was expanded to portions of day and areas of the beam not counted. Methods of spatial and temporal expansion are detailed in the following two sections.

Spatial Expansion. Total ensonification of the water column was not possible on the right bank. To expand net upstream fish counts for areas of the water column not sampled, beam characteristics and water cross-sectional area were quantified. For each range sector (i) of the beam in stratum k, area expansion factors were expressed as the ratio of water cross-sectional area to beam cross-sectional area. Area in each sector of the beam was calculated as $a_{i,k}$:

$$a_{i,k}=\left[\left((0.5)\,(r_{i,k}^{2})\right)\frac{b\pi}{180}\right]-\left[\left((0.5)\,(r_{i-1,k}^{2})\right)\frac{b\pi}{180}\right]$$

where: $a_{i,k}$ = area (m^2) within sector i and stratum k.

$r_{i,k}$ = distance (m) from transducer to the outer edge of sector i in stratum k.

b = beam width (degrees).

River cross-sectional areas were estimated using measurements of water level and transducer position relative to a fixed reference point, river bottom profiles, and hydroacoustic beam range. These methods are more readily visualized with the aid of the drawing presented in Figure 3. Beginning and ending ranges relative to the reference stake were calculated for each sector of the beam in a stratum. Water depths at each range were obtained from a bottom profile and were adjusted for changes in water level occurring since bottom profile measurement. Sonar beam width at range defined the upper corners of the bottom stratum, and this area was calculated as the sum of the areas of a rectangle and two right triangles. The surface stratum area for sector i was then derived as the area defined by the range beginning and end points and the two upper corners of the bottom stratum (the sum of areas of a rectangle and a right triangle). Count expansion required defining the following parameters for each of the three hydroacoustic beams used:

R_i = River cross-sectional area in sector i.
S_i = Surface stratum cross-sectional area in sector i.
B_i = Bottom stratum cross-sectional area in sector i.
s_i = starting range in sector i.
e_i = ending range in sector i.

f_i = starting depth of the bottom stratum in sector i.
g_i = ending depth of the bottom stratum in sector i.
h_i = starting depth of the surface stratum in sector i.
m_i = ending depth of the surface stratum in sector i.
t_k = relative transducer position in location k.
b = beam width in degrees.

Then:

$$R_i = 0.5(e_i - s_i)(g_i + f_i)$$

$$S_i = 0.5(e_i - s_i)(m_i + h_i)$$

$$B_i = \left(\frac{\tan b}{360}\right)(e_i - s_i)((e_i - t) + (s_i - t))$$

Temporal Expansion. The spatially expanded daily net number of upstream moving targets for each sector ($n_{i,d}^{exp}$) was divided by the proportion of the time period sampled to estimate $N_{i,d}$, the temporally and spatially expanded estimate of the number of fish in sector i on day d.

$$N_{i,d} = n_{i,d}^{exp} \frac{(24)(60)}{t_{i,d}}$$

where: $N_{i,d}$ = estimated fish passage in sector i on day d

$n_{i,d}^{exp}$ = net number of upstream targets in sector i on day d expanded for areas not sampled

$t_{i,d}$ = time (minutes) sampled in sector i on day d

Implicit in expanding the number of targets is the assumption that fish are uniformly distributed within the area or time strata being expanded.

Estimation of Missing Data. Unstable river bottom conditions on the left bank resulted in periods of time during which no acoustic data were collected. Estimation of these missing data was accomplished with a model developed using standard correlation analysis. Left bank fish count data were examined to determine the level of correlation with left and right bank gill net CPUE and with right bank fish count data. Data were stratified temporally to correspond with known changes in species composition.

Species Allocation

Sampling Design

Perhaps the most difficult component of the escapement estimation program is the allocation of sonar counts to species. The presence of migratory and resident species, with similar migratory timing and behavior and different sizes and body shapes, are primary causes of difficulty in estimation of species proportions. Gill nets are the most appropriate sampling tool available in this environment because they will capture all salmon species present and can be deployed in the spatial strata that are sampled hydroacoustically. The breadth of the size distribution of fish in the river, however, is greater than the breadth of fish sizes that may be effectively captured in any one mesh size of gill net. Therefore, it is necessary to use a suite of mesh sizes to sample the fish population.

For each fish species or similarly-sized species group encountered in the Yukon we chose two gill net mesh sizes which together would effectively capture fish throughout the entire range of previously documented lengths. Thus, two mesh sizes fished for chinook salmon, two mesh sizes fished for chum and coho salmon, and two mesh sizes fished for pink salmon, whitefish, and other species.

Since species composition varies between river banks, a stratified systematic sampling design was employed with left and right bank strata. Waters along each bank were sampled between 1000 and 1300 and between 1700 and 2000 hours each day. Time periods for allocation purposes were based on catch of 120 fish of 300 mm or greater length. Sample size was determined from multinomial proportions estimation theory (Thompson 1987) for accuracy (d) of 0.1 and precision (α) of a one-in-ten chance of not having the correct species proportion (p_i) within the interval $p_i \pm d$ for all i categories, where i equals three categories of fish present in the river at a given point in the salmon migration.

Equipment and Procedures

Six gill nets measuring 45.7 m long and 7.6 m deep were used for test fishing. Mesh sizes (stretched) were 101.6 mm, 127.0 mm, 139.7 mm, 165.1 mm, 190.5 mm, and 215.9 mm. Drifts of approximately 10 minutes duration were made alternately along left and right banks. Care was taken to maintain similar effort among mesh sizes. Gill nets were drifted through the same areas on each bank throughout the season. Reduced water levels, however, resulted in fish distribution to greater ranges on the left bank after August, necessitating establishment of inshore and offshore drifts. Fish distribution remained unchanged on the right bank and the inshore ends of the nets were fished as close as possible to shore.

To calculate total fishing time four parameters were measured for each drift: 1) net start out; 2) net full out; 3) net start in; 4) net full in. At the end of each drift the net was hauled into the boat as quickly as possible and fish were disentangled. Each fish was identified to species, measured (mid-eye to tail fork for salmon and snout to tail fork for non-salmon), and checked for signs of wedging or tangling.

Analytical Methods

Gill nets capture fish in one of two ways; individuals may be wedged between the dorsal fin and the gill opercula, or they may become tangled in the web by their teeth or maxillaries. The probabilities of these events are specific to fish length, gill net mesh size, and species. Catches are adjusted for sampling effort and for differential probability of being captured among species, length categories, and gill net mesh sizes. The relative standardized CPUE by species are used to apportion expanded fish counts.

Estimation of Relative Abundance. When a fish encounters a gill net any of three possibilities may occur: 1. the fish is captured by being wedged; 2. the fish is captured by tangling its teeth or maxillaries in the web; or 3. the fish escapes. Definitions for each species and mesh size are:

- p_w = the probability of capture by wedging given encounter of the gear.
- p_t = the probability of capture by tangling given encounter of the gear.
- p_e = the probability of escape given encounter of the gear.

