Sonar Enumeration of Chum Salmon in the South Fork Koyukuk River, 1990

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ABSTRACT

From August 2 to September 25, 1990, Bendix side-scanning sonar fish counters were used to enumerate chum salmon *Oncorhynchus keta* escapement into the South Fork Koyukuk River. Low water levels during August enabled the use of one sonar counter to cover the entire river. Higher water in September made it necessary to deploy two sonar counters across river from one another with beams aimed approximately perpendicular to the shoreline. A total of 19,485 chum salmon was counted during the 55-d counting period. Escapement peaked on August 13, and 50% of the run had passed the sonar site by August 22. The escapement estimate is conservative since counts do not include fish passing before August 2 and after September 25.

The accuracy of daily sonar counts was checked and adjusted accordingly with oscilloscope calibrations and systematic visual observations from a counting tower. Visual observations during August 7-27 showed that 22% of oscilloscope counts were caused by species other than chum salmon. Visual observations were not possible during the high water period (August 28-September 25), making it necessary to extrapolate species composition estimates from the low water period (August 7-27) to adjust high water sonar counts. The necessity of using two sonars during the high water period probably caused some fish to be counted twice and some fish to pass by the site undetected. Only 1,184 fish could have been double counted; however, there was an unknown potential for undetected fish.

Early (August 7-13) and late (September 12-16) season genetic samples differed significantly, which suggests temporal and/or spatial reproductive isolation of chum salmon stocks upstream from the sampling site. Early and late season samples did not differ significantly in age composition, sex ratio, or mean length. For the combined early and late season gill net sample (N=147), age 0.3 predominated (67%), males comprised 70% of the sample, and mean length (mid-eye fork length) averaged 586 mm.

A helicopter survey was attempted on September 26 for comparison to the total sonar count. Weather conditions were extremely poor during the survey and no salmon were seen.

Escapement estimates with ground survey methods, such as sonar or floating weir, would need to be continued on this river to determine variability in run size between years. Surveys should be conducted over a longer time period (early July through September) and include additional genetic sampling to better define chum salmon populations in the South Fork Koyukuk River. The complications caused by high water in this study might be avoided in future sonar studies by using a different site (upstream from Fish Creek) and/or longer range, more sophisticated sonar equipment providing target strength information. The best assessment of species composition and chum salmon run size might be provided by a floating weir; however, the cost would be higher than sonar.

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INTRODUCTION

Accurate salmon escapement counts on Yukon River tributaries are important for assessing annual harvest management guidelines, predicting run strength based on brood year returns, and influencing current U.S./Canada salmon treaty negotiations for allocating transboundary chinook *Oncorhynchus tshawytscha* and chum salmon *O. keta*. Due to the size of the Yukon River drainage (854,700 km^2), estimating spawning escapement to all tributaries is not economically feasible. The primary method of survey is by aerial reconnaissance of selected key index streams. These surveys are flown during peak spawning periods to estimate instantaneous escapement, not total escapement. Since 1959, the Alaska Department of Fish and Game (Department) has had primary responsibility for collecting escapement data.

In 1985, the U.S. Fish and Wildlife Service (Service) began assisting with treaty negotiations by accepting responsibility for inventorying Yukon River system salmon stocks on federal lands where escapement data were lacking. Studies by the Service (Daum et al. 1991, Daum 1991, Daum and Troyer 1992) and by the Department (Barton 1986, 1987, 1988) have demonstrated the importance of estimating total escapement, since aerial surveys often yield unreliable estimates of relative abundance. In 1990, the Service initiated a one-year study using side-scanning sonar to estimate total escapement of chum salmon in the South Fork Koyukuk River, which flows through the Kanuti National Wildlife Refuge.

Side-scanning sonar equipment has been used successfully since the mid-1960's to enumerate adult salmon on more than 20 different river systems in Alaska (Gaudet 1990). Sonar equipment, although costly, is particularly useful in river systems where other counting methods, such as counting towers and weirs, are not feasible. In 1990, sonar projects on the Yukon River drainage included the Anvik River to enumerate summer chum salmon, the Chandalar and Sheenjek rivers to enumerate fall chum salmon, and the lower Yukon River at Pilot Station to estimate total run sizes of chum, chinook, and coho salmon *O. kisutch*.

Two species of Pacific salmon migrate up the South Fork Koyukuk River; chum salmon is the most abundant, followed by chinook salmon (Barton 1984). The Yukon River system is unique in having two distinct runs of chum salmon: a summer run that spawns primarily in July and August, and a fall run that spawns primarily in September and October. Summer chum salmon spawn predominately in U.S. tributaries, whereas fall chum and chinook salmon spawn in both U.S. and Canadian tributaries. Past aerial surveys suggest that both summer and fall runs are present in the South Fork Koyukuk River (Barton 1984; Rost *in preparation*). The fall run is particularly important for Yukon River treaty negotiations, because accurate estimates of spawning escapement are needed to equitably allocate stocks between U.S. and Canadian fishermen.

The objectives of this study were to: 1) estimate total escapement of South Fork Koyukuk River chum salmon in August and September using side-scanning sonar; 2) collect tissue samples early and late in the season for genetic stock identification to clarify the existence of two genetically distinct stocks in this river; 3) quantify and compare age, sex, and length composition of the early and late portions of the chum salmon run; and 4) obtain an aerial count of escapement for comparison to the sonar count.

STUDY AREA

The South Fork Koyukuk River originates in the southern foothills of the Brooks Range and flows 435 km into the Koyukuk River, a major tributary of the Yukon River (Figure 1). The middle and lower reaches of the South Fork Koyukuk River are characterized by gravel substrate. The water is typically clear but brown stained by peatland leachates. Heavy rains in August and September are common and can cause increased turbidity. The region has a continental subarctic climate characterized by extreme temperatures, -56.7 to 33.9°C (National Weather Service 1989). Rivers in this region are ice-free for about four months a year (June-September).

The largest tributaries of the South Fork Koyukuk River are the Jim River and Fish Creek, entering 82 km and 31 km above the mouth, respectively. Between these two tributaries, the South Fork Koyukuk River is generally shallow and braided with an average gradient of .083%. Below Fish Creek, the river is a single channel with steep cut banks alternating with gravel bars and an average gradient of .043%. Chum salmon spawning areas identified prior to this study were upstream from Fish Creek, primarily in the vicinity of the Jim River confluence (Barton 1984).

MATERIALS AND METHODS

Escapement Estimate

Site selection.—A 4-d reconnaissance of the lower 31 km of the South Fork Koyukuk River was conducted July 10-13, 1990 to select a sonar site. The criteria used for sonar site selection included: 1) a single channel, 2) a location downriver from known spawning tributaries, 3) uniform bottom contour with gradually sloping shorelines, 4) uniform flow rate so that fish swimming speed was relatively constant, and 5) a location well below spawning areas to avoid fish milling behavior, thus avoiding multiple counts of the same individual(s). Bottom profiles were obtained at five potential sites by wading and measuring depths at 2 m intervals.

Sonar deployment.—The sonar operation was initiated on August 2. Early August was chosen as a beginning time because it preceded fall chum salmon runs in two other Yukon River tributaries, the Chandalar and Sheenjek rivers (Simmons and Daum 1989, Daum and Simmons 1991, and Daum et al. 1991, Daum 1991, Daum and Troyer 1992; Barton 1986, 1987, 1988). The sonar operation was terminated on September 26 because of cold weather which caused ice build-up on sonar equipment and weirs.

Chum salmon were counted during low water conditions (August 2-27) with one 1978 Bendix side-scan sonar fish counter deployed from the south bank (Figure 2). Higher water beginning August 28 required a second counter, which was deployed from the north bank (August 31-September 25) 86 m upriver from the south bank counter. The counting range (length of the sonar beam) during the low water period averaged 11.3 m; during the high water period counting ranges on the north and south banks averaged 19.8 m and 12.2 m, respectively (Figure 3). Each counting range was subdivided into 12 sectors.

