Hydroacoustic Study of Upstream Migrating Adult Salmon in the Susitna River during 1985

FINAL REPORT

BioSonics™

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Prepared for

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EXECUTIVE SUMMARY

The Susitna River is one of the primary producers of salmon in the Upper Cook Inlet drainage. In order to quantify the spatial and temporal distributions of migrating adult salmon in the lower river, Alaska Department of Fish and Game contracted BioSonics, Inc. to conduct a fixed-location hydroacoustic study during the summer of 1985.

The objectives of this study were to estimate the horizontal and vertical distributions and acoustic size of migrating adult salmon. Hydroacoustic monitoring took place from July 15 to August 8. Two dual-beam hydroacoustic systems were used to monitor salmon within nine sampling cells along a predetermined transect at river mile 28. Data were digitized and recorded on video tape and processed post-season.

Between July 24 and August 1, 91% of the adult salmon passed. Fifty percent had passed by July 28.

Upstream- and downstream-moving fish had similar horizontal distributions across the river. For the total season, approximately 88% of the estimated upstream fish passage passed through the cell nearest the west shore (cell 9), 7% through the cell nearest the east shore (cell 1), and 5% through the shallow cell near the middle of the river (cell 4). Approximately 75% of the salmon run passed within 60 ft (18.3 m) of the west shore (cell 9), and 86% within 80 ft (24.4 m).

Due to concerns that hydraulic conditions below Petes Point were contributing to milling of salmon along the west shore, a test site (cell X) above Petes Point was monitored. Supplemental horizontal distributions were calculated substituting data from cell X for cell 9 data. For period IV, 25%, 35%, and 40% of the upstream moving fish passed through cells 1, 4, and 9, respectively. A total of 35% of the fish passed within 60 ft (18 m) of the west shore. It is felt that the true horizontal distribution lay somewhere between the cell 9 and cell X distributions.

Along the west shore (cell 9) fish tended to be oriented near the bottom, the upstream moving fish more so than downstream-moving fish. Horizontal and vertical distributions suggested that fish were oriented toward low water velocity (i.e., near the shores, shallow areas, and bottom of the river).

For the entire study period, the mean acoustic sizes of upstream- and downstream-moving fish were -35.4 and -34.4 dB, respectively, corresponding to mean total fish lengths of approximately 53 and 60 cm.

Fish target velocities for the study period were faster for upstream-moving fish than downstream-moving fish. For cell 1, target velocities were 2.2 fps (0.69 m/sec) and 1.8 fps (0.55 m/sec) for upstream and downstream moving fish, respectively. Cell 4 velocities were similar. Estimated mean velocities for cell 9 were 1.2 fps (0.36 m/sec) and 1.1 fps (0.33 m/sec).

During the study period, 48% of the monitored fish were moving upstream, and 52% downstream. This high incidence of downstream movement was probably due in large part to hydraulic conditions caused by water being forced around Petes Point just upstream of the study site.

Apparently some upstream moving fish passed undetected. Undetected fish were probably located near the bottom and near shore. Several improvements to the application of the hydroacoustic technique are noted that should improve monitoring of the near-bottom and near-shore fish:

> A more hydraulically stable test site upstream of Petes Point was sampled; 79% of the fish monitored here were moving upstream. This site or another in the vicinity should prove a more representative sample than cell 9.
>
> Elliptical dual-beam transducers could be used to better monitor near the bottom and at close ranges to the transducer. Two transducers could be used in tandem to more efficiently sample near the surface and across an irregular bottom.
>
> Results from 1985 suggest that transducer aiming angles shallower than 45° (e.g., 30° or 15°), could be effectively used. This would increase the signal-to-noise ratio by approximately 50%-100%, allowing closer aiming of the acoustic beam near the bottom.
>
> Sample time at cells without fish should be reduced in the future. This would increase sample time elsewhere, and reduce variability in fish passage estimates.
>
> A more stable work platform is important for accurate aiming of acoustic beams. A stable boat or semi-permanent bottom mount for transducers would greatly benefit monitoring near the bottom.
>
> Monitoring of the fish nearest shore would be enhanced by a weir to deflect fish away from shore, although during high water periods a weir may be difficult to maintain.

A fish tracking computer program was used to analyze the data in this report. There is potential for a program based on this routine to be modified to enumerate migrating adult salmon in the Susitna River on a real-time basis.

Since a large pink salmon run and other factors could affect fish horizontal distributions, any future fish enumeration strategy should incorporate plans to periodically examine the horizontal distributions of fish across the river.

It is recommended that hydroacoustic monitoring of migrating adult salmon in the Susitna River be continued in 1986. Improvements to the technique developed in 1985 data collection and analysis could be implemented. Objectives would include enumeration of the adult salmon escapement, periodic estimation of horizontal distributions, estimates of vertical distributions, and estimation of acoustic size.

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1.0 INTRODUCTION

1.1 Background

The Susitna River is one of the primary producers of salmon in the Upper Cook Inlet drainage. In order to maximize production from the salmon stocks of the inlet, the Alaska Department of Fish and Game (ADF&G) has in the past attempted to enumerate the Susitna River runs in-season. In the lower river, multiple channels, rapidly changing physical and hydrological conditions, and lack of fish passage data in the offshore area of the river have frustrated these attempts.

In order to quantify the spatial and temporal distributions of migrating adult salmon in the lower Susitna River, ADF&G contracted BioSonics, Inc. to conduct a fixed-location hydroacoustic study during the summer of 1985.

1.2 Study Objectives

The primary objectives of this study were to estimate the following:

1) horizontal distribution of migrating adult salmon,

2) vertical distribution of migrating adult salmon, and

3) acoustic size (target strength) of migrating adult salmon.

1.3 Site Description

The Susitna River lies northwest of Anchorage, Alaska, and drains into the Upper Cook Inlet (Figure 1). Susitna Station is located approximately 31 miles (50 km) north-northwest from Anchorage at river mile (RM) 26, and served as base camp for the field study. At RM 28, the Susitna River is joined by its first main tributary, the Yentna River. Approximately 2 miles downstream of this confluence, the Susitna River splits into multiple channels separated by islands with established vegetation. Below the Yentna River, the only significant reach where the river flows in a single channel is between Susitna Station (RM 26) and the mouth of the Yentna River. The study transect was located in this reach, at approximately RM 28.

Typical flows at Susitna Station during July and August are 80-120 kcfs. During the 1985 field study, water levels fluctuated 3.4 ft (104 cm). At times debris was present in the river. Water visibility was usually less than 2 inches (5 cm). Water temperatures ranged from 48-56 °F (9-13.5 °C).

The Susitna River is the primary producer of chum (*Onchorhynchus keta*), pink (*O. gorbuscha*), and chinook salmon (*O. tshawytscha*), and one of the primary producers of sockeye salmon (*O. nerka*) in the Upper Cook Inlet. Silver salmon (*O. kisutch*) also occur.

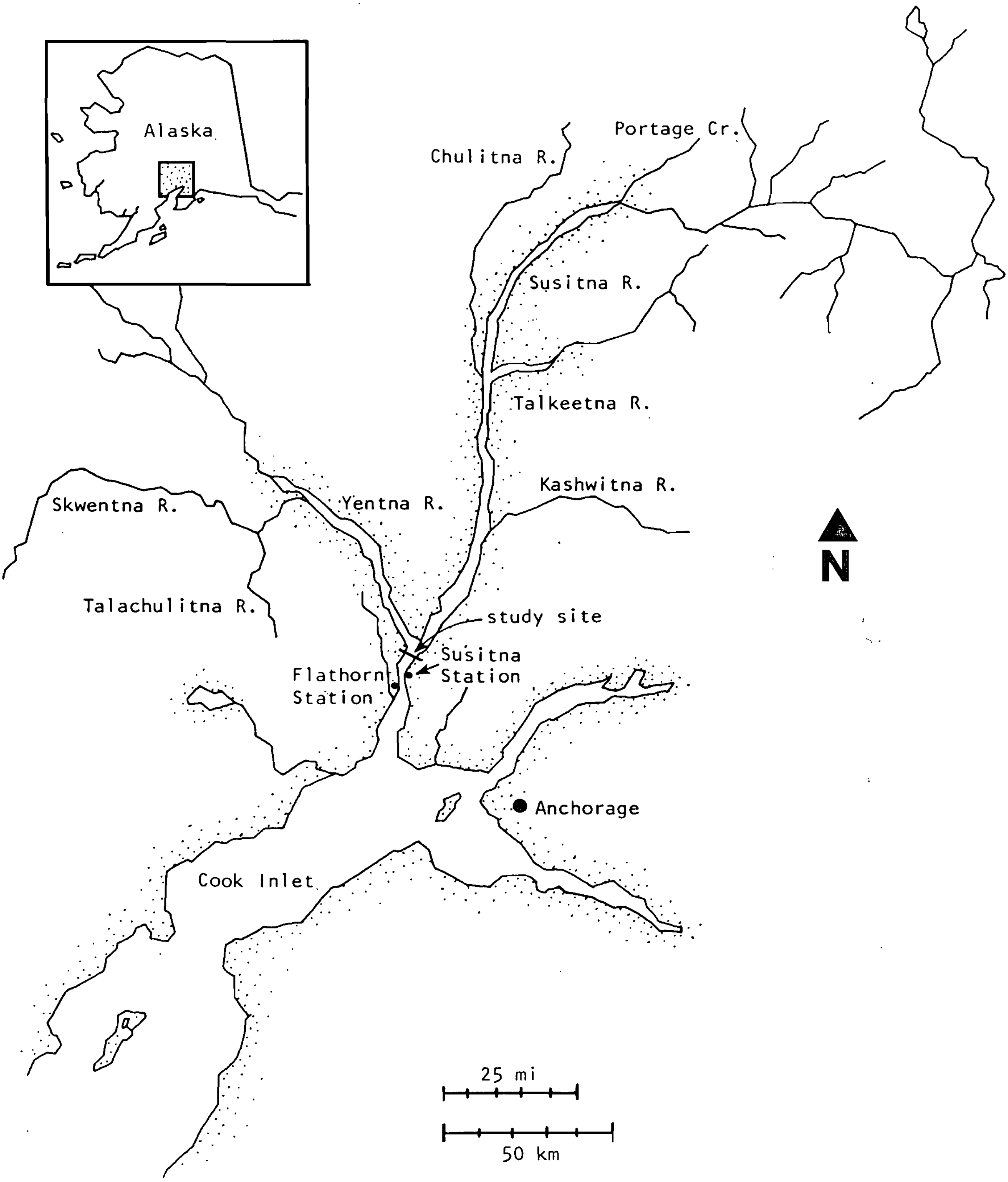


Figure 1. Susitna River drainage, showing Susitna Station and the 1985 study site location.

2.0 GENERAL METHODS

2.1 Introduction

Over the last several years hydroacoustic technology and applications have been developed to allow accurate measurements of fish abundance, distribution, size, and behavior under a wide variety of conditions (Burczynski 1979, Kanciruk 1982, Ransom and Raemhild 1985, Wirtz and Acker 1979 and 1981). Hydroacoustic techniques are non-obtrusive; they do not injure fish or affect their behavior.

In a traditional mobile survey, the hydroacoustic equipment is mounted on a moving boat and samples fish as the acoustic beam passes over them. In a fixed-location hydroacoustic study, the location and aiming angle of the transducer remain stable and the fish are monitored as they pass through the acoustic beam. Fixed-location hydroacoustics have been used to study juvenile salmonids' migration on the Columbia River (Raemhild et al. 1984), striped bass behavior on the Hudson River (BioSonics 1984), and the migrational characteristics of various South American species in the Rio Parana (Ransom et al. 1985, Steig et al. 1985). In a typical fixed-location study, the transducer is attached to a permanent structure or an anchored buoy or boat.

2.2 Data Collection

2.2.1 Sample Design

Fixed-location hydroacoustic sampling was conducted along an established transect across the Susitna River. The sample transect was located where the river was contained in a single channel, was relatively narrow, and had minimal turbulence. The transect was 1851 ft (564.3 m) long from the anticipated high water boundary, and was divided into nine sample cells numbered from east to west (Figure 2). The transect was measured with a hand-held range finder and marked with buoys and shore markers. The three cells nearest each shore were each 200 ft (61.0 m) wide, and the remaining three cells in the center of the river were each 217 ft (66.2 m) wide. The maximum depth along the transect (28.4 ft (8.4 m) at low water) occurred in cells 6 and 7, as did the maximum velocity (over 6 fps (1.8 m/s) at the surface during low water) (Figure 3). A shallow sand bar was located just upstream from cell 4. Water velocities were very low there and near both shores (<0.5 fps (0.15 m/sec) throughout the water column). A depth profile summary appears in Appendix A.

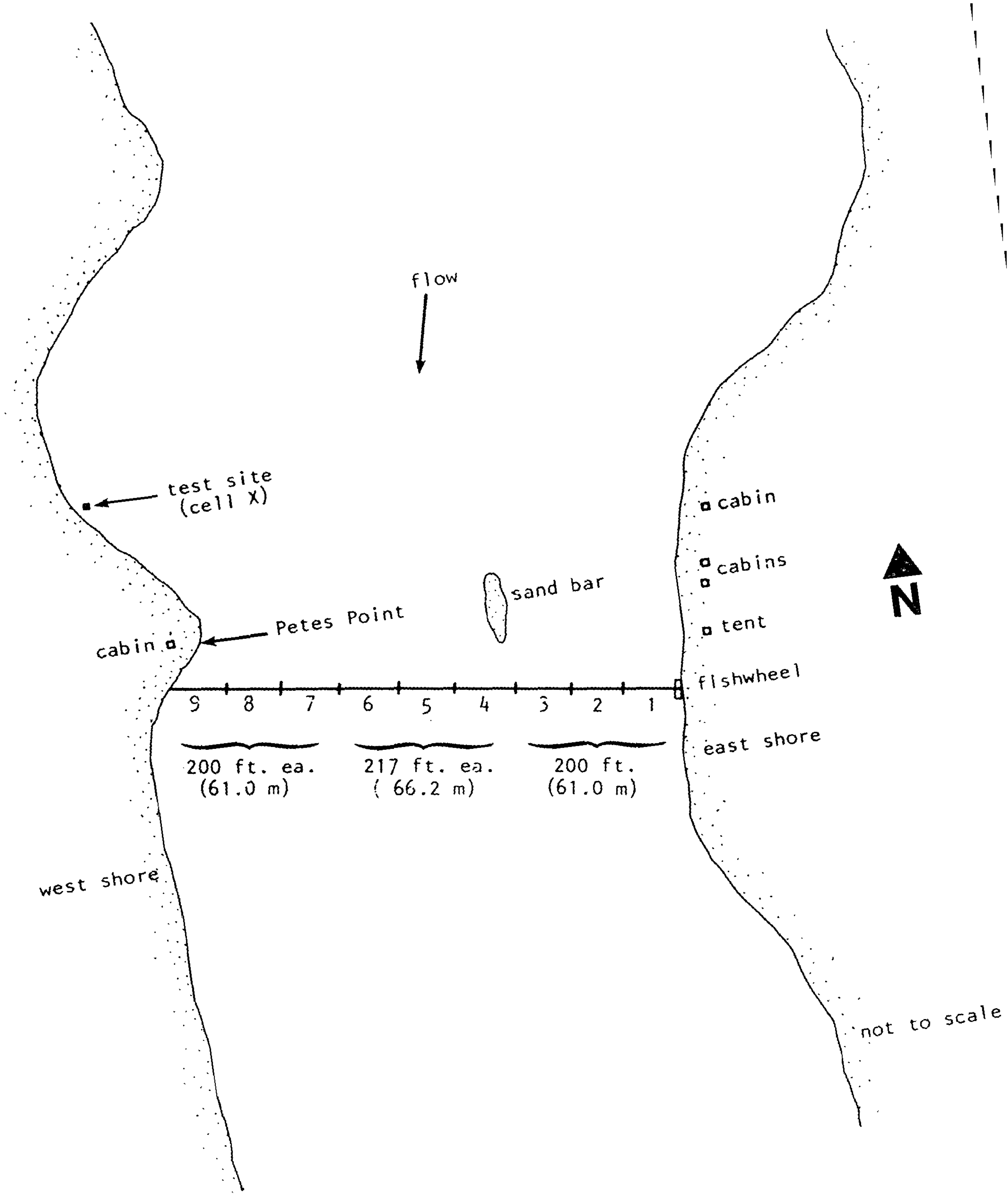
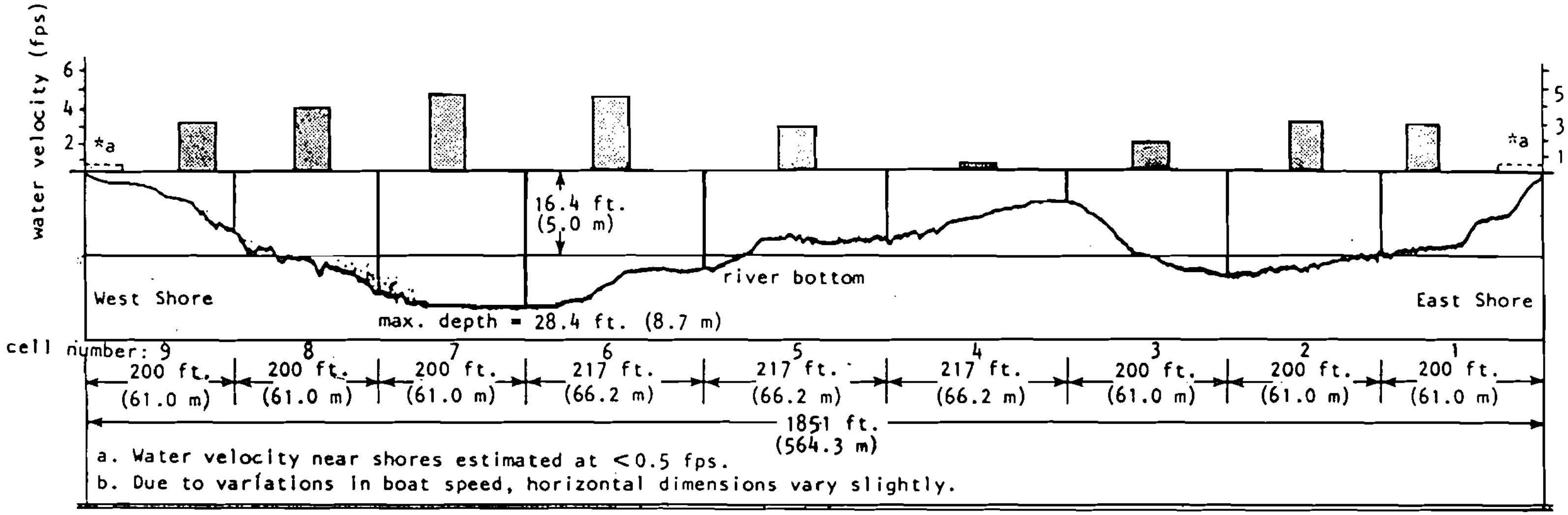


Figure 2. Study site, sample transect, and sample cell locations at RM 28. Susitna River, 1985.



a. Water velocity near shores estimated at <0.5 fps.

b. Due to variations in boat speed, horizontal dimensions vary slightly.

Figure 3. Sample cells and depth profile along the transect sampled hydroacoustically in 1985. Transect was recorded July 18. Transducer was 21 inches (53 cm) below the water surface. Susitna Station staff gauge was 0.9 feet (27 cm) above the lowest water level observed during the study (August 6). Susitna River, 1985.

Hydroacoustic sampling of migrating salmon took place for 25 days from 2200 h on July 14 to 1800 h on August 8, 1985. Sampling was conducted daily in two 10-h shifts: 2200-0800 h and 0800-1800 h. The 4-h period from 1800-2200 h was usually not sampled. Shifts were numbered sequentially. A list of dates and times for each shift appears in Appendix B.

Hydroacoustic sampling was conducted from a boat which was anchored sequentially in each of the sample cells. During each 10-h shift, each cell was sampled once for 45 min, with the exception of the near-shore cells (cells 1 and 9). Within each of these two cells, two different locations were sampled for 30 min each. Sample locations within cells were chosen randomly, except for cells 1 and 9, which were sampled from as near shore as practical and near the center of the off-shore half of the cell (i.e., 150 ft (45 m) from shore). The sequence in which cells were sampled was rotated each day. Infrequent exceptions to the sampling plan described above were mandated by high water velocities, floating debris, high winds, or equipment maintenance requirements.

An additional site, cell X, was monitored periodically from July 29 to August 8. This site was located along the west shore approximately 600 ft (183 m) upstream from Petes Point (Figure 2).

A description of typical data collection parameters appears in Appendix C. A detailed record of the parameters for each individual sample is held in files at BioSonics, Inc. in Seattle and at the Soldotna, Alaska offices of ADF&G. These parameters include sample date, start time, and duration; type and orientation of deployment; sample location along the sample transect; and maximum sample range.

During the low water period, water velocities were measured on July 24 and August 6 with a Marsh-McBirney portable water current meter. Water velocities were taken at six depths, near the center of each cell except cells 1 and 9, where they were taken approximately 150 ft offshore.

Concurrent with hydroacoustic sampling, ADF&G conducted fishwheel sampling along the east bank at cell 1 (Figure 2). Gill net drift sampling also took place near the sample transect. Downstream approximately 6 mi (10 km), four additional fishwheels were sampled at Flathorn Station (Figure 1).

2.2.2 Hydroacoustic Equipment, Operation, and Calibration

Two dual-beam hydroacoustic systems were mounted in a boat 24 ft (7.3 m) long by 5 ft (1.5 m) wide. Dual-beam systems were used so that the acoustic size (i.e., target strength) and direction of movement of individual fish could be estimated as described below. A complete description of the hydroacoustic equipment, including operation and calibration, is presented in Appendix D.

Primary data were obtained from surface-mounted transducers attached to the boat (Figures 4 and 5). Where depth permitted, a transducer was deployed and oriented 30° downward and downstream. This was denoted a "downward-aimed transducer." In the two sample cells nearest shore (i.e., cells 1 and 9) and in cell 4, a transducer was aimed horizontally into the river and 45° downstream. This was denoted a "side-aspect transducer." In cells 1 and 9, transducers were positioned as near the shore as practical. In cell 4 the boat was located near the shallowest area and the transducer was aimed toward the middle of the river. Frequently in deep water cells 2, 3, and 5, a side-aspect transducer was aimed 45° downstream and near the surface.

At cell 9, a second side-aspect transducer was aimed from the sample boat (typically 20-30 ft (6-9 m) offshore) into shore, 45° downstream. In deep-water cells 2, 3, and 5, secondary information was occasionally provided by a bottom-mounted transducer aimed upward 30° off vertical, and downstream.

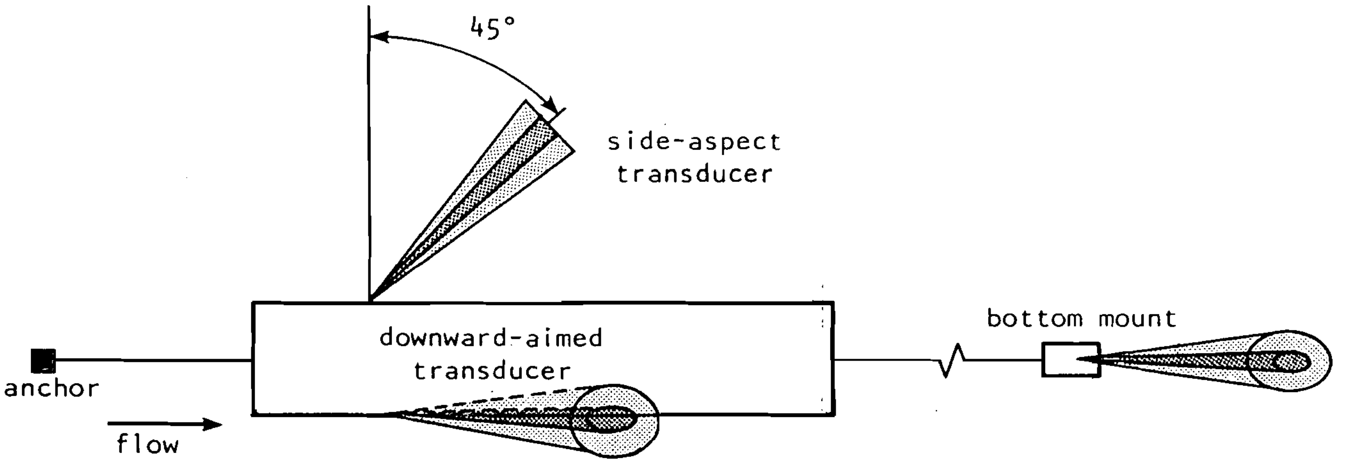
The procedure for aiming side-aspect transducers was to slowly rotate them toward the bottom until they began to pick up strong bottom returns, then rotate them up slightly until the maximum bottom returns were less in amplitude than the mark threshold (which corresponded to the return from the smallest anticipated salmon). The ensonified volume included the river substrate to a degree. This is possible without obscuring fish traces when the bottom (usually mud or sand) is less reflective than the smallest targets of interest (i.e., the bottom has a smaller target strength and is more acoustically absorptive than the smallest fish).

Off-axis orientations of transducers (i.e., non-perpendicular to fish movement) enabled determination of a fish's general direction of movement from change-in-range information, as described in Appendix D.

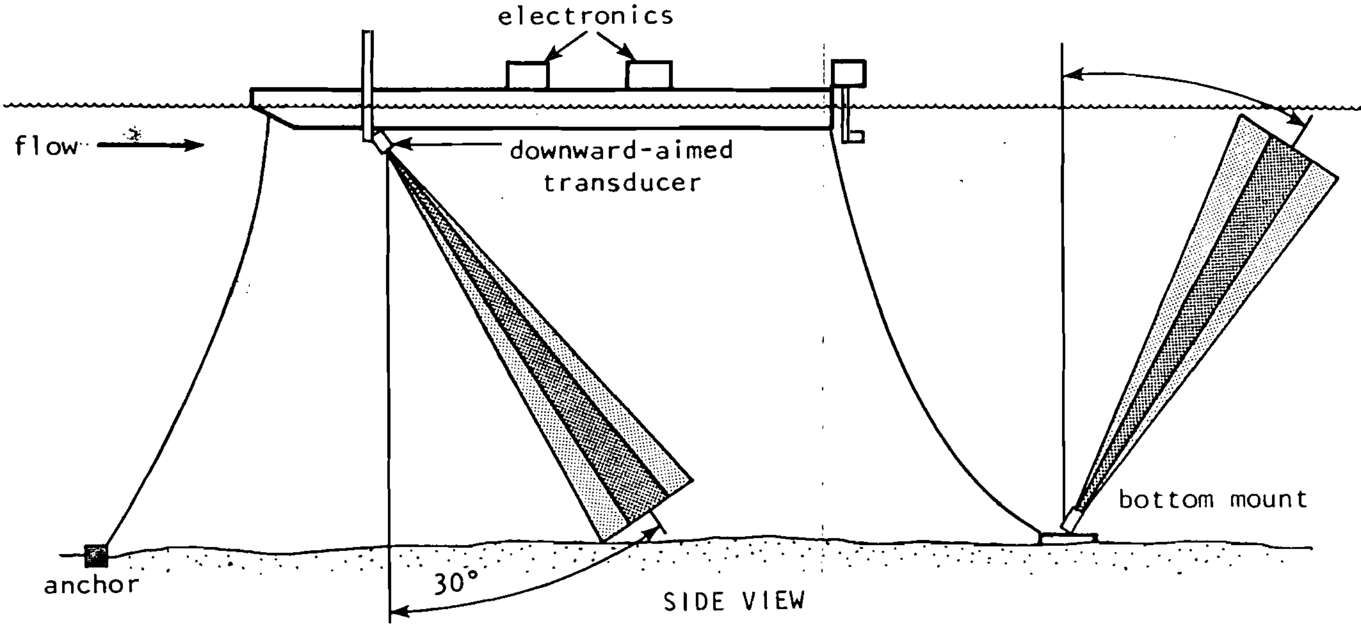
2.3 Data Reduction, Storage, and Analysis

All dual-beam data were digitized and recorded on video tape in the field. These tapes stored the primary data base. At BioSonics' Seattle laboratory, data were played back through the Model 181 Dual-Beam Processor, converted to computer files, and stored on floppy diskettes. Maximum amplitudes of the echo signals for both channels were used to calculate fish acoustic size (i.e., target strength), as detailed in Appendix E.

Because the dual-beam transducers were aimed at either 30° or 45° downstream (for downward-aimed and side-aspect transducers, respectively), the resulting dual-beam data files could be analyzed with custom software (TRACKER) to track a fish's general change-in-range. That is, the TRACKER program automatically



TOP VIEW



SIDE VIEW

Figure 4. Location and orientation of transducers on sample boat. Susitna River, 1985.