- E = the number of fish that escape capture given encounter of the gear.
- W = the number of fish that are captured by being wedged or gilled.
- T = the number of fish that are captured by being tangled.
- N = the number of fish that encounter the gear in a given sampling period.

$$N=W+T+E \qquad [1]$$

$$p_w+p_t+p_e=1 \qquad [2]$$

$$W=p_w(N) \qquad [3]$$

$$T=p_t(N) \qquad [4]$$

$$E=p_e(N)$$ [5]

Substituting [2] and [5] into [1] gives the following expression for N:

$$N=\frac{W+T}{p_w+p_t}$$ [6]

This is simply the number of fish of a given species captured in a particular mesh size net adjusted for gill net selectivity, or $\acute{W}$. This is seen by defining a new variable, U, the ratio of wedged to tangled fish in the catch. Then:

$$U=\frac{W}{T}$$ [7]

$$U=\frac{p_w N}{p_t N}$$ [8]

$$U=\frac{p_w}{p_t}$$ [9]

$$p_t=\frac{p_w}{U}$$ [10]

Substituting [10] into [6] gives the following:

$$N=\frac{W+T}{(p_w+\frac{p_w}{U})}$$

$$N=\frac{1}{p_w}\left(\frac{W+T}{1+\frac{1}{U}}\right)$$

$$N=\frac{1}{p_w}\left(\frac{W+T}{1+\frac{T}{W}}\right)$$

$$N=\frac{1}{p_w}\left(\frac{W(W+T)}{W+T}\right)$$

$$N=\frac{W}{p_w}$$

$$N=\acute{W}$$

Both W and T are observed quantities from the test fishery and p_w must be estimated. It is assumed that p_w is dependent on the length of the fish encountering the gear but p_t is not. Estimates of p_w are derived by adjusting the CPUE of gilled fish for selectivity of the gear and comparing adjusted and unadjusted CPUE values. Estimation of p_t is not necessary in this procedure.

Two mesh sizes are used to sample each species and selectivity curves are produced following methods developed by Peterson (1966). These curves represent the selectivity coefficients (S_L) by size category (indexed by L). Tangled fish are excluded from the catches used to estimate the selectivity curves. Therefore this selectivity represents differing gilling or wedging properties of the nets. The S_Ls are strictly dependant on the fish girth-length relationship relative to the mesh perimeter (i.e., twice the stretch mesh length) (Hamley 1975). Thus, the selectivity coefficients depend on mesh size, fish species, and size within fish species.

Each gill net mesh size that is fished will give an estimate of the number of each species of fish that encounter the gear (N_{ms}). Consequently there are m independent estimates of relative abundance for each species. These must be combined in some meaningful estimate of relative abundance. Unfortunately each mesh size efficiently samples only a limited portion of the size spectrum of available fish. Further, different mesh sizes sample different size groups of fish. In this situation it is not correct to simply average the estimates of relative abundance given by the two mesh sizes. The estimate of abundance must be stratified by length according to the selectivity properties of the gear relative to the length distribution of the population of the species being sampled. To see this consider a hypothetical case where two meshes of gear are fished (Figure 4). Here mesh 1 effectively samples fish of length between k_s^{k1} and k_s^{u1} (interval I_s^1); and mesh 2 samples fish of length between k_s^{k2} and k_s^{u2} (interval I_s^2). These intervals can be defined based on the wedging selectivity curves. The size interval of fish that are fully recruited to the mesh size is the size interval where selectivity is above some arbitrary minimum selectivity coefficient threshold, say 0.30.

Estimates of abundance based on catches from a particular mesh size reflect only the population available to the gear and are, in general, different for different mesh sizes. For example, in the hypothetical case of Figure 4 the abundance of species s based on mesh 1 is for the component of the population of length contained in the interval I_s^1 only; the abundance based on mesh 2 is for the component of the population of length contained in the interval I_s^2 only. These populations are different, but share a common element which is the population of length contained in the interval (k_s^{k2}, k_s^{u1}). This interval is subsequently referred to as I_s^{common}.

If the two meshes collectively sample the entire population, then the estimate of abundance of species s can be made based on sampling with the two meshes of gill nets. The population can be stratified into three mutually exclusive or segregated length classes or subpopulations based on selectivity curves for the two meshes used to sample the population. The first length class is all fish of length strictly less than can be effectively sampled by the larger mesh ($< k_s^{k2}$), the second is fish of lengths that are effectively sampled by both mesh sizes (i.e., contained in the interval (k_s^{k2}, k_s^{u1})) and the third length class is fish of length greater than the largest size class effectively sampled by the smaller of the mesh sizes ($>k_s^{u1}$). These length groups are called $\hat{N}_s^L$, $\hat{N}_s^{common}$, and $\hat{N}_s^U$. Note that catches from the small mesh size is used to estimate $\hat{N}_s^L$, catches from both mesh sizes are used to estimate $\hat{N}_s^{common}$, and catches from the large mesh size are used to estimate $\hat{N}_s^U$. Because these length classes are mutually exclusive, the estimated abundance of species s ($\hat{N}_s$) is the sum of the estimated abundance of the three length classes.

Since sampling effort is not constant among mesh sizes fished, and the abundance of those fish effectively captured by both mesh sizes is estimated with catches from two mesh sizes, the abundances of the three length classes must be standardized to unit effort by dividing by the appropriate number of fathom-hours fished of gears used during the period. Finally, the total CPUEs over all size classes are compared between species within a sampling period to determine percent composition of the run by species. Species proportions are multiplied by sonar counts, using the appropriate sampling period, to estimate individual species passage.

The CPUE of species s adjusted for selectivity and based on the collective sampling of the two meshes of gear is $\hat{N}_s$, where:

$$\hat{N}_s = \frac{\hat{N}_s^L}{E_1} + \frac{\hat{N}_s^{common}}{E_1 + E_2} + \frac{\hat{N}_s^U}{E_2}$$

$\hat{N}_s^L$ = the number of fish of species s and length between k_s^{k1} and k_s^{k2} encountered.

$\hat{N}_s^{common}$ = the number of fish of species s and length between k_s^{k2} and k_s^{u1} encountered.

$\hat{N}_s^U$ = the number of fish of species s and length between k_s^{u1} and k_s^{u2} encountered.

E_1 = effort fished with the smaller of the two mesh sizes.

E_2 = effort fished with the larger of the two mesh sizes.

The proportion of species s (P_s) is:

$$P_s = \frac{\hat{N}_s}{\sum_{1}^{S} \hat{N}_s}$$

Fish catches were stratified by fishing site (left and right banks) and by species apportionment period in this analysis.

Estimation of Daily Fish Passage. Estimates of daily passage rates for each species were calculated by integrating the results of both the hydroacoustic counting and species apportionment segments of the project. Daily estimates for species s on bank b were calculated as $N_{s,b}$, where:

$$N_{s,b} = P_{s,b} N_{b,d}$$

and:

$P_{s,b}$ = the proportion of species s on bank b during the time period.

$N_{b,d}$ = the number of fish passing bank b on day d.

Migratory Run Timing. The mean date of migration and associated standard deviation for each fish species present in the Yukon River while the project was operational was calculated following the method outlined by Mundy (1982).

RESULTS

Hydroacoustic Counting

Estimation of Total Daily Passage

The Yukon sonar project was operational from 8 June through 11 September in 1989. Net upstream fish counts, temporal and spatial expansion factors, sampling times, and fish passage estimates for each day are presented in Appendix Tables 24 and 25. A temporal expansion factor of six resulted from four hours of sampling within each 24-hour day. Spatial expansion factors on the right bank ranged from 1.0 (no expansion) to 3.1, depending on water level and fish distance from the transducer. Spatial expansion factors remained relatively constant throughout the season due to the stability of the river bottom at the sampling site.