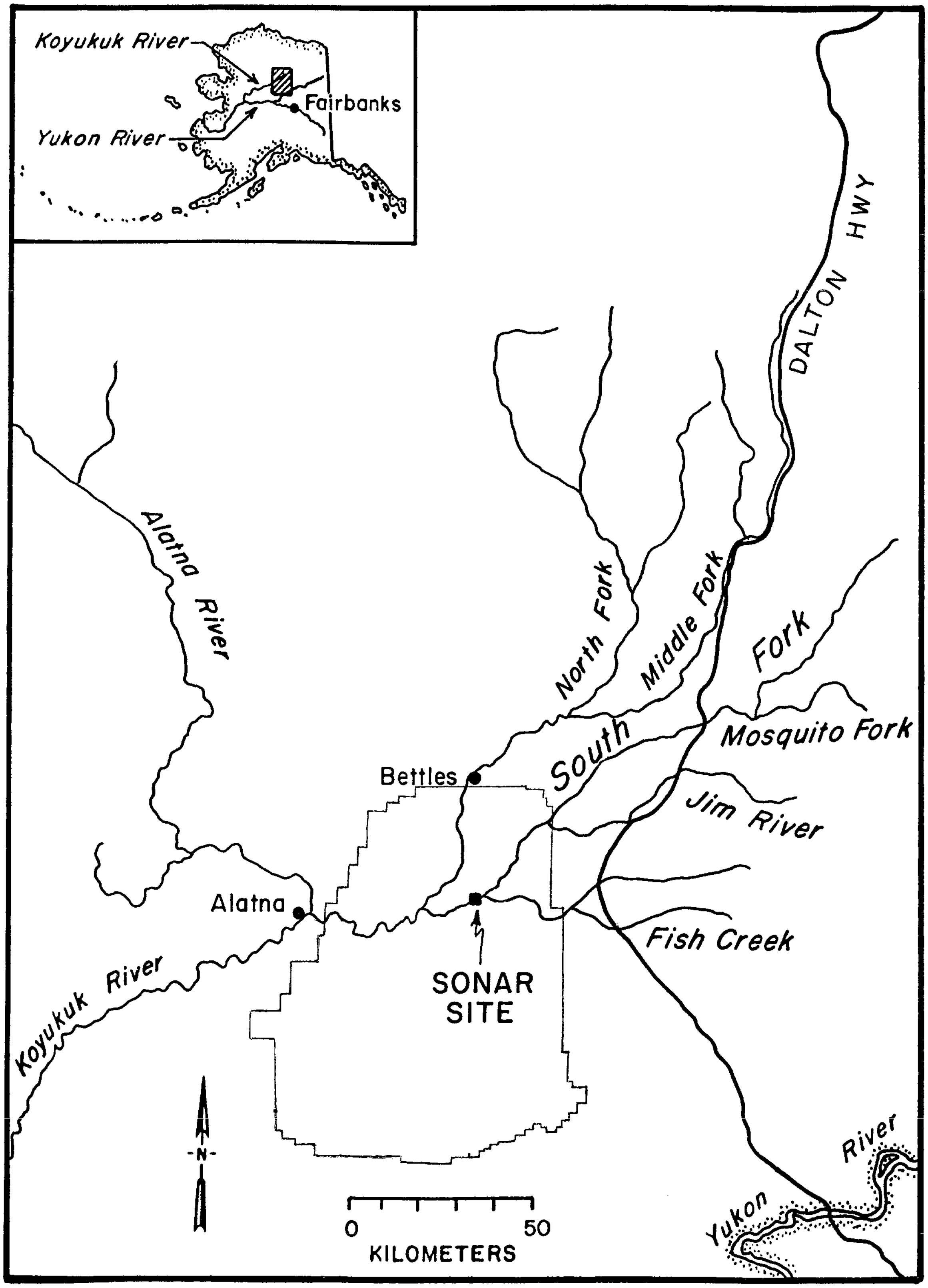

FIGURE 1.—Study area and location of the sonar site on the South Fork Koyukuk River.

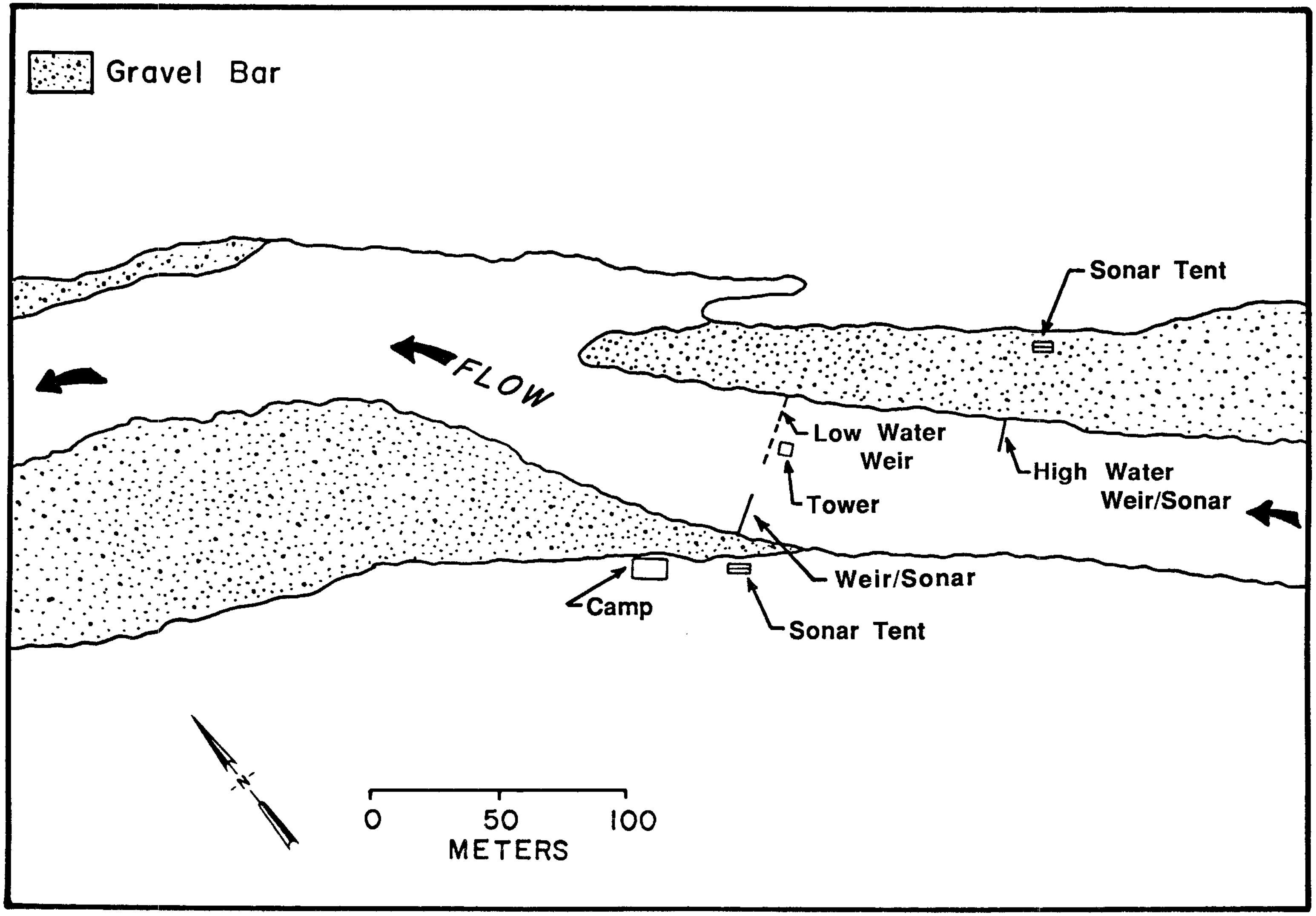

FIGURE 2.-Site map of the South Fork Koyukuk River sonar facilities.