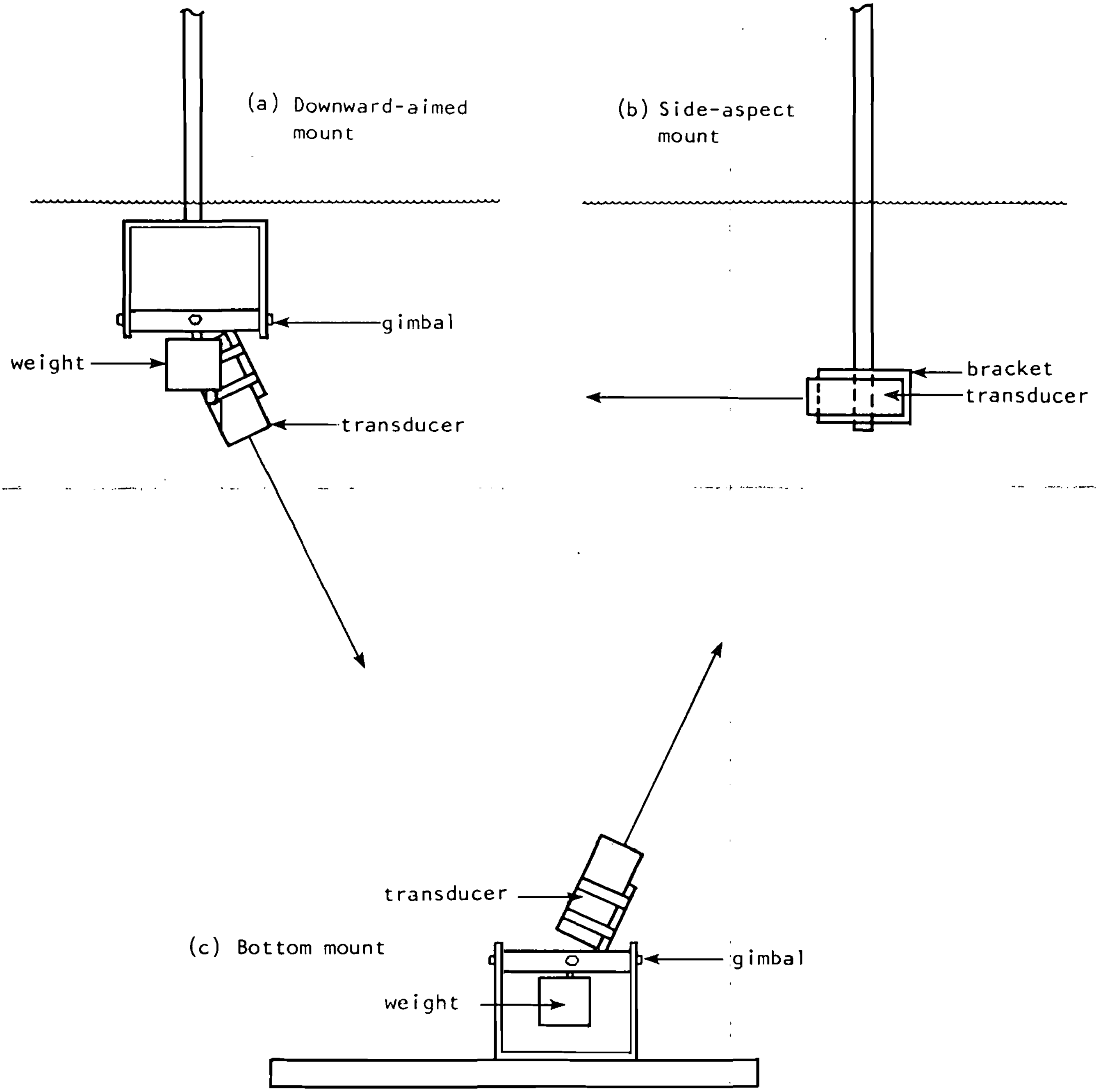


Figure 5. Transducer mounts. Susitna River, 1985.

determined the fish's direction of movement (i.e., either upstream or downstream). The output from TRACKER for all samples was checked against the fish counts from the corresponding chart recorder echograms. These procedures are detailed in Appendix F.

Occasionally, samples included spurious bottom returns, and TRACKER would overestimate fish passage. The data tapes for these samples were processed separately. The individual fish traces from samples were entered manually from the chart recorder echograms and then weighted as for all other data as described below.

The only data not incorporated in the results was that from the offshore side-aspect transducers monitored in cells 1 and 9, aimed toward shore and 45° downstream. These transducers monitored the same general area as the onshore side-aspect transducers. During data analysis it was determined that the data from the latter was of higher integrity since it had much less interference and better sampled the geometry of the cells.

Individual fish detections were sorted by direction of movement and weighted as follows. Each fish was sorted into a specific range stratum (i.e., for horizontal, side-aspect transducers these corresponded to a section) and weighted proportionately to two factors. The first weighting factor expanded the raw fish detections within a section for the proportion of the cross-sectional area of the section that was not acoustically sampled. The second weighting factor was equal to the full width of the section divided by the width sampled. The raw fish sampled within each section were multiplied by the appropriate weighting factors for that section, resulting in weighted fish. Fish passage rates (quantity of fish/min) were obtained by section by dividing the weighted number of fish by the elapsed sample time for the sample in consideration. All further analysis was conducted from these estimates of weighted fish passage rates. The data analysis procedure is explained in more detail in Appendix G.

A description of typical raw and weighted fish data appears in Appendix H. A detailed record of data parameters for individual samples are held in files at BioSonics, Inc. in Seattle, and the Soldotna, Alaska offices of ADF&G. These parameters include, by sample and section, the number of raw fish detections, weighting factor, number of weighted fish, and weighted fish/min.

In addition, computer diskettes containing the unweighted data base from which the results were obtained have been supplied to ADF&G (Soldotna). Their contents are described in Appendix H.

3.0 RESULTS AND DISCUSSION

3.1 Objective 1: Horizontal Distribution of Migrating Adult Salmon

3.1.1 Detailed Methods

In order to determine multi-day periods for which to calculate mean horizontal distributions, a daily run timing index was calculated as the percentage by shift (expanded to 12 h) of the total passage throughout the sample season (Section 3.1.2). This index indicated an initial 7-d period of very low escapement (period 0), followed by four periods of higher passage:

I: July 22-25 (4 d),
II: July 26-30 (5 d),
III: July 31-August 3 (4 d), and
IV: August 4-8 (5 d).

In addition, distributions were calculated for the following two combinations of periods:

I-II: July 22-30 (9 d), and
I-IV: July 22-August 8 (18 d).

Horizontal distributions across the river were calculated as the relative percentage within each cell of total river passage. Distributions were calculated for each shift, for upstream and downstream migrating fish separately. In the field it became apparent that most fish passed through the two shore-most cells (cells 1 and 9), so within these cells distributions were further divided into six sections numbered from the shore out into the river. Sections 1-5 were each 20 ft (6.1 m) wide, and section 6 was 100 ft (30.5 m) wide.

Horizontal distributions for each of the six periods were calculated in two manners. To obtain measures of variability around horizontal distributions by period, mean distributions for a given period were calculated from individual distributions by shift. That is, each shift represented a replicate. These distributions are denoted below as "mean horizontal distributions." In the second method, the fish passage by shift (expanded to 12 h) was totaled by cell for a given period. Horizontal distributions for that period were then calculated from the total passage in individual cells during that period. These distributions are denoted "horizontal distributions weighted for abundance." This latter method was adopted when it became clear that distributions were highly variable when passage rates were low (Appendix I).

Midway through the study, it was felt that hydraulic conditions caused by the river passing around Petes Point could be contributing to milling of salmon along the west shore. A high proportion of downstream moving fish was observed. In an effort to examine this situation, several test sites along the west shore upstream of Petes Point were investigated. One, cell X, was chosen and was periodically monitored from July 29 to August 8. Supplemental horizontal distributions were calculated for appropriate periods by substituting cell X fish passage estimates for cell 9 estimates.

3.1.2 Results and Discussion

Run Timing

The run timing indices are presented in Figure 6, Table 1, and Appendix J.

Fish passage rates from shift to shift were highly variable. Fish numbers were very low from July 15-21, followed by major passage peaks July 24, 27, and 29, and moderate peaks July 26 and August 1. Fish numbers decreased thereafter. The highest mean fish passage rates occurred during period II, with lower rates in periods I, III, and IV, respectively. The run timing index by shift for the whole season indicated that 91% of the adult salmon passed between July 24 and August 1.

Hydroacoustic run timing generally tracked the trends of Flathorn Station fishwheel catches but were more variable and approximately a day later (Figure 6 and Table K1). Fifty percent cumulative passage was reached on July 28 according to both indices.

ADF&G fish wheel catches from Flathorn Station for periods I and II were comprised mostly of sockeye salmon, with the balance primarily of pink and coho salmon. Periods III and IV yielded mostly pink salmon, with the balance primarily sockeye and coho salmon (Table K2).

The higher variability in the acoustic estimates can be attributed in large measure to the smoothed nature of fishwheel data, which consists of total numbers of fish collected over typically a 24-h sample period. Examination of the acoustically-derived run timing (Table 1) and the Flathorn Station fishwheel catches (Table K1) during the same period bears this out. The acoustic estimate is less smooth, partly because they are for 12-h periods, but also because they are based on samples taken at three locations (cells 1, 4, and 9), taken typically for 30-45 min/sample per location per shift.

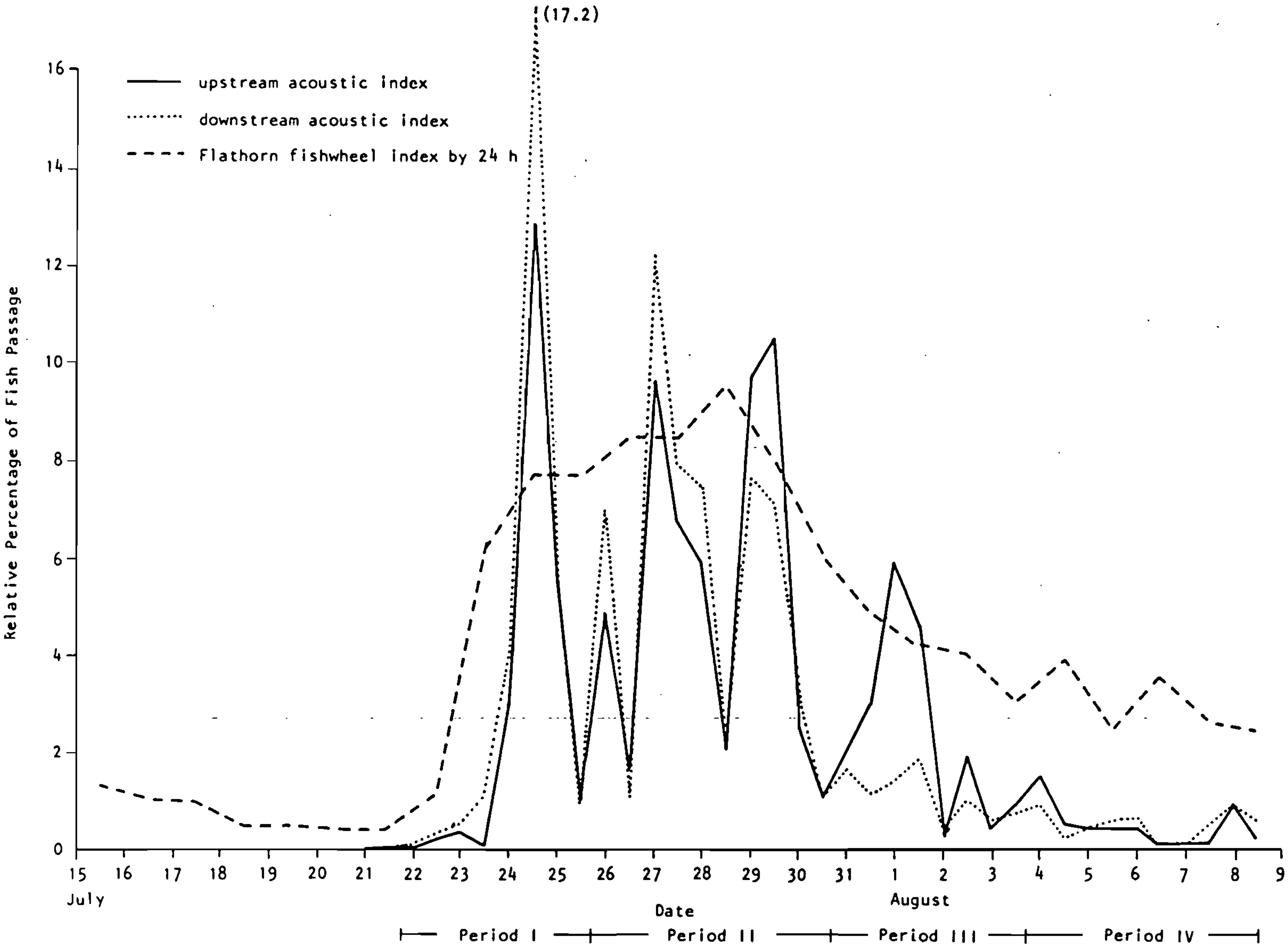


Figure 6. Run timing of fish passage by 12 h period, by direction of movement. Susitna River, 1985.

Table 1. Run timing of fish passage by 12-h period for upstream-moving fish (Susitna River 1985).

	Date	Shift Number	Relative Percentage	Cumulative Percentage
July	15	1	0	0
		2	0	0
	16	3	0	0
		4	0	0
	17	5	0	0
		6	0	0
	18	7	0	0
		8	0	0
	19	9	0	0
		10	0	0
	20	11	0	0
		12	0	0
	21	13	0.1	0.1
		14	0.1	0.2
	22	15	0	0.2
		16	0.2	0.4
	23	17	0.3	0.7
		18	0.1	0.8
	24	19	3.0	3.8
		20	12.8	16.6
	25	21	5.1	21.7
		22	0.9	22.6
	26	23	4.8	27.4
		24	1.5	28.9
	27	25	9.7	38.6
		26	6.7	45.3
	28	27	5.8	51.1
		28	2.0	53.1
	29	29	9.7	62.8
		30	10.5	73.3
	30	31	2.6	75.9
		32	1.0	76.9
	31	33	2.0	78.8
		34	3.0	81.8

Table 1, cont.

Date	Shift Number	Relative Percentage	Cumulative Percentage
August 1	35	5.8	87.6
	36	4.5	92.2
2	37	0.2	92.4
	38	1.8	94.2
3	39	0.4	94.6
	40	0.8	95.4
4	41	1.5	96.9
	42	0.5	97.4
5	43	0.4	97.8
	44	0.4	98.2
6	45	0.4	98.6
	46	0.1	98.7
7	47	0.1	98.8
	48	0.1	98.9
8	49	0.9	99.8
	50	0.2	100.0

We would expect longer hydroacoustic sample times at individual cells to result in a reduction of this variability. The ideal situation would be to sample at each cell continuously, although this is probably impractical.

Variability Among Individual Horizontal Distributions by Shift

Individual horizontal distributions for each shift appear in Appendix L. All distributions show that all of the fish were located in the shoremost cells (cells 1 and 9) and the shallow cell in the middle of the river (cell 4).

An examination of individual horizontal distributions reveals much variability in percentages for cells 1, 4, and 9 among shifts (Tables L1 and L2). While it is true that there is variability within distributions from shift to shift regardless of the fish passage rate, the magnitude of the variablility appears to be correlated with the magnitude of fish passage during the shift (Figure 6 and Table 1). That is, high variability appears to accompany low passage rates, and low variability accompanies high passage rates. A visual selection of distributions from shifts with corresponding low passage rates and high passage rates, from Table 1 (relative run timing) and Table L1 (horizontal distributions of upstream moving fish by shift), seems to bear this out.

Such a relationship pointed to a fundamental question: could we justifiably treat the replicates (individual distributions by shift) as independent samples taken from a homogenous population, since this should be a prerequisite for any further parametric statistical manipulations such as calculations of means and measures of variability. We felt we could not prudently do so.

While the species composition within individual periods I-IV may have remained relatively stable, the rates with which the fish passed the hydroacoustic sample transect was apparently highly variable (Table 1). The acoustic estimates were less smooth, partly because they were for 12-h periods, but also because they were based on samples taken at three locations (cells 1, 4, and 9), taken typically from 30-45 min/sample shifts. In a statistical context, this suggested that the statistical populations sampled at a given location were different, not homogeneous, between samples. A schooling or pulsed manner of fish migration, or changes in hydraulic conditions between samples could contribute to this.

To test this, data were blocked into high and low passage groups, and the variances between blocks tested. The variances were found to be significantly different, and thus from different populations (Appendix I). That is, the high passage block was from a different statistical population than the low passage block. This being the case, samples from the two blocks should not be mixed and treated as replicates from a homogenous population.

Based on these findings, we felt it prudent to stress horizontal distributions by period calculated from the sum of estimated fish passage, by cell, throughout a given period (distributions weighted for fish abundance) as more representative of the fish runs than the mean distributions. However, mean horizontal distributions from distributions by shift were calculated for comparison, and are presented below.

Horizontal Distributions Weighted for Fish Abundance

The horizontal distributions weighted for fish abundance are presented by period in Table 2 and Appendix M.

The vast majority of the fish occurred in the westernmost cell (cell 9). For the entire study period (periods I-IV), the weighted distributions showed approximately 88% of all estimated upstream fish passage occurred in cell 9, and approximately 7% and 6% in cells 1 and 4, respectively (Figure 7 and Table 2). Percentages by period for cell 9 varied from 61-92%. For cells 1 and 4, percentages varied from 4-13% and 3-18%, respectively.

The weighted distributions over the season were nearly identical for upstream and downstream moving fish. The largest difference between upstream and downstream distributions occurred in period III, where in cell 1 a higher proportion of downstream moving fish (31% of river total) was observed than for upstream fish (11%).

Mean Horizontal Distributions from Distributions by Shift

The mean horizontal distributions appear by period in Appendix N. All mean distributions indicate the majority of the upstream-moving fish (53-84%) occurred in the westernmost cell (cell 9), although not as many as for the distributions weighted for abundance. For the total season, approximately 17% and 13% of the fish were observed in cells 1 and 4, respectively. By period, cell 1 and 4 mean percentages ranged from 4-34% and 8-20%, respectively.

Horizontal Distributions Within Cells 1 and 9

Figures and tables of distributions within cells 1 and 9 appear by period in Appendices M and N for abundance-weighted and mean horizontal distributions, respectively.

Table 2. Summary of horizontal distributions of adult salmon across the river, weighted for fish abundance (Susitna River 1985).

			Relative Percentage of Fish									
Period		Fish	East Shore			Cell Number				West Shore		
Number	Dates	Direction	1	2	3	4	5	6	7	8	9	Total
I	7/22-25	Upstream	8.8	0	0	3.2	0	0	0	0	88.0	100.0
		Downstream	5.4	0	0	5.7	0	0	0	0	88.9	100.0
II	7/26-30	Upstream	4.0	0	0	5.0	0	0	0	0	91.0	100.0
		Downstream	4.7	0	0	3.6	0	0	0	0	91.8	100.0
III	7/31-8/3	Upstream	10.8	0	0	7.7	0	0	0	0	81.6	100.0
		Downstream	31.2	0	0	7.4	0	0	0	0	61.4	100.0
IV	8/4-8	Upstream	13.1	0	0	18.2	0	0	0	0	68.7	100.0
		Downstream	13.1	0	0	12.4	0	0	0	0	74.5	100.0
I-II	7/22-30	Upstream	5.4	0	0	4.5	0	0	0	0	90.1	100.0
		Downstream	4.9	0	0	4.3	0	0	0	0	90.8	100.0
I-IV	7/22-8/8	Upstream	6.7	0	0	5.7	0	0	0	0	87.6	100.0
		Downstream	6.8	0	0	4.9	0	0	0	0	88.3	100.0

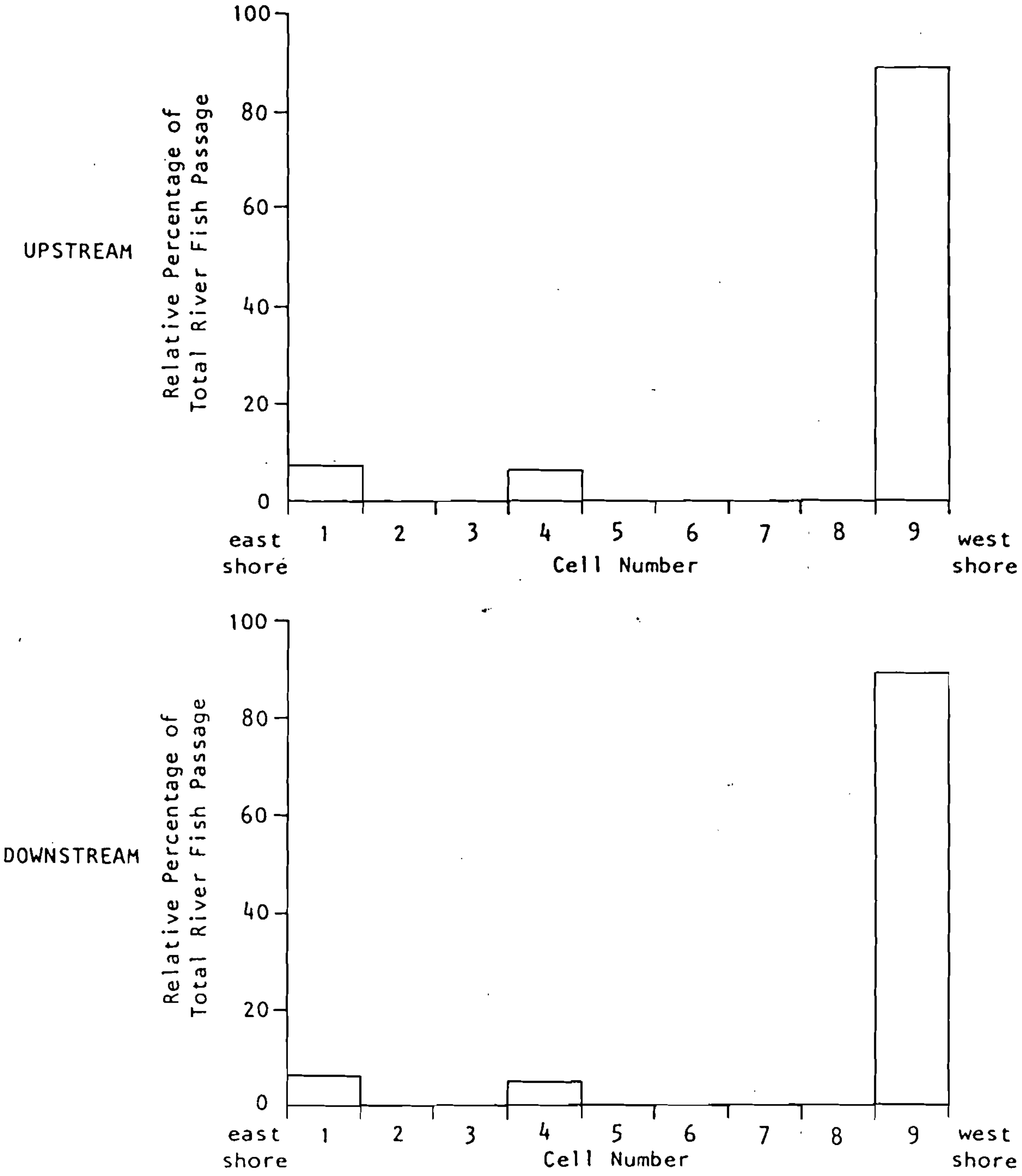


Figure 7. Horizontal distribution of adult salmon across the river, weighted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

Distributions within these two near-shore cells were heavily weighted toward shore, with some drop off in fish percentages in sections 1 and 2 (to 20 and 40 ft (6.1 and 12.2 m) from shore). The distributions by period show that most of the fish within cells 1 and 9 were found within 60 ft (18.3 m) of shore. Indeed, the total study period distribution weighted for abundance indicates that 75% of the fish across the whole river passed within 60 ft (18.3 m) of the west shore, and 86% within 80 ft (24.4 m) While the magnitudes of the percentages were smaller on the east bank, the fish were similarly shore-oriented. Within cell 1, 6% of the total river passage passed within 60 ft (18.3 m) of the shore, and 7% within 80 ft (24.4 m) (Figure 8 and Table 3).

Horizontal Distributions Based on Cell X above Petes Point

Substituting the results from cell X for those of cell 9 for shift 31 and for period IV, horizontal distributions were calculated and are presented in Figure 9 and Table 4.

While the same trend of highest passage through cell 9 are usually apparent, the magnitude is lower. For period IV, 25%, 35%, and 40% of the upstream moving fish passed through cells 1, 4, and 9, respectively. A total of 35% of the fish passed within 60 ft (18 m) of the west shore (Figure 10 and Table 5).

Discussion

While no fish were monitored in cell 3, ADF&G did net some fish here. After cell 4, cell 3 had the lowest mean water column velocity of any cell.

Cell 3 was sampled in the same fashion as other deep cells, with a downward-aimed transducer and a side-aspect transducer. Occasionally a bottom-mounted transducer aimed up toward the surface was also sampled. The downward-aimed transducer was aimed 30° downstream and toward the bottom. The side-aspect transducer was aimed toward the surface and to the west, 45° downstream.

The mean water velocity in cell 3 was relatively high (1.5 fps (0.46 m/sec)), and over seven times that of cell 4 (Appendix A). Examination of the cell 3 bottom profile reveals a quick drop in depth just east of the cell 3/4 boundary (Figure 3). Due to the apparent pulsed nature of the upstream passage of adult salmon, it is possible that some fish passed undetected in cell 3. It is highly unlikely that the numbers were near the magnitude of fish passing through either cells 1 or 4.

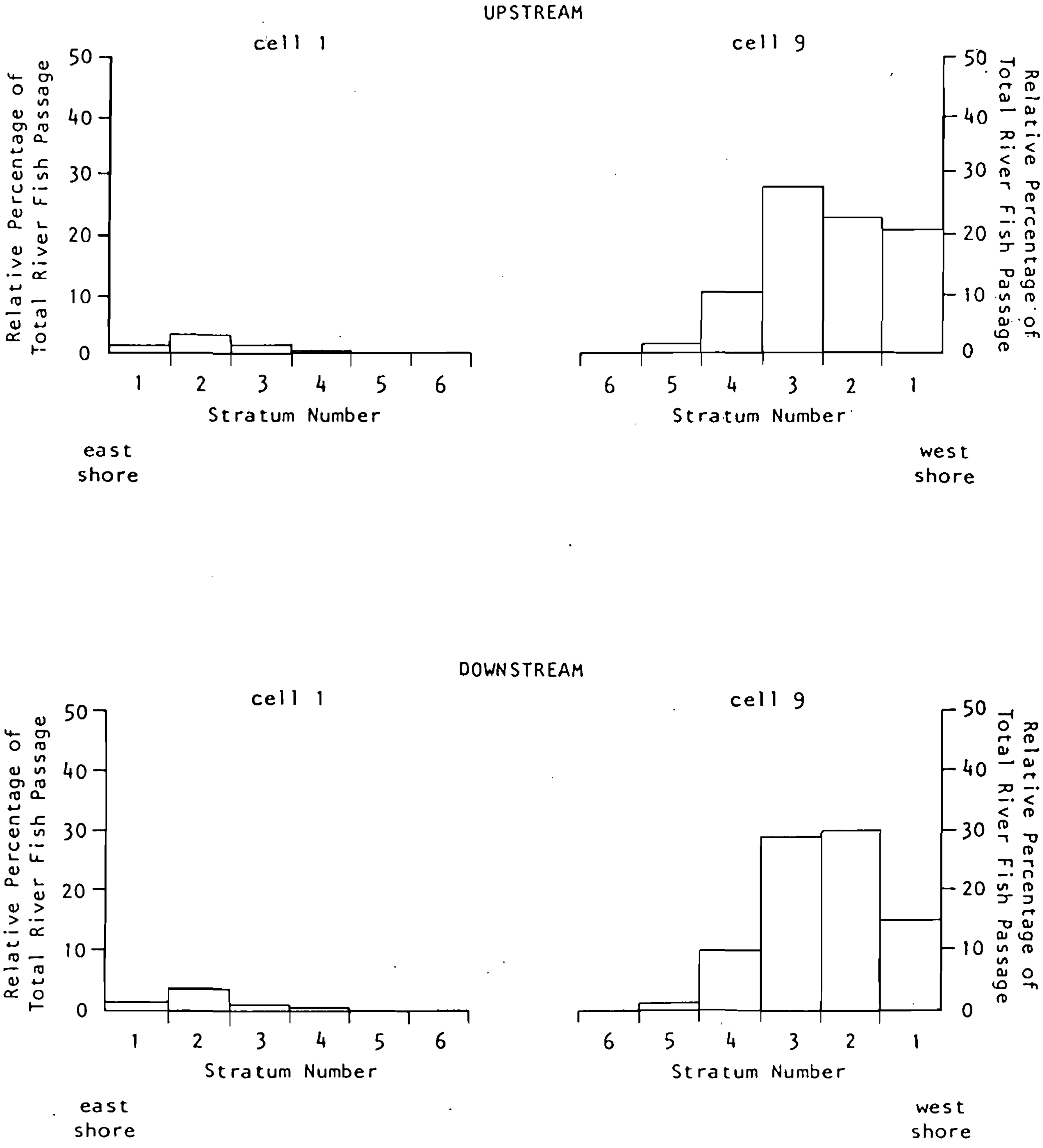


Figure 8. Horizontal distributions within cells 1 and 9, weighted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table 3. Summary of horizontal distributions of adult salmon within the near-shore cells, weighted for fish abundance (Susitna River 1985).