Daily and seasonal fish passage estimates by bank are summarized in Appendix Tables 1, 2, and 3. A total of 2,794,328 fish passed the sampling site; 71 percent (1,975,498) and 29 percent (818,831) of the total passed the left and right banks (Figure 5). The highest daily passage (100,332 fish) occurred on 20 June.

Estimation of Missing Data

Right bank sonar data and left and right bank CPUE data for early (08 June - 18 July) and late (19 July - 11 September) season migrations showed varying levels of correlation with left bank sonar data. For the early season, left bank fish counts were most highly correlated with right bank counts (r^2 = 0.59). This relationship (Y = 9632.87+1.59X) was used to estimate fish passage on the left bank post-seasonally for the following days: June 14, 15, 16, 19, 20, and July 04, 1989. During the late season, left bank fish counts were most highly correlated with left bank gill net CPUE (r^2 = 0.73). The sonar was operational every day during the late season and post-seasonal estimation was not required.

Species Allocation

Estimation of Species Proportions

Sampling of the migrant fish population for use in estimation of species proportions began on 08 June and continued through 11 September. Gill net catch and effort during that period by day, mesh size, and species are tabled for left, right, and combined banks in Appendix Tables 4, 5, and 6. The 101.6 mm mesh net was fished 149 times (463.18 fm-hrs), the 127 mm mesh was fished 139 times (440.25 fm-hrs), the 139.7 mm mesh was fished 279 times (860.41 fm-hrs), the 165.1 mm mesh was fished 282 times (880.72 fm-hrs), the 190.5 mm mesh was fished 114 times (291.84 fm-hrs), and the 215.9 mm mesh was fished 111 times (315.92 fm-hrs). The catch totaled 6,757 fish, of which 2,999 (44 percent) were captured on the left bank and 3,758 (56 percent) were captured on the right bank. Right bank catch was higher than that on the left bank due to better fishing conditions (no snags) and higher total effort levels.

A total of 170 chinook salmon were captured in 190.5 and 215.9 mm mesh gill nets. The majority (86 percent) were gilled or wedged; the remaining 14 percent were tangled. Forty two percent of the gilled fish were caught in 190.5 mm gear and the remaining 58 percent were caught in 215.9 mm gear. Catch on the left bank totaled 99 chinook salmon (58 percent) while catch on the right bank totaled 71 chinook salmon (42 percent). No chinook salmon were captured in nets drifted offshore to check for extended fish distribution.

Summer chum salmon catches totaled 2,606 in 139.7 and 165.1 mm gill nets. Of these, 2,348 (90 percent) were gilled or wedged and 258 (10 percent) were tangled in both gear sizes. Sixty percent of the fish were captured in the 139.7 mm mesh nets. A total of 1,382 fish (53 percent) were caught on the left bank while 1,224 (47 percent) were caught on the right bank.

A total of 907 fall chum were captured in 139.7 and 165.1 mm gill nets. Eight hundred forty five fish (93 percent) were gilled or wedged, and of these, 56 percent were captured in the 139.7 mm mesh nets. A total of 344 fish (37 percent) were captured on the left bank while 563 (63 percent) were captured on the right bank.

Coho salmon gill net catches in 139.7 and 165.1 mm mesh gill nets totaled 531 fish. The majority (90 percent) were either gilled or wedged with 288 (54 percent) and 189 (36 percent) in the 139.7 and 165.1 mm nets. A total of 87 (16 percent) were captured on the left bank while 444 (84 percent) were captured on the right bank.

The remainder of the gill net catch was composed of sockeye salmon, pink salmon, and non salmon species. Only seven sockeye salmon and four pink salmon were captured in 1989. Non-salmon catches, however, were substantial. Non-salmon species included humpback whitefish *(Coregonus pidschian)*, broad whitefish *(C. nasus)*, Least cisco *(C. sardinella)*, sheefish *(Stenodus leucichthys)*, northern pike *(Esox lucius)*, burbot *(Lota lota)*, and dolly varden *(Salvelinus malma)*. The majority (94 percent) of the 154 fish captured were either gilled or wedged with 93 (64 percent) and 52 (36 percent) in the 101.6 and 127 mm gill nets. A total of 72 fish (47 percent) were caught on the left bank while 82 fish (53 percent) were caught on the right bank.

Length frequencies, regression coefficients and statistics, and selectivity coefficients and curves used to estimate the number of fish of each species encountering each of the two nets fished are presented by species in Appendices 5 through 10. These estimates, as well as raw catch, catch adjusted for net selectivity, wedging probability and effort appear in Appendix 11. Summer chum salmon dominated the species composition (Figure 6) between 08 June and 18 July, comprising between 65 and 100 percent of the population. Fall chum salmon were the most abundant species between 18 July and 07 September, although coho salmon and non-salmon species dominated on some days due to the pulsed entry pattern of the fall chum salmon. Coho salmon dominated after 07 September.

Estimation of Daily Passage

The total estimated fish passage of 2,794,328 fish is apportioned to species in Table 1, and histograms of daily fish passage by species are shown in Figures 7 and 8. Time periods and species proportions used in this analysis are presented in Table 2. Left bank, right bank, and combined bank estimates of fish passage by day and species are listed in Appendix tables one through three. Migratory timing statistics appear in Table 3. Estimates are discussed by species in the following text.

The estimated chinook salmon escapement past the sampling site was 79,362 fish or 2.8 percent of the total salmon escapement. The highest daily passage occurred on 19 June when 6,889 chinook were counted. Most chinook salmon (77 percent) traveled along the left bank. The migration was in progress at project start-up on 8 June and continued until 19 July. The mean date of chinook salmon migration was 26 June (s.d.= 10).

Summer chum salmon were the most abundant species counted; an estimated 1,622,331 passed the site between 08 June and 18 July. This escapement level represents 58 percent of the total fish passage in 1989. The majority (69 percent) passed along the left bank. The migration was in progress when the project became operational on 8 June; a total of 4,805 summer chum were counted on this date. The mean date of migration is 27 June (s.d. = 10). The migration was complete by 19 July.

An estimated 684,840 fall chum salmon passed the sonar site representing 24.5 percent of the total fish passage in 1989. The highest daily passage (39,242) occurred on 21 August. The largest segment of the fall chum run (75 percent) passed along the left bank. Fall chum were present at river mile 123 from 13 July until the last day of operation (11 September). Although the fall chum run was not complete, daily passage had dropped to 2,171 fish per day. The mean date of migration is 08 August (s.d. = 14).

The coho salmon run consisted of an estimated 174,631 fish through the last day of operation in 1989. The coho run comprised only 6.2 percent of the total season fish passage. The highest daily passage was 13,376 coho salmon on 22 August. Coho salmon were more evenly distributed between banks than were other species; 53 percent passed the left bank and 47 percent passed the right bank. Coho salmon were present at the site from 5 August through the termination of sampling. The migration was not yet complete on the last day of operation, as indicated by an estimated daily count of 2,773 fish. Based on the days sampled, the coho run mean date of migration is 05 August (s.d. = 9).