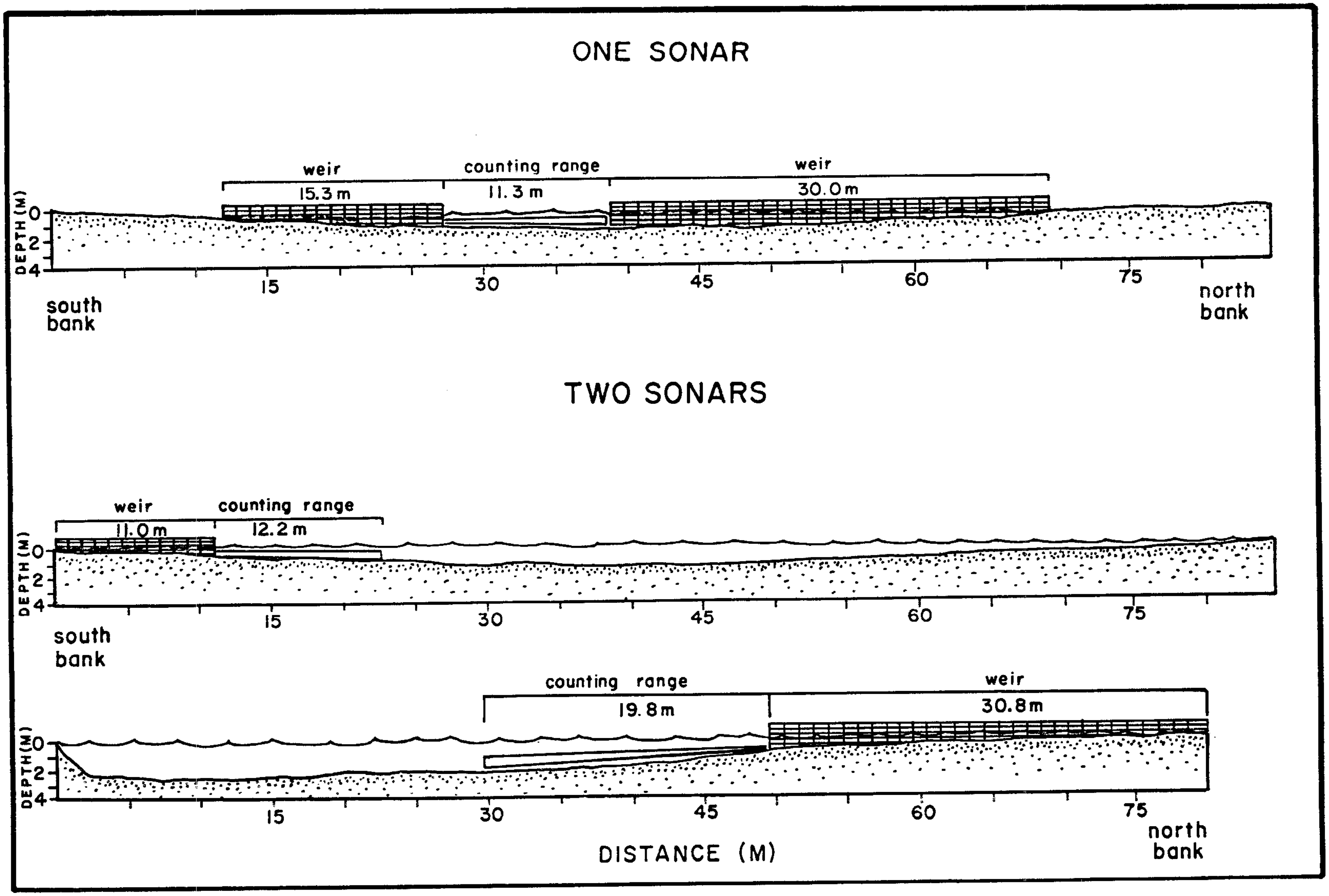

FIGURE 3.–River channel profiles of the single and dual sonar facilities, operated August 2-27 and August 31-September 25, 1990, respectively.

The sonar counters were deployed and operated according to the guidelines described by Bendix Corporation (1980). Because of the evenly sloped and relatively uniform bottom at the sonar site, the artificial substrates normally used with these systems were not deployed. Instead, transducers were mounted on plastic frames and secured with sandbags at a depth of 0.5-1.5 m (design adapted from Barton 1986). The transducers were oriented perpendicular to shore, and aiming was fine-tuned with three handwheels on the back of the transducer bracket. Transducer beam angles were 2° and 4°, with the wider beam used for fish detection in sectors 1-6 of the counting range and the narrower beam covering sectors 7-12.

A wire fence weir (5 x 10 cm mesh) was installed 1 m downstream and extended 1 m beyond the transducer to keep salmon from passing between the shoreline and the transducer face. During high water, single weirs averaging 30.8 m and 11.0 m long were used on the north and south banks, respectively. During low water, two weirs (averaging 15.3 m and 30.0 m long) deployed across from each other at the south bank site effectively forced fish to pass through the sonar beam.

To determine if the transducer was aimed low enough to detect salmon along the bottom, an artificial "fish" (a 1 liter lead-weighted glass container attached to monofilament line) was suspended at various depths in each of the 12 sectors of the counting range. When the container transected the sonar beam it registered as a valid count on the counter and simultaneously appeared as a sharp "spike" on the Tektronix 323 oscilloscope used to monitor the counter. The sonar beam was aimed as close to the river bottom as possible (2-8 cm) without causing false counts due to bottom irregularities.

A river elevation gauge was installed at the south bank sonar site and monitored throughout the season. Water elevation was recorded daily at 1800 hours to the nearest 0.3 cm. A permanent gauging site was established on a group of three birch trees directly across river from the south bank sonar so water elevation comparisons could be made between 1990 and future years if sonar studies of this river are continued. The possible relationship of daily water elevation to daily sonar count was examined by linear regression ($P = 0.05$; Systat 1988).

Fish velocity adjustment.—To determine if the number of fish registered by the sonar counter equaled the number of fish passing through the sonar beams, comparisons were made between oscilloscope observations and counter output once every 4 h for 30-minute "calibration" periods. When a fish passed through the beam, a returning echo was displayed on the oscilloscope and a corresponding count should have registered on the sonar counter. Adjustments to the fish velocity control (counter pulse rate) were made when the oscilloscope count exceeded 14 fish and the sonar count differed from the oscilloscope count by more than 15% during the 30-minute calibration. The new fish velocity control setting was calculated as follows:

New fish velocity setting = (sonar count / scope count) x fish velocity setting.

A different formula was used for calibration periods when visual observations (described below under Species Composition) were made:

New fish velocity setting = (sonar count / visual count[1]) x Fish velocity setting.

Visual counts were considered to be more accurate than oscilloscope counts because the oscilloscope provided relatively limited ability to distinguish chum salmon from other fish species.

Species composition.—Systematic visual observations were made to check the accuracy of sonar counts, including estimates of the percentage of sonar counts due to species other than chum salmon. Observations were made from a 5 m high counting tower, placed 3 m upstream from the weir and directly across the river from the south bank sonar counter (Figure 2). Two 6.0 x 1.5 m white minnow seines were affixed to the river bottom to provide a contrasting background for viewing fish. The portion of the river corresponding to the sonar counting range was observed for 30-minute periods coinciding with calibrations. An observer in the tower communicated by handheld radio with the oscilloscope observer. Sonar and oscilloscope counts were recorded by the oscilloscope observer before visual counts were radioed back. The oscilloscope observer then tallied 1) sonar, oscilloscope, and tower counts of fish visually identified as chum salmon, and 2) sonar and oscilloscope counts caused by debris and other species. Other species were identified to species when possible.

Visual counts were conducted primarily during the daylight and dusk hours (0500-2400) of August 7-27. Visual counts were not possible after August 27 due to increased turbidity caused by high water. An average of three of the six daily calibrations were accompanied by a visual count. Visual sampling included the dusk calibration period (2000-2400 hours) on each day (N=21), and evening (1600-2000 hours) and afternoon (1200-1600 hours) calibrations on most days (N=15 and N=13 respectively). Early (0400-0800 hours) and late morning (0800-1200) calibration periods were sampled visually on 7 and 5 d, respectively.

Visual counts with artificial lights were attempted after dark (0000-0100 hours) on August 24-27. Different intensities of white light were tested, including a Q-beam spot light/flood light (with 200,000 and 100,000 candlepower settings) and a two mantle Coleman lantern. Lights were mounted on poles and positioned 3-5 m above the river illuminating the area covered by the sonar beam. Observations were made of fish response to artificial lights.

Early in the study, gill net sampling was evaluated as a possible alternative to tower counts for determining species composition. From August 4 to August 13, a 15.2 X 1.8 m monofilament gill net with equal length panels of 5.1 and 6.4 cm bar mesh was fished continuously (parallel to shore) off the end of the weir opposite the south bank sonar counter. Also during that period, two 15.2 X 3.0 m multifilament gill nets with 7.5 cm bar mesh were fished for an average of 20 h/d. The multifilament nets were alternated daily between six sites including both fast and slow water areas within 500 m upstream and downstream from the sonar counter. The two net types were evaluated for their effectiveness in catching the various species counted by sonar.

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[1]Visual and sonar counts of chum salmon only, excluding other species and debris.

Sonar count adjustment.—Daily fish counts were adjusted with two equations using data from the six 30-minute calibration periods. Equation 1 adjusted the daily sonar count based on oscilloscope observations, as follows:

(1) Scope-adjusted count = $[(\Sigma O_a / \Sigma C_a) \times \Sigma T] + \Sigma [(O_b / C_b) \times T]$; where,

O_a = Oscilloscope count during calibration period when fish velocity control is not changed;
C_a = Sonar count during calibration period when fish velocity control is not changed;
O_b = Oscilloscope count during calibration period when fish velocity control is changed;
C_b = Sonar count during calibration period when fish velocity control is changed;
T = Total sonar count for corresponding 4-h period.

Equation 2 was used to correct for the discrepancy between oscilloscope and visual observations, as follows:

(2) Adjusted daily count = $(\Sigma V_c / \Sigma O_c) \times$ scope-adjusted count; where,

V_c = Visual count of chum salmon during calibration period when both tower and oscilloscope observations were made, including the visual count at dusk on the previous day;
O_c = Oscilloscope count during calibration period when both tower and oscilloscope observations were made, including the oscilloscope count at dusk on the previous day.

By multiplying the scope-adjusted count by the ratio of visual counts to oscilloscope counts, spurious oscilloscope counts due to species other than chum salmon were factored out of the daily sonar count. The counts at dusk from the previous day were included because they were considered the best estimate of the proportion of chum salmon counted by the oscilloscope just after dark (0000-0200 hours). When visual counts were not available (August 2-6 and August 28-September 25), the mean daily ratio of visual counts to oscilloscope counts (averaged over August 7-27) was used in equation 2.

For three periods of temporary sonar shutdown (2-4 d) due to high water, daily counts were estimated by linear interpolation of the adjusted daily counts from the day preceding and the day following the shutdown. Hourly counts and sector counts for the periods of sonar shutdown were estimated by linear interpolation. All reported data are in adjusted form.

Genetic Sampling

Two samples of 75 chum salmon were collected for genetic stock identification. Early (August 7-13) and late (September 11-16) samples were collected for genetic comparison. Fish were collected with 15.2 X 3.0 m multifilament gill nets with 7.5 cm bar mesh. Heart, liver, retinal, and muscle tissues were taken from each fish, frozen in liquid nitrogen, and transported to the Service's genetics laboratory in Anchorage for electrophoretic analysis.