			Relative Percentage of Fish													
Period		Fish	Cell 1 (East Shore) Section*							Cell 9 (West Shore) Section*						
No.	Dates	Direction	1	2	3	4	5	6	Sum	1	2	3	4	5	6	Sum
I	7/22-25	Upstream	1.6	2.5	1.6	3.1	0	0	8.8	12.1	41.7	24.4	6.5	3.3	0	88.0
		Downstream	0.4	3.1	0.8	1.1	0	0	5.4	26.0	34.6	19.3	7.4	1.7	0	88.9
II	7/26-30	Upstream	0.2	3.0	0.7	0	0	0	4.0	24.9	14.9	34.6	14.1	2.6	0	91.0
		Downstream	0.7	3.3	0.6	0.1	0	0	4.7	12.7	31.6	35.3	10.2	2.0	0	91.8
III	7/31-8/3	Upstream	2.2	5.3	3.2	0	0	0	10.8	28.0	30.9	15.5	6.4	0.9	0	81.6
		Downstream	2.0	2.9	6.2	0	0	0	31.2	9.2	17.5	13.1	19.0	2.7	0	61.4
IV	8/4-8	Upstream	0	0.2	2.9	0	0	0	13.1	7.4	12.5	30.6	16.1	2.0	0	68.7
		Downstream	2.2	6.5	4.4	0	0	0	13.1	0	21.8	25.1	23.1	4.5	0	74.5
I-II	7/22-30	Upstream	0.6	2.9	1.0	0.9	0	0	5.4	21.2	22.7	31.6	11.9	2.8	0	90.1
		Downstream	0.6	3.2	0.7	0.5	0	0	4.9	17.3	32.7	29.8	9.2	1.9	0	90.8
I-IV	7/22-8/8	Upstream	0.9	3.7	1.5	0.7	0	0	6.7	21.8	23.7	28.6	11.1	2.4	0	87.6
		Downstream	1.5	3.9	1.1	0.4	0	0	6.8	15.8	30.7	29.3	10.5	2.0	0	88.3

* Section 1 is nearest shore. Each section is 20 ft (6.1 m) wide, except section 6 which is 100 ft (30.5 m) wide.

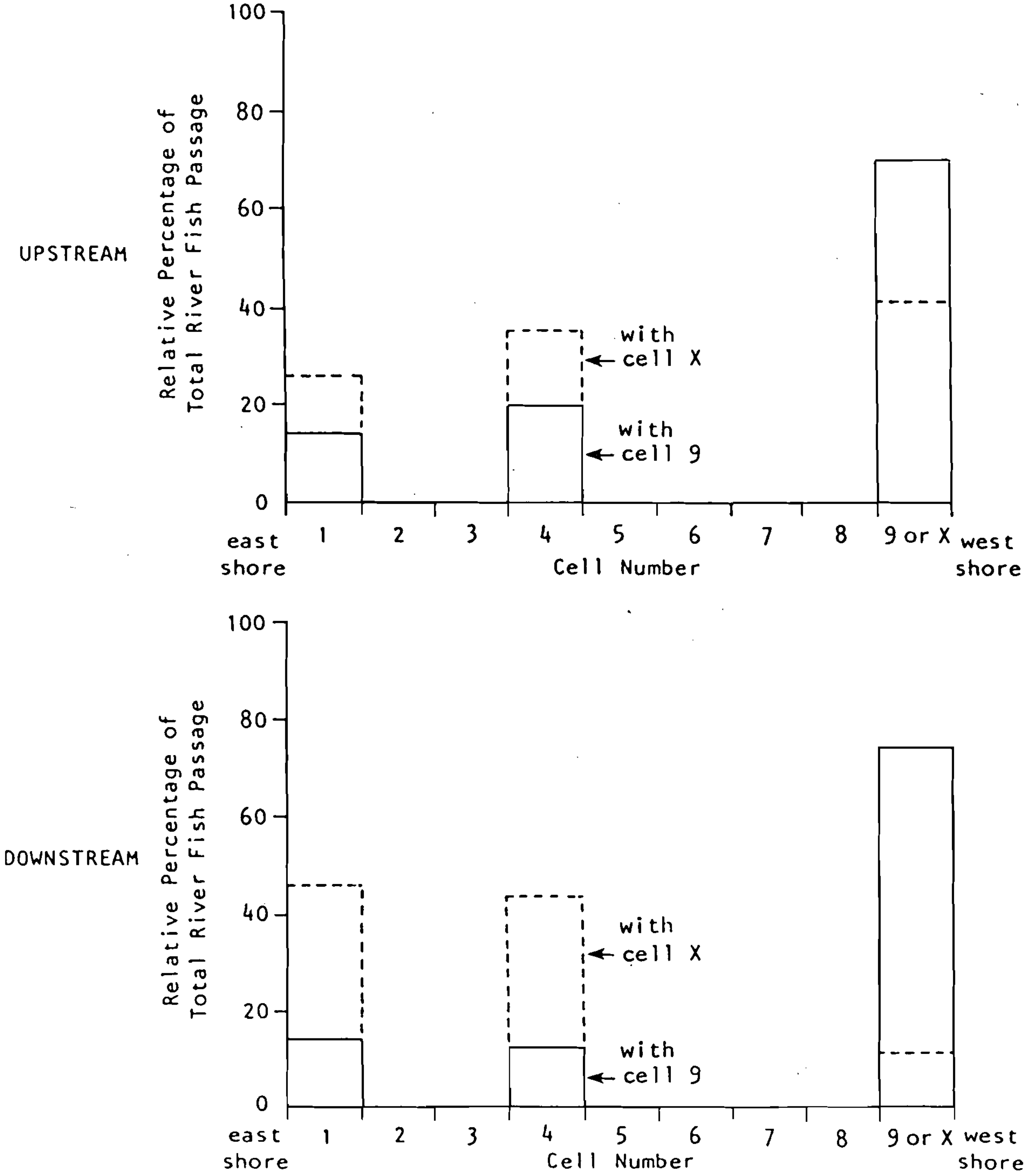


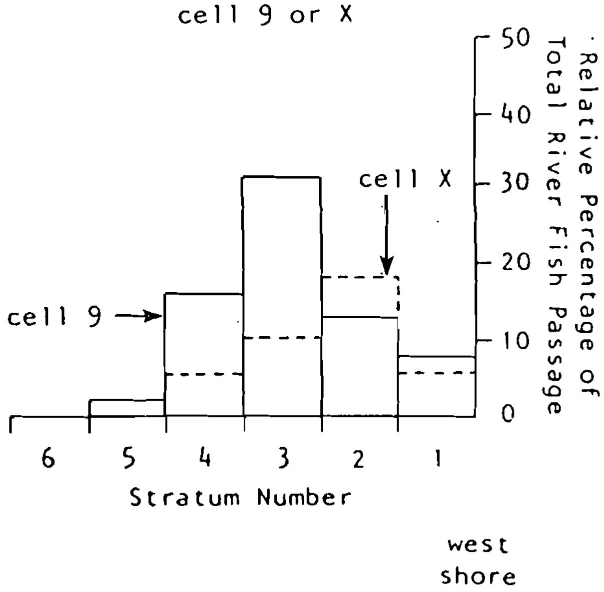
Figure 9. Horizontal distributions of adult salmon across the river, weighted for fish abundance, calculated with cell 9 or cell X, for Period IV (August 4-8). Susitna River, 1985.

Table 4. Horizontal distributions of adult salmon across the river, weighted for fish abundance, using cell X fish passage rates (Susitna River 1985).

	East		Relative Percentage of Fish by Cell					West	
Period	1	2	3	4	5	6	7	8	X	Total
				Upstream						
Shift 31	0	0	0	34.4	0	0	0	0	65.6	100.0
(cell 9	0	0	0	16.1	0	0	0	0	83.9	100.0)*
IV	25.0	0	0	34.5	0	0	0	0	40.5	100.0
(cell 9	13.1	0	0	18.2	0	0	0	0	68.7	100.0)
				Downstream						
Shift 31	16.1	0	0	36.1	0	0	0	0	47.8	100.0
(cell 9	2.9	0	0	6.6	0	0	0	0	90.5	100.0)
IV	47.5	0	0	43.2	0	0	0	0	11.1	100.0
(cell 9	13.1	0	0	12.4	0	0	0	0	74.5	100.0)

* The original horizontal distribution (weighted for fish abundance) with results from cell 9 below Petes Point is presented for comparison.

UPSTREAM



DOWNSTREAM

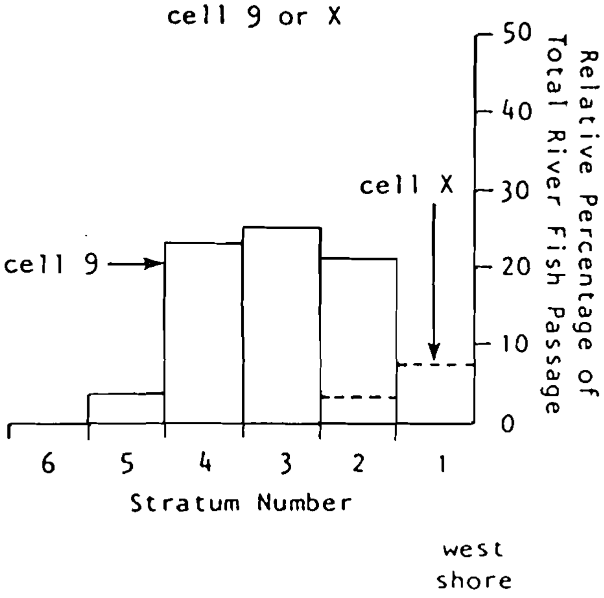


Figure 10. Horizontal distributions within cells 9 and X, weighted for fish abundance, for period IV (August 4-8) (Susitna River, 1985).

Table 5. Horizontal distributions of adult salmon within cell X above Petes Point, weighted for fish abundance (Susitna River 1985).

		Relative Percentage of Fish by Section						
Period	Direction	1	2	3	4	5	6	Total
IV	Upstream	5.6	19.4	10.4	5.1	0	0	40.5
(cell 9		7.4	12.5	30.6	16.1	2.0	0	68.7)*
IV	Downstream	7.8	3.3	0	0	0	0	11.1
(cell 9		0	21.8	25.1	23.1	4.5	0	74.5)

* The original horizontal distribution (weighted for fish abundance) with results from cell 9 below Petes Point is presented for comparison.

The horizontal distributions weighted for fish abundance were calculated from the total numbers of fish passing through each cell during a given period. Due to the variability in horizontal distributions among shifts with low passage rates, it is believed that the weighted distributions are more representative of all fish passing within a given period than the mean distributions calculated from the individual horizontal distributions by shift.

Much milling was observed, as indicated by the high proportion of downstream moving fish (Appendix P). If the rate of milling were not equal in each cell, then milling would bias the distributions toward the cells with the highest milling rates. Due to the hydrological conditions caused by Petes Point, it is possible that the rate of milling was higher at cell 9 than at cells 1 or 4. This could have resulted in a horizontal distributions that were biased high at cell 9.

Also, the Flathorn Station fishwheel samples collected 6 mi (10 km) downstream from the hydroacoustic sample transect indicated a less pronounced distribution of fish on the west bank (37.8%). The mean percentage of the west bank fishwheel was the highest of all four fishwheels, however (Table K2).

The distributions based on cell X indicate a west shore percentage closer to that of the west shore fishwheel at Flathorn Station. The cell X results should be interpreted with caution, however, since they were obtained during a period of reduced fish passage, and at reduced sample times (typically 20 min vs. 30-45 min at cell 9). It is likely that the true horizontal distribution across the river lies somewhere between the cell X and cell 9 distributions.

The extremely shore-oriented distributions of migrating salmon could be attributed in large part to the low water velocities observed at these locations. Remembering that most fish were within 60 ft (18 m) of the two shores, a comparison of Figures 3 and 7 suggests a correlation between fish distribution and low water velocities. Most fish were located where water velocities were < 0.5 fps (0.15 m/s).

Mean fish target velocities are presented in Appendix Q. Estimated mean velocities throughout the season for cell 1 were 2.2 fps (0.69 m/s) and 1.8 fps (0.55 m/s) for upstream and downstream moving fish, respectively. Cell 4 velocities were similar. Estimated mean velocities for cell 9 were 1.2 fps (0.36 m/sec) and 1.1 fps (0.33 m/sec) for upstream and downstream moving fish, respectively. In order for these fish to swim upstream in the deep water cells 6-8, where water velocities averaged 3.3-4.3 fps (1.0 - 1.3 m/s) (Appendix A), they would have had to expend much more energy.

As the within-cell distributions show, there was a drop in fish numbers in the section nearest shore. This drop could be attributed in part to shallower depths near-shore, and thus a smaller cross-sectional area with which to accommodate fish passage. It is more likely that some fish nearest the transducer passed undetected. Non-detection could have been due to the small sample volume nearest the transducers, or to the fish being bottom-oriented (Section 3.2). If the unmonitored fish were more dense than those monitored (the probable case if fish were bottom oriented), these instances would result in an underestimate of fish numbers. Throughout the course of data collection and analysis, several improvements to the hydroacoustic applications of this study were suggested that would improve the probability of detecting these fish (Section 5.0).

It should be emphasized that the horizontal distributions presented here were based on data from only one sample season. For a variety of biological, hydrological, and climatic reasons, distributions may vary from year to year. This was not a year of a large pink salmon run; in 1986 numbers of pinks should be much larger. How similar horizontal distributions in 1986 will be to those of 1985 remains to be seen.

3.2 Objective 2: Vertical Distribution of Migrating Adult Salmon

3.2.1 Detailed Methods

Vertical distribution analysis was planned for each deep water cell for the same six periods for which the horizontal distributions were developed. Since virtually no adult salmon were observed in these deep cells, the only vertical distributions available were from the shallow, near-shore areas which were monitored by the side-aspect, horizontally aimed transducers.

Twice on July 28, during relatively high fish passage, a side-aspect transducer was aimed alternately near the surface and near the bottom. The standard procedure for aiming side-aspect transducers was to slowly rotate them toward the bottom until they began to pick up strong bottom returns, then rotate them up slightly until the maximum bottom returns were less in amplitude than the mark threshold (which corresponded to the return from the smallest salmon anticipated). For sampling in cell 9 for vertical distribution estimates, we aimed the transducer down slightly farther than usual (1°). This orientation monitored the bottom stratum, and was aimed into the substrate to a degree. This is possible without obscuring fish traces when the bottom (usually mud or sand) is less reflective than the smallest targets of interest (i.e., the bottom has a smaller target strength and is more acoustically absorptive than the smallest fish.

The surface stratum was monitored by tilting the transducer up a slight amount (approximately 3°) from this lower position. The two acoustic volumes overlapped each other at a range of approximately 40 ft (12.2 m). The maximum range sampled was 79 ft (24 m), but 82% of the fish were detected at ranges of 16-43 ft (5-13 m). Fish detections were counted by direction of movement, and relative percentages of fish numbers between the two strata were calculated.

The small sample size was the result of allocation of the very limited sample time available to more important tasks.

3.2.2 Results and Discussion

Results from individual samples are presented in Appendix R. Results from each sample were similar. Seventeen percent of the fish were located in the upper stratum, and 83% in the bottom stratum (Table 6).

Table 6. Vertical distribution of fish over two strata in cell 9 (Susitna River 1985).

Stratum		Mean Relative Percentage of Fish*		
		Upstream	Downstream	Total
		Vertical Distribution By Direction of Fish Movement		
1	Surface	13.0	21.2	16.6
2	Bottom	87.1	78.9	83.5
		-----	-----	-----
	Total	100.0	100.0	100.0
		Fish Movement by Direction within Surface Stratum		
1	Surface	38.9	61.2	100.0
		Fish Movement by Direction within Bottom Stratum		
2	Bottom	52.8	47.2	100.0

* Means of two tests completed July 28.

Of the upstream moving fish, 13% were located in the upper stratum, and 87% in the lower one. Downstream-moving fish were also found primarily in the bottom stratum, but tended to be less bottom oriented than upstream-moving fish (79% vs. 87%, respectively).

Examining the results on a stratum by stratum basis, 39% of the fish in the upper stratum were moving upstream and 61% downstream. In the bottom stratum, 53% were moving upstream and 47% downstream.

While not quantified, similar trends toward bottom orientation of fish were observed throughout the study while aiming side-aspect transducers in cells 1, 4, and 9.

It is conceivable that the same factor that caused fish to orient near the shores also tended to affect their vertical distribution. The highest water velocities occurred near the surface, decreasing with depth until the minimum velocities were observed at the bottom (Appendix A). It is also conceivable that salmon actively swimming upstream tended to be more bottom oriented than those moving downstream. Unlike upstream-moving fish, downstream-moving fish would gain no great benefit from an extreme bottom orientation.

3.3 Objective 3: Acoustic size of migrating adult salmon

3.3.1 Detailed Methods

Target strength (acoustic size) was calculated for individual fish. Mean target strengths were calculated for each of the six periods, for upstream and downstream moving fish separately, and converted to approximate total fish lengths. These procedures are explained in detailed in Appendix E.

3.3.2 Results and Discussion

Mean target strengths and corresponding fish lengths appear in Table 7. Target strength frequency distributions for the total study period appear in Figure 11, and distributions by individual period appear in Appendix S.

The mean target strengths for the season were -35.4 dB and -34.4 dB (equivalent to approximately 53 and 60 cm) for upstream- and downstream-moving fish, respectively. The largest mean target strengths were observed in period I (-33.8 dB and -33.2 dB, (65 cm and 69 cm) for upstream and downstream fish). Mean target strengths for periods I-IV ranged from -36.9 dB to -33.2 dB (44-69 cm).

The large spread in target strength distributions (approximately 14 dB) could be partly a function of variability in orientation of fish relative to the horizontal aiming angle of the transducer. The conversion from target strength to length assumes that fish remained oriented parallel to flow, and 45° to the transducer. Variability in this orientation would result in a larger spread in the distribution (Figure E2).

ADF&G fishwheel catches from Flathorn Station for periods I and II were comprised mostly of sockeye salmon, with the balance primarily of pink and coho salmon. Periods III and IV yielded mostly pink salmon, with the balance primarily sockeye and coho salmon (Table K2).

Table 7. Mean acoustic size of adult salmon (Susitna River 1985).

Period No.	Dates	Upstream				Downstream			
		TS*	SD	N	Length**	TS*	SD	N	Length**
I	7/22-25	-33.8	3.12	808	64.5	-33.2	3.41	969	69.3
II	7/25-30	-36.1	2.14	1279	48.9	-35.0	2.52	1479	55.8
III	7/31-8/3	-36.9	2.05	136	44.4	-36.1	2.56	107	48.9
IV	8/3-8	-36.2	2.18	87	48.3	-34.9	2.98	97	56.5
I-II	7/22-30	-35.3	2.80	2087	53.8	-34.3	3.05	2448	60.7
I-IV	7/22-8/8	-35.4	2.77	2310	53.2	-34.4	3.05	2652	60.0

* At side aspect, 45° toward head-on from broadside.
** Predicted total length in cm, calculated as described in Appendix C.

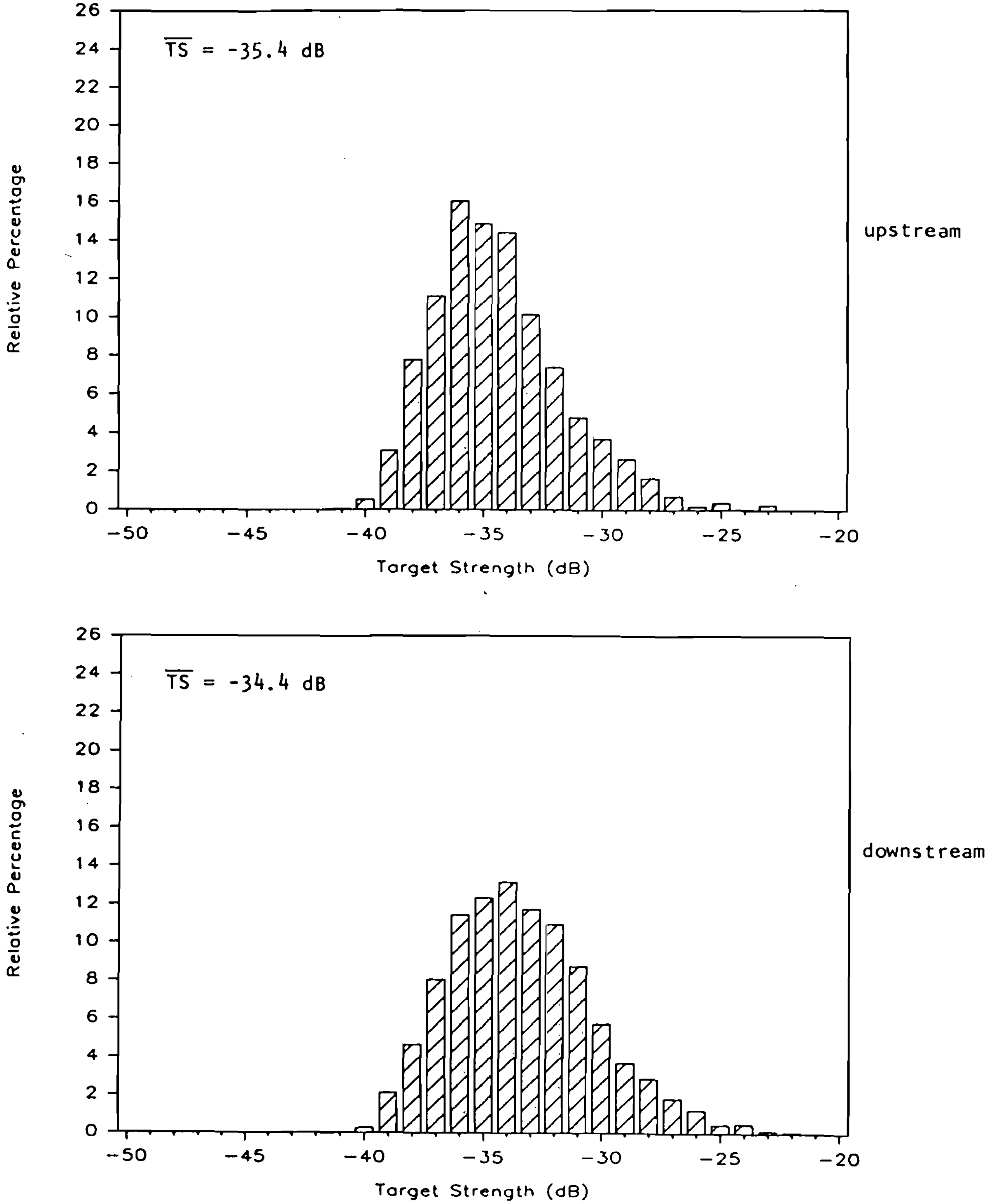


Figure 11. Acoustic size distribution of fish at side-aspect 45° during Periods I-IV (July 22 - August 8). Susitna River, 1985.

4.0 CONCLUSIONS

1. Hydroacoustic monitoring of migrating adult salmon in the Susitna River took place from July 15 to August 8, 1985.

2. Between July 24 and August 1, 91% of the upstream migrating adult salmon passed. Fifty percent had passed by July 28.

3. During the study period, approximately 88% of the estimated upstream fish passage passed through the cell nearest the west shore (cell 9), 7% through the cell nearest the east shore (cell 1), and 6% through a shallow cell near the middle of the river (cell 4).

4. During the study period, approximately 75% of the estimated upstream fish passage passed within 60 ft (18.3 m) of the west shore (cell 9), and 86% within 80 ft (24.4 m). This trend of shoreward orientation was also observed on the east shore (cell 1).

5. Due to concerns of the effect of hydraulic conditions on milling of salmon along the west shore, a test site (cell X) above Petes Point was monitored. Supplemental horizontal distributions were calculated substituting data from cell X for cell 9 data. For period IV, 25%, 35%, and 40% of the upstream-moving fish passed through cells 1, 4, and 9, respectively. A total of 35% of the fish passed within 60 ft (18 m) of the west shore. It is felt that the true horizontal distribution lay somewhere between the cell 9 and cell X distributions.

6. Along the west shore (cell 9) fish tended to be oriented near the bottom, upstream moving fish more so than downstream-moving fish.

7. Horizontal and vertical distributions suggested that fish were oriented toward low water velocities (i.e., near shore, in shallow areas, and near the bottom of the river).

8. For the entire study period, the mean acoustic sizes of upstream- and downstream-moving fish were -35.4 dB and -34.4 dB, respectively, corresponding to mean total fish lengths of approximately 53 and 60 cm.

9. During the study period, 48% of the fish monitored were moving upstream, and 52% downstream. It is believed that this high incidence of downstream movement was due in large part to hydrological conditions caused by water being forced around Petes Point upstream of the sample site.

10. At a more hydraulically stable test site upstream of Petes Point (cell X), 79% of the monitored fish were moving upstream.

11. Fish target velocities for the study period were faster for upstream moving fish than downstream fish. For cell 1, target velocities were 2.2 fps (0.69 m/sec) and 1.8 fps (0.55 m/sec) for upstream and downstream moving fish, respectively. Cell 4 velocities were similar. Estimated mean velocities for cell 9 were 1.2 fps (0.36 m/sec) and 1.1 fps (0.33 m/sec).

12. It appears that some upstream-moving fish passed undetected. These fish were probably located near the bottom and near shore. Several improvements in the application of the hydroacoustic technique were developed which would improve monitoring of the near-bottom and near-shore fishes. The flexibility of this technique lends itself to timely implementation of these improvements.

5.0 RECOMMENDATIONS FOR FUTURE EFFORT

The 1985 Susitna River hydroacoustic study was initiated with very little direct knowledge of the spatial distributions of adult salmon in the river. This necessitated a flexible sampling strategy based on a wide variety of sampling contingencies. During data collection in the field and data analysis in the laboratory, refinements to the acoustic sampling technique were developed that enhanced hydroacoustic enumeration of adult salmon in the river. These developments have resulted in the following recommendations for future monitoring of adult salmon in the Susitna River.

5.1 Objectives

The 1985 study demonstrated the ability of fixed-location hydroacoustics to monitor salmon in the Susitna River. It is recommended that hydroacoustic monitoring of migrating adult salmon in the Susitna River be continued in 1986. The objectives of that study would be as follows:

1) estimate escapement of adult salmon in the Susitna River in the general vicinity of Susitna Station,

2) during periods of high fish passage, periodically estimate the horizontal distribution of salmon across the river,

3) estimate the vertical distribution of fish within the near-shore cells, and

4) estimate the target strength of adult salmon.

5.2 Methods

Based on the experience gained in 1985, we recommend monitoring Susitna River salmon in a manner similar to that used in 1985, but with significant improvements.

5.2.1 Improved Sampling Near Shore

Since adult salmon were shore oriented in 1985, effective sampling of the near-shore areas is of paramount importance. Developments which should be implemented to monitor the fish in these areas are listed below.

Elliptical Transducers

Dual-beam transducers with elliptical beam patterns are available with a 3° x 10° narrow beam and 7° x 21° wide beam (Figure 12). (Circular-beam transducers of 6° and 15° were used in 1985.) These transducers would better monitor near shore and at close ranges to the transducers. Since their ensonified volumes are wider in the horizontal plane than normal dual-beam transducers (10° vs 6°), their use would result in 67% more ensonifications of fish passing through the acoustic beam, and improved detection of fish near the transducer.

Two Stacked Transducers in Tandem

Two elliptical transducers would more effectively sample the areas near shore and at close ranges (Figure 13). Using a multiplexer, these transducers could be sampled simultaneously. This orientation would also permit estimation of vertical distributions for the two strata sampled. Multiple transducers could also be strategically placed and aimed to compensate for irregular bottom profiles.

Short Weir

Fish target velocities were slow enough to allow ample ensonifications at all but the closest ranges. In 1985, migrating adult salmon were visually observed very close to the west shore, in water as little as 6-12 inches (15-30 cm) deep.