All non-salmon species were pooled to apportion hydroacoustic counts. Total estimated passage in 1989 was 233,109 fish representing 8.3 percent of all fish passage. The peak daily passage was 11,497 fish on 16 August. A total of 193,408 fish (83 percent) passed the left bank while 39,701 fish (17 percent) passed the right bank. These species were present from 8 June through the last day of counting. Whitefish species accounted for the majority of non-salmon species intercepted in 1989. They were present from 14 June through the last day of counting.

DISCUSSION

Hydroacoustic Counting

Estimation of Total Daily Fish Passage

Hydroacoustic fish passage estimates, though extremely precise, may be subject to bias attributable to errors in fish counting, or to errors in expansion factor development and species composition. First, there may exist areas of the river cross section utilized by salmon that are not being sampled. In the Yukon River the nearshore water column is intensively sampled and data gathered to date suggests that fish are not migrating in mid-river areas. Changes in the dynamic riverine environment, however, may prompt changes in fish behavior. Mid-river areas should therefore be systematically sampled each year to assure that all migratory pathways are either ensonified or otherwise accounted for.

Another counting problem is downstream-directed targets counted as debris which may in fact be fish. Some downstream-directed fish traces are easily identified from trace patterns on chart recordings. Other, less easily identifiable traces may require qualification through establishment of some type of ground truth project. Recent work on the left bank of the Yukon with a transducer aimed directly upstream showed that 12 percent of the 1500 targets passing through the beam were moving downstream. Identification of targets may be accomplished through use of gill nets or dual-beam target strength information.

Spatial expansion factors, used only on the right bank in 1989, may also bias fish passage estimates if the true cross-sectional area of the beam is different from that calculated based on acoustic parameters under which the system is operating. This is a property of average fish target strength and attitude (position in the sonar beam) which varies within and between years and should be frequently measured.

These errors are probably consistent over time and, if occurring, will be manifest in consistent differences between sonar and other estimates of population size. Controlling bias requires careful and continuous evaluation of bottom topography, calculation of beam size, and identification of downstream-moving targets and fish migratory pathways.

Other factors associated with counting passing targets contribute to variance in fish passage estimates. The most serious of these factors on the Yukon is the physical instability of the left bank site. The constantly shifting bottom sediments at this location make transducer deployment and operation a continual challenge. A site that appears perfectly suited for transducer location may change in a matter of hours to one that is unusable. Rapidly changing water levels tend to erode or deposit bottom sediments with the net effect being burial of the transducer. This both reduces sampling and increases personnel costs. Changes in transducer pod design and retrieval procedures have alleviated some of the difficulties caused by left bank river bottom instability. The risk of equipment loss and the amount of effort expended retrieving equipment have been cut substantially. Until another method of transducer deployment is found, however, there will continue to be days with reduced sampling on the left bank and subsequent estimation of passage through interpolation or modeling based on the right bank fish passage.

Species Allocation

Estimation of Species Proportions

In addition to rendering the sonar equipment inoperable for six percent of the 1989 season, the left bank also caused problems for the species allocation gillnetting portion of the project. An unusually high number of snags (submerged trees) found within the testfishing sites affected both the area and amount of time fished with certain nets. Non-random deployment of nets within the area of fish migration may result in over- or under-representation of certain species depending on whether or not species are spatially segregated. The condition of all nets fished during the early season may have also affected their efficiency and ultimately the species allocation of the sonar counts.

Three sources of variance may exist in the species proportion estimator. Selectivity coefficients of the gill nets for each species have been estimated based on only current year length frequency data. The resultant small catches, combined with the degree of stratification required to use this technique, results in sample sizes that are smaller than desired and selectivity coefficient estimates that are highly variable. Additionally, the division of the catch from two mesh sizes into three groups for selectivity adjustment, wedging probability estimation, and subsequent combination into a CPUE value for the species is based on an arbitrarily chosen selectivity/length threshold. The sensitivity of wedging probability and CPUE values to choice of a threshold value should be examined and the resultant variance should be estimated. The third source of variance is that resulting from the estimation of multinomial proportions. Estimation of variance of the species proportion program is planned for 1990-1991.

Estimation of Daily Passage

The Yukon River Sonar project has developed into an important tool for estimating salmon escapement both in-season and annually. Daily in-season escapement estimates are provided to fishery managers within eight hours of cessation of sampling for that day. Consistent production of timely escapement information has made the sonar project an integral part of lower Yukon River fishery management strategy, particularly during fall chum salmon migrations. Problems that lead to lack of confidence in sonar estimates, as well as uncertainties as to how the sonar fish escapement estimates may best be considered in managing fisheries, still exist and lessen program impact during chinook and summer chum salmon runs. Large strides have been made in program effectiveness since inception, but there are areas requiring further improvement. Some of these areas fall outside the realm of data collection and analysis, and instead exist in fishery manager's understanding of and concomitant attitude toward hydroacoustically obtained information. Research efforts in areas of valid management concern and timely reporting of results have fallen victim to personnel turnover and funding shortages in the past. Recent improvements in both of these areas should ensure a better product and subsequent improved credibility in the future.

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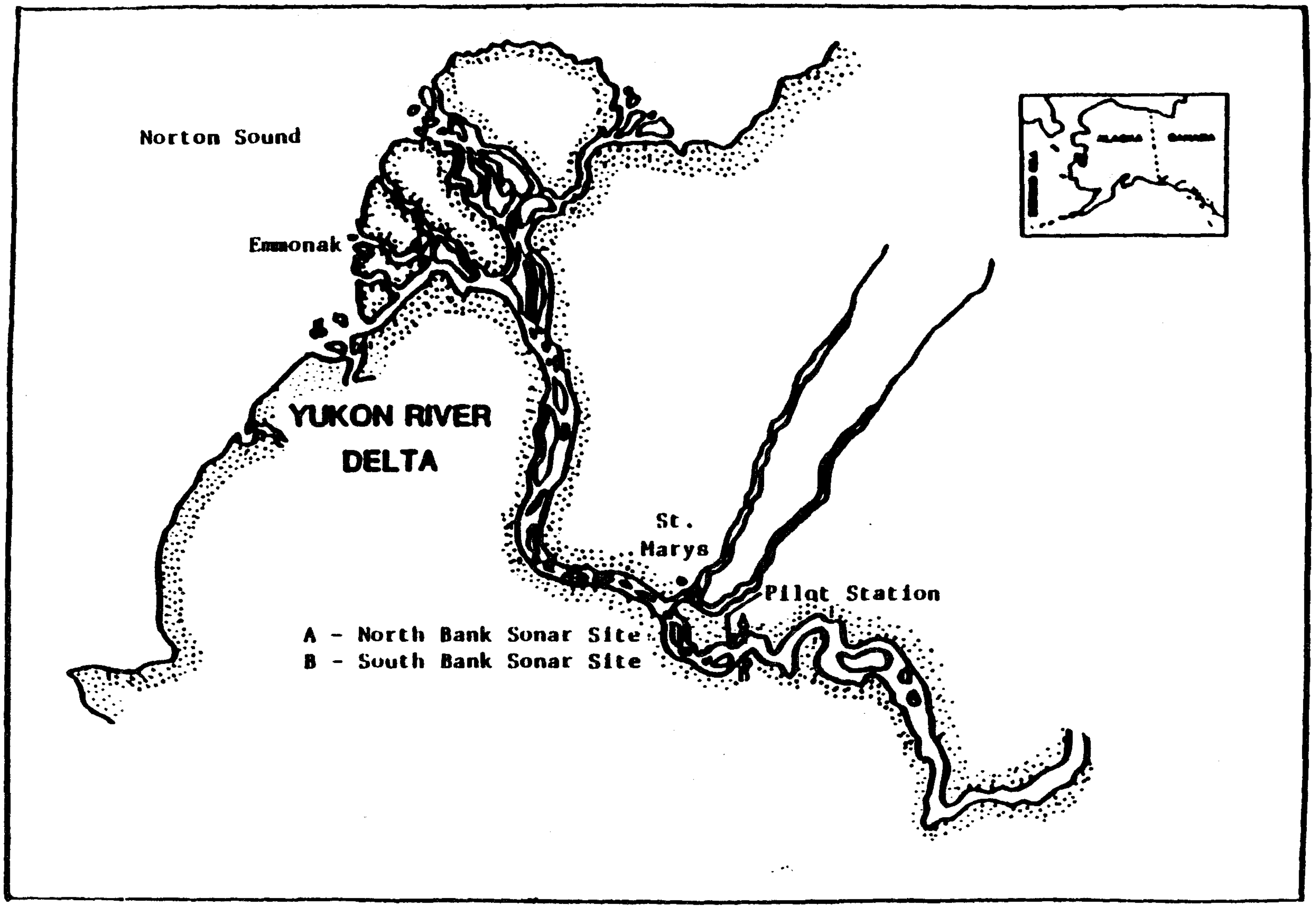