Age, Sex, and Length Composition

Before chum salmon tissue samples were taken for genetic analysis, length from mid-eye to fork in caudal fin was measured to the nearest 5 mm. Sex was determined by visual inspection of the gonads. Ages were determined using three vertebrae collected from each fish in the early and late genetic samples. Vertebrae were cleaned, dried, and aged by two readers using direct light and a magnifying glass. Disagreements between readers were resolved with a third reading. Unreadable samples were discarded. Ages were reported by the European method (Koo 1962): number of freshwater annuli followed by number of saltwater annuli.

Age and sex composition of early and late samples, and age composition of males and females were compared with chi-square analyses ($P = 0.05$; Zar 1984). Mean lengths were compared by sex and by sampling period with two-way ANOVA ($P = 0.05$; Systat 1988). Length data were summarized in length frequency histograms with 5 mm increments.

Aerial Survey

An aerial survey was conducted to determine the relationship between aerial and sonar counts and to develop an expansion factor. The expansion factor is the number by which an aerial count (which tends to underestimate escapement) is multiplied to approximate the sonar count, a more accurate estimate of total escapement. September 26 was chosen as the survey date to approximate the timing of the two previous aerial surveys (September 28, 1971 and September 25, 1985) which had counted fall chum salmon in this river. The survey was flown in the morning (1000-1130 hours) with a Hughes 500-D helicopter (90 m above ground level) from Fish Creek upriver to 21 km below the Dalton Highway crossing, a total distance of 103 river km. The upper South Fork Koyukuk River (between Dalton Highway and Mosquito Fork) and the Jim River were not surveyed due to poor weather and light conditions.

RESULTS AND DISCUSSION

Escapement Estimate

The adjusted chum salmon escapement count for the South Fork Koyukuk River in 1990 was 19,485 fish. This is a conservative estimate of the annual escapement because counts do not include fish passage before the sonar facilities were in operation and after counting ceased. This escapement estimate is more than 20 times greater than aerial survey counts from previous years. Only two previous aerial surveys were conducted in September and can be compared to the sonar count in this study. One survey was rated fair (ratings based on light and water conditions) and documented 653 fish on September 28, 1971 (Barton 1984); another survey was rated poor and documented 969 fish on September 25, 1985 (Rost *in preparation*). This large disparity between sonar and aerial survey estimates emphasizes the need to evaluate aerial counts on rivers where survey conditions are less than optimal.

Site selection.—Although several potential sites were examined for sonar deployment, only one site met all five criteria for site selection. This site was located 2 km below the Fish Creek confluence, at one of the few sites on the lower river with gravel bars directly across from one another (Figure 2). At the sonar site, the river was 53 m wide and 0.7 m deep at low water, and 85 m wide and 3.3 m deep at high water.

Run timing.—Daily counts ranged from 39 to 1,752 fish/d with an average of 354 fish/d (Appendix 1). Daily counts were less than 100 fish/d on August 2 and 3, the first 2 d of sonar counting. For the last 6 d of sonar counting, counts were less than 250 fish/d and declining. Thus, the majority of the run apparently was encompassed by the 55-d period of sonar operation.

The highest daily count was recorded on August 13 (1,752 fish), and this was the only day that fish passage exceeded 1,000 fish. The median passage date was August 22, 19 d earlier than the chum salmon run in the Chandalar River (Daum and Troyer 1992), which is about the same distance ($\pm$ 10 river km) from the mouth of the Yukon River.

The escapement curve showed a unimodal distribution (Figure 4). Daily counts rose rapidly to a peak and then declined to low but variable counts for the rest of the study. The majority of the run (60%) passed the sonar site during the period August 2-27, when water discharge was consistently low (Figure 5). Daily discharge increased and became more variable after August 27.

For the entire season, water elevation and daily sonar count were negatively correlated ($r = -0.32$, $N = 46$, $P < 0.02$), apparently because low water prevailed during the majority of the run and higher water occurred late in the run when daily counts were relatively low. Discharge did not appear to affect daily fish passage, as the largest fluctuations in sonar counts occurred in mid-August when water elevation was stable. However, during high water (August 31-September 25), daily sonar counts were positively correlated with the daily water elevations from 4 d earlier ($r = 0.76$, $N = 20$, $P < 0.0002$). Increases in discharge may have stimulated the movement of fish which were downstream from the sonar site. If water elevation does influence run timing, the influence may occur only when water elevations are relatively high.

Fish passage was concentrated in the late evening and early morning hours (Figure 6). Seventy-eight percent of the run was counted during hours of low light (2200-0700 hours). The highest counts occurred at dusk and after dark (between 2300 and 0100 hours).

Horizontal fish distribution.—When one sonar counter was used (August 2-27), fish passage was concentrated in sectors 3-7 (Figure 7). Sectors 3-7 comprised 63% of the 11,740 fish counted during this period. The distribution of counts by sector reflects the fish behavior frequently observed from the counting tower: groups of chum salmon swimming up the sides of the river tended to angle out into the middle to pass between the weirs. Fish tended to run closer to the south weir than the north weir, as indicated by greater counts in sectors 1-6 (south side) than in sectors 7-12 (north side).

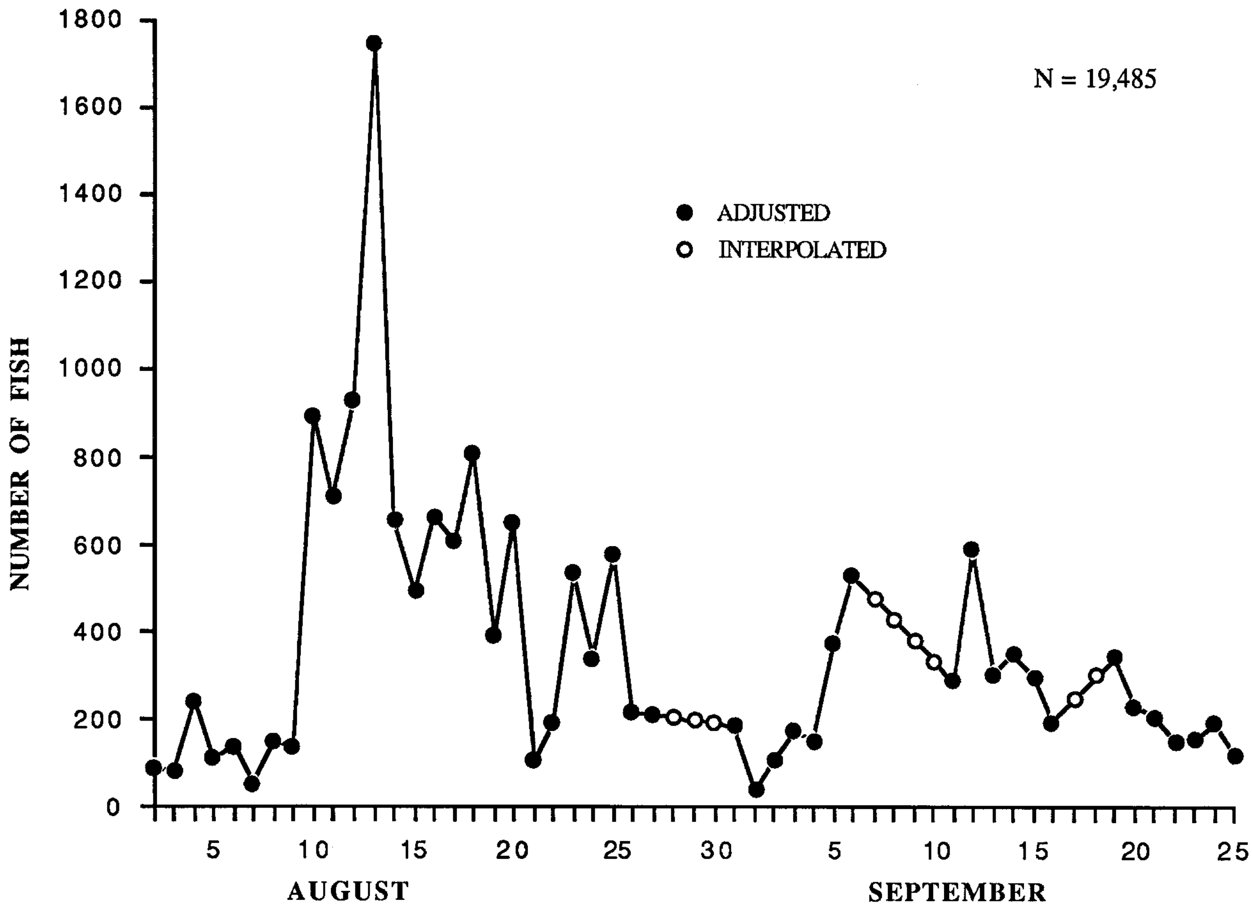

FIGURE 4.—South Fork Koyukuk River chum salmon run timing, based on daily sonar counts, August 2-September 25, 1990.