A weir 5-10 ft (2-3 m) would greatly enhance detectability of near shore fish. Any weir used should require as little maintenance as possible and retain provisions to deal with rapid hydraulic changes, i.e., be quickly deployable and retrievable.

Battery Power

To reduce the possibility of boat avoidance by migrating adult salmon, batteries instead of gasoline powered electrical generators should be used to power the hydroacoustic electronics.

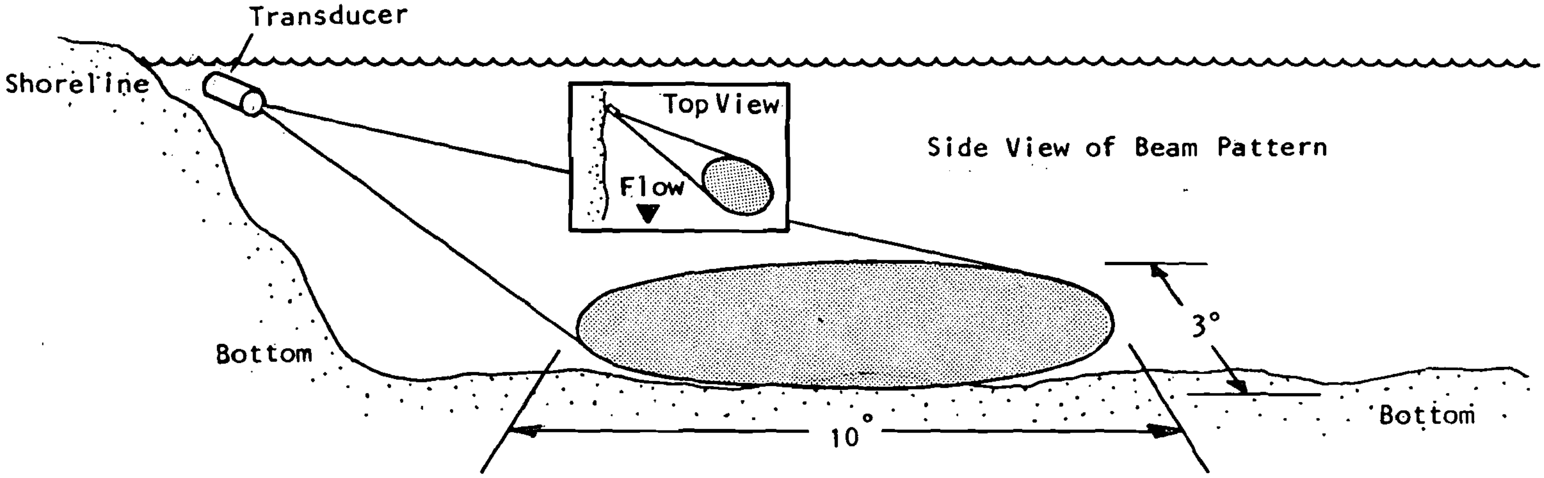


Figure 12. Elliptical transducer proposed for use in side-aspect. Susitna River, 1985

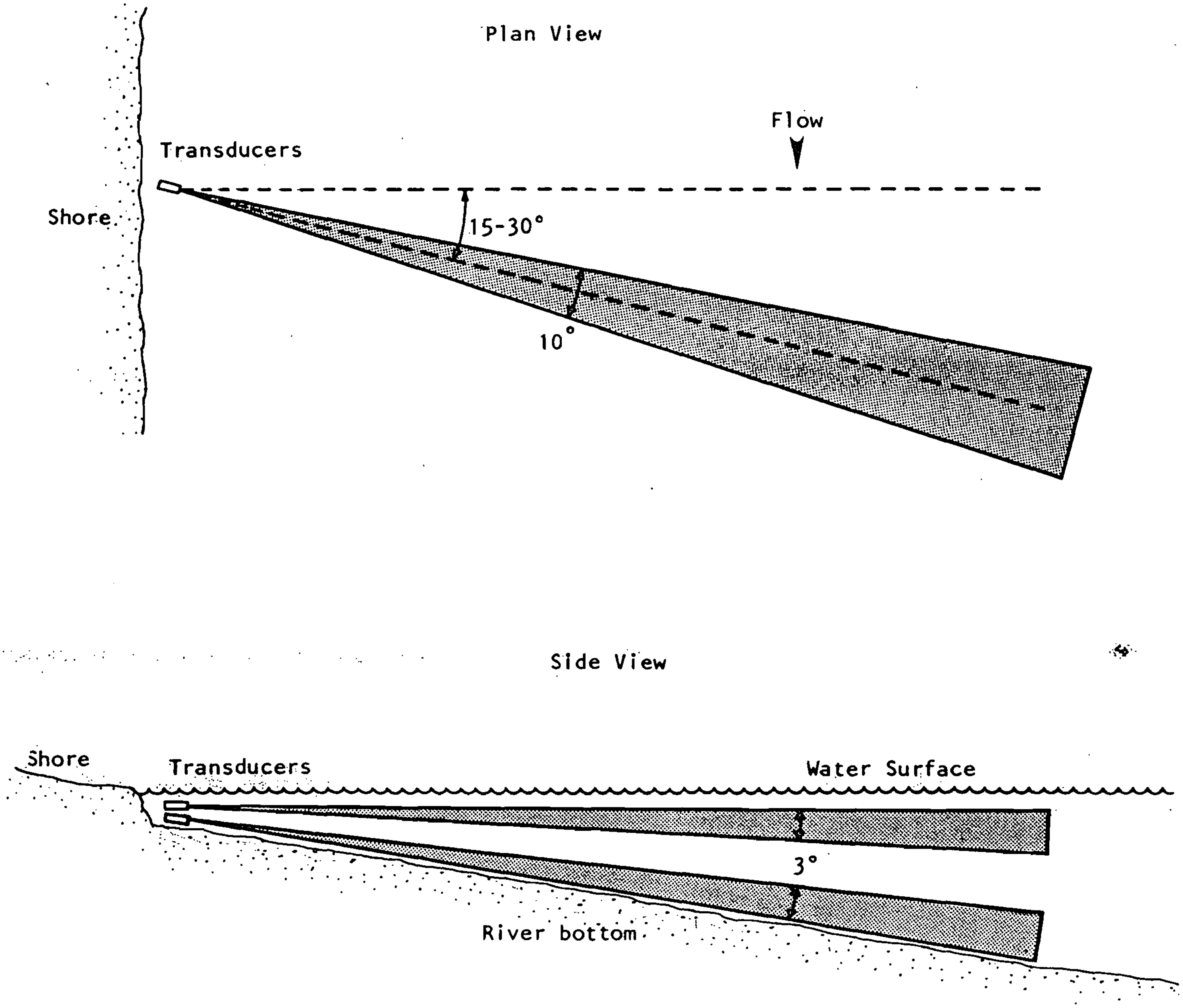


Figure 13. Two side-aspect elliptical transducers monitoring in tandem. Susitna River, 1985.

5.2.2 Improved Sampling Near the Bottom

Since adult salmon were bottom oriented in 1985, it is important to efficiently sample near the substrate. This is best done with side-aspect transducers, and as noted below.

Elliptical Transducers

Elliptical transducers place a wider sample volume nearer the bottom than do circular transducers. Since fish near the bottom would be within an elliptical beam longer, this would result in more ensonifications per fish, and improved detectability.

Shallower Side-Aspect Aiming Angles

The data from the side-aspect, horizontally-scanning transducers were collected at an aiming angle of 45° downstream. For fish detected in the side aspect, signal strength is greatest at 90° to the longitudinal axis of the fish, (i.e., broadside) (Figure E2). By aiming transducers downstream 15-30°, the signal strength of returns can be increased by approximately 3-6 dB (50-100%), over returns at a 45° aiming angle (Appendix E). This increased signal-to-noise ratio would allow closer aiming of transducers to the bottom, thereby improving the probability of detecting fish near the bottom.

More Stable Work Platform

Occasional ambiguity was introduced into the 1985 data by an inability to hold steady the side-aspect transducers, and hence their corresponding ensonified volumes. Boat movements hindered critical aiming close to the substrate of the river. A more stable boat or semi-permanent transducer mount placed on the bottom would benefit aiming near the river bottom.

Boat movement in the roll axis most affected the data, particularly that from the side-aspect transducers, since the aiming of these transducers was most critical. The most severe effect of boat movement was the intermittent introduction of bottom returns of amplitude greater than the minimum target threshold. This would result in the bottom drifting in and out of the echogram. Strong bottom returns severely impacted the ability of the automatic fish tracking software to count the fish, since the program would periodically count the bottom as fish. This had the effect of either reducing the amount of acceptable sample time, increasing the amount of analysis time, or both. Probably as little as a 2° roll would add significant interference to the data. The roll of the boat used in 1985 was occasionally much more than this. A boat such as a 16-20 ft Boston Whaler should provide ample stability.

Light, semi-permanent mounts can be used in 1986. These will be highly mobile and allow transducer aiming adjustments from the surface. These mounts would have the benefit of allowing sampling of the exact same area from sample to sample, and would be unaffected by boat movement.

5.2.3 Reduce Effects of Fish Milling: Improved Siting

The west shore just below Petes Point (cell 9) exhibited a high proportion of downstream-moving fish (52%) (Table P4), and similar trends were observed at cells 1 and 4 (Tables P2 and P3). From July 30 to August 8, supplemental monitoring was conducted 10 times at cell X, where hydrological conditions were improved. Here, 79% of the detected fish were moving upstream. This site and others along the west shore will be investigated in 1986.

The most desirable near-shore sites would have a smooth bottom profile, a soft substrate, a minimum of turbulence, and a relatively rapid initial drop in depth at shore. Moving the west shore sample site to cell X and adopting a diagonal sample transect from cell X to cell 1 would be one alternative.

5.2.4 Increased Sample Time

Reduce Sample Time at Cells without Fish

Limiting hydrocoustic sampling to cells where fish were monitored in 1985 would permit longer sample times at these cells. This should provide less variable estimates of fish passage rates from shift to shift. If sampling were limited to three locations instead of the eleven sampled in 1985, sample times at each cell could be increased from 30-45 min to 3 h, approximately five fold. Cell 3 could be sampled simultaneously with cell 4.

Tandem Transducers

Multiplexing between two stacked elliptical transducers would further double the sample power devoted to a cell.

5.2.5 Compare Horizontal Distributions Between 1985 and 1986

Since a large pink run or hydrological conditions could affect fish horizontal distributions, any enumeration strategy should incorporate plans to periodically examine the horizontal distributions of fish across the river. During periods of high fish passage, sample time could probably be devoted to this task without jeopardizing other objectives.

During periods of high fish passage, all nine cells across the river could be periodically sampled for one shift to estimate the horizontal distribution of fish across the river. If fish densities were high enough, mobile surveys along the sample transect could prove a quicker means of estimating horizontal distributions.

5.2.6 Hydroacoustically Sample Cell 3

ADF&G personnel captured some salmon in cell 3 during the 1985 study. Using a multiplexer, acoustic sampling of cell 3 could take place concurrent with sampling of cell 4. Elliptical transducers will be aimed horizontally into cells 3 and 4 from a sample boat anchored at the boundary between the two cells.

5.2.7 Sample During High Water

To sample during high water or rapidly fluctuating water levels and debris loads, boat-mounted transducer mounts will be retained. In addition, semi-permanent bottom mounts will be tested in the shallow cells.

Any weirs used will need to require as little maintenance as possible and retain provisions to deal with hydraulic changes. Weirs should be short (5-10 ft (2-3 m)), and like bottom mounts, quickly deployable and retrievable.

5.2.8 Sample High Densities of Fish

Any sampling strategy in even numbered years will require enough flexibility to deal with high densities of pink salmon, and large numbers of spawned out fish drifting downstream. All data will be digitized and recorded on video tape. Where densities require, these tapes can later be played through a digital echo integrator to estimate total biomass (Bursczynski 1979, Kanciruk 1982). Trace type distributions from echograms can be used to apportion biomass to upstream- and downstream-moving fish.

5.2.9 Equipment Setup

The data collection crew should arrive at least one week prior to commencement of actual sampling in order to search for optimum sampling sites, determine bottom profiles, test elliptical transducers, test transducer mounts, and perform standard target measurements to better define sample locations relative to the surface and bottom.

The location of the sample volume relative to the bottom and surface can be verified in the field as described below. This would assist evaluation of other improvements in their ability to enhance monitoring near the bottom.

The degree to which acoustic beams can be aimed near the bottom and surface is largely a function of the bottom type and surface conditions. Accurate measurement of the location of sample volumes relative to boundaries (the bottom substrate and the surface) is a manpower and time consuming endeavor requiring use of a standard target, preferably of the target strength of the smallest fish anticipated.

5.2.10 Flexibility of Applications

The flexibility of the hydroacoustic technique applied in this study lends itself to timely evaluation and implementation of the improvements discussed above. Conditions can change rapidly in the Susitna River. On occasion, 1985 water levels and debris loads rose quickly, mandating changes in transducer placements and placement techniques. The basic mounts and sampling techniques employed in 1985 were flexible enough to permit rapid altering of sampling strategies to compensate for these changes, and will be retained in 1986.

5.2.11 Development of a Real-Time Fish Counter

A fish tracking computer program was used to analyze the data in this report. There is potential for a modification of this routine to be developed to enumerate migrating adult salmon in the Susitna River on a near real-time basis. Such a system could be ready for field trials in 1986. An alternative would be to regularly count fish from chart recorder echograms in the field, enter them into a portable computer, and expand the counts appropriately.

5.2.12 Options to Reduce Costs

While collecting and analyzing data in 1985, several areas of potential cost reduction were noted. All require reductions in the volume of data collected and analyzed, and would presumably result in an increase in variability around estimates of fish passage rates.

Single Shift Operation

By reducing sampling from two to one shift per day, manpower in the field can be reduced from four to three. This would also reduce analysis time, and save approximately two man months of labor costs. In addition, time would be available for other periodic tasks such as mobile transects to obtain horizontal distributions.

Non Real-Time Fish Counting

By not attempting to produce estimates of fish passage in near real-time, the costs of one data analyst and associated computer equipment can be saved.

Training of ADF&G Personnel

Up to one ADF&G employee per shift could be trained in the deployment and operation of the hydroacoustic equipment. By retaining supervision of the operation by experienced BioSonics personnel, monitoring of deployment, data collection, and data processing for quality control can be assured. Training would lead to ADF&G operation and processing of the data under BioSonics direction, and eventually to total ADF&G operation of the hydroacoustic enumeration system.

ACKNOWLEDGEMENTS

BioSonics, Inc. would like to thank the following ADF&G personnel for their able and unselfish contribution to the success of this project: Ken Tarbox, Bruce King, Randal Davis, Mark Clark, and the rest of the ADF&G crew at Susitna Station.

We would also like to thank Kurt Shuey for his very helpful assistance with data collection in the field, and Lisa Russell for her able assistance with dual-beam data processing and data analysis in Seattle.

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APPENDIX A: Depth Profile, Water Levels, and Water Velocity Profile of the Susitna River

Table A1. Summary of depth profile along hydroacoustic sample transect (Susitna River 1985).

Distance in feet* from Shore or Boundary	Depth in feet by cell**								
	1	2	3	4	5	6	7	8	9
0	0	14.8	18.9	7.1	13.1	17.5	26.3	22.3	0
10	3.2	--	--	--	--	--	--	--	1.2
20	5.4	15.1	18.3	7.4	13.6	18.7	27.0	23.4	1.5
30	8.1	--	--	--	--	--	--	--	1.6
40	8.9	15.8	19.3	6.3	14.2	19.4	27.2	22.0	1.9
50	9.8	--	--	--	--	--	--	--	1.9
60	10.1	16.3	18.4	6.9	13.8	19.5	27.7	20.6	2.1
70	10.4	--	--	--	--	--	--	--	2.1
80	10.8	16.5	18.3	7.6	15.0	19.7	27.4	19.7	2.6
90	12.1	--	--	--	--	--	--	--	3.0
100	13.6	16.5	17.3	8.1	14.1	20.4	16.9	19.5	3.6
120	14.2	16.6	16.8	8.8	13.8	21.8	25.8	17.7	4.2
140	14.6	17.4	15.4	9.5	13.1	22.4	25.4	15.4	4.8
160	14.7	17.9	13.6	9.7	14.3	24.3	24.5	15.7	6.6
180	14.9	18.1	10.8	11.1	15.3	25.9	23.6	12.3	8.3
200	14.8	18.9	7.1	12.1	16.1	25.7	22.3	9.7	9.7
217	--	--	--	13.1	17.5	26.3	--	--	--

* All distances from east shore, except cell 9 from west shore.

** Relative to lowest water level on August 6.

Table A2. Water levels, based on daily Susitna Station staff gauge readings (Susitna River 1985).

	Date	Water Level (feet) (Relative to 8/6 Low)*
July	15	1.1
	16	0.8
	17	0.9
	18	0.9
	19	1.0
	20	1.3
	21	2.1
	22	3.4
	23	2.3
	24	1.1
	25	0.6
	26	0.3
	27	0.5
	28	0.5
	29	0.7
	30	0.8
	31	0.8
August	1	0.6
	2	0.5
	3	0.5
	4	0.5
	5	0.4
	6	0.0
	7	0.3
	8	0.3

* Relative to lowest water level on August 6.

Table A3. Mean water velocity profile and depths during low water period (Susitna River 1985).

			Velocity in fps Percentage of Total Depth**					
Cell	Depth Range* ft (m)	Surface	20%	40%	60%	80%	bottom	Mean
1	0-14.1 (0-4.3)	3.4	3.2	2.8	2.8	2.4	2.2	2.8
2	14.1-16.9 (4.3-5.2)	3.4	2.8	2.6	2.8	2.2	2.2	2.7
3	6.8-17.1 (2.1-5.2)	2.4	2.0	2.6	1.4	0.6	0.2	1.5
4	5.7-12.0 (1.7-3.7)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5	12.0-15.8 (3.7-4.8)	2.4	3.1	2.8	2.2	1.4	1.4	2.2
6	15.9-25.7 (4.8-7.8)	7.0	6.2	3.4	3.0	3.0	3.0***	4.3
7	22.4-28.4 (6.8-8.7)	6.2	3.4	3.2***				4.3
8	7.5-22.6 (2.3-6.9)	5.2	3.0	3.0	1.8***			3.3
9	0-7.5 (0-2.3)	4.1	3.0	2.4	2.2	2.0	2.0	2.6

* At lowest water level during study, on August 6.

** Velocities measured July 24 to August 6, during stable low water period.

*** The end of the deployment cable (18 ft (5.5m)) was reached before flow meter reached the bottom.

APPENDIX B: Sample Times for Each Shift

Shift Number	Day/ Night	Start		End	
		Date	Hour	Date	Hour
		Period 0			
1	N	7 14	2200	7 15	800
2	D	7 15	800	7 15	1800
3	N	7 15	2200	7 16	800
4	D	7 16	800	7 16	1800
5	N	7 16	2200	7 17	800
6	D	7 17	800	7 17	1800
7	N	7 17	2200	7 18	800
8	D	7 18	800	7 18	1800
9	N	7 18	2200	7 19	800
10	D	7 19	800	7 19	1800
11	N	7 19	2200	7 20	800
12	D	7 20	800	7 20	1800
13	N	7 20	2200	7 21	800
14	D	7 21	800	7 21	1800
		Period I			
15	N	7 21	2200	7 22	800
16	D	7 22	800	7 22	1800
17	N	7 22	2200	7 23	800
18	D	7 23	800	7 23	1800
19	N	7 23	2200	7 24	800
20	D	7 24	800	7 24	1800
21	N	7 24	2200	7 25	800
22	D	7 25	800	7 25	1800
		Period II			
23	N	7 25	2200	7 26	800
24	D	7 26	800	7 26	1800
25	N	7 26	2200	7 27	800
26	D	7 27	800	7 27	1800
27	N	7 27	2200	7 28	800
28	D	7 28	800	7 28	1800
29	N	7 28	2200	7 29	800
30	D	7 29	800	7 29	1800
31	N	7 29	2200	7 30	800
32	D	7 30	800	7 30	1800

APPENDIX B, cont.

Shift Number	Day/ Night	Start		End	
		Date	Hour	Date	Hour
		Period III			
33	N	7 30	2200	7 31	800
34	D	7 31	800	7 31	1800
35	N	7 31	2200	8 1	800
36	D	8 1	800	8 1	1800
37	N	8 1	2200	8 2	800
38	D	8 2	800	8 2	1800
39	N	8 2	2200	8 3	800
40	D	8 3	800	8 3	1800
		Period IV			
41	N	8 3	2200	8 4	800
42	D	8 4	800	8 4	1800
43	N	8 4	2200	8 5	800
44	D	8 5	800	8 5	1800
45	N	8 5	2200	8 6	800
46	D	8 6	800	8 6	1800
47	N	8 6	2200	8 7	800
48	D	8 7	800	8 7	1800
49	N	8 7	2200	8 8	800
50	D	8 8	800	8 8	1800

Appendix C: Summary of Data Collection Parameters

Table C1 is a sample of the detailed summary of data collection parameters supplied to ADF&G. Parameters were supplied for each sample collected beginning with shift 15. Parameters include the start date and time of the sample, and the duration of the sample. The maximum range sampled is included, as is the cell number. For cells 1 and 9, the location of the sample boat (onshore (as near shore as practical) or offshore (usually at 15 ft (46 m) from shore)) is included. The distance from shore is entered, along with which shore it was measured from. The last entry designates whether a side-aspect or downward-looking transducer was sampled.

Downward-aimed transducers were located 12 inches (30 cm) below the surface. Side-aspect transducers were 12 inches (30 cm) deep in cell 9, and 24 or 36 inches (61 or 91 cm) deep in cells 1 and 4.

Table C1. Date, time, sample length, maximum range, and location for sample sequences performed on the Susitna River July 21 2250-July 23, 1722 h, 1985.

month/ date	start time	sample length (min)	maximum range (feet)	sample cell	distance from shore (feet)	E or W bank	transducer orientation
7/21	2250	30	65.6	9 ON	25	W	SIDE SCAN
7/21	2329	32	65.6	9 OFF			SIDE SCAN
7/22	10	46	131.2	4	630	E	SIDE SCAN
7/22	108	30	42.7	1 ON	10	E	SIDE SCAN
7/22	145	60	19.2	1 OFF			SIDE SCAN
7/22	255	13		2	300	E	DOWN LOOK
7/22	314	45		3	558	E	DOWN LOOK
7/22	408	29	23.0	5	957	E	DOWN LOOK
7/22	448	32		8	252	W	DOWN LOOK
7/22	525	17	11.5	7	540	W	DOWN LOOK
7/22	552	13		6	600	W	DOWN LOOK
7/22	844	46		5	957	E	DOWN LOOK
7/22	952	50		6	780	W	DOWN LOOK
7/22	1055	45		8	375	W	DOWN LOOK
7/22	1153	41		7	580	W	DOWN LOOK
7/22	1304	32	65.3	9 OFF			SIDE SCAN
7/22	1346	26	131.2	9 ON	20	W	SIDE SCAN
7/22	1432	31	105.0	1 ON	6	E	SIDE SCAN
7/22	1509	30	78.7	1 OFF			SIDE SCAN
7/22	1545	30	131.2	4	630	E	SIDE SCAN
7/22	1624	31		2	297	E	DOWN LOOK
7/22	1702	45		3	540	E	DOWN LOOK
7/22	2227	30		7	570	W	DOWN LOOK
7/22	2306	29		8	390	W	DOWN LOOK
7/22	2355	31	65.6	9 ON	20	W	SIDE SCAN
7/23	32	30	45.9	9 OFF			SIDE SCAN
7/23	112	60	65.6	1 ON	8	E	SIDE SCAN
7/23	149	30	75.5	1 OFF			SIDE SCAN
7/23	230	43	131.2	4	620	E	SIDE SCAN
7/23	327	45	19.7	3	588	E	DOWN LOOK
7/23	420	45		2	300	E	DOWN LOOK
7/23	517	45		5	967	E	DOWN LOOK
7/23	610	46		6	780	W	DOWN LOOK
7/23	838	42		7	450	W	DOWN LOOK
7/23	936	45	23.0	8	291	W	DOWN LOOK
7/23	1039	30	72.2	9 OFF			SIDE SCAN
7/23	1119	30	45.9	9 ON	12	W	SIDE SCAN
7/23	1225	25	114.8	1 OFF			SIDE SCAN
7/23	1312	30	78.7	1 ON	6	E	SIDE SCAN
7/23	1408	46	131.2	4	625	E	SIDE SCAN
7/23	1504	45		2	255	E	DOWN LOOK
7/23	1554	44	19.7	3	510	E	DOWN LOOK
7/23	1644	30	18.0	5	947	E	DOWN LOOK
7/23	1722	30		6	805	W	DOWN LOOK

APPENDIX D: Hydroacoustic System Equipment, Operation, and Calibration

Equipment Description

Each BioSonics dual-beam hydroacoustic data collection system consisted of the following components: a dual-beam 420 kHz transducer, a dual-beam echo sounder/transceiver, a chart recorder, and an oscilloscope. A video tape recording system was also used to record the echo sounder output for later laboratory analysis. Equipment was powered by a portable gasoline generator. A block diagram of the basic system is shown in Figure D1. Table D1 lists specific manufacturers and model numbers of the electronic equipment used.

Equipment Operation

The echo sounder is the core of the system, and is described in detail by Wirtz and Acker (1979 and 1981) and Ehrenberg (1984a, 1984b).

The hydroacoustic data collection system works as follows: when triggered by the Model 101 Echo Sounder, a high-frequency transducer emits short sound pulses in a relatively narrow beam aimed toward an area of interest. As these sound pulses encounter fish or other targets, echoes are reflected back to the transducer which then reconverts the sound energy to electrical signals. The signals are then amplified by the echo sounder at a time-varied-gain (TVG) which compensates for the loss of signal strength due to absorption and geometric spreading of the acoustic beam with distance from the transducer. Thus, equally-sized targets produce the same signal amplitudes at the echo sounder output regardless of their distance from the transducer. A target's range from the transducer is determined by the timing of its echo relative to the transmitted pulse. This process is described in more detail by Albers (1965), Burczynski (1979), and Urich (1975).

The echo sounder relays the returning TVG-amplified signals to the chart recorder and the oscilloscope. The return signals are visually displayed on the oscilloscope for monitoring of echo strengths and durations. Individual fish traces are displayed on the chart recorder's echograms which provide a record of all targets detected throughout the study. The threshold circuit on the chart recorder eliminates signals of strengths less than the echo levels of interest.

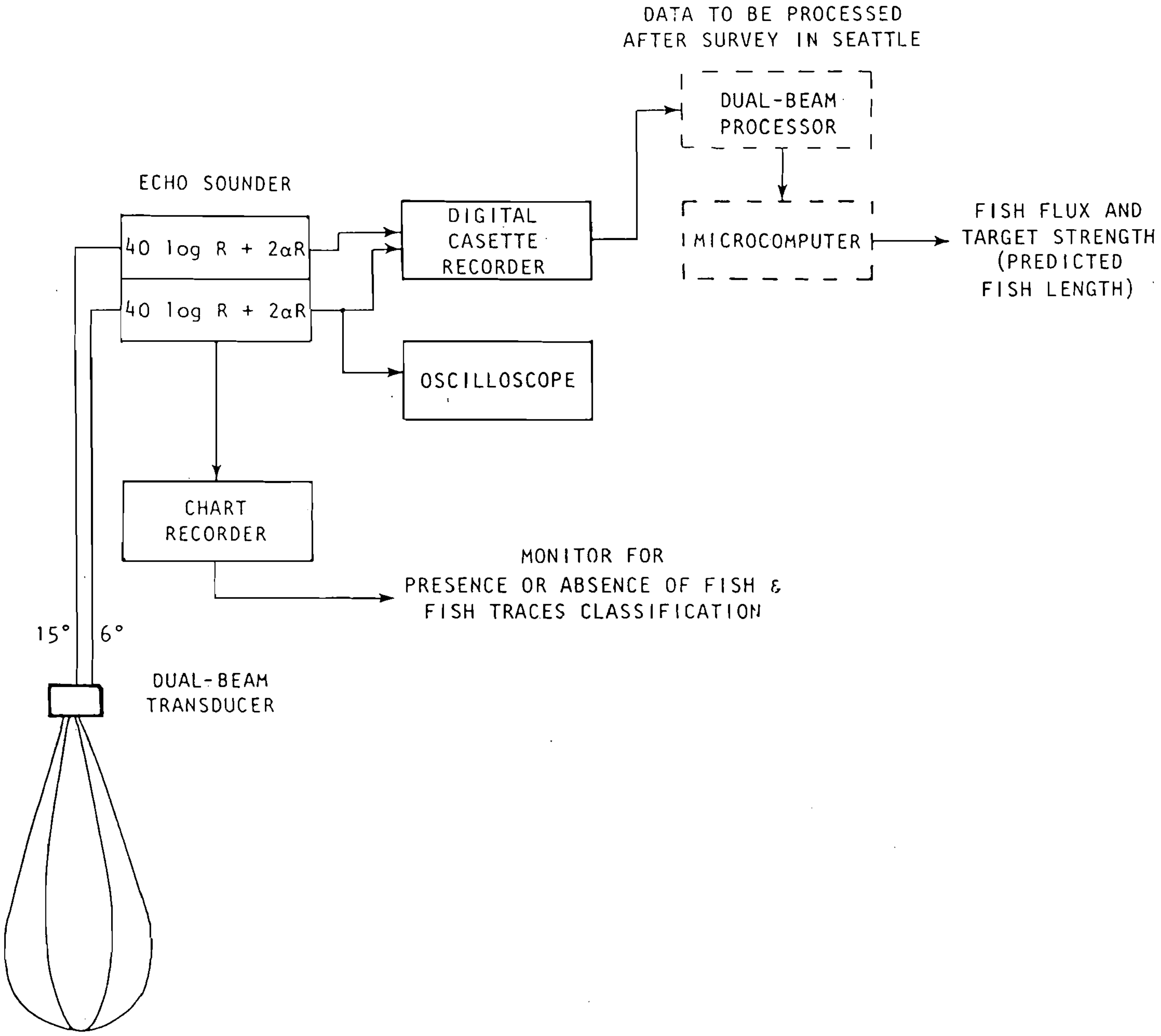

Figure D1. BioSonics dual-beam system for echo surveys.