Figure 1. Map of the lower Yukon River showing the two sites used for hydroacoustic escapement enumeration in 1989.

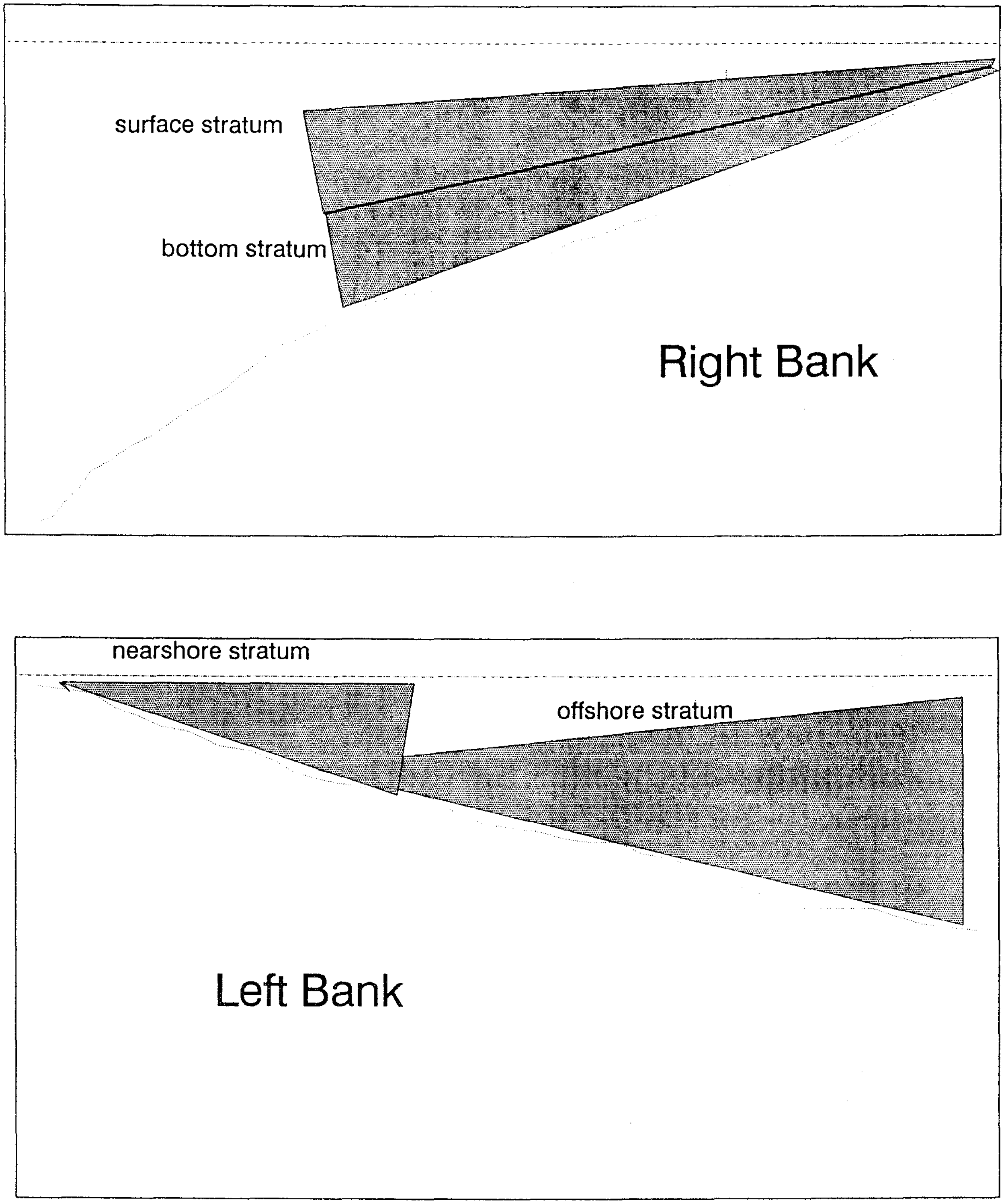

Figure 2. Areas of the Yukon River cross section sampled hydroacoustically at km 197 in 1989.