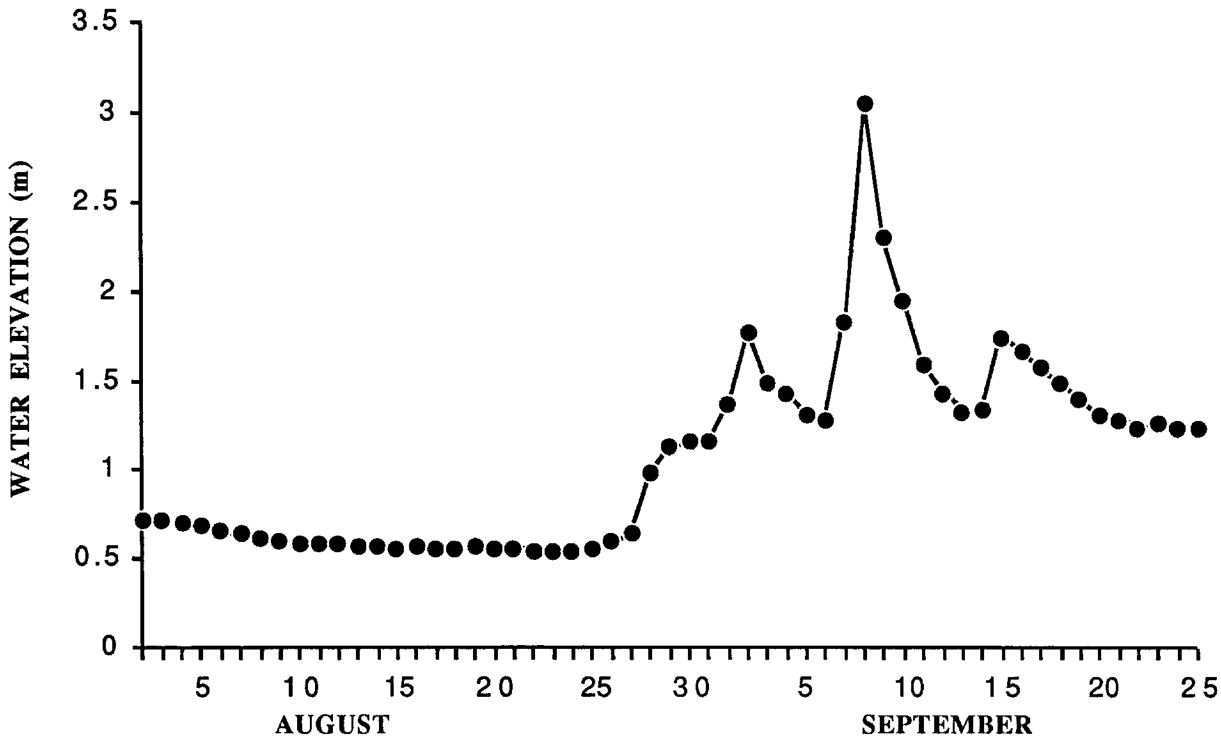

FIGURE 5.—Daily water elevation in the South Fork Koyukuk River, August 2-September 25, 1990.

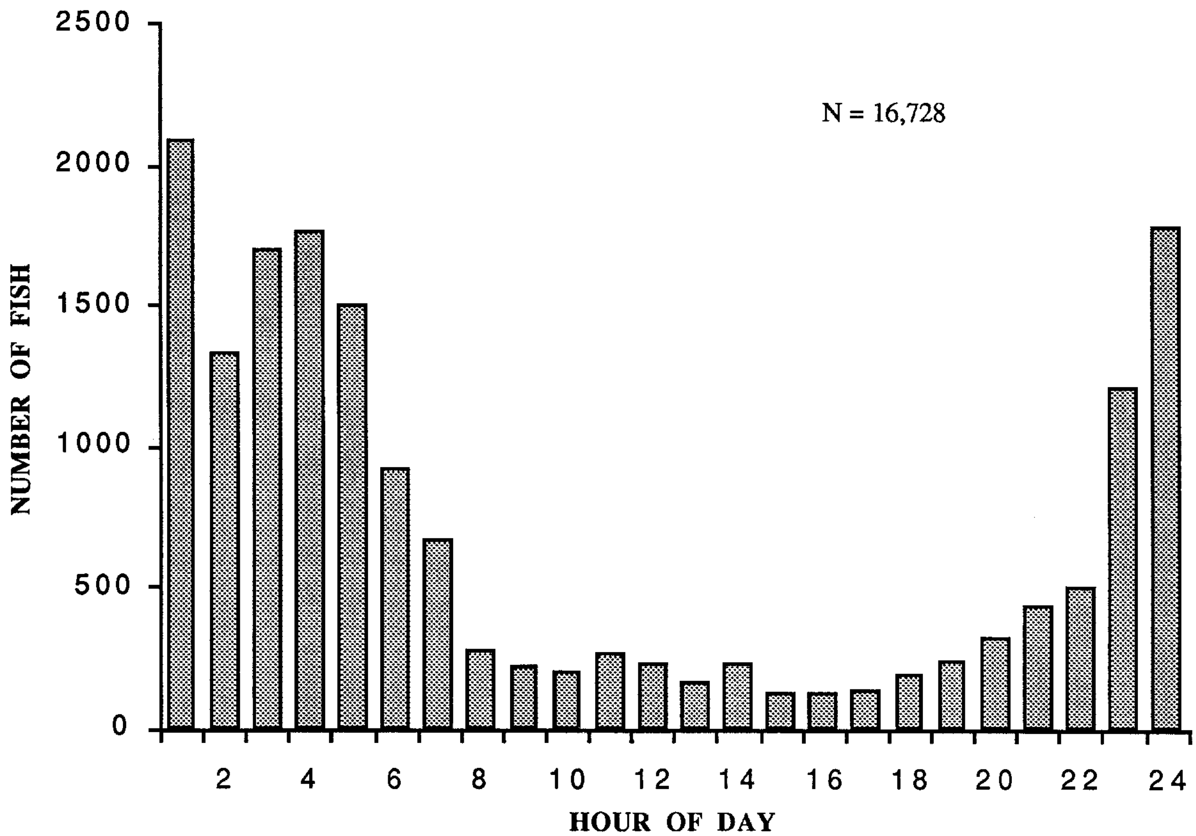

FIGURE 6.—Temporal distribution of South Fork Koyukuk River chum salmon, August 2-September 25, 1990. Data from days of interpolated counts are not included.

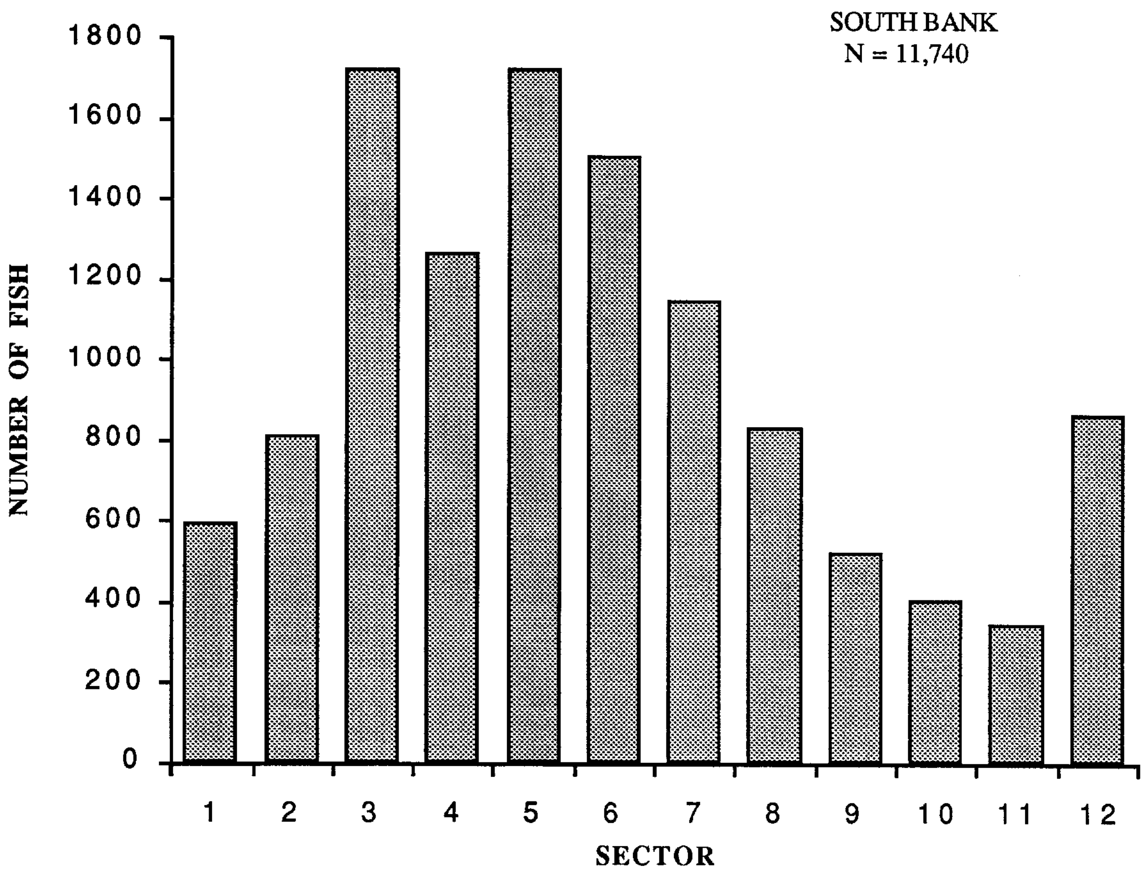

FIGURE 7.—Sector counts of South Fork Koyukuk River chum salmon from the south bank sonar station, August 2-27, 1990.