Table D1. Manufacturers and model numbers of electronic equipment used by BioSonics, Inc. at Susitna River, 1985.

Item	Manufacturer	Model Number
Echo Sounder/Transceivers	BioSonics, Inc.	101
Dual-Beam Processor	BioSonics, Inc.	181
Chart Recorders	BioSonics, Inc.	115
Dual-Beam Transducers (6° x 15°)	BioSonics, Inc.	SP06
Oscilloscopes	Hitachi Denshi, Ltd.	V-352
Digital Audio Processors	Sony	PCM-F1
Video Recorders	Sony	B VCR
Tape Recorder Interfaces	BioSonics, Inc.	171
Microcomputers	Compaq IBM NorthStar	Portable XT(hard disk) Advantage
Computer Printers	Epson	FX-80 LX-80
Generators	Honda	EM-3000

Note: Specifications for equipment can be obtained by contacting BioSonics, Inc.

Pulse rates were 10 pings/sec. This was sufficient to obtain ample ensonifications of fish to determine change-in-range and classify direction of movement.

Due to the near-range limits of the time-varied-gain amplification, effective acoustic sampling did not take place at ranges closer than 1.0 m (3.28 ft) to the transducer. For side-aspect transducers the maximum range sampled varied due to changes in water levels, river bathymetry, and specific sampling locations.

Past experience has indicated that with a smooth, sandy bottom, a side-aspect transducer can see a -42 dB target to within 2-3 inches (5-8 cm) of the bottom. Since Susitna River salmon were typically of much larger target strength (-37 dB minimum at 45° side aspect), and the substrate was typically sand or mud, Susitna River transducers should have seen closer to the bottom.

The maximum range sampled is presented in the data collection parameter summaries (Appendix C).

System Calibration

The acoustic system was calibrated before the study began and after returing to Seattle. Calibration assured that an echo from a target of known acoustic size passing through the axis of the acoustic beam produced a specific output voltage at the echo sounder. Once this voltage was known, an accurate (±0.5°) estimate of the actual sensitivity beamwidth (or "effective" beamwidth) for a given target strength could be determined for each transducer, based on sensitivity plots and target strengths.

Based on the calibration information, the adjustable print threshold on the chart recorder was set to the equivalent of -37 dB (for 30° off dorsal and 45° off horizontal side-aspect). This size target would be seen to the -3 dB points (1 way) of the transducer (typically 6°). This target strength corresponded to a fish approximately 44 cm total length. A detailed description of the calibration of hydroacoustic systems can be found in Albers (1965) and Urich (1975).

Migrant Detection Criteria

Within the analysis software, potential fish targets had to satisfy two criteria to be classified as fish: 1) the strength of target echoes had to exceed a predetermined threshold; and 2) the targets had to exhibit redundancy (i.e., had to be detected by consecutive pulses).

The data collection system was calibrated so that the chart recorder would mark targets with target strengths greater than -37 dB within the specified beamwidth (at the -3 dB points 1 way) of the transducer. This target strength was chosen to correspond to the smallest adult salmon sampled from 1975 to 1985 by ADF&G (female pink salmon in 1982, age 0.2, approximately 44 cm total length). The conversion was based on the target strength/size relationship discussed in Appendix E.

At least four successive ensonifications were required for a target to be classified as a fish. The vast majority of fish observed were sequentially detected more than four times. The reasons for this high redundancy were: 1) the relatively wide beamwidths of the transducers; and 2) the high pulse repetition rates (10 pings/sec); and 3) the relatively slow target velocity of the fish (Appendix Q). This redundancy criterion enhanced fish detectability in the presence of background interference, and was necessary to obtain sufficient change-in-range information to determine direction of fish travel.

Direction of Movement

Since transducers were in fixed locations at aiming angles that were not perpendicular to the direction of fish travel or river flow, it was possible to distinguish direction of movement for individual fish. As a fish passed through an ensonified volume, a succession of echoes on the echogram indicated a fish's change-in-range relative to the transducer. Since the transducer's positioning was known, this change-in-range information expressed the fish's direction of movement. Figure D2 shows typical fish movement through an ensonified volume, and a corresponding echogram trace caused by such a fish. A copy of an echogram from the Susitna River study shows actual fish traces with change-in-range (Figure D3).

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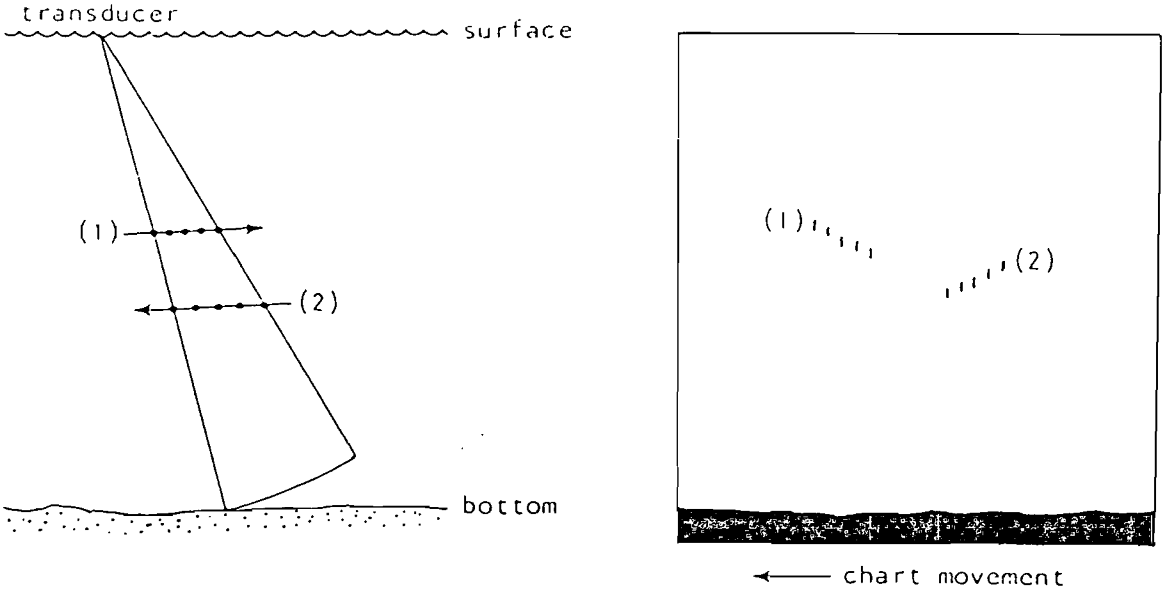

Figure D2. Fish movement through an oblique ensonified sphere resulting in change-in-range for fish traces on echogram.

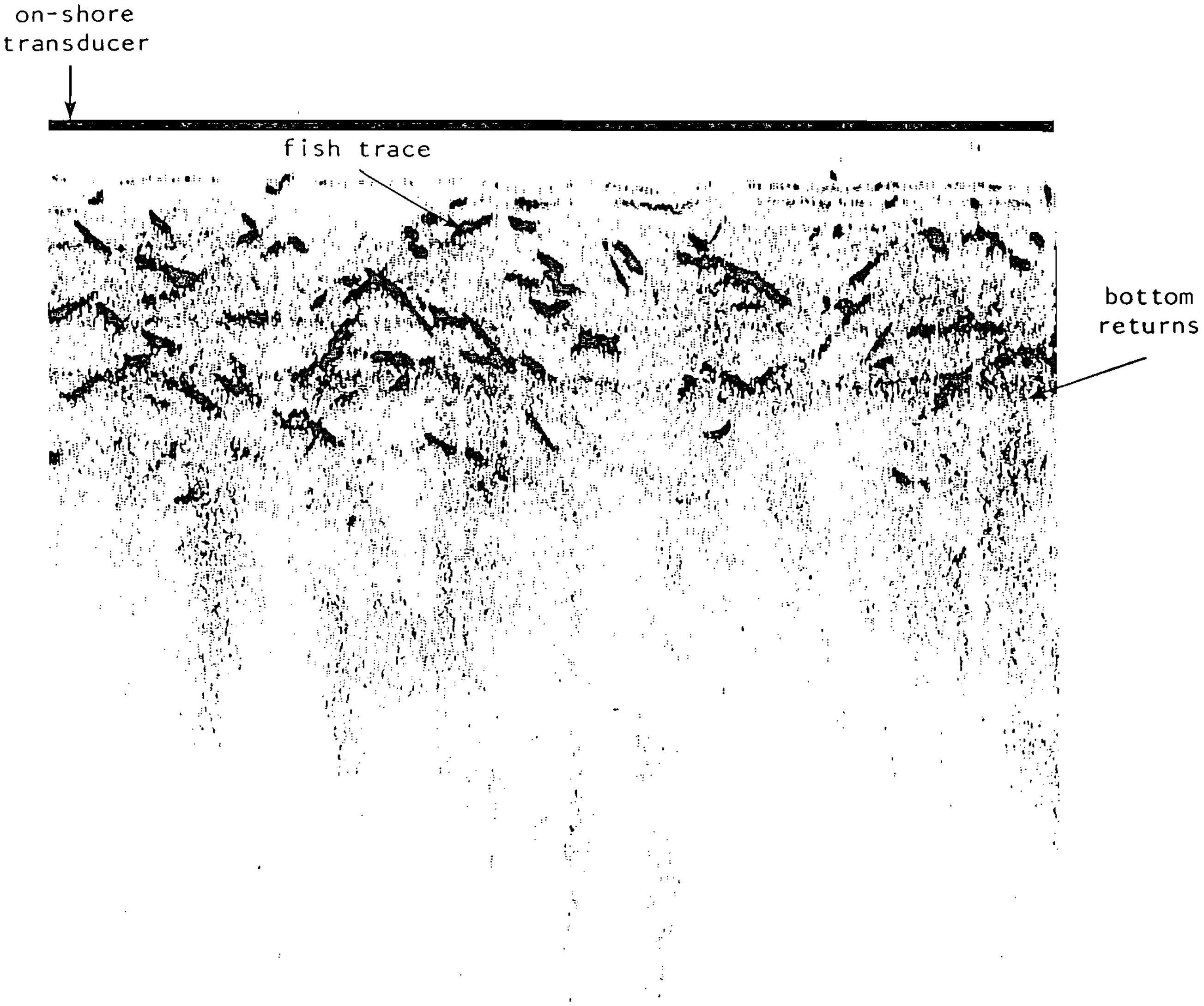

Figure D3. Echogram from side-mounted horizontal transducer, looking into the river and aimed 45° downstream. Susitna River, 1985.

APPENDIX E: Dual-beam Target Strength Measurements and Interpretation

Target Strength and Backscattering Cross Section Calculation

A fish's target strength is a measure of its echo reflecting power. The larger the target strength, the more sound energy the fish will reflect when ensonified by a transmitted pulse. Acoustic backscattering from a fish is a complex phenomenon. The intensity of an echo reflected from a fish depends on a variety of factors including acoustic frequency and the fish's size, orientation, and swim bladder characteristics. (Much of the echo energy reflected from a fish is due to the gas-filled swim bladder.) Despite the many variables that can affect a fish's reflecting properties, empirical relationships have been derived between average fish length and average target strength when measured from the dorsal aspect. (Haslett 1969, Love 1971, McCartney and Stubbs 1971).

In the last decade, techniques have been developed to measure target strengths of freely swimming fish in their natural habitats (Burczynzki and Dawson 1984; Ehrenberg 1984a, 1984b).

Target strengths are expressed on a logarthmic scale in decibels. Typical values range from -60 dB to -20 dB. The arithmetic equivalent of target strength (TS) is the backscattering cross section (σ_{bs}) in units of m^{-2} where:

$$TS = 10 \log(\sigma_{bs}) \qquad (1)$$

For simplicity, the following principles are explained in arithmetic terms.

The voltage output of a single-beam hydroacoustic system is related to a fish's backscattering cross section (and target strength) by the following equation:

$$V^2 = k \, \sigma_{bs} \, b^2(\theta,\emptyset) \qquad (2)$$

where

V = detected output of an echo sounder set at [40 log(R) + 2aR] time-varied-gain. The echo intensity (I) is proportional to V^2.

k = a constant determined from system calibration and equipment settings.

σ_{bs} = backscattering cross section of the fish. This is a measure of the fish's acoustic reflecting power in the direction of the transducer. Target strength is related to TS by equation (1).

$b(\theta,\phi)$ = beam pattern factor of the transducer. This is the ratio of the acoustic beam's transmitted intensity (I) at the angular coordinates (θ,ϕ) to that at the acoustic axis of the transducer; i.e.,

$$b(\theta,\phi) = \frac{I(\theta,\phi)}{I(0,0)}$$

$b(\theta,\phi)$ is also a measure of the transducer's receiving sensitivity. Because a single-beam echo sounder uses the same transducer for both transmitting and receiving, this quantity is squared in equation (2).

Under controlled laboratory conditions, the values of V^2, k, and $b^2(\theta,\phi)$ can be measured and equation (2) solved for σ_{bs}. However, under field conditions (either mobile or fixed-location surveys), the b^2 value cannot be measured because there is no way to determine a fish's exact coordinates (θ,ϕ) in the beam. In other words, a single-beam system cannot make direct in situ target strength measurements because the fundamental equation (2) contains two unknowns (σ_{bs}, b^2).

A dual-beam system overcomes this problem by introducing a second transducer element, and hence a second equation. The b^2 value is factored out and equations (3) and (4) are solved for σ_{bs}. Specifically, a dual-beam system transmits pulses on a narrow-beam transducer element and receives echoes on both narrow- and wide-beam elements (Figure E1). The narrow- and wide-beam squared voltage outputs are:

$$V_n^2 = k_n \sigma_{bs} b_n{}^2(\theta,\phi) \qquad (3)$$

$$V_w^2 = k_w \sigma_{bs} b_n(\theta,\phi) b_w(\theta,\phi) \qquad (4)$$

For simplicity of mathematics, assume that a dual-beam system is designed so that $b_w(\theta,\phi) = 1$ over the main lobe of the narrow beam; that is, the effective beam pattern factor of the wide beam is engineered to unity[1]. With this consideration, the ratio of

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[1] It is not necessary that a dual-beam system be designed so that $b_w = 1$ over the main lobe of the narrow beam as long as the relationship between b_n and b_w/b_n can be computed. The BioSonics Dual-Beam System operates with $b_w \neq 1$, but the principles are the same. Differences are corrected using parameters in the post-processing software.

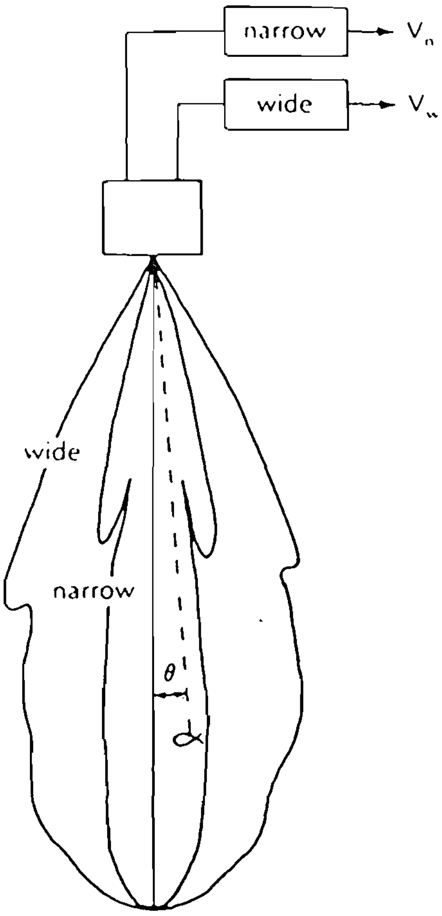


Figure E1. Beam patterns of narrow- and wide-transducer elements showing a fish within both beams.

the squared voltages (3) and (4) from the received echo signal becomes:

$$\frac{V_n^2}{V_w^2} = \frac{k_n \; b_n(\theta,\emptyset)}{k_w} \qquad (5)$$

Rearranging gives:

$$b_n(\theta,\emptyset) = \frac{V_n^2 \; k_w}{V_w^2 \; k_n} \qquad (6)$$

Inserting this $b_n(\theta,\emptyset)$ value into equation (3) and rearranging allows computation of a fish's backscattering cross section according to:

$$\sigma_{bs} = \frac{V_w^2 \; k_n}{V_n^2 \; k_w^2} \qquad (7)$$

Target strengths are then computed according to equation (1).

The BioSonics Model 181 Dual-Beam Processor operates by first selecting only single target echoes based on the single-echo detection criteria entered by the user. Maximum amplitudes of these echo signals (V_n and V_w) are then used to calculate σ_{bs} for individual fish. The σ_{bs} values are then converted to target strengths in dB, as described below.

Procedure Followed to Relate Acoustic Size (i.e., Target Strength) to Fish Length

The echo reflecting power of fish, which is commonly expressed as target strength or backscattering cross section (σ_{bs}) can provide a good estimate of the size of acoustically sampled fish. The target strength in dB and backscattering cross section in m^2 of sampled fish can be measured by the dual-beam echo sounder where

$$TS = 10 \log (\sigma_{bs})$$

The principles of a dual-beam sounder are given in Burczynski and Dawson (1984) and Ehrenberg (1984a,b).

In general, larger fish reflect more acoustic energy than smaller fish. However, acoustic backscattering from fish is a complex phenomenon and the intensity of the reflected echo depends on many factors, including the fish's orientation toward the transducer, it's size, anatomy, and swim bladder characteristics, as well as the acoustic frequency used. While much of the acoustic energy reflected from a fish is due to its gas-filled swim bladder, species without swim bladders can also be good acoustic reflectors.

Despite the many variables that can affect fish reflecting properties, Love (1971) derived an empirical relationship between average fish length and average target strength when measured from the dorsal aspect. The relationship is based on Love's laboratory measurements on 8 species of fish (anesthetized) and data from at least 16 other species as reported by other researchers. Expressed in terms of acoustic frequency, Love's formula is:

1) for individual fish ensonified from the dorsal aspect:

$$TS = 19.1 \log(L) - 0.9 \log(f) - 62.0$$

where TS = target strength (dB)

f = frequency (kHz)

L = fish length (cm)

For salmon and some other species, BioSonics has found that the Love formula applies well to <u>in situ</u> measurements of target strengths using the Dual-Beam System. In joint dual-beam acoustic and trawl surveys, the average TS of fish populations, as measured by the Dual-Beam System, correlated well with the average measured length of the trawl-caught fish. However, due to the complex nature of acoustic backscattering from fish, the spread in the target strength data is often wider than the spread in the measured fish length data (Burczynski and Johnson 1983, Burczynski et al. 1983).

Off Angle Target Strength Compensation

The relationship described above is for dorsally oriented fish. For the 1985 Susitna River study, monitoring was conducted in two orientations relative to the fish, (1) dorsally, 30° off vertical toward the anterior, and (2) horizontally, 45° off broadside toward the anterior.

To compensate for the off vertical aspect, we followed Love (1977) and Haslett (1977), and subtracted 4 dB from the dorsal target strength. The adjusted target strength was then used for target strength to length relationships and mark threshold and beam width calculations.

To adjust for the side aspect orientation, we relied on Dahl (1982) and Haslett (1977). A sample plot of target strength directivity for a 52 cm salmonid is presented in Figure E2. A corresponding smoothed plot for three salmonids (40, 52, and 61 cm) appears in Figure E3. These fish were near the size of Susitna River salmon (Table 7).

The mean difference between the dorsal and side aspect target strengths was 4 dB (Table E1). For the purposes of target strength to length relationships and mark thresholding and beam-width calculations, 4 dB was subtracted from the dorsal target strength.

Side-Aspect Target Strength at Shallower Aiming Angles

To investigate the advantages of side-aspect aiming angles shallower than 45° (i.e., more broadside to the fish), we relied on Dahl (1982) and Haslett (1977). The differences between 30° and 45°, and 15° and 45° target strengths are presented in Figure E3 and Table E2 for three fish 40-61 cm in length.

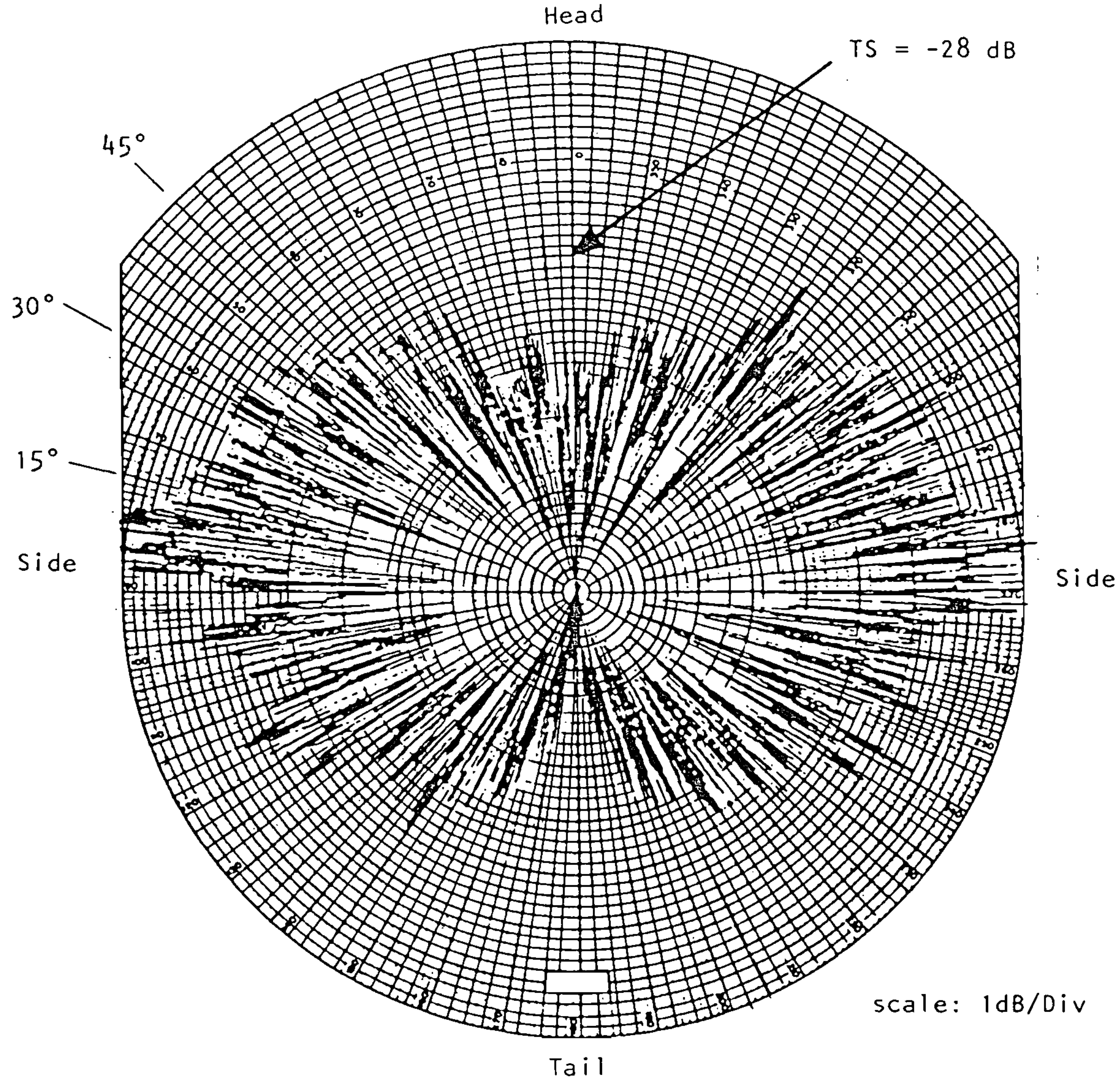
By aiming transducers at 15° more broadside to the fish (i.e., from 45° to 30° transducer aiming angle downstream), over 3 dB of signal strength gain is realized. By aiming transducers 30° more broadside (i.e.,. from 45° to 15°), over 6 dB of gain is realized. These are equivalent to approximately 50% and 100% increases in signal strength, increases which extend the signal-to-noise ratio and permit aiming transducers closer to the bottom.

Table E1. Difference between dorsal and 45° side-aspect target strength (Susitna River 1985).

Length* (cm)	Dorsal** TS (dB)	45° Side-* Aspect TS (dB)	Difference in TS (dB)
40	-33.8	-40.6	6.8
52	-31.6	-34.7	3.1
61	-30.3	-32.4	2.1
			mean = 4.0

* Dahl (1982)

** Love (1971)



0° = head aspect 90° = side aspect 180° = tail aspect

Figure E2. Polar plot (420 kHz) of fish directivity in the yaw plane for a 52 cm salmonid (Dahl 1982).

Table E2. Difference between side-aspect target strength at 15°, 30°, and 45° aiming angles, from Dahl (1982) (Susitna River 1985).

	Target Strength				
Fish Length	Aiming Angle*			Difference	
(cm)	15°	30°	45°	45° to 30°	45° to 15°
40	31.5	36.7	40.5	3.8	9.0
52	28.7	30.2	34.6	4.4	5.9
61	26.8	30.8	32.7	1.9	5.9
			mean	3.4	6.9

* 0° = broadside, 90° = head-on

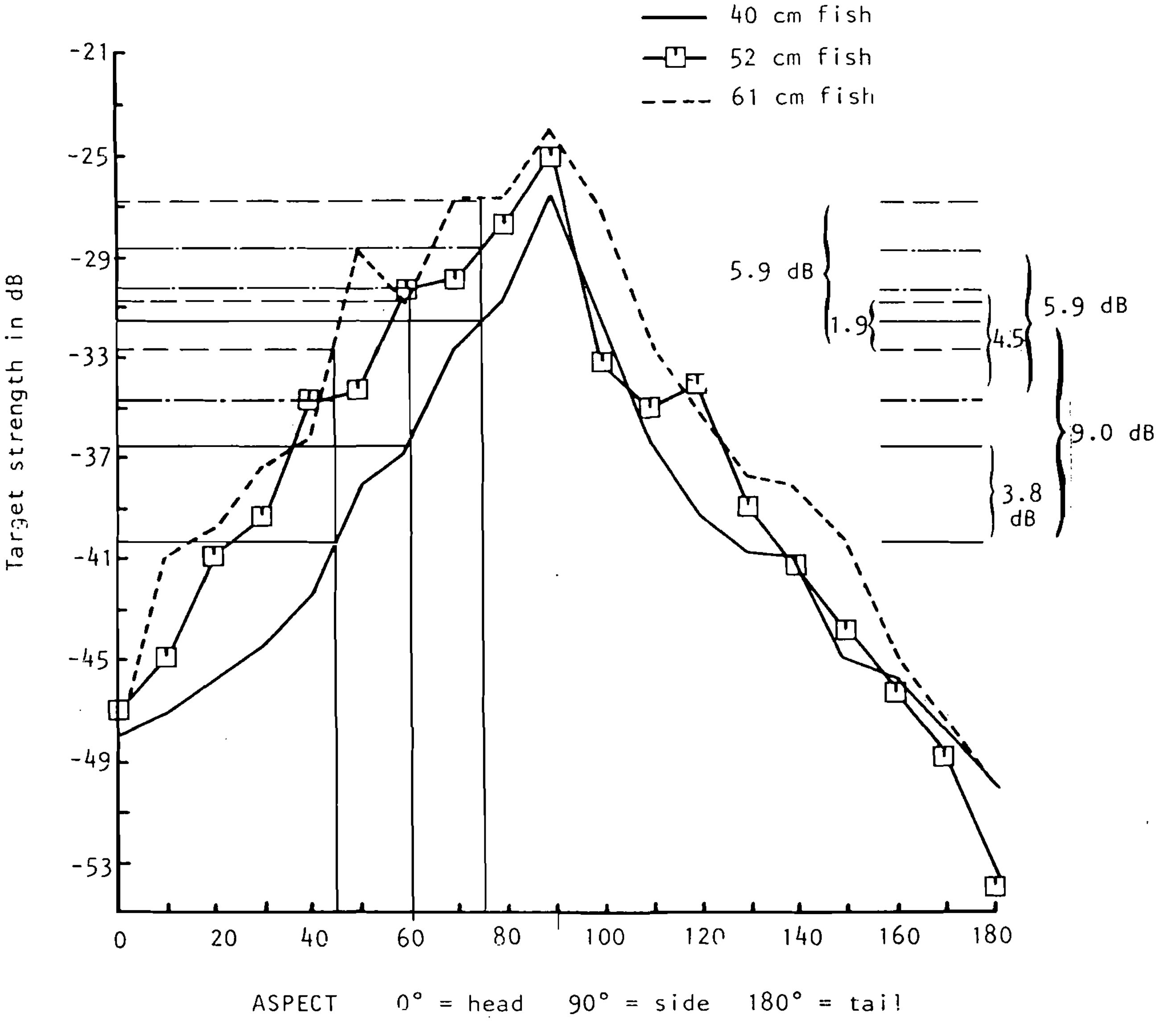


Figure E3. Plot of mean smoothed fish directivity (mean target strength in 10° increments (Dahl 1982).