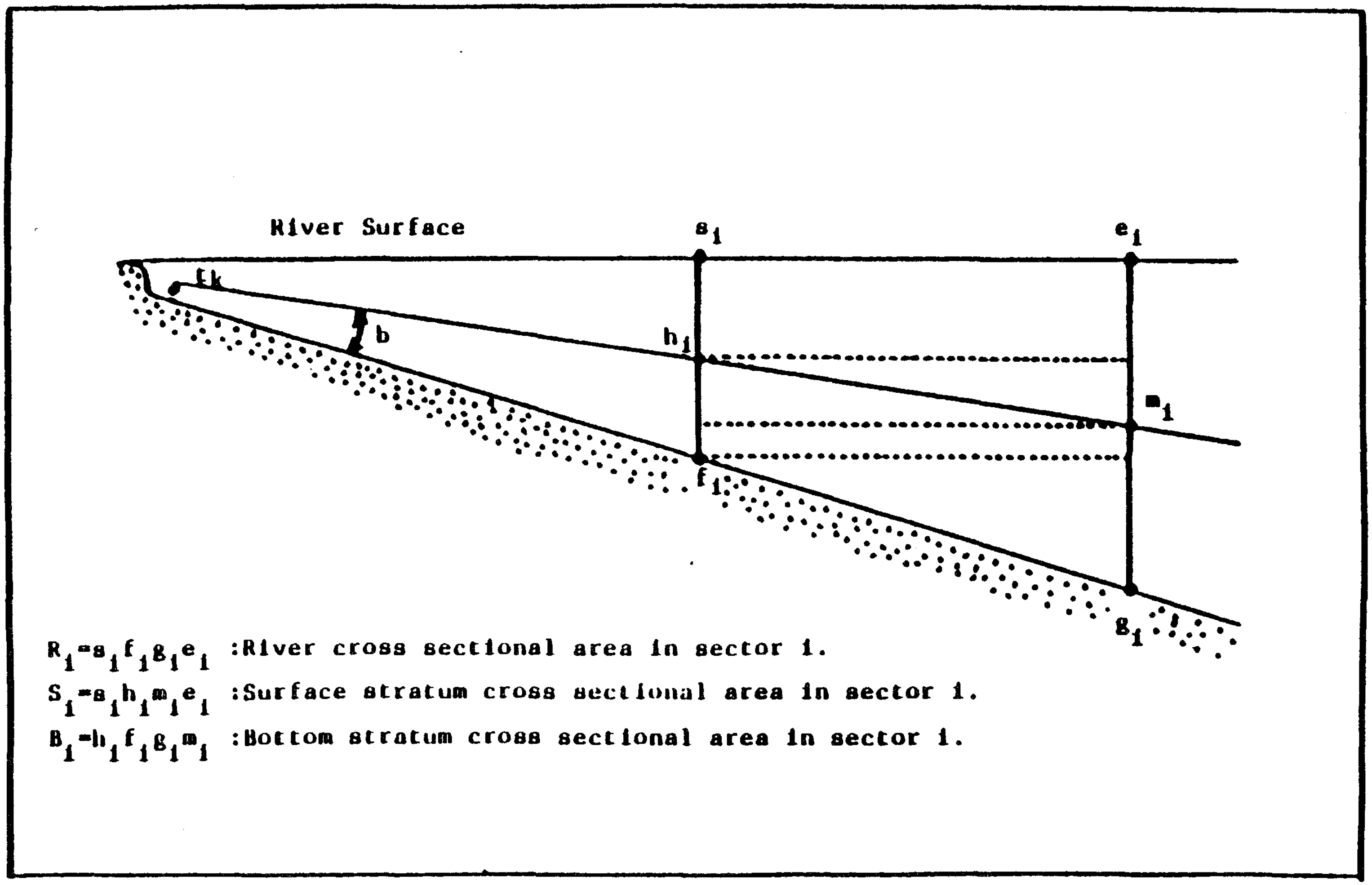

Figure 3 . Geometric representation of Yukon River and hydroacoustic beam cross sectional areas used for calculation of spatial expansion factors for counts of fish obtained hydroacoustically in 1989.

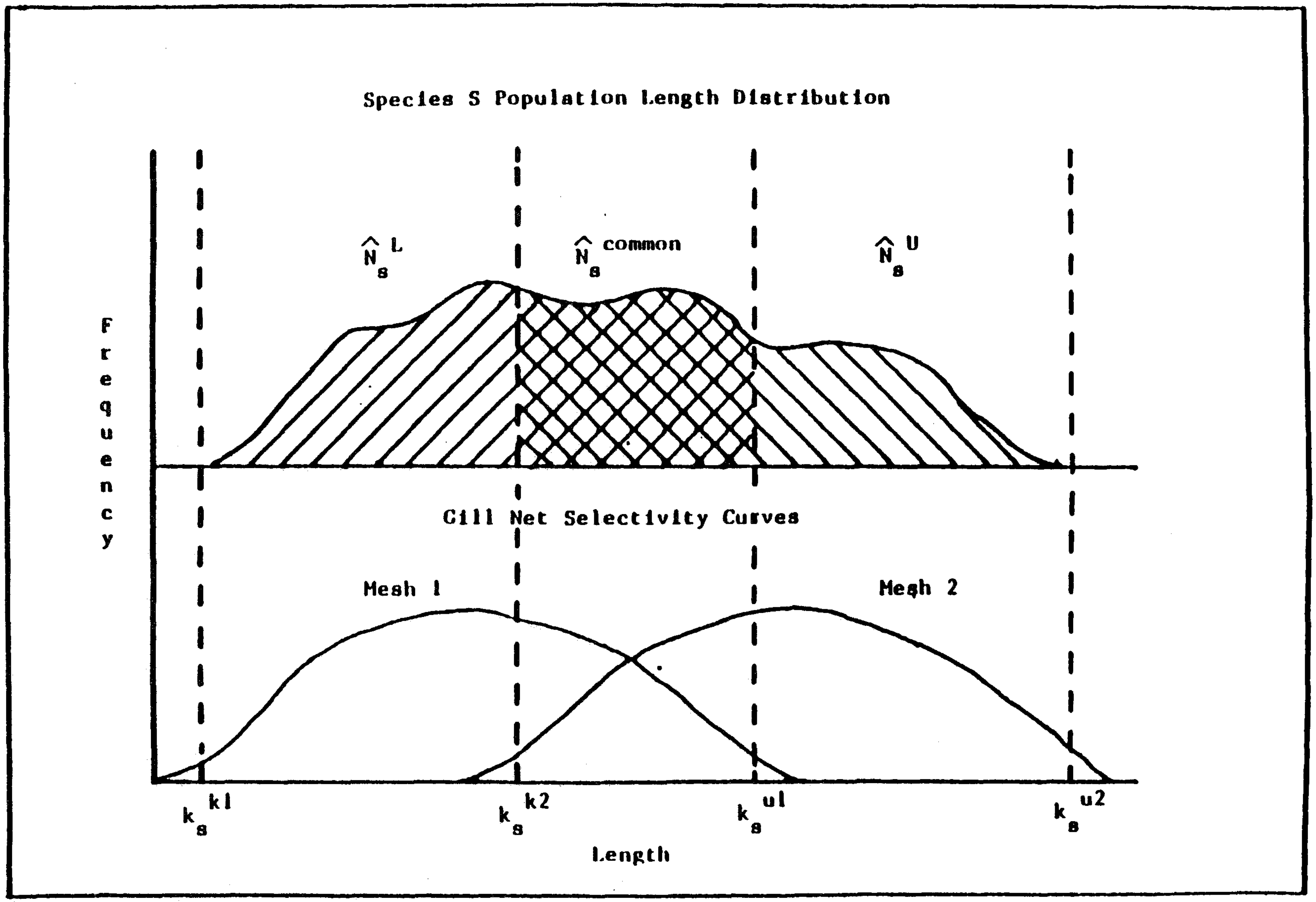

Figure 4. Hypothetical population length distribution and gill net selectivity curves.