When high water required the use of two sonar counters (August 31-September 25), most of the fish were counted along the north bank (Figure 8). The north bank comprised 83% of the 7,160 fish counted during this period. The north bank count exceeded the south bank count on all but two days.

The distributions of north and south bank counts by sector suggest that some fish were beyond the range of sonar detection (Figure 9). On the south bank, outer sector counts were low relative to nearshore sector counts (sectors 7-12 had 27% of the total), indicating that the majority of the fish along the south bank were detected. In contrast, counts were numerous in the north bank outer sectors (sectors 7-12 had 54% of the total). More fish may have been counted if the north and south bank sonar beams were set at greater ranges. However, sonar ranges were reduced and an unsonified section of 7.2 m was left in the middle of the river (Figure 3) to decrease the probability of counting fish twice. A fish would be counted twice if it passed through the south bank sonar beam and then moved upriver across current through the north bank sonar beam.

Some double counts were likely because a fish counted at the outer edge of the south bank sonar beam would need to move only 7.2 m across current while traveling 86 m upriver to be counted at the outer edge of the north bank sonar beam. In this case, the maximum possible overestimate due to double counting is 1,184 fish (the south bank total when two sonar counters were used). In contrast, there was an unknown potential for underestimating the run with this sonar configuration, since all fish moving directly upriver through the unsonified section and some fish moving across current away from the north bank would be missed by both sonar counters.

Sonar deployment.—Placement of the sonar counters more in line with each other across river may have reduced the likelihood of missed fish and double counting. However, we found that the sonar beams interfered with each other if they were less than 15 m apart. At this site, the north bank sonar counter was positioned 86 m upriver because of unsuitable bottom contours closer to the south bank sonar facility. Range limitations of the 1978 Bendix sonar equipment (30.5 m maximum range) did not allow coverage of the entire river with a single sonar beam during the high water period (August 27-September 25).

Fish velocity adjustment.—When one sonar counter was used, the minimum number of 15 fish for considering a velocity control adjustment occurred in 23% of the calibrations; of those calibrations, 59% necessitated a velocity adjustment. When two sonar units were used, none of the south bank calibrations and only 8% of the north bank calibrations had 15 or more fish. When this minimum was obtained on the north bank, the velocity adjustment rate was 89%. The high rates of fish velocity adjustment are indicative of frequent changes in chum salmon swimming speeds during the season.

Species composition.—Visual counts from the counting tower (August 7-27) showed that five fish species other than chum salmon were present and in some cases were counted by sonar: Arctic grayling *Thymallus arcticus*, longnose sucker *Catostomus catostomus*, northern pike *Esox lucius*, chinook salmon *O. tshawytscha*, and humpback whitefish *Coregonus pidschian*. During the periods of visual observation, 57% of the sonar counts and 78% of the oscilloscope counts were visually confirmed as chum salmon (Table 1). Most of the other counts were caused by individual longnose suckers (approximately 300-450 mm), individual large Arctic grayling (approximately 300-400 mm), and groups of smaller Arctic grayling.

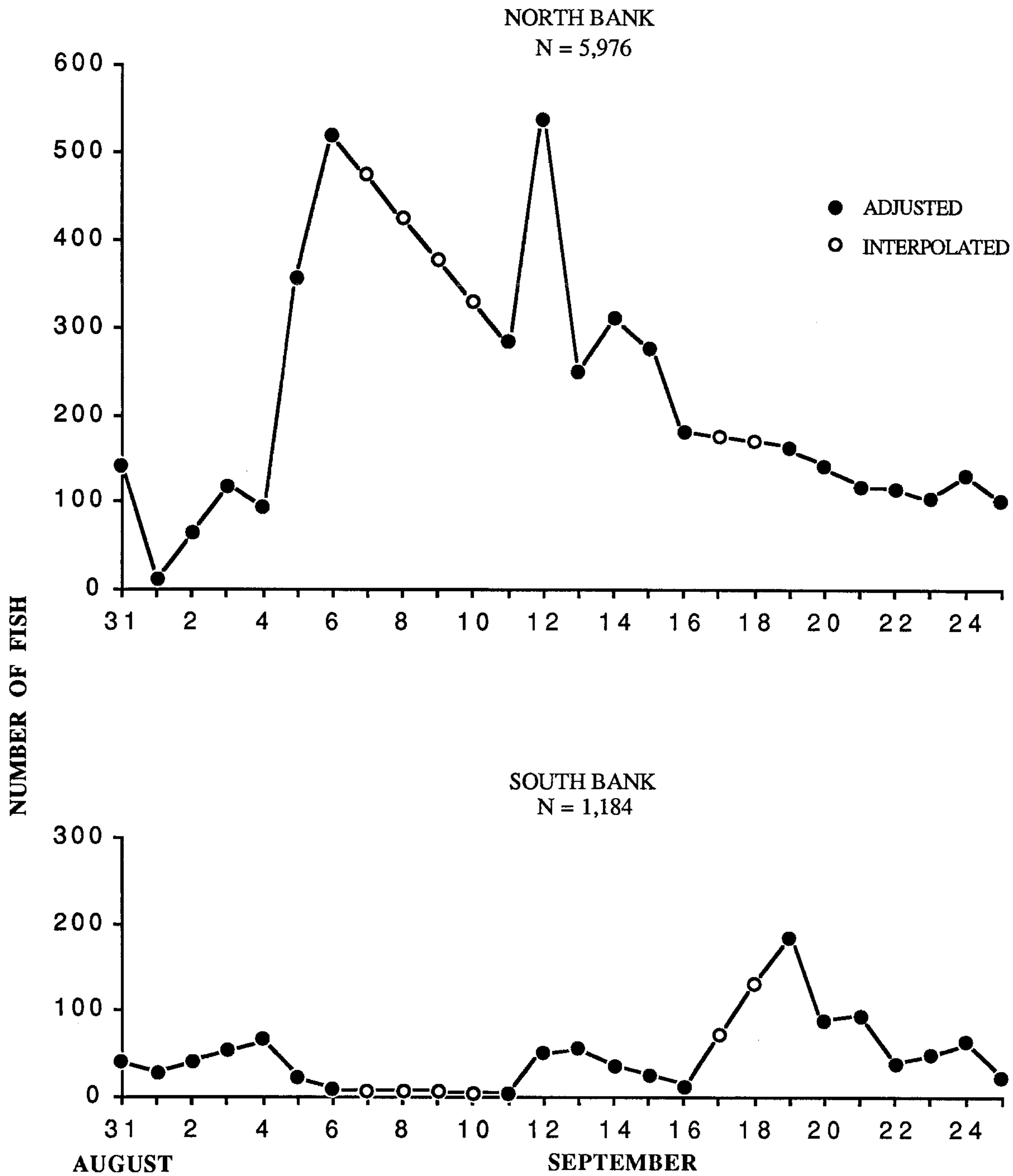

FIGURE 8.—South Fork Koyukuk River chum salmon run timing by river bank, August 31-September 25, 1990.