APPENDIX F: Operation and Quality Control of the Automatic Fish Tracking Program, TRACKER

The dual-beam transducers were aimed at 30° (dorsal aspect) or 45° (side aspect) downstream. The dual-beam processed computer files were analyzed with custom software (TRACKER) incorporating the capability to determine change-in-range trends and target strength simultaneously. That is, target strength and direction of movement were estimated for individual fish, enabling review of acoustic size results for only upstream or downstream moving fish.

Since the fixed-aspect transducers operated at high pulse rates (10 pulses per second), each target usually had several echoes recorded during passage through the acoustic beam. Using several operator input parameters, including a window of time and range estimated by the maximum expected velocity and the maximum expected change-in-range, echoes returning from the same target were grouped together. This allowed calculation of mean target strength within the group of echoes belonging to one target. Since the transducer was aimed at an angle not perpendicular to the primary direction of fish travel, then the range upon entering the acoustic beam was not the same as the range of exit from the acoustic beam (Appendix D). Using this information, the angle of fish passage (A) through the acoustic beam was calculated according to the formula:

$$A = \text{arctangent } (R/D)$$

where: A = angle of passage through the acoustic beam with respect to the transducer axis,

R = change-in-range of target as it passes through the beam, and

D = distance traveled through the beam.

With a downstream orientation of the transducer, fish traveling upstream had a positive angle through the acoustic beam and fish traveling downstream had a negative angle. The target strength of each target was estimated, and a mean target strength for upstream traveling fish and a mean target strength for downstream traveling fish were independently calculated. A more detailed description of TRACKER and its input parameters and operation can be found in Johnston (1985).

Since TRACKER was able to distinguish a series of ensonifications for a single fish, it was in effect able to automatically detect fish. Addition post-processing software weighted raw fish detections and calculated fish passage rates for upstream and downstream moving fish, simultaneously. This procedure is described in Appendix G.

APPENDIX G: Data Reduction and Analysis

Weighting Factor

The extrapolation of individual fish detections to a representation of all fish in the cell first took into account the cone-like geometry of the acoustic beam produced by the transducer, and the geometry of the cell.

For side-aspect orientations, it was assumed that a sample representative of the entire water column was obtained. In cells 1, 4 and 9, a relatively large proportion of the water column (and cross sectional area) was sampled (typically 20-80%).

Each fish was sorted into a specific range stratum. For horizontal, side-aspect transducers each stratum corresponded to one of the sections. The raw fish counts were weighted by section by two factors. The first weighting factor was calculated as the mean water depth for the section divided by the mean beam width. This factor, in effect, expanded the raw fish detections for the proportion of the cross-sectional area of the section that was not acoustically sampled. The second weighting factor was equal to the full width of the section (20 or 100 ft) divided by the width sampled. The raw fish sampled within each section were multiplied by the appropriate weighting factors for that section. The end result was the number of weighted fish that passed through that section during the sample. Fish passage rates (quantity of fish/min) were obtained by dividing the weighted number of fish by the elapsed sample time. To obtain a passage rate for an entire cell, the rates for each section were summed.

Invariably, not all individual samples for a cell over a period would produce values for each section, due to interference, boat location, and boat movement. These missing data were extrapolated from the other samples within the same period which contained data for these sections. All subsequent data analyses were performed on these estimates of fish passage rates.

Horizontal Distributions

Once total passage rates were calculated by direction for each cell across the river, the horizontal distribution across the river was calculated as the relative percentage individual cells represented of the grand total passage rate for the whole river. Horizontal distributions were calculated separately for upstream and downstream moving fish.

Horizontal distributions were calculated for each shift. Horizontal distributions for each of the six periods were calculated in two manners. To obtain measures of variability around horizontal distributions by period, mean distributions for a given period were calculated from individual distributions by shift. That is, each shift represented a replicate. These distributions are denoted as "mean horizontal distributions." In the second method, the fish passage by shift (expanded to 12 h) was totaled by cell for a given period. Horizontal distributions for that period were then calculated from the total passage in individual cells during that period. These distributions are denoted "horizontal distributions weighted for abundance." This latter method was adopted when it became clear that distributions were most variable when passage rates were lower (Appendix I).

Vertical Distribution

Vertical distributions in cell 9 were calculated as the proportion by stratum of the total raw fish detections for both strata. Vertical distributions were calculated separately for upstream- and downstream-moving fish.

Fish Target Speed

Fish target speed is the actual speed of the fish relative to a stationary point as measured acoustically. Thus, fish target speeds equal swimming speeds only when there is no current. That is, the timing speed of a fish moving downstream would be its target speed minus the water velocity.

Once the mean target strength was known, it was used with the appropriate beam patterns factor to estimate average beamwidth. The mean chord length of fish traveling through the ensonified volume was calculated as a function of this average beamwidth and range.

Fish target velocities were calculated from the estimated mean time spent in the beam for a high number of fish (for our purposes we sorted for period and direction). This mean was then divided into the estimated mean chord length for the fish; this resulted in one mean velocity for the data set.

APPENDIX H: Summary by Period of Typical Data and Weighting Parameters

The output from TRACKER formed the data base from which all data analyses were completed. This complete data base is contained on IBM-format computer diskettes (5-1/4 inch (13.3 cm) floppy diskettes) held at BioSonics, Inc. offices in Seattle, and ADF&G offices in Soldotna, Alaska.

A sample of a TRACKER output summary file appears in Table H1. For files that were created manually, dummy values appear in all but items 1 and 6. This occurred in approximately 3% of the files.

A sample of the data and weighting parameter summary appears in Table H2. In the tables, the sample start data and time is followed by the cell number, transducer orientation, and shift number. All results are presented for upstream and downstream moving fish separately. The data file name keys results to the TRACKER data base file. The results are presented by stratum (i.e., by section for side-aspect transducers). The five columns within each stratum heading present each step of the analysis from number of raw fish detections to final estimates of fish passage rates.

The summaries are presented for only samples in which fish were detected.

Table H1. Format of summary file output from TRACKER.

```
 Fish   Ping   Target    Mean Nar. Num.  Mean    Target  Time    Fish
Number Number Strength   Pulse W. Pings  Range   Angle   in Beam Velocity
------ ------ --------   -------- -----  ------  ------  ------- --------

     1  7182.  -37.401    .5002     4     5.650   -3.20   1.2000  1.475
     2  8265.  -35.047    .4502     4     5.700   -3.17    .5000  3.572
     3  8549.  -34.716    .4502     4    17.500   -1.03   1.8000  3.042
     4  9439.  -39.698    .4836     4    10.925  -10.64   1.9000  1.830
     5  9732.  -38.002    .4252     8     7.650   -4.72   1.4000  1.715
     6 10004.  -34.925    .4269     5    18.675    8.18   2.4000  2.460
     7 14001.  -34.970    .4502     4    18.400   -3.93   1.5000  3.847
     8 18614.  -31.703    .4335     4    12.475   12.14   1.5000  2.662
     9 18632.  -33.154    .4669     6    10.475   23.60   2.3000  1.555
    10 18656.  -33.059    .3835     4     8.550  -10.46   1.2000  2.267
    11 18668.  -33.121    .4836     4     7.625   21.47   1.8000  1.424
    12 18681.  -32.785    .4502    20     7.775   14.78   8.4000   .300
    13 18738.  -32.582    .4669     5     7.525  -31.31   2.6000  1.060
    14 18855.  -38.598    .4002     4     8.350   29.56   2.0000  1.502
    15 19008.  -38.164    .4169     4     5.200   40.36   1.4000  1.525
```

Table H2.

Date, time, sampling location, sampling shift #, direction of fish movement, data filename, raw fish, weighting factor, weighted fish, weighted fish/minute, and extrapolated weighted fish/minute by six range strata. Sampling sequences performed on the Susitna River, July 22-25, 1985.

						Strata 1					Strata 2					Strata 3					Strata 4					Strata 5					Strata 6					Totals			
Month/date	Start time	Sample cell, transducer orientation	Sampling shift #	Direction of movement	Data filename	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighting factor	Weighted fish	Weighted fish/minute	Extrapolated weighted fish/minute	Raw fish	Weighted fish	Weighted fish/minute	Extrapolated weighte
7 /22	10	4 SIDE	15	UP	15E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.0	0.000	0.
7 /22	10	4 SIDE	15	DN	15E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	3	2.03	6.1	0.133	0.133	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	3	6.1	0.133	0.
7 /21	2250	9 ON SIDE	15	DN	15J2	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	1.80	1.8	0.060	0.060	0	0.00	0.0	0.000	0.002	0	0.00	0.0	0.000	0.000	1	1.8	0.060	0.
7 /21	2250	9 ON SIDE	15	UP	15J2	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.0	0.000	0.
7 /22	1432	1 ON SIDE	16	UP	16A1	0	0.00	0.0	0.000	0.000	1	2.80	2.8	0.090	0.090	0	0.00	0.0	0.000	0.000	7	1.32	9.2	0.297	0.297	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	8	12.0	0.387	0.
7 /22	1432	1 ON SIDE	16	DN	16A1	0	0.00	0.0	0.000	0.000	2	2.80	5.6	0.181	0.181	0	0.00	0.0	0.000	0.000	2	1.32	2.6	0.084	0.084	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	4	8.2	0.265	0.
7 /22	1346	9 ON SIDE	16	UP	16J2	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.0	0.000	0.
7 /22	1346	9 ON SIDE	16	DN	16J2	0	0.00	0.0	0.000	0.121	2	2.80	5.6	0.215	0.215	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	2	5.6	0.215	0.
7 /23	112	1 ON SIDE	17	DN	17A1	0	0.00	0.0	0.000	0.000	2	2.70	5.4	0.180	0.180	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.021	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	2	5.4	0.180	0.
7 /23	112	1 ON SIDE	17	UP	17A1	0	0.00	0.0	0.000	0.000	1	2.70	2.7	0.090	0.090	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.056	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	2.7	0.090	0.
7 /22	2355	9 ON SIDE	17	DN	17J1	0	0.00	0.0	0.000	0.160	4	2.20	8.8	0.284	0.284	6	1.00	6.0	0.194	0.194	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.012	0	0.00	0.0	0.000	0.000	10	14.8	0.477	0.
7 /22	2355	9 ON SIDE	17	UP	17J1	0	0.00	0.0	0.000	0.053	2	2.20	4.4	0.142	0.142	3	1.00	3.0	0.097	0.097	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.019	0	0.00	0.0	0.000	0.000	5	7.4	0.239	0.
7 /23	1312	1 ON SIDE	18	DN	18A1	0	0.00	0.0	0.000	0.000	5	2.50	12.5	0.417	0.417	1	1.70	1.7	0.057	0.057	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	6	14.2	0.473	0.
7 /23	1312	1 ON SIDE	18	UP	18A1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.0	0.000	0.
7 /23	1408	4 SIDE	18	DN	18E1	0	0.00	0.0	0.000	0.222	2	5.10	10.2	0.222	0.222	3	1.82	5.5	0.120	0.120	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	5	15.7	0.341	0.
7 /23	1408	4 SIDE	18	UP	18E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	2	1.82	3.6	0.078	0.078	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	2	3.6	0.078	0.
7 /23	1119	9 ON SIDE	18	DN	18J1	0	0.00	0.0	0.000	0.000	13	1.36	17.7	0.590	0.590	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.264	0	0.00	0.0	0.000	0.022	0	0.00	0.0	0.000	0.000	13	17.7	0.590	0.
7 /23	1119	9 ON SIDE	18	UP	18J1	0	0.00	0.0	0.000	0.000	1	1.36	1.4	0.047	0.047	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.006	0	0.00	0.0	0.000	0.004	0	0.00	0.0	0.000	0.000	1	1.4	0.047	0.
7 /24	43	1 ON SIDE	19	DN	19A3	0	0.00	0.0	0.000	0.072	2	4.75	9.5	0.317	0.317	3	2.19	6.6	0.220	0.220	8	1.57	12.6	0.420	0.420	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	13	28.7	0.957	1.
7 /24	43	1 ON SIDE	19	UP	19A3	0	0.00	0.0	0.000	0.307	2	4.75	9.5	0.317	0.317	7	2.19	15.3	0.510	0.510	10	1.57	15.7	0.523	0.523	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	19	40.5	1.350	1.
7 /24	220	4 SIDE	19	DN	19E1	0	0.00	0.0	0.000	0.096	1	4.40	4.4	0.096	0.096	9	1.57	14.1	0.307	0.307	3	1.03	3.1	0.067	0.067	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	13	21.6	0.470	0.
7 /24	220	4 SIDE	19	UP	19E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	1.57	1.6	0.035	0.035	2	1.03	2.1	0.046	0.046	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	3	3.7	0.080	0.
7 /23	2317	9 ON SIDE	19	UP	19J1	9	5.72	51.5	1.717	1.717	25	1.00	25.0	0.833	0.833	0	0.00	0.0	0.000	0.412	0	0.00	0.0	0.000	0.151	0	0.00	0.0	0.000	0.108	0	0.00	0.0	0.000	0.000	34	76.5	2.550	3.
7 /23	2317	9 ON SIDE	19	DN	19J1	15	5.72	85.8	2.860	2.860	41	1.00	41.0	1.367	1.367	0	0.00	0.0	0.000	0.637	0	0.00	0.0	0.000	0.896	0	0.00	0.0	0.000	0.074	0	0.00	0.0	0.000	0.000	56	126.8	4.227	5.
7 /24	1103	1 ON SIDE	20	UP	20A1	1	5.40	5.4	0.159	0.159	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.100	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	5.4	0.159	0.
7 /24	1103	1 ON SIDE	20	DN	20A1	1	5.40	5.4	0.159	0.159	1	2.20	2.2	0.065	0.065	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.027	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	2	7.6	0.224	0.
7 /24	1225	4 SIDE	20	DN	20E1	0	0.00	0.0	0.000	0.098	1	4.40	4.4	0.098	0.098	1	1.60	1.6	0.036	0.036	4	1.03	4.1	0.091	0.091	2	1.00	2.0	0.044	0.044	3	99.50	298.5	6.633	0.000	11	310.6	6.902	0.
7 /24	1225	4 SIDE	20	UP	20E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	1.60	1.6	0.036	0.036	2	1.03	2.1	0.047	0.047	3	1.00	3.0	0.067	0.067	1	99.50	99.5	2.211	0.000	7	106.2	2.360	0.
7 /24	1010	9 ON SIDE	20	DN	20J1	9	33.33	300.0	10.000	10.000	388	1.13	438.4	14.613	14.613	157	1.00	157.0	5.233	5.233	20	1.00	20.0	0.667	0.667	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	574	915.4	30.513	30.
7 /24	1010	9 ON SIDE	20	UP	20J1	2	33.33	66.7	2.223	2.223	348	1.13	393.2	13.107	13.107	161	1.00	161.0	5.367	5.367	6	1.00	6.0	0.200	0.200	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	517	626.9	20.897	20.
7 /25	551	1 ON SIDE	21	DN	21A1	0	0.00	0.0	0.000	0.000	2	2.48	5.0	0.167	0.167	2	1.55	3.1	0.103	0.103	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	4	8.1	0.270	0.
7 /25	551	1 ON SIDE	21	UP	21A1	0	0.00	0.0	0.000	0.000	3	2.48	7.4	0.247	0.247	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	3	7.4	0.247	0.
7 /25	630	4 SIDE	21	UP	21E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	1	1.00	1.0	0.020	0.020	1	1.00	1.0	0.020	0.020	0	0.00	0.0	0.000	0.000	2	2.0	0.040	0.
7 /25	630	4 SIDE	21	DN	21E1	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	4	1.48	5.9	0.118	0.118	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	4	5.9	0.118	0.
7 /25	435	9 ON SIDE	21	DN	21J1	0	0.00	0.0	0.000	0.904	18	2.69	48.4	1.613	1.613	128	1.00	128.0	4.267	4.267	52	1.00	52.0	1.733	1.733	25	1.00	25.0	0.833	0.833	0	0.00	0.0	0.000	0.000	223	253.4	8.447	9.
7 /25	435	9 ON SIDE	21	UP	21J1	0	0.00	0.0	0.000	0.504	15	2.69	40.3	1.343	1.343	95	1.00	95.0	3.167	3.167	62	1.00	62.0	2.067	2.067	33	1.00	33.0	1.100	1.100	0	0.00	0.0	0.000	0.000	205	230.3	7.677	8.
7 /25	1805	1 ON SIDE	22	UP	22A1	1	6.60	6.6	0.143	0.143	4	2.25	9.0	0.196	0.196	1	3.00	3.0	0.065	0.065	0	0.00	0.0	0.000	0.163	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	6	18.6	0.404	0.
7 /25	1805	1 ON SIDE	22	DN	22A1	0	0.00	0.0	0.000	0.000	7	2.25	15.8	0.343	0.344	1	3.00	3.0	0.065	0.065	0	0.00	0.0	0.000	0.048	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	8	18.8	0.409	0.
7 /25	1300	4 SIDE	22	DN	22E1	0	0.00	0.0	0.000	0.276	3	4.13	12.4	0.276	0.276	15	1.47	22.0	0.489	0.489	13	1.00	13.0	0.289	0.289	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	31	47.4	1.053	1.
7 /25	1300	4 SIDE	22	UP	22E1	0	0.00	0.0	0.000	0.000	3	4.13	12.4	0.276	0.276	8	1.47	11.8	0.262	0.276	2	1.00	2.0	0.044	0.262	0	0.00	0.0	0.000	0.044	0	0.00	0.0	0.000	0.000	13	26.2	0.582	0.
7 /25	1933	9 ON SIDE	22	DN	22J4	0	0.00	0.0	0.000	0.072	3	1.27	3.8	0.127	0.127	4	1.00	4.0	0.133	0.133	1	11.40	11.4	0.380	0.380	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	8	19.2	0.640	0.
7 /25	1933	9 ON SIDE	22	UP	22J4	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.00	0.0	0.000	0.000	0	0.0	0.000	0.
					Sums:	38		521.4	17.261	20.146	902	77.650		37.855	37.856	616		660.5	21.089	22.151	196		220.7	7.0347	8.9846	64		64	2.0644	2.3498	4		398	8.8444	0	1820	3023.	94.149	91

APPENDIX I: Statistical Analysis of Variability in Horizontal Distributions Between Shifts

For upstream moving fish, the data were blocked into two groups and tested, by cell, to see if the lower passage group had a statistically higher variance than the higher passage group. In Test A, the groups contained horizontal distributions for shifts where less than 1% of the season total fish passage occurred, and distrbutions for shifts where more than 1% of the fish passage occurred. This level of passage was chosen because it split the 35 shifts into two blocks of nearly equal sample size. The relative percentages by shift were transformed (arcsin) by cell, and means and variances calculated (Table I1). We found the variances of the low passage group to be significantly higher than the variances of high passage group at $p<0.05$ for cells 1 and 9.

In Test B, we also examined groups of distributions with lower and higher passages (<0.8% and >2.0%), and found the low passage variances to be significantly higher than the variances of the high passage group at $p<0.005$ for all three cells.

These results indicate that there is more variability in distributions with low passage rates. Also, it is most unlikely that the pairs of variances represent the same parametric variance, i.e., are from the same homogenous population (statistically speaking). As such it would be unwise to treat samples from both low and high passage blocks as replicates from the same statistical population, and perform parametric statistical manipulations on them.

We should emphasize that even had the tests shown no significant difference between the variances of the two blocks, we would not have recommended treating the by-shift horizontal distributions as replicates, for the reasons discussed in the text.

Table I1. Summary of test for variance differences between horizontal distributions of low and high passage rates (Susitna River 1985).

Passage Level	N	Parameter	Transformed Parameters by Cell*		
			Cell 1	Cell 4	Cell 9
			Test A		
<1.0%	17	Mean	27.63	18.39	47.90
		Variance	648.87	328.84	645.16
>1.0%	18	Mean	13.07	13.78	68.50
		Variance	60.30	163.15	133.15
		F test	10.76	2.02	4.85
		p (to reject H_o)	<0.001	<0.10	<0.005**
			Test B		
<0.8%	13	Mean	27.52	13.87	51.84
		Variance	763.05	287.35	602.53
>2.0%	13	Mean	12.66	9.16	72.47
		Variance	81.04	52.54	69.46
		F test	9.42	5.47	8.67
		p (to reject H_o)	<0.001	<0.005	<0.001**

* Arcsin transformation.

** H_o: $var_h = var_l$
H_a: $var_h > var_l$

Appendix J: Run Timing: Relative Percentage of Season Total Fish Passage by 12-h Periods.

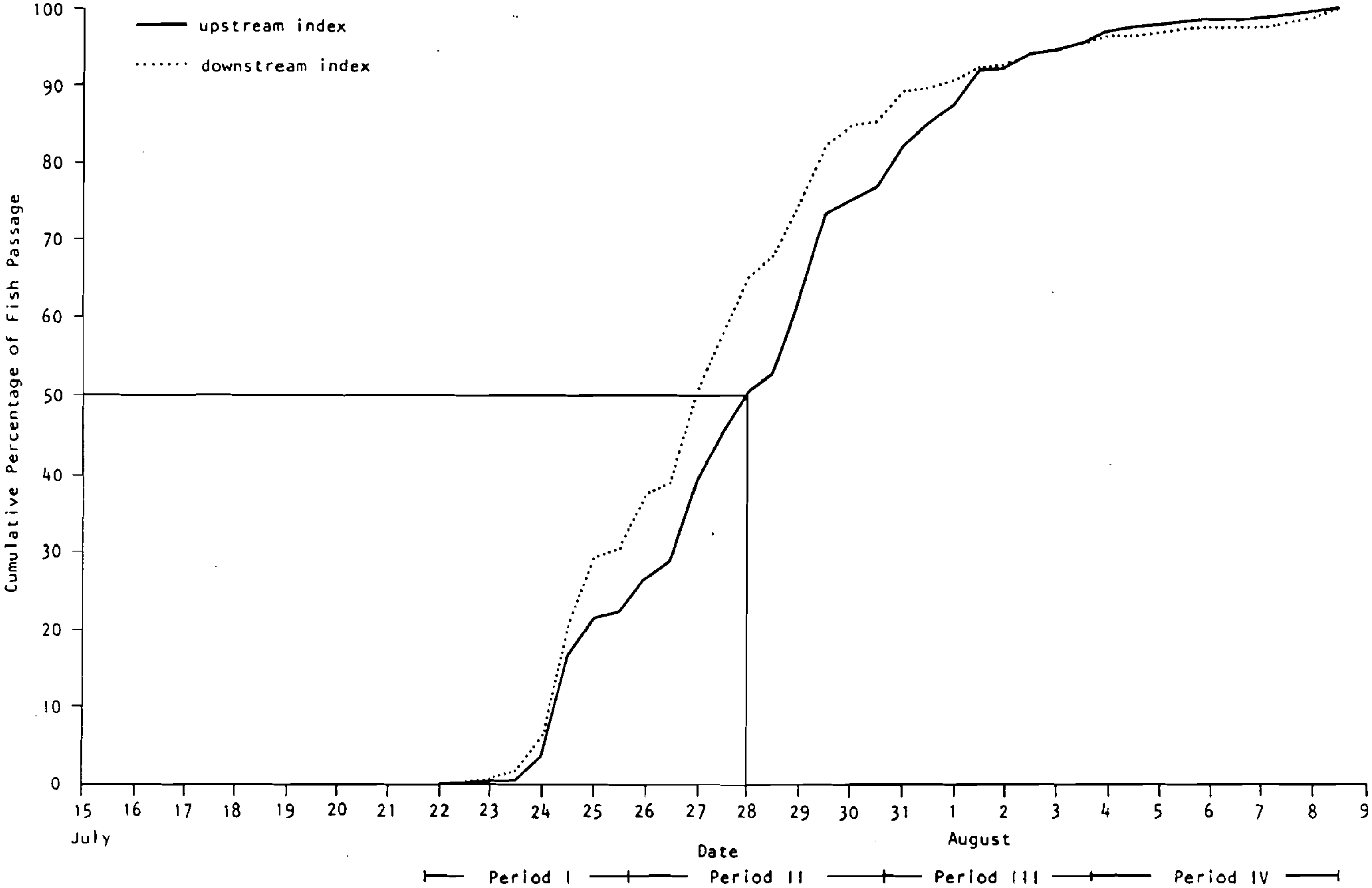


Figure J1. Run timing: cumulative percentage of 12 h season total fish passage, by direction of movement. Susitna River, 1985.

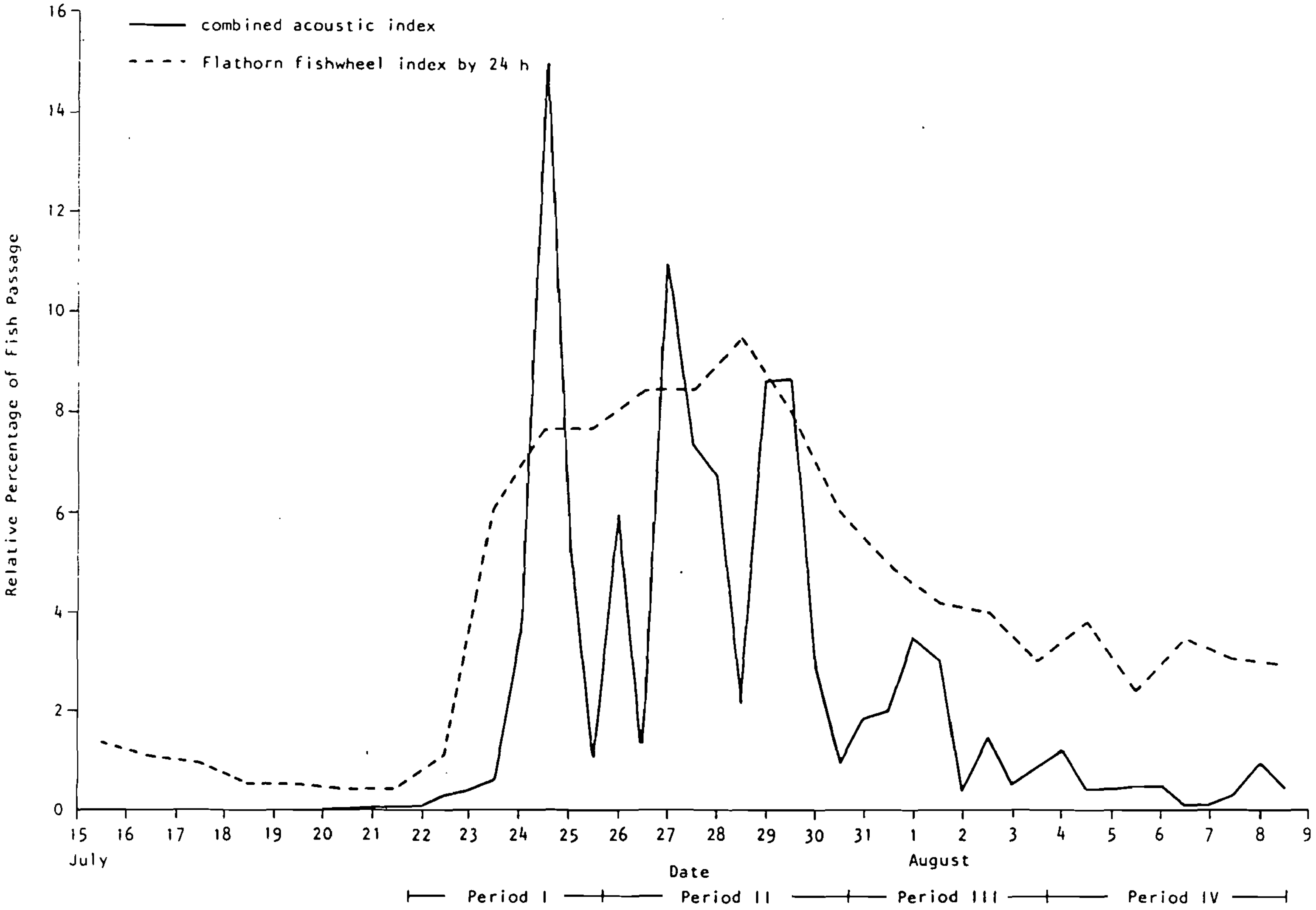


Figure J2. Run timing: relative percentage of 12 h season total fish passage, upstream and downstream moving fish combined. Susitna River, 1985.