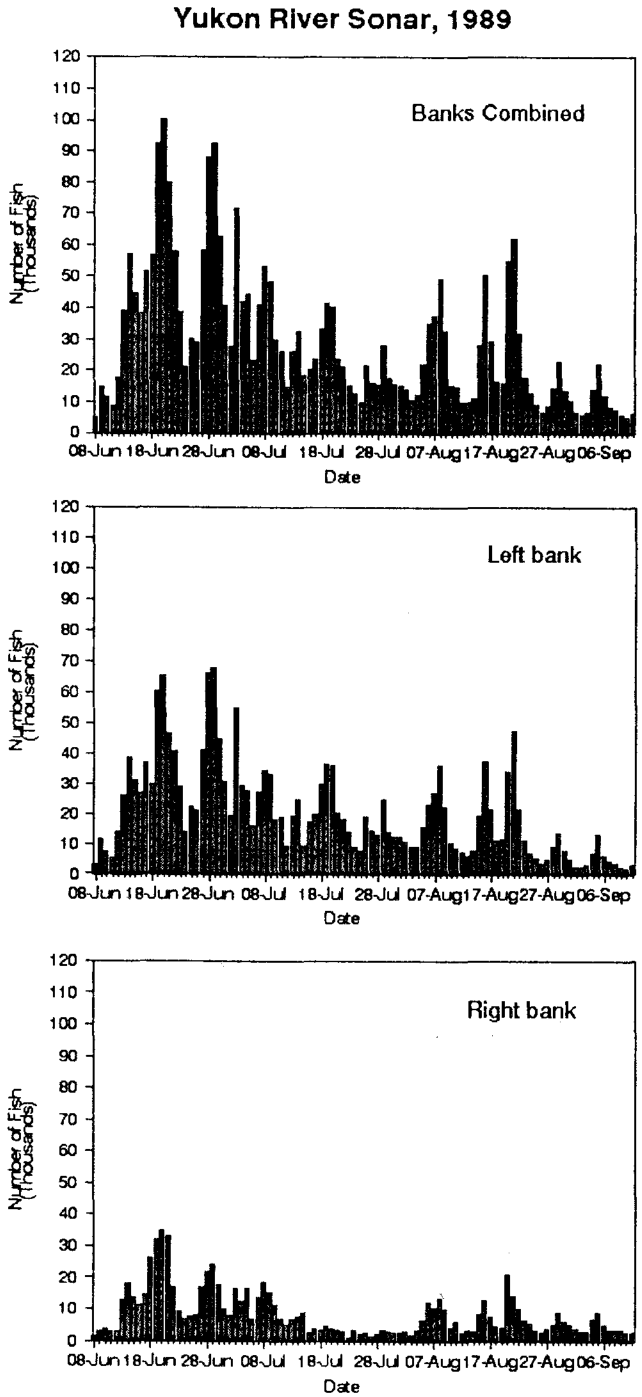

Figure 5. Daily fish passage estimates for combined banks, left bank, and right bank at km 197, Yukon River, 1989.

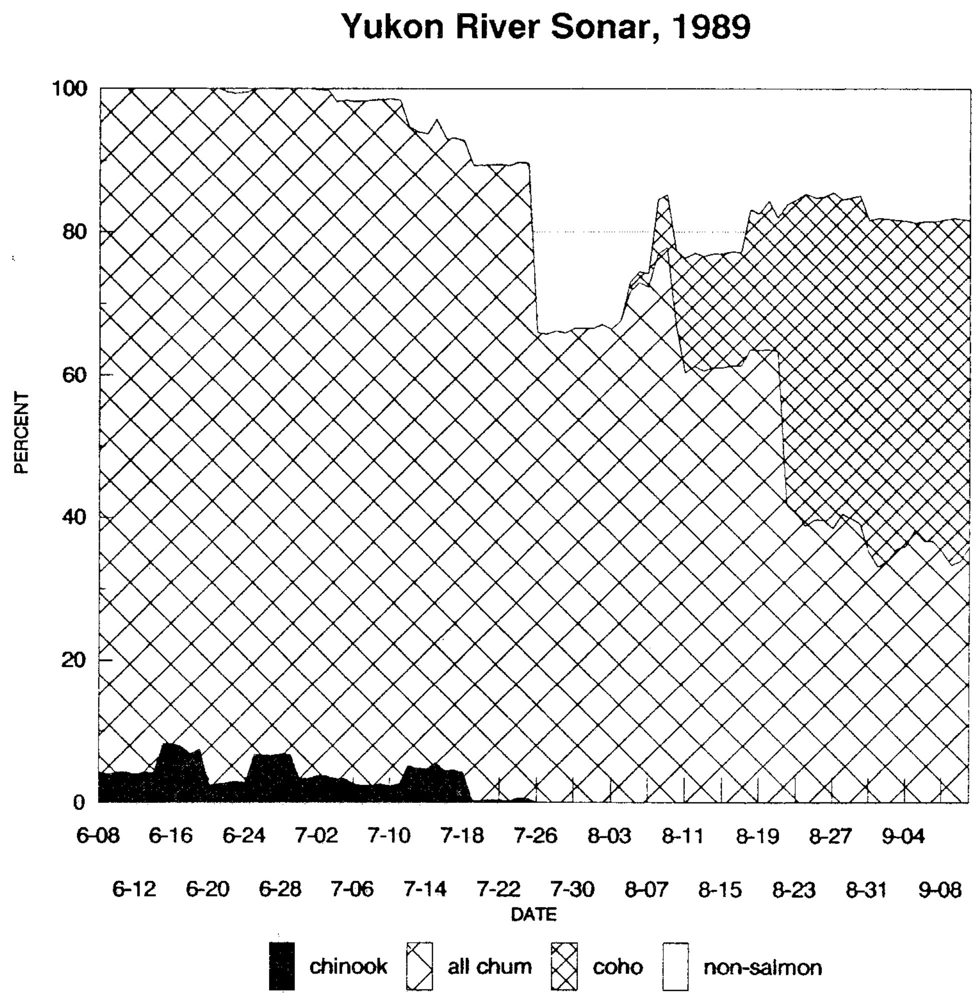

Figure 6. Species proportions between 08 June and 11 September at km 197, Yukon River, 1989.