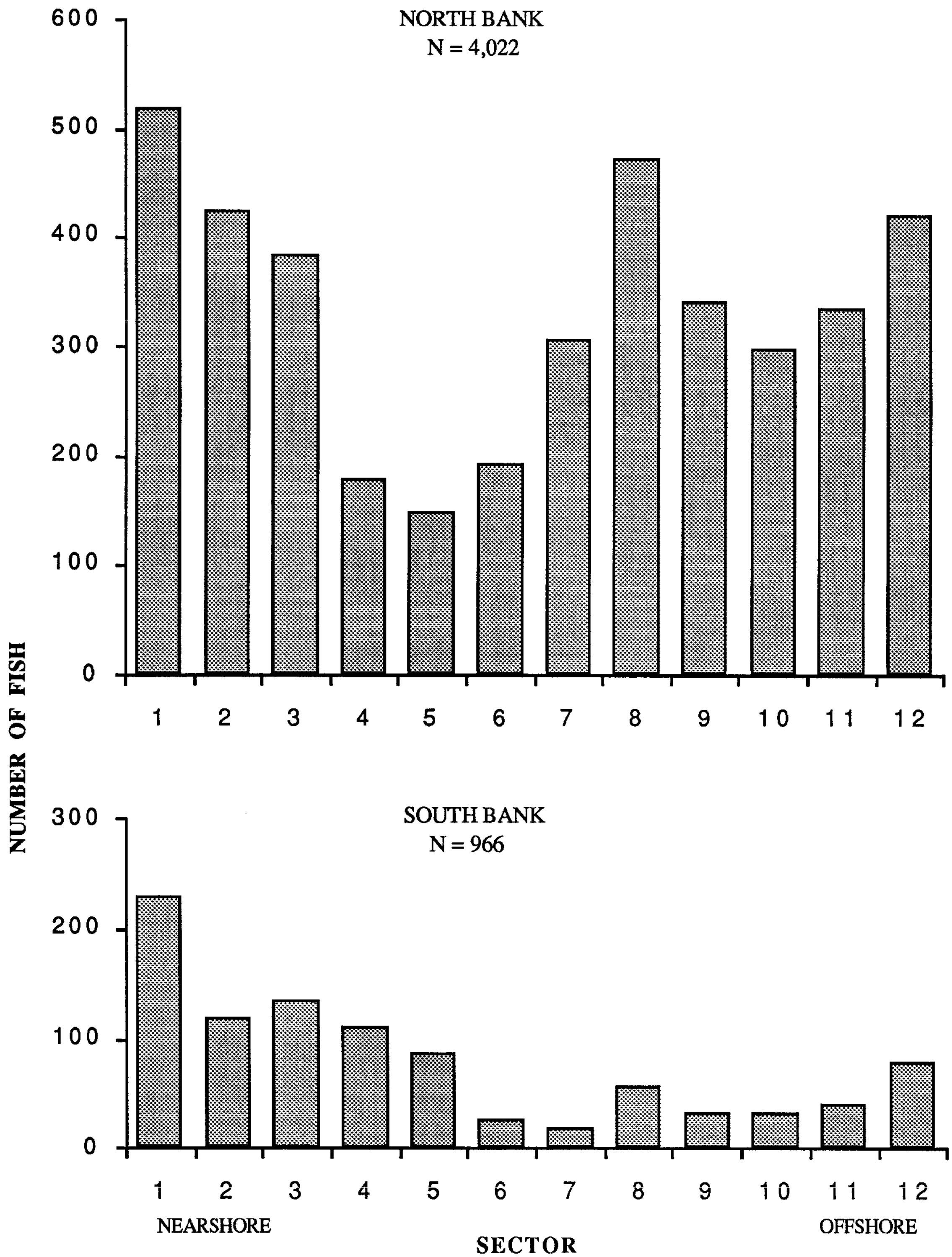

FIGURE 9.—Sector counts of South Fork Koyukuk River chum salmon by river bank, August 31-September 25, 1990. Data from days of interpolated counts are not included.

TABLE 1.—Comparison of simultaneously conducted sonar, oscilloscope, and tower counts of chum salmon, other species, and debris in the South Fork Koyukuk River, August 7-27, 1990.

	Counts		
Source of count[a]	Sonar	Oscilloscope	Tower[b]
Chum salmon	1,058	1,063	948
Other species	570	127	—
Debris	35	32	—
Total	1,663	1,222	—
% Visually confirmed chums[c]	56.7	77.6	—

[a]Count source determined by visual observation.
[b]Tower observer did not note the number of individuals of other species and debris present, but did tell the scope observer what caused a sonar and scope count if it was not a chum salmon.
[c]% Visually confirmed chums = (tower count of chum salmon / total count).

Arctic grayling and longnose suckers often moved slowly through or held in the sonar beam, whereas chum salmon crossed the beam more quickly. This difference in swimming speeds allowed oscilloscope observers to distinguish Arctic grayling and longnose suckers from chum salmon in some instances. Northern pike, chinook salmon, humpback whitefish, and debris were not readily distinguished from chum salmon on the sonar or oscilloscope.

The use of artificial lights for visual counts after dark (0000 to 0100 hours) was unsuccessful because the lights noticeably altered chum salmon behavior, causing a biased assessment of swimming speed. Chum salmon encountering the edge of the illuminated area usually turned quickly and moved back downriver, holding there for indefinite periods. When chum salmon did cross the illuminated area, they usually darted across at a much greater swimming speed than was observed just before dark when the river was not illuminated. The least intense light tested (two-mantle Coleman lantern) appeared to cause less darting behavior than the Q-beam spot light or flood light. However, even with the lantern, darting behavior was observed in about half the chum salmon crossing the illuminated area.

Monofilament and multifilament gill nets proved unreliable for estimating species composition because they were ineffective in catching Arctic grayling and longnose suckers (Table 2). The multifilament mesh may have been too large for these species, and the monofilament nets may not have fished the bottom effectively in the fast water adjacent to the sonar beam. In one instance, a longnose sucker was observed passing under the monofilament net. Gill netting was discontinued after August 13 because of its ineffectiveness in capturing Arctic grayling and longnose suckers and because tower counts provided a more accurate alternative for estimating species composition. When high water and increased turbidity made visual counts impossible,

TABLE 2.—Species composition of gill net catches in the South Fork Koyukuk River, August 4-13, 1990.

Net type (cm bar mesh)	Effort (h)	Number caught: Chum salmon	Northern pike	Chinook salmon	Humpback whitefish	Arctic grayling	Longnose sucker
Multifilament (7.5)	370	90	5	2	1	0	0
Monofilament (5.1,6.4)	216	8	3	1	3	0	0

gill netting was attempted again but was abandoned because debris and increased flow greatly reduced net effectiveness.

Sonar count adjustment.—Because the oscilloscope observer distinguished other species from chum salmon more frequently than the sonar unit did (Table 1), sonar counts were generally higher than oscilloscope counts. Daily sonar counts were adjusted with an average factor of 0.743 to give the daily scope-adjusted counts. Daily scope-adjusted counts were further adjusted with an average factor of 0.768[1], the mean daily ratio of visual chum salmon count to oscilloscope count, to give the adjusted daily count. The mean daily ratio of visual to oscilloscope count was obtained from the period (August 7-27) when 57% of the run passed the sonar site. This ratio was extrapolated to the rest of the season assuming that the proportion of oscilloscope counts caused by other species and debris did not change significantly after water levels increased. Debris was not noticeably abundant after the water level began to decrease (September 8). However, the proportions of other species, including humpback whitefish (which migrate upriver to spawn in September and October; Morrow 1980), may have changed from what they were in August.

Genetic Sampling

Early (August 7-13) and late (September 11-16) season genetic samples differed significantly in gene frequencies ($P < 0.05$; Richard Wilmot, National Marine Fisheries Service, personal communication), which suggests temporal and/or spatial reproductive isolation of stocks upstream from the sampling site. Sampling from the spawning grounds would be necessary to determine whether the observed divergence is related to homing to different locations, or to different timing of spawning between stocks. Aerial surveys have shown that live fish are on the spawning grounds from mid-July to November (Barton 1984), so it will be necessary to take genetic

[1]This number is a mean daily ratio including dusk counts from the previous day (as described in Methods), and thus is different from the overall ratio shown in Table 1.

samples from earlier and later in the season to quantify temporal genetic variability among South Fork Koyukuk River chum salmon.

Age, Sex, and Length Composition

Vertebrae were unreadable for three fish from the original sample of 150. Early and late season chum salmon samples were combined because they did not differ significantly in age composition ($P > 0.10$), or sex ratio ($P > 0.25$). Two-way ANOVA showed no significant differences in mean length by sampling period or sex, and no interaction between these two variables ($P > 0.40$). Age 0.3 (66.7%) predominated the combined sample (Table 3), followed by age 0.4 (26.5%), age 0.2 (4.1%), and age 0.5 (2.7%). There was no significant difference between males and females in age composition ($P > 0.25$).

The prevalence of males (70% of the combined sample) may be due, in part, to gill net selectivity for males, which have more kipe development than females. Kipe and tooth development of males would tend to make them more catchable than females over a range of sizes, and may explain the greater length range of males in the gill net catch (Figure 10).

TABLE 3.—Length and age composition, by sex, of chum salmon collected from the South Fork Koyukuk River, August 7-September 16, 1990.

		Mid-eye Fork Length (mm)			Age Composition (%)			
Sex	N	Mean	SD	Range	0.2	0.3	0.4	0.5
Male	103	585	38	455-692	5.8	66.0	26.2	2.0
Female	44	589	24	545-650	0	68.2	27.3	4.5
Both sexes	147	586	35	455-692	4.1	66.7	26.5	2.7