Table J1. Run timing of fish passage by 12-h period for downstream-moving fish (Susitna River 1985).

	Date	Shift Number	Relative Percentage	Cumulative Percentage
July	15	1	0	0
		2	0	0
	16	3	0	0
		4	0	0
	17	5	0	0
		6	0	0
	18	7	0	0
		8	0	0
	19	9	0	0
		10	0	0
	20	11	0	0
		12	0	0
	21	13	0.1	0.1
		14	0.1	0.2
	22	15	0.1	0.3
		16	0.3	0.6
	23	17	0.5	1.1
		18	1.1	2.2
	24	19	4.1	6.3
		20	17.2	23.5
	25	21	5.4	28.9
		22	1.4	30.3
	26	23	6.9	37.2
		24	1.0	38.2
	27	25	12.1	50.3
		26	1.8	58.1
	28	27	7.4	65.5
		28	2.4	67.9
	29	29	7.7	75.6
		30	7.0	82.6
	30	31	3.2	85.8
		32	1.0	86.8
	31	33	1.6	88.4
		34	1.1	90.5

Table J1, cont.

	Date	Shift Number	Relative Percentage	Cumulative Percentage
August	1	35	1.4	90.9
		36	1.8	92.7
	2	37	0.3	93.0
		38	1.0	94.0
	3	39	0.6	94.6
		40	0.7	95.3
	4	41	0.8	96.1
		42	0.2	96.3
	5	43	0.4	96.7
		44	0.5	97.2
	6	45	0.6	97.8
		46	0.1	97.9
	7	47	0.1	98.0
		48	0.5	98.5
	8	49	0.9	99.4
		50	0.6	100.0

Table J2. Run timing of fish passage by 12-h period for upstream- and downstream-moving fish combined (Susitna River 1985).

	Date	Shift Number	Relative Percentage	Cumulative Percentage
July	15	1	0	0
		2	0	0
	16	3	0	0
		4	0	0
	17	5	0	0
		6	0	0
	18	7	0	0
		8	0	0
	19	9	0	0
		10	0	0
	20	11	0	0
		12	0.1	0.1
	21	13	0.1	0.2
		14	0.1	0.3
	22	15	0.1	0.4
		16	0.3	0.7
	23	17	0.4	1.1
		18	0.6	1.7
	24	19	3.6	5.3
		20	15.0	20.3
	25	21	5.3	25.6
		22	1.1	26.7
	26	23	5.9	32.6
		24	1.3	33.9
	27	25	10.9	44.8
		26	7.2	52.0
	28	27	6.6	58.6
		28	2.2	60.8
	29	29	8.6	69.4
		30	8.6	78.0
	30	31	2.9	80.9
		32	1.0	81.9
	31	33	1.8	83.7
		34	2.0	85.7

Table J2, cont.

	Date	Shift Number	Relative Percentage	Cumulative Percentage
August	1	35	3.5	89.2
		36	3.1	92.3
	2	37	0.3	92.6
		38	1.4	94.0
	3	39	0.5	94.5
		40	0.8	95.3
	4	41	1.2	96.5
		42	0.4	96.9
	5	43	0.4	97.3
		44	0.5	97.8
	6	45	0.5	98.3
		46	0.1	98.4
	7	47	0.1	98.5
		48	0.3	98.8
	8	49	0.9	99.7
		50	0.4	100.1

APPENDIX K: Flathorn Station Fishwheel Catch Results

Table K1. Relative run timing from the Flathorn Station fishwheel catch data (Kenneth Tarbox, ADFG, personal communication) (Susitna River 1985).

Date	Total Catch	Relative Percent	Cumulative Percent
July 15	196	1.3	1.3
16	173	1.1	2.4
17	158	1.0	3.4
18	85	0.5	3.9
19	75	0.5	4.4
20	60	0.4	4.8
21	68	0.4	5.2
22	193	1.2	6.4
23	951	6.1	12.5
24	1202	7.7	20.2
25	1197	7.7	27.9
26	1302	8.4	36.3
27	1300	8.4	44.7
28	1478	9.5	54.2
29	1242	8.0	62.2
30	931	6.0	68.2
31	766	4.9	73.1
August 1	647	4.2	77.3
2	616	4.0	81.3
3	461	3.0	84.3
4	588	3.8	88.1
5	372	2.4	90.5
6	551	3.5	94.0
7	486	3.1	97.1
8	444	2.9	100.0
Total	15542	100.0	

Table K2. Flathorn Station fishwheel catches during the period of hydroacoustic sampling (Kenneth Tarbox, ADFG, personal communication)(Susitna River 1985).

		Numbers of Fish Sampled				
Period	Species	Fishwheel* East Right	Fishwheel East Left	Fishwheel West Right	Fishwheel** West Left	Total
	sockeye	33	67	21	108	229
0	pink	56	164	39	143	402
	chum	1	1	0	1	3
7/15-	coho	12	23	6	17	58
21	chinook	8	12	3	8	31
	total	110	267	69	277	723
	sockeye	118	633	460	974	2185
I	pink	33	304	159	195	691
	chum	12	84	37	28	161
7/22-	coho	9	157	124	144	434
25	chinook	0	4	0	4	8
	total	172	1182	780	1345	3479
	sockeye	228	1115	340	1741	3424
II	pink	195	644	143	555	1537
	chum	109	199	23	62	393
7/26-	coho	75	337	104	304	820
30	chinook	0	1	2	1	4
	total	607	2296	612	2663	6178
	sockeye	178	156	76	280	690
III	pink	396	192	70	287	945
	chum	195	56	15	11	277
7/31-	coho	197	130	44	140	511
8/3	chinook	3	2	1	0	6
	total	969	536	206	718	2429
	sockeye	217	185	50	335	787
IV	pink	429	345	56	299	1129
	chum	166	46	3	7	222
8/4-8	coho	57	45	10	75	187
	chinook	4	0	0	3	7
	total	873	621	119	719	2332
7/15-8/8	Total	2731	4902	1786	5722	15141
	Percentage	18.0	32.4	11.8	37.8	100.0

* Located on the east shore.
** Located on the west shore.

APPENDIX L: Horizontal Distributions by Shift

Table L1. Summary of horizontal distributions of upstream migrating adult salmon, by shift (Susitna River 1985).

Date	Shift Number	Relative Percentage across River by Cell 1	2	3	4	5	6	7	8	9	Total
July 22	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
23	17	31.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.1	100.0
	18	0.0	0.0	0.0	58.0	0.0	0.0	0.0	0.0	42.0	100.0
24	19	33.5	0.0	0.0	1.6	0.0	0.0	0.0	0.0	64.9	100.0
	20	1.2	0.0	0.0	0.7	0.0	0.0	0.0	0.0	98.1	100.0
25	21	2.9	0.0	0.0	0.4	0.0	0.0	0.0	0.0	96.7	100.0
	22	39.8	0.0	0.0	60.2	0.0	0.0	0.0	0.0	0.0	100.0
26	23	2.4	0.0	0.0	3.6	0.0	0.0	0.0	0.0	94.0	100.0
	24	7.7	0.0	0.0	43.3	0.0	0.0	0.0	0.0	49.0	100.0
27	25	0.6	0.0	0.0	1.9	0.0	0.0	0.0	0.0	97.5	100.0
	26	13.1	0.0	0.0	1.2	0.0	0.0	0.0	0.0	85.7	100.0
28	27	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.3	100.0
	28	4.3	0.0	0.0	12.7	0.0	0.0	0.0	0.0	83.0	100.0
29	29	2.4	0.0	0.0	0.7	0.0	0.0	0.0	0.0	96.9	100.0
	30	3.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	91.7	100.0
30	31	0.0	0.0	0.0	16.1	0.0	0.0	0.0	0.0	83.9	100.0
	32	0.0	0.0	0.0	33.7	0.0	0.0	0.0	0.0	66.3	100.0
31	33	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.5	100.0
	34	12.8	0.0	0.0	2.7	0.0	0.0	0.0	0.0	84.5	100.0
1	35	5.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	94.4	100.0
	36	4.1	0.0	0.0	15.8	0.0	0.0	0.0	0.0	80.1	100.0
2	37	58.4	0.0	0.0	13.7	0.0	0.0	0.0	0.0	27.9	100.0
	38	10.3	0.0	0.0	19.4	0.0	0.0	0.0	0.0	70.3	100.0
3	39	62.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.3	100.0
	40	51.4	0.0	0.0	27.9	0.0	0.0	0.0	0.0	20.7	100.0
4	41	3.2	0.0	0.0	42.5	0.0	0.0	0.0	0.0	54.3	100.0
	42	27.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	73.0	100.0
5	43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
	44	22.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.1	100.0
6	45	20.3	0.0	0.0	15.9	0.0	0.0	0.0	0.0	63.8	100.0
	46	49.1	0.0	0.0	26.2	0.0	0.0	0.0	0.0	24.7	100.0
7	47	0.0	0.0	0.0	26.0	0.0	0.0	0.0	0.0	74.0	100.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
8	49	20.9	0.0	0.0	6.0	0.0	0.0	0.0	0.0	73.1	100.0
	50	0.0	0.0	0.0	16.4	0.0	0.0	0.0	0.0	83.6	100.0

Table L2. Summary of horizontal distributions of downstream migrating adult salmon, by shift (Susitna River 1985).

	Shift	Relative Percentage across River by Cell									
Date	Number	1	2	3	4	5	6	7	8	9	Total
July 22	15	0.0	0.0	0.0	68.1	0.0	0.0	0.0	0.0	31.9	100.0
	16	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.0	100.0
23	17	23.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.3	100.0
	18	24.7	0.0	0.0	29.4	0.0	0.0	0.0	0.0	45.9	100.0
24	19	13.9	0.0	0.0	7.6	0.0	0.0	0.0	0.0	78.5	100.0
	20	0.8	0.0	0.0	1.2	0.0	0.0	0.0	0.0	98.0	100.0
25	21	2.8	0.0	0.0	1.2	0.0	0.0	0.0	0.0	96.0	100.0
	22	18.3	0.0	0.0	53.2	0.0	0.0	0.0	0.0	28.5	100.0
26	23	7.6	0.0	0.0	0.7	0.0	0.0	0.0	0.0	91.7	100.0
	24	26.1	0.0	0.0	28.6	0.0	0.0	0.0	0.0	45.3	100.0
27	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
	26	5.8	0.0	0.0	0.6	0.0	0.0	0.0	0.0	93.6	100.0
28	27	2.5	0.0	0.0	3.3	0.0	0.0	0.0	0.0	94.2	100.0
	28	11.2	0.0	0.0	13.3	0.0	0.0	0.0	0.0	75.5	100.0
29	29	3.6	0.0	0.0	2.0	0.0	0.0	0.0	0.0	94.4	100.0
	30	5.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	88.2	100.0
30	31	2.9	0.0	0.0	6.6	0.0	0.0	0.0	0.0	90.5	100.0
	32	21.0	0.0	0.0	21.6	0.0	0.0	0.0	0.0	57.4	100.0
31	33	5.2	0.0	0.0	6.1	0.0	0.0	0.0	0.0	88.7	100.0
	34	34.4	0.0	0.0	8.7	0.0	0.0	0.0	0.0	56.9	100.0
1	35	11.8	0.0	0.0	2.6	0.0	0.0	0.0	0.0	85.6	100.0
	36	7.1	0.0	0.0	3.8	0.0	0.0	0.0	0.0	89.1	100.0
2	37	12.3	0.0	0.0	32.9	0.0	0.0	0.0	0.0	54.8	100.0
	38	54.7	0.0	0.0	15.4	0.0	0.0	0.0	0.0	29.9	100.0
3	39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
	40	75.2	0.0	0.0	7.3	0.0	0.0	0.0	0.0	17.5	100.0
4	41	5.0	0.0	0.0	34.3	0.0	0.0	0.0	0.0	60.7	100.0
	42	49.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.8	100.0
5	43	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87.8	100.0
	44	25.5	0.0	0.0	14.7	0.0	0.0	0.0	0.0	59.8	100.0
6	45	21.2	0.0	0.0	7.4	0.0	0.0	0.0	0.0	71.4	100.0
	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
7	47	0.0	0.0	0.0	52.4	0.0	0.0	0.0	0.0	47.6	100.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
8	49	19.7	0.0	0.0	11.2	0.0	0.0	0.0	0.0	69.1	100.0
	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0

Table L3. Summary of mean horizontal distributions of upstream adult salmon within the near-shore cells by shift, (Susitna River 1985).

		Relative Percentage of Fish														
	Shift	Cell 1							Cell 9							
Date	Number	1	2	3	4	5	6	Sum	1	2	3	4	5	6	Sum
July															
22	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	16	0.0	23.3	0.0	76.7	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	17	0.0	19.7	0.0	12.3	0.0	0.0	32.0	11.6	31.1	21.2	0.0	4.2	0.0	68.1
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.6	0.0	4.4	3.0	0.0	42.0
24	19	6.2	6.4	10.3	10.5	0.0	0.0	33.4	34.6	16.8	8.3	3.0	2.2	0.0	64.9
	20	0.7	0.0	0.0	0.4	0.0	0.0	1.2	10.4	61.5	25.2	0.9	0.0	0.0	98.0
25	21	0.0	2.9	0.0	0.0	0.0	0.0	2.9	5.9	15.9	37.4	24.4	13.0	0.0	96.6
	22	10.0	13.7	4.6	11.4	0.0	0.0	39.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	23	0.0	1.8	0.6	0.0	0.0	0.0	2.4	34.4	19.9	32.6	7.1	0.0	0.0	94.0
	24	0.0	7.7	0.0	0.0	0.0	0.0	7.7	16.0	0.0	24.5	7.2	1.2	0.0	48.9
27	25	0.0	0.6	0.0	0.0	0.0	0.0	0.6	34.4	36.3	16.2	7.6	2.9	0.0	97.4
	26	0.0	11.4	1.7	0.0	0.0	0.0	13.1	24.5	6.9	30.5	21.4	2.3	0.0	85.6
28	27	0.0	1.8	3.9	0.0	0.0	0.0	5.7	33.5	10.4	40.8	7.4	2.2	0.0	94.3
	28	0.0	4.3	0.0	0.0	0.0	0.0	4.3	32.1	0.0	48.9	0.0	1.9	0.0	82.9
29	29	0.0	2.4	0.0	0.0	0.0	0.0	2.4	8.7	24.5	48.4	15.1	0.2	0.0	96.9
	30	0.9	1.9	0.3	0.0	0.0	0.0	3.1	23.7	0.0	36.1	25.1	6.7	0.0	91.6
30	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.9	3.3	47.2	15.0	2.5	0.0	83.9
	32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.0	6.8	16.5	9.8	1.2	0.0	66.3
31	33	0.0	2.3	3.1	0.0	0.0	0.0	5.4	0.0	3.9	81.4	9.2	0.0	0.0	94.5
	34	3.6	9.2	0.0	0.0	0.0	0.0	12.8	0.0	63.0	18.1	3.4	0.0	0.0	84.5
Aug.															
1	35	0.0	0.7	4.5	0.0	0.0	0.0	5.2	86.5	0.0	2.4	5.5	0.0	0.0	94.4
	36	0.0	4.1	0.0	0.0	0.0	0.0	4.1	0.0	63.4	7.2	8.2	1.3	0.0	80.1
2	37	0.0	39.5	18.9	0.0	0.0	0.0	58.4	0.0	0.0	9.3	18.6	0.0	0.0	27.9
	38	5.5	4.8	0.0	0.0	0.0	0.0	10.3	2.8	50.5	7.6	5.8	3.5	0.0	70.2
3	39	3.4	30.8	8.4	0.0	0.0	0.0	62.6	18.6	0.0	4.7	4.7	9.3	0.0	37.3
	40	12.0	15.8	23.5	0.0	0.0	0.0	51.3	5.8	0.0	9.2	5.5	0.0	0.0	20.5
4	41	0.0	3.2	0.0	0.0	0.0	0.0	3.2	6.3	0.0	30.8	17.2	0.0	0.0	54.3
	42	0.0	27.0	0.0	0.0	0.0	0.0	27.0	11.7	11.5	47.5	0.0	2.3	0.0	73.0
5	43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	42.1	46.3	0.0	0.0	100.0
	44	0.0	11.7	11.2	0.0	0.0	0.0	22.9	8.9	0.0	58.4	9.7	0.0	0.0	77.0
6	45	0.0	10.4	9.9	0.0	0.0	0.0	20.3	5.3	0.0	13.5	27.0	18.0	0.0	63.8
	46	0.0	49.1	0.0	0.0	0.0	0.0	49.1	2.6	0.0	0.0	22.0	0.0	0.0	24.6
7	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	21.8	43.7	0.0	0.0	74.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.0	52.9	32.8	3.3	0.0	99.9
8	49	0.0	15.8	5.1	0.0	0.0	0.0	21.0	4.8	44.9	14.9	8.5	0.0	0.0	73.1
	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	48.4	25.5	0.0	0.0	0.0	83.6

Table L4. Summary of mean horizontal distributions of downstream adult salmon within the near-shore cells, by shift (Susitna River 1985).

		Relative Percentage of Fish													
	Shift	Cell 1							Cell 9						
Date	Number	1	2	3	4	5	6	Sum	1	2	3	4	5	6	Sum
July															
22	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.8	1.0	0.0	31.8
	16	0.0	30.0	0.0	14.0	0.0	0.0	44.0	20.1	35.8	0.0	0.0	0.0	0.0	55.9
23	17	0.0	21.2	0.0	2.5	0.0	0.0	23.7	18.8	33.4	22.8	0.0	1.4	0.0	76.4
	18	0.0	21.8	3.0	0.0	0.0	0.0	24.8	0.0	30.8	0.0	13.8	1.1	0.0	45.7
24	19	1.0	4.3	3.0	5.6	0.0	0.0	13.9	38.5	18.4	8.6	12.1	1.0	0.0	78.6
	20	0.5	0.2	0.0	0.1	0.0	0.0	0.8	32.1	46.9	16.8	2.1	0.0	0.0	97.9
25	21	0.0	1.7	1.1	0.0	0.0	0.0	2.8	9.3	16.6	43.8	17.8	8.6	0.0	96.1
	22	0.0	13.7	2.6	1.9	0.0	0.0	18.2	2.9	5.1	5.3	15.2	0.0	0.0	28.5
26	23	0.0	5.8	1.8	0.0	0.0	0.0	7.6	15.2	34.7	33.8	6.4	1.6	0.0	91.7
	24	0.0	26.1	0.0	0.0	0.0	0.0	26.1	7.2	12.3	19.9	5.0	1.0	0.0	45.4
27	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	54.9	20.2	6.3	1.8	0.0	99.9
	26	0.0	4.9	0.9	0.0	0.0	0.0	5.8	15.1	44.2	23.8	8.4	2.0	0.0	93.5
28	27	0.0	2.0	0.5	0.1	0.0	0.0	2.6	14.5	31.6	33.8	12.2	2.0	0.0	94.1
	28	0.0	10.0	1.1	0.0	0.0	0.0	11.1	13.4	0.0	60.5	0.0	1.6	0.0	75.5
29	29	1.3	2.2	0.0	0.1	0.0	0.0	3.6	3.3	31.3	48.5	11.2	0.0	0.0	94.3
	30	2.4	2.0	0.5	0.1	0.0	0.0	5.0	10.9	0.0	48.9	23.7	4.7	0.0	88.2
30	31	0.0	1.4	1.4	0.1	0.0	0.0	2.9	12.0	9.9	56.3	10.2	2.0	0.0	90.4
	32	10.7	4.4	3.0	2.8	0.0	0.0	20.9	4.6	19.0	22.4	9.9	1.4	0.0	57.3
31	33	0.0	5.2	0.0	0.0	0.0	0.0	5.2	3.2	0.0	82.0	3.4	0.0	0.0	88.6
	34	8.7	25.7	0.0	0.0	0.0	0.0	34.4	0.0	10.3	32.1	11.2	3.2	0.0	56.9
August															
1	35	6.2	0.0	5.6	0.0	0.0	0.0	11.8	46.4	0.0	3.0	29.9	6.2	0.0	85.5
	36	0.0	7.2	0.0	0.0	0.0	0.0	7.2	0.0	47.8	15.6	22.8	2.8	0.0	89.0
2	37	0.0	0.0	12.4	0.0	0.0	0.0	12.4	0.0	0.0	12.2	42.6	0.0	0.0	54.8
	38	54.7	0.0	0.0	0.0	0.0	0.0	54.7	0.0	12.8	12.8	3.3	0.9	0.0	29.8
3	39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	44.2	16.4	29.5	3.3	0.0	100.0
	40	12.4	38.5	24.3	0.0	0.0	0.0	75.2	2.2	0.0	3.8	11.5	0.0	0.0	17.5
4	41	0.0	0.0	5.0	0.0	0.0	0.0	5.0	0.0	0.0	27.2	31.2	2.2	0.0	60.6
	42	49.2	0.0	0.0	0.0	0.0	0.0	49.2	0.0	13.8	17.5	0.0	19.5	0.0	50.8
5	43	0.0	12.2	0.0	0.0	0.0	0.0	12.2	0.0	0.0	41.8	40.8	5.1	0.0	87.7
	44	0.0	8.9	16.6	0.0	0.0	0.0	25.5	0.0	26.6	22.2	11.1	0.0	0.0	59.9
6	45	0.0	14.3	6.8	0.0	0.0	0.0	21.1	0.0	0.0	6.2	46.6	18.6	0.0	71.4
	46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	0.0	0.0	100.0
7	47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.9	35.7	0.0	0.0	47.6
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.3	10.8	36.5	4.4	0.0	100.0
8	49	0.0	14.9	4.8	0.0	0.0	0.0	19.7	0.0	35.0	28.1	6.0	0.0	0.0	69.1
	50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.7	43.3	0.0	0.0	0.0	100.0

Appendix M: Horizontal Distributions of Adult Salmon Across the River, Weighted for Fish Abundance

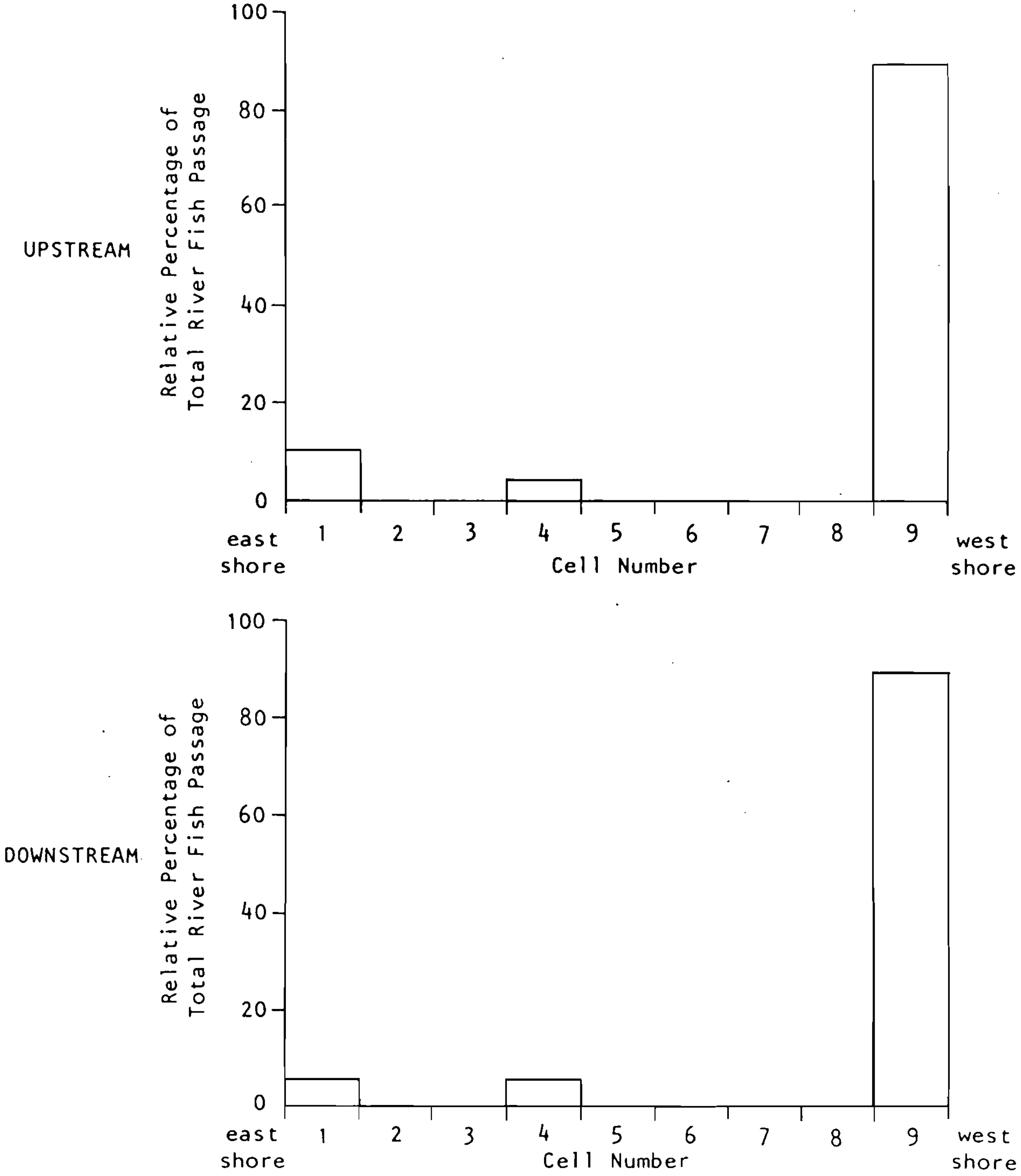


Figure M1. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period I (July 22-25). Susitna River, 1985.

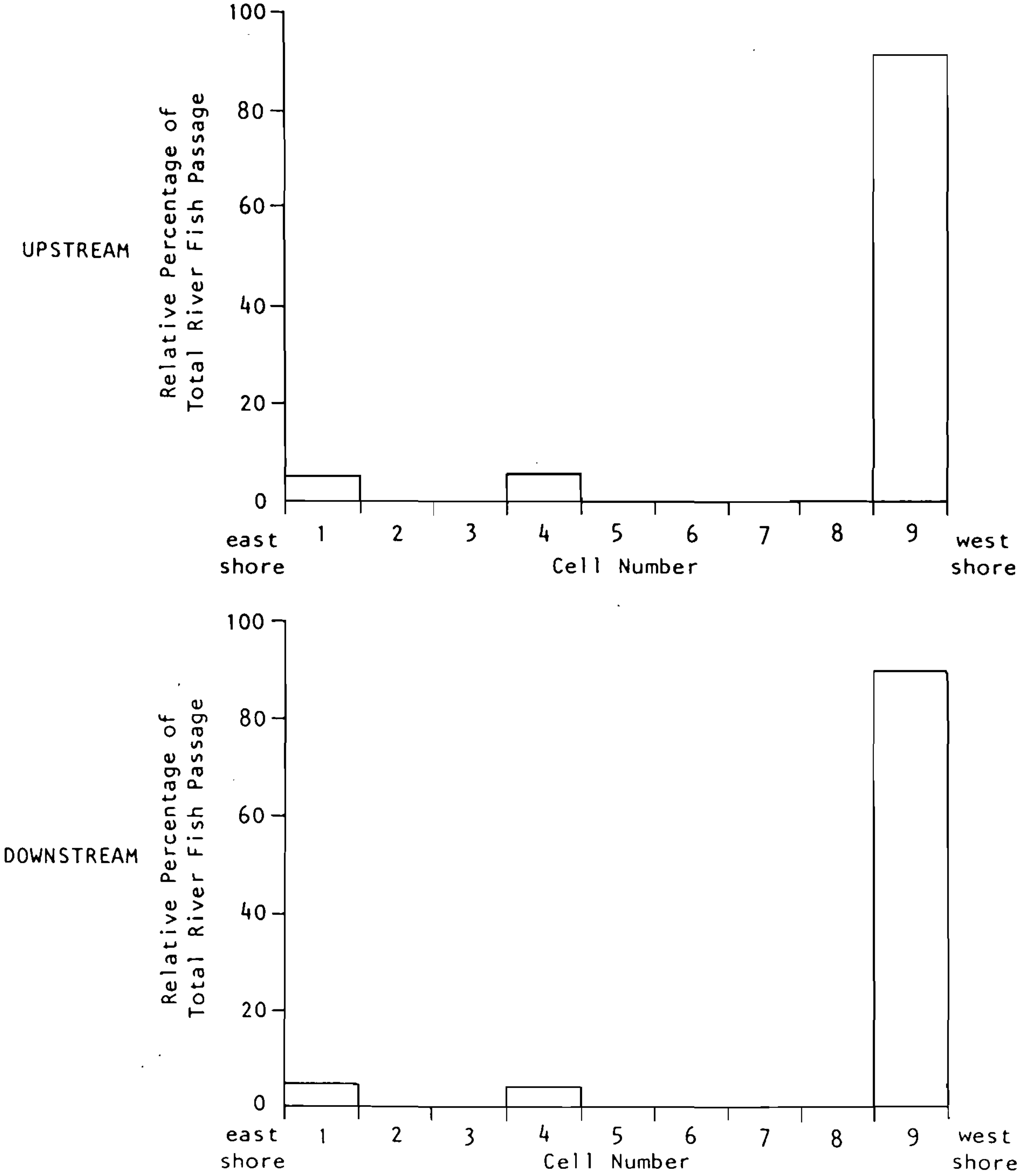


Figure M2. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period II (July 26-30). Susitna River, 1985.