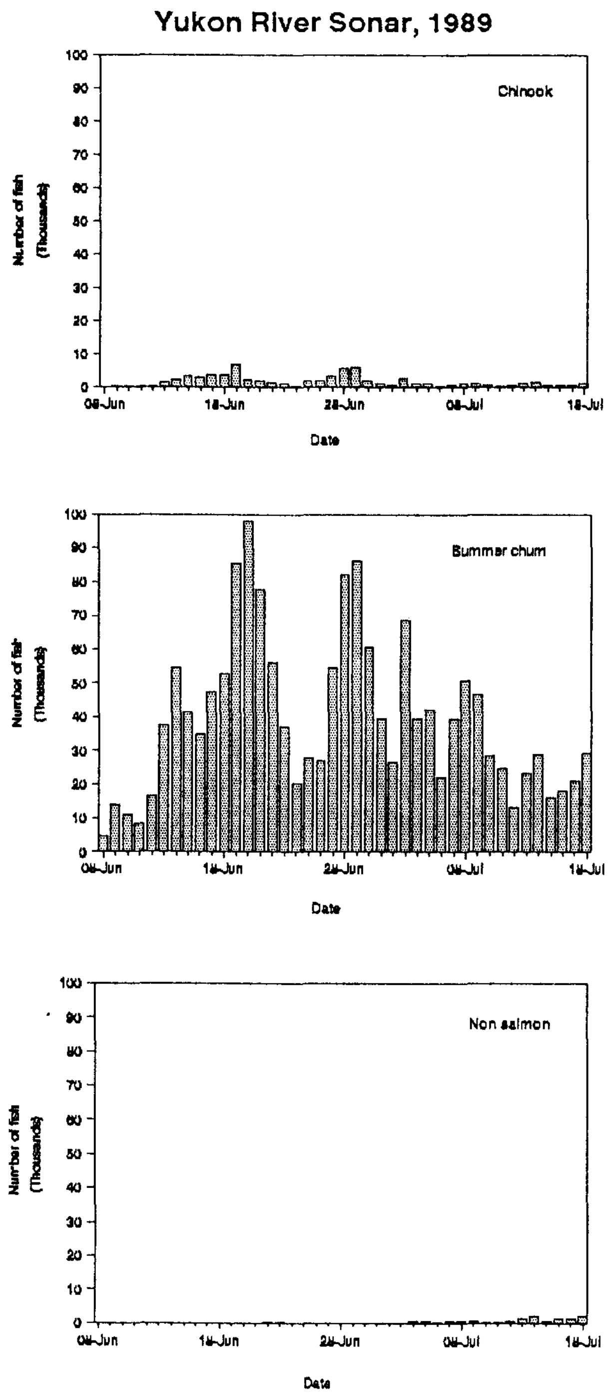

Figure 7. Daily fish passage estimates for chinook salmon, summer chum salmon, and non-salmon species at km 197, Yukon River, 1989.

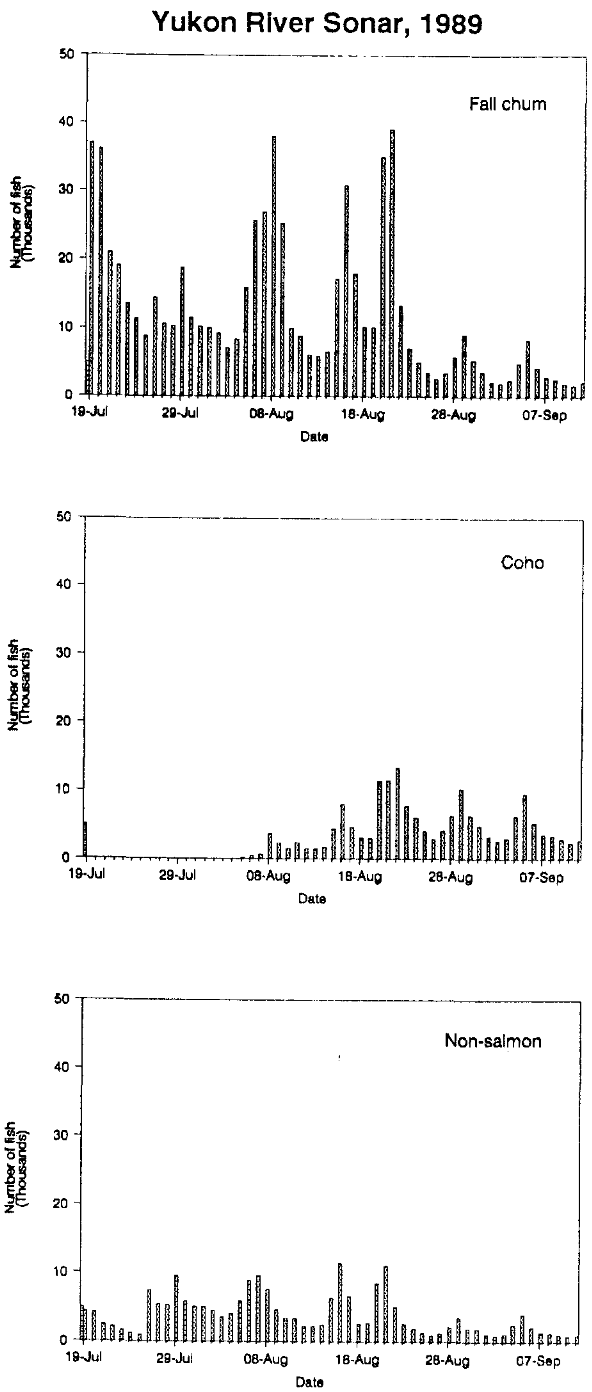

Figure 8. Daily fish passage estimates for fall chum salmon, coho salmon, and non-salmon species at km 197, Yukon River, 1989.

Table 1. Estimated escapement of chinook, summer chum, fall chum, and coho salmon, and non-salmon species past river km 197, Yukon Sonar, 1989.

Chinook	Summer chum	Fall chum	Coho	Non-salmon	Total
79,362	1,622,331	684,840	174,631	233,109	2,794,328

Table 2. Species allocation time periods and species proportions for left and right bank Yukon River sonar escapement estimates, 1989.

Right Bank

Dates	Chinook	Summer Chum	Fall Chum	Coho	Non-salmon	n
08-16 June	0.054	0.945	0	0	0	127
17-19 June	0.038	0.962	0	0	0	118
20-21 June	0.031	0.969	0	0	0	136
22-24 June	0.013	0.987	0	0	0	117
25-27 June	0.023	0.977	0	0	0	130
28 June-01 July	0.025	0.975	0	0	0	142
02-05 July	0.038	0.956	0	0	0.006	117
06-08 July	0.012	0.982	0	0	0.006	132
09-11 July	0.013	0.987	0	0	0	120
12-18 July	0.075	0.926	0	0	0	122
19-25 July	0.021	0	0.893	0	0.085	122
26 July-04 Aug.	0	0	0.753	0	0.247	151
05-06 August	0	0	0.895	0.046	0.064	151
07-09 August	0	0	0.922	0.066	0.012	130
10-17 August	0	0	0.563	0.171	0.266	141
18-21 August	0	0	0.644	0.292	0.063	142
22-23 August	0	0	0.253	0.670	0.076	121
24-30 August	0	0	0.255	0.665	0.079	136
31 Aug-11 Sept.	0	0	0.215	0.619	0.166	176

Left Bank

Dates	Chinook	Summer Chum	Fall Chum	Coho	Non-salmon	n
08-14 June	0.035	0.965	0	0	0	120
15-19 June	0.094	0.906	0	0	0	133
20-21 June	0.021	0.979	0	0	0	180
22-24 June	0.034	0.958	0	0	0.008	121
25-29 June	0.082	0.918	0	0	0	131
30 June-03 July	0.036	0.964	0	0	0	152
04-11 July	0.030	0.947	0	0	0.022	121
12-18 July	0.038	0.880	0	0	0.082	134
19-25 July	0	0	0.891	0	0.109	134
26 July 07 Aug	0	0	0.646	0	0.353	121
08-10 August	0	0	0.715	0.078	0.207	121
11-21 August	0	0	0.631	0.154	0.214	137
22 Aug-11 Sept.	0	0	0.492	0.308	0.200	143

Table 3. Run timing parameters, based on hydroacoustic escapement estimates of chinook, summer chum, fall chum, coho and pink salmon, and other (pooled) species at river mile 123, Yukon Sonar, 1989.

Species	Run Timing Parameters [1/]			
	Start	End	Mean	SD of Mean
Chinook	08 June	18 July	26 June	10
Summer chum	08 June	18 July	27 June	10
Fall chum	19 July	11 Sept.	08 August	14
Coho	05 August	11 Sept.	25 August	9
Non-salmon	08 June	11 Sept.	09 August	15

[1/] Run timing is based on the counts obtained during project operation. The actual run timing may differ depending on the portion of the escapement occurring before and after project start-up and termination dates.