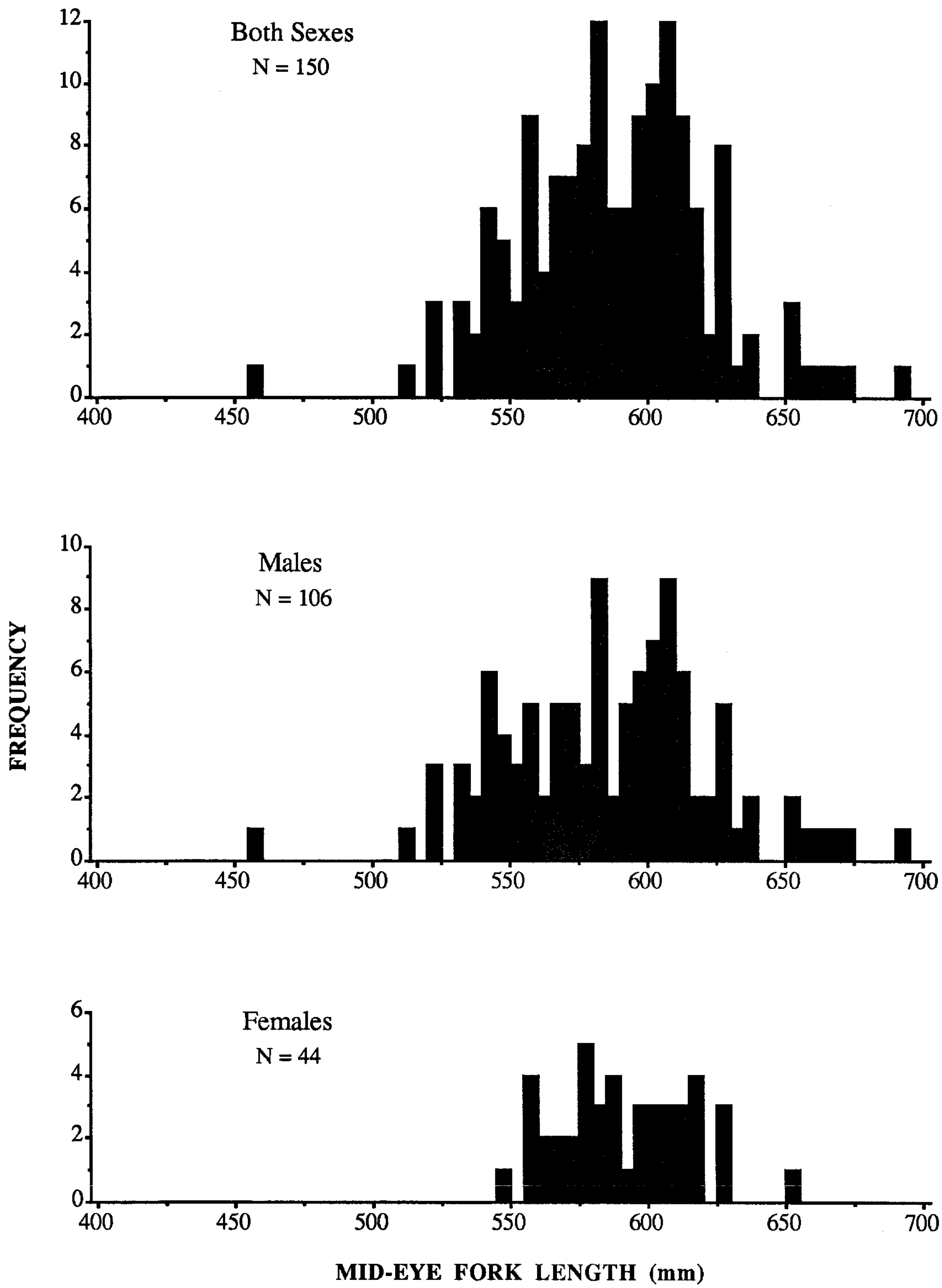

FIGURE 10.—Length frequency of chum salmon combined and by sex in the gill net catch from the South Fork Koyukuk River, August 7-September 16, 1990. Gill nets were multifilament with 7.5 cm bar mesh.

Aerial Survey

A helicopter survey was attempted on September 26 for comparison to the total sonar count; however, low clouds and snow caused extremely poor lighting, and no salmon were seen. Seventy-one percent of the previous aerial surveys on this river were rated fair or poor (Barton 1984). Cloud cover and turbidity were the primary factors reducing the effectiveness of aerial surveys.

Study Recommendations

Escapement counts would need to be continued on this river to determine variability in run size between years. These should be ground surveys such as by sonar, counting tower, or floating weir, because aerial surveys do not appear to be an adequate means of assessing escapement in this river. Side-scanning sonar proved to be most effective when water levels were low, providing good visibility for estimating species composition and the opportunity for using a single sonar counter with extensive weirs.

High water presented two main problems in this study which might be avoided in future escapement studies. First, the dual sonar configuration needed for high water probably caused missed fish and double counting. Several hydroacoustic systems have greater range capabilities than the 1978 model Bendix counter and would allow coverage of this river with a single sonar beam. A long range sonar counter has been used successfully on the Sheenjek River at a site with bottom contours similar to the north bank site in this study (Barton 1988). Another improvement for high water conditions would be relocating the sonar site upstream of Fish Creek, where flow is reduced by about one third. The reduced flow at an alternative site 3 km above the Fish Creek confluence made it suitable for a single 1978 Bendix sonar counter in mid-September when two sonar counters were still necessary at the site downriver. Sonar operations above Fish Creek would require monitoring the chum salmon escapement into Fish Creek, a known spawning tributary. However, aerial surveys suggest that Fish Creek escapement may be very low (Barton 1984).

The second problem encountered during high water was obtaining species composition information without the benefit of visual counts. Estimates of species composition are essential to interpreting sonar data accurately for this river, because other species are present and were often counted as chum salmon by the sonar and oscilloscope. The problem of determining species composition might be partially solved by 1) moving the sonar site above Fish Creek, where visual counts would be possible under higher water conditions, and/or 2) using more sophisticated sonar equipment (such as dual-beam or split-beam systems) which measure target strength and allow some ability to distinguish between different sizes of fish (Ehrenberg 1983).

With any type of sonar used, some additional sampling method would be required to verify species composition. In high, turbid water this method would most likely be gill netting. Gill netting done in this study might be improved upon by using twisted monofilament nets including smaller mesh sizes (< 5.1 cm bar mesh). High water will tend to limit stationary gill net sets to nearshore areas, but drift netting may be used to sample mid-river. Both drift and stationary sets will likely be hindered by debris if water elevation is as high as it was in 1990.

A floating weir may be the best approach to determining species composition and obtaining an accurate estimate of chum salmon escapement. Floating weirs have been used successfully to determine salmon escapement in the Uganik and Tuluksak rivers, which have multiple species and are of about the same size as the South Fork Koyukuk River (Booth *in preparation*; Harper *in preparation*). Floating weirs may become temporarily ineffective in very high water (water elevations > 2 m above the low water mark; Jeff Booth, Service, Kenai, personal communication); however, in 1990 this limitation would have disabled a weir on the South Fork Koyukuk River for only about 2 days, and perhaps not at all if the weir were located above Fish Creek. Drawbacks of weir projects are cost (approximately 2-3 times more than a sonar project in the first year, and about the same as a sonar project in subsequent years) and a slight hindrance to boat traffic (Doug Palmer, Service, Kenai, personal communication).

With any method used, future studies should determine chum salmon escapement beginning in early July and continuing through the end of September. Beginning the project in early July will help determine if there are one or two temporally separated chum salmon runs (summer and fall) in this river and will also allow enumeration of the chinook salmon run. Genetic samples of chum salmon should be collected from spawning grounds in July and late September to determine the extent of temporal and spatial genetic variability within season and, when compared to samples collected in 1990, between seasons.

Aerial surveys need not be attempted again in conjunction with a sonar or weir project on the South Fork Koyukuk River. The effectiveness of aerial surveys is highly dependent on water and weather conditions, as shown by the poor results in 1990, when the survey was conducted under low clouds. Sub-optimal survey conditions are common on the South Fork Koyukuk River (Barton 1984), making aerial surveys unreliable for a long term management data base of escapement.

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APPENDIX 1.—South Fork Koyukuk River daily adjusted chum salmon counts from north and south bank sonar stations, August 2-September 25, 1990.

Date	South bank	North bank	Combined	Cumulative
08-02	94		94	94
08-03	81		81	175
08-04	243		243	418
08-05	108		108	526
08-06	143		143	669
08-07	59		59	728
08-08	155		155	883
08-09	132		132	1,015
08-10	898		898	1,913
08-11	710		710	2,623
08-12	930		930	3,553
08-13	1,752		1,752	5,305
08-14	653		653	5,958
08-15	493		493	6,451
08-16	668		668	7,119
08-17	604		604	7,723
08-18	810		810	8,533
08-19	387		387	8,920
08-20	657		657	9,577
08-21	102		102	9,679
08-22	188		188	9,867
08-23	537		537	10,404
08-24	340		340	10,744
08-25	575		575	11,319
08-26	212		212	11,531
08-27	209		209	11,740
08-28[a]			202	11,942
08-29[a]			195	12,137
08-30[a]			188	12,325
08-31	40	141	181	12,506
09-01	28	11	39	12,545
09-02	40	65	105	12,650
09-03	52	118	170	12,820
09-04	65	90	155	12,975
09-05	21	356	377	13,352
09-06	8	520	528	13,880
09-07[a]	7	473	480	14,360
09-08[a]	6	425	431	14,791
09-09[a]	5	378	383	15,174

APPENDIX 1.—Continued

South Fork Koyukuk River daily adjusted chum salmon counts from north and south bank sonar stations, August 2-September 25, 1990.

Date	South bank	North bank	Combined	Cumulative
09-10[a]	5	330	335	15,509
09-11	4	283	287	15,796
09-12	49	541	590	16,386
09-13	55	250	305	16,691
09-14	36	313	349	17,040
09-15	25	276	301	17,341
09-16	12	183	195	17,536
09-17[a]	69	177	246	17,782
09-18[a]	126	171	297	18,079
09-19	184	165	349	18,428
09-20	87	142	229	18,657
09-21	92	118	210	18,867
09-22	38	114	152	19,019
09-23	47	104	151	19,170
09-24	61	131	192	19,362
09-25	22	101	123	19,485
Total	12,924[b]	5,976[b]	19,485	

[a]Due to high water, counts estimated by linear interpolation.
[b]Bank totals do not include August 28-30, when estimates of bank counts were not possible.