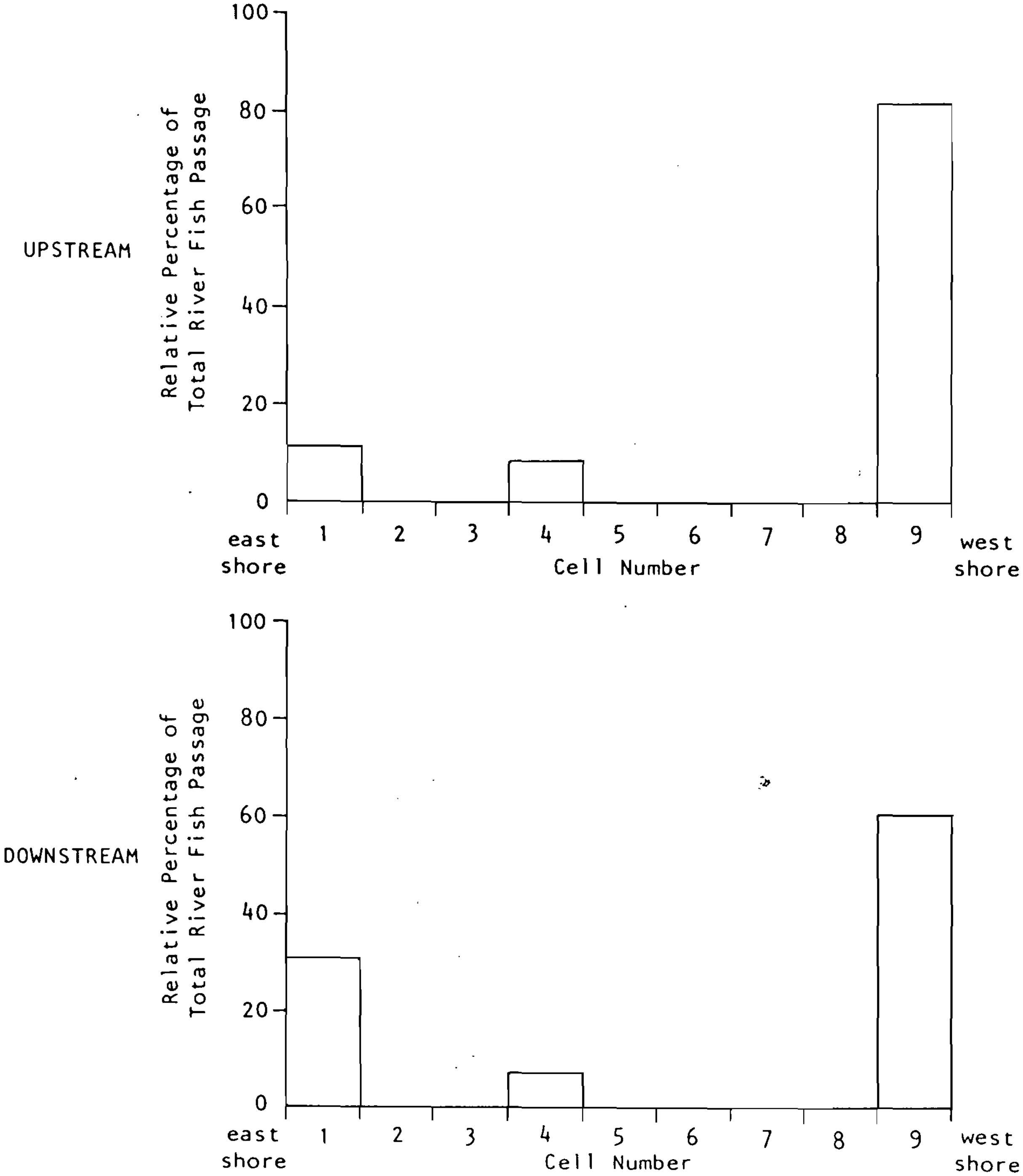


Figure M3. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period III (July 31 - August 3). Susitna River, 1985.

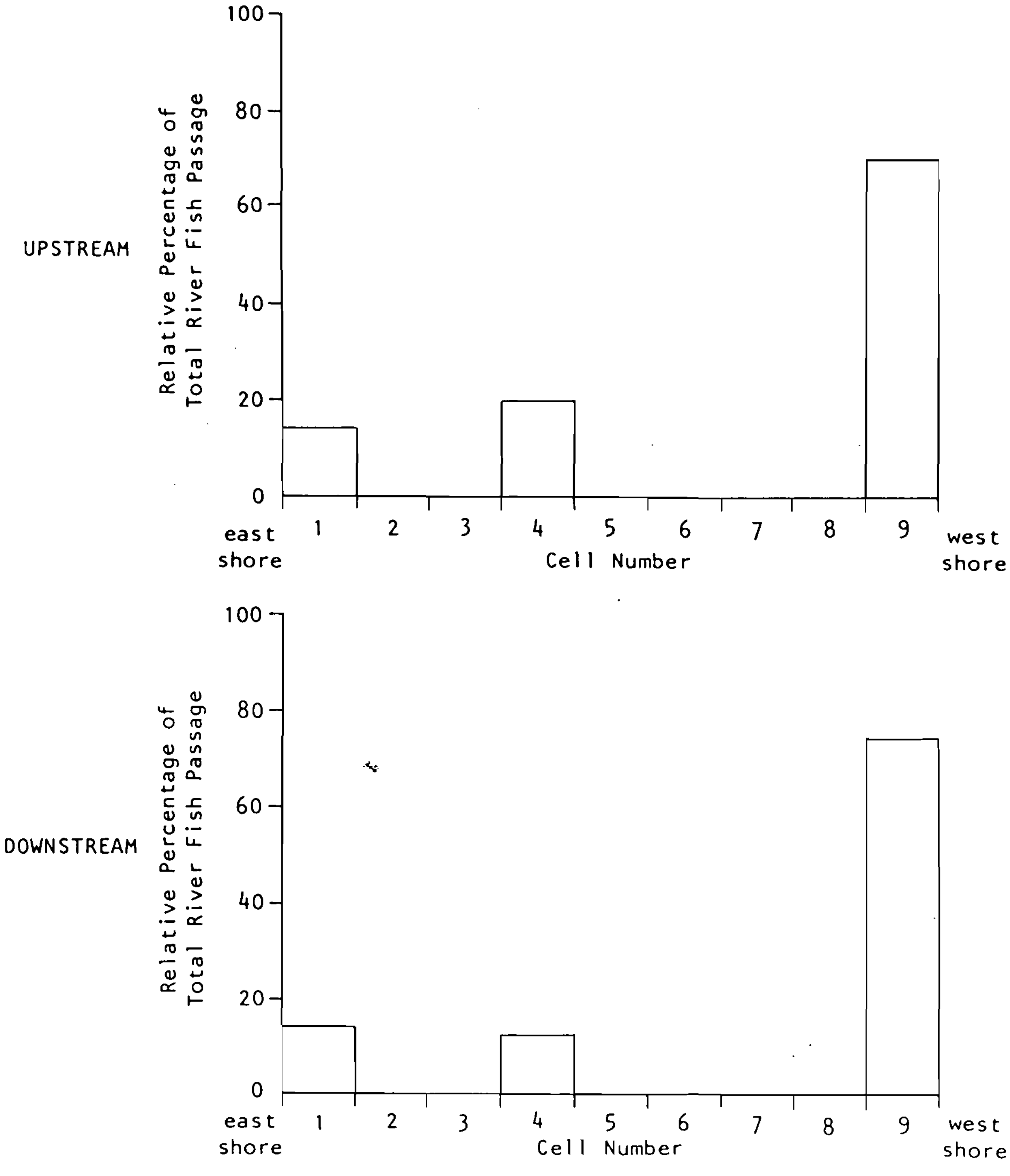


Figure M4. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period IV (August 4-8). Susitna River, 1985.

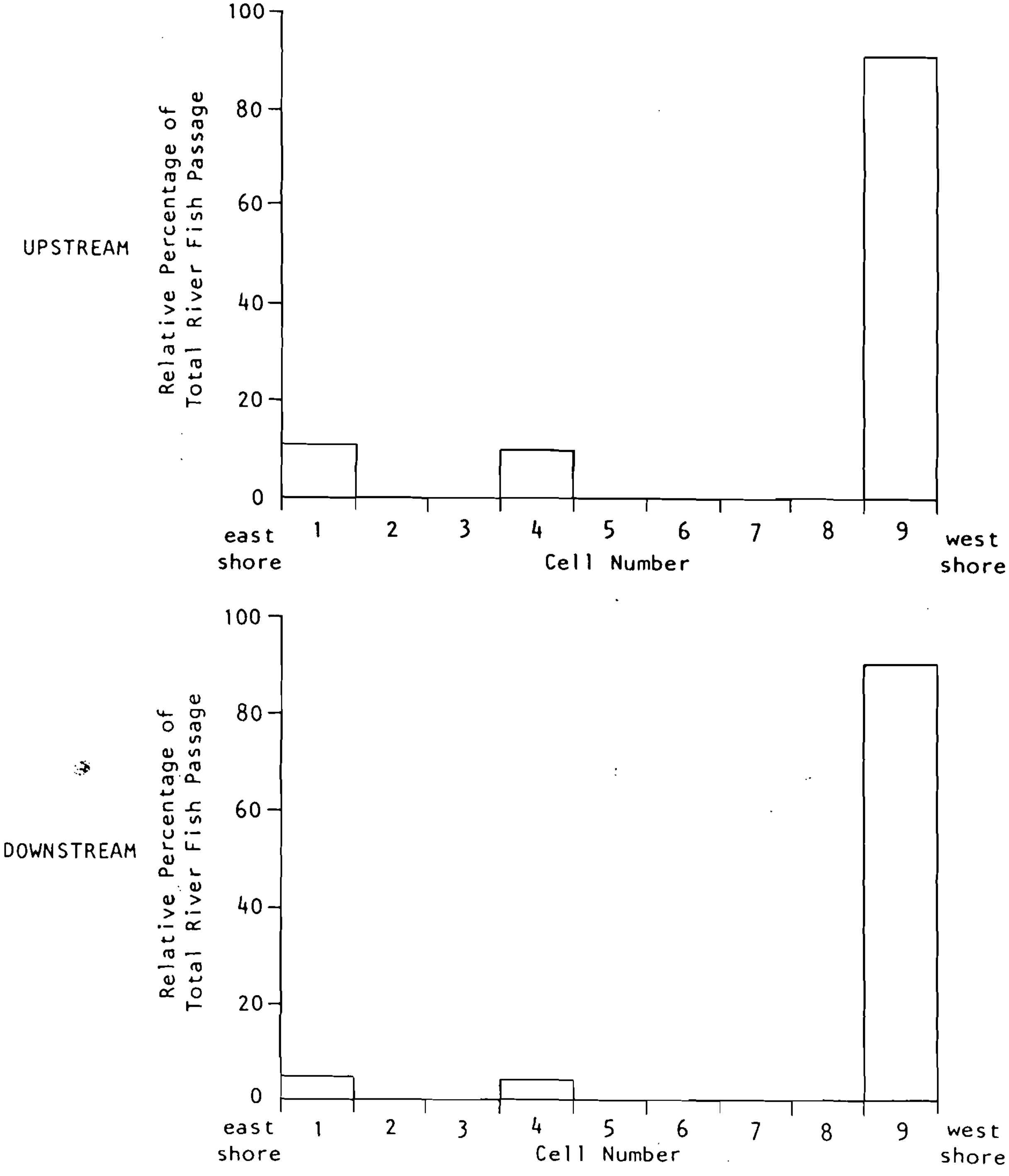


Figure M5. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Periods I and II (July 22-30). Susitna River, 1985.

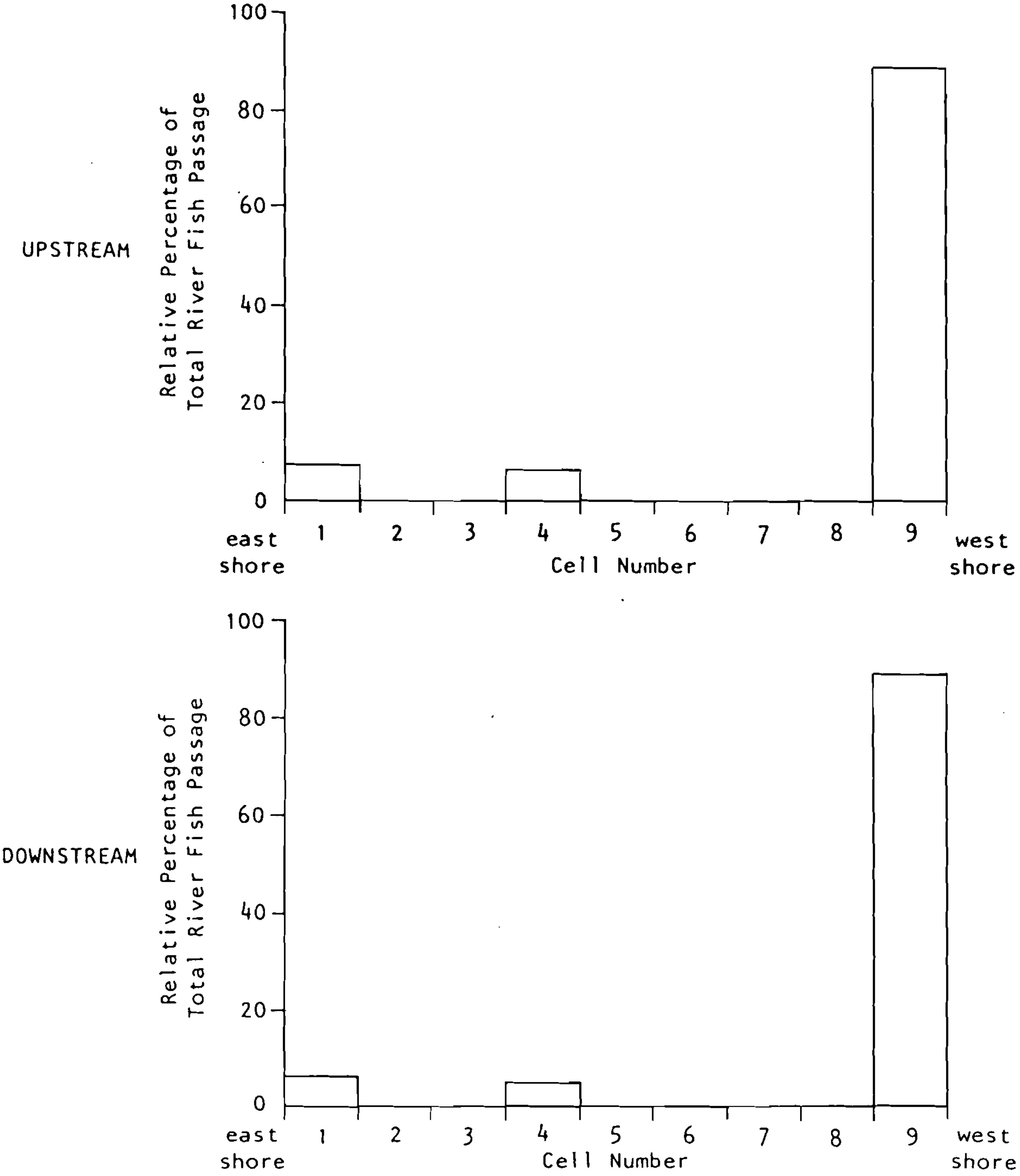


Figure M6. Horizontal distribution of adult salmon across the river, weighted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

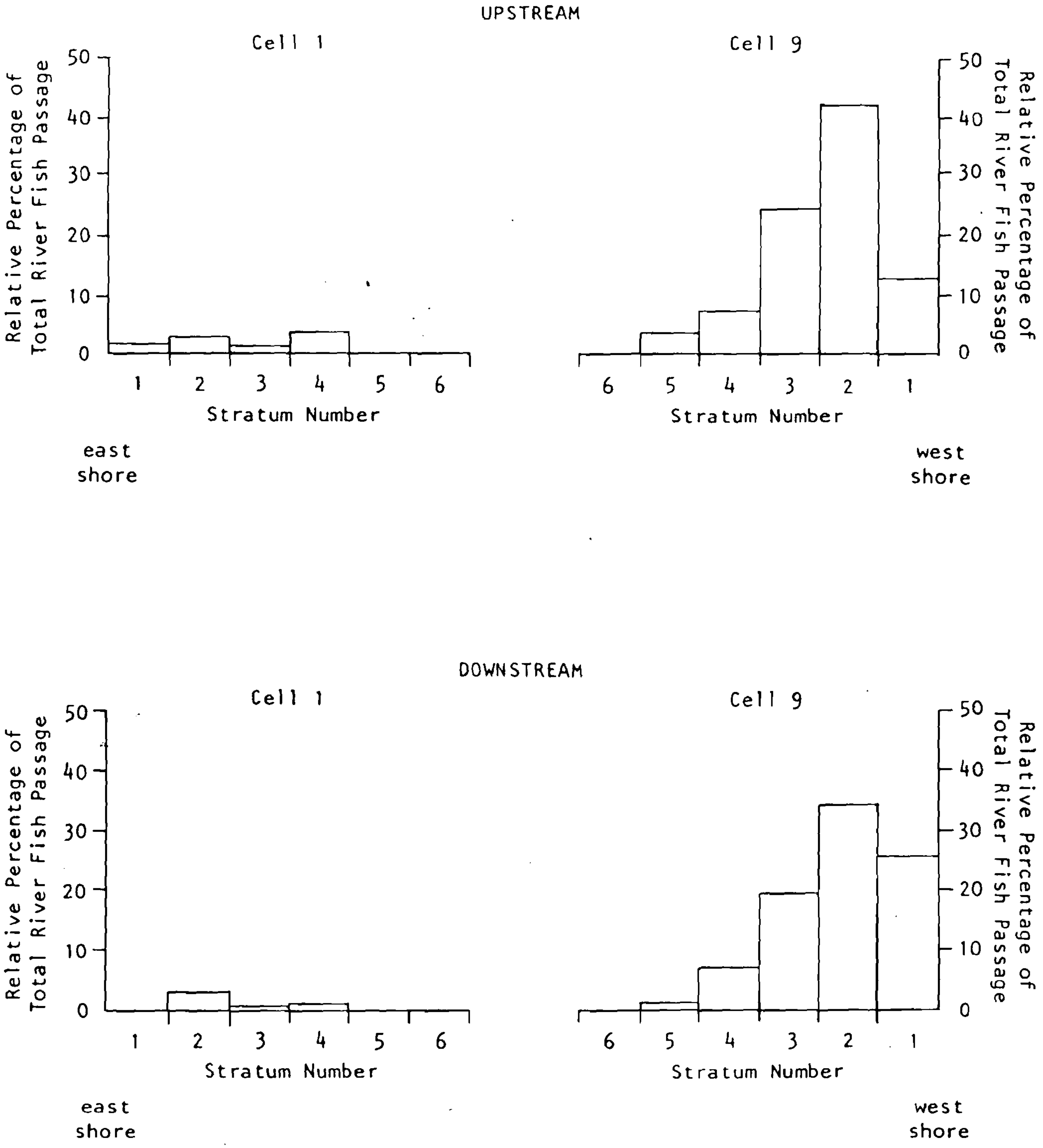


Figure M7. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period I (July 22-25). Susitna River, 1985.

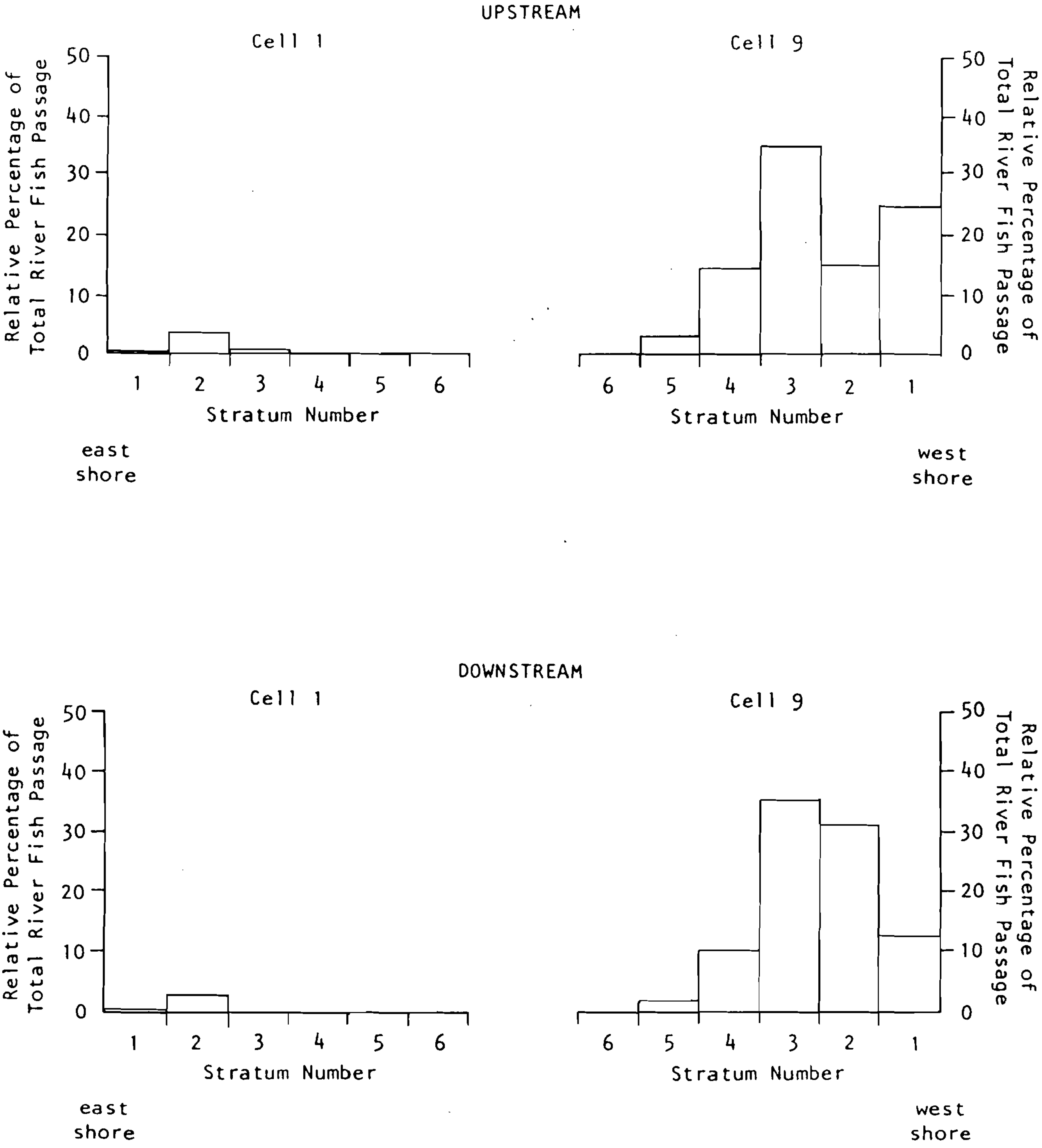


Figure M8. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period II (July 26-30). Susitna River, 1985.

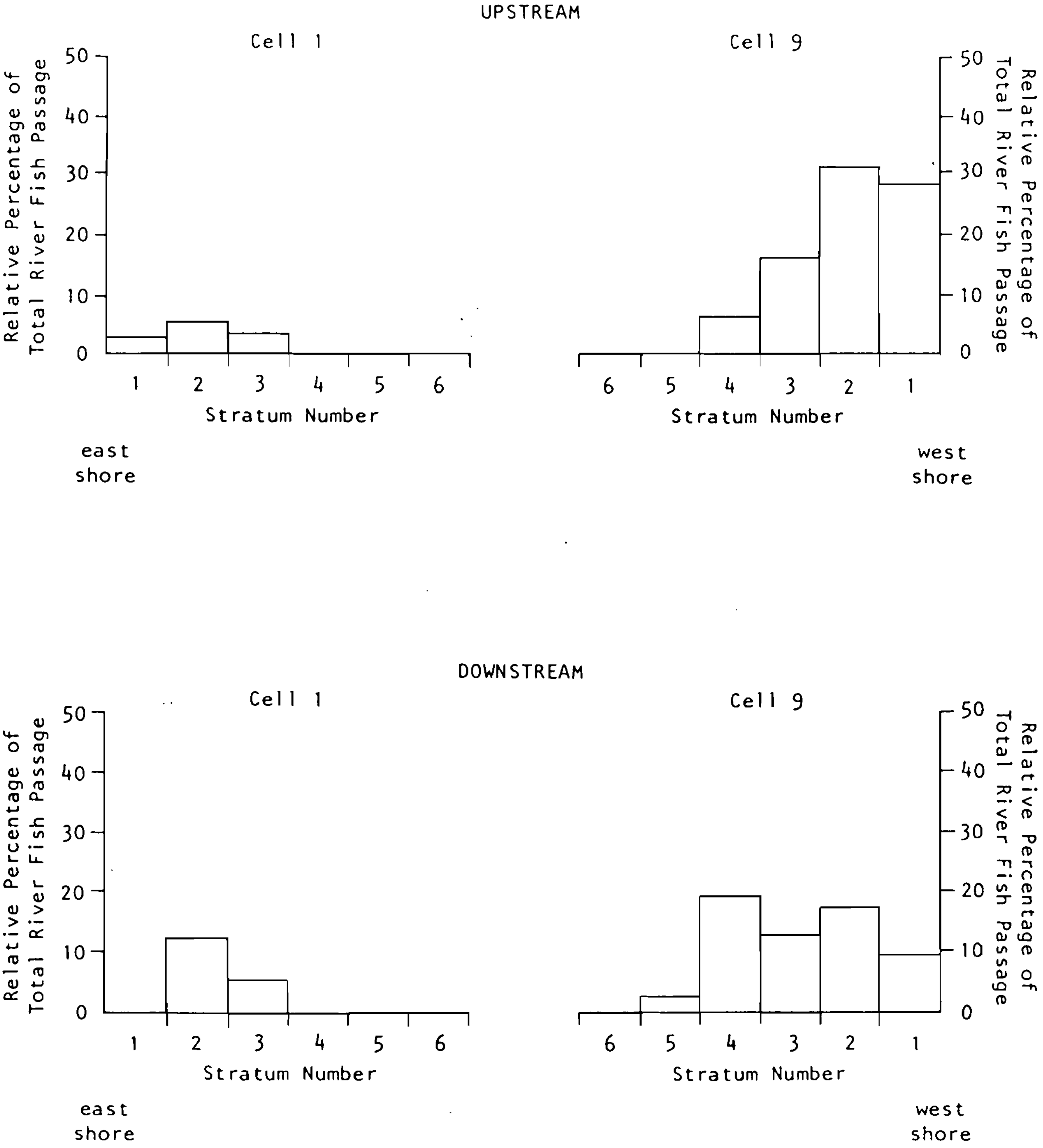


Figure M9. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period III (July 31 - August 3). Susitna River, 1985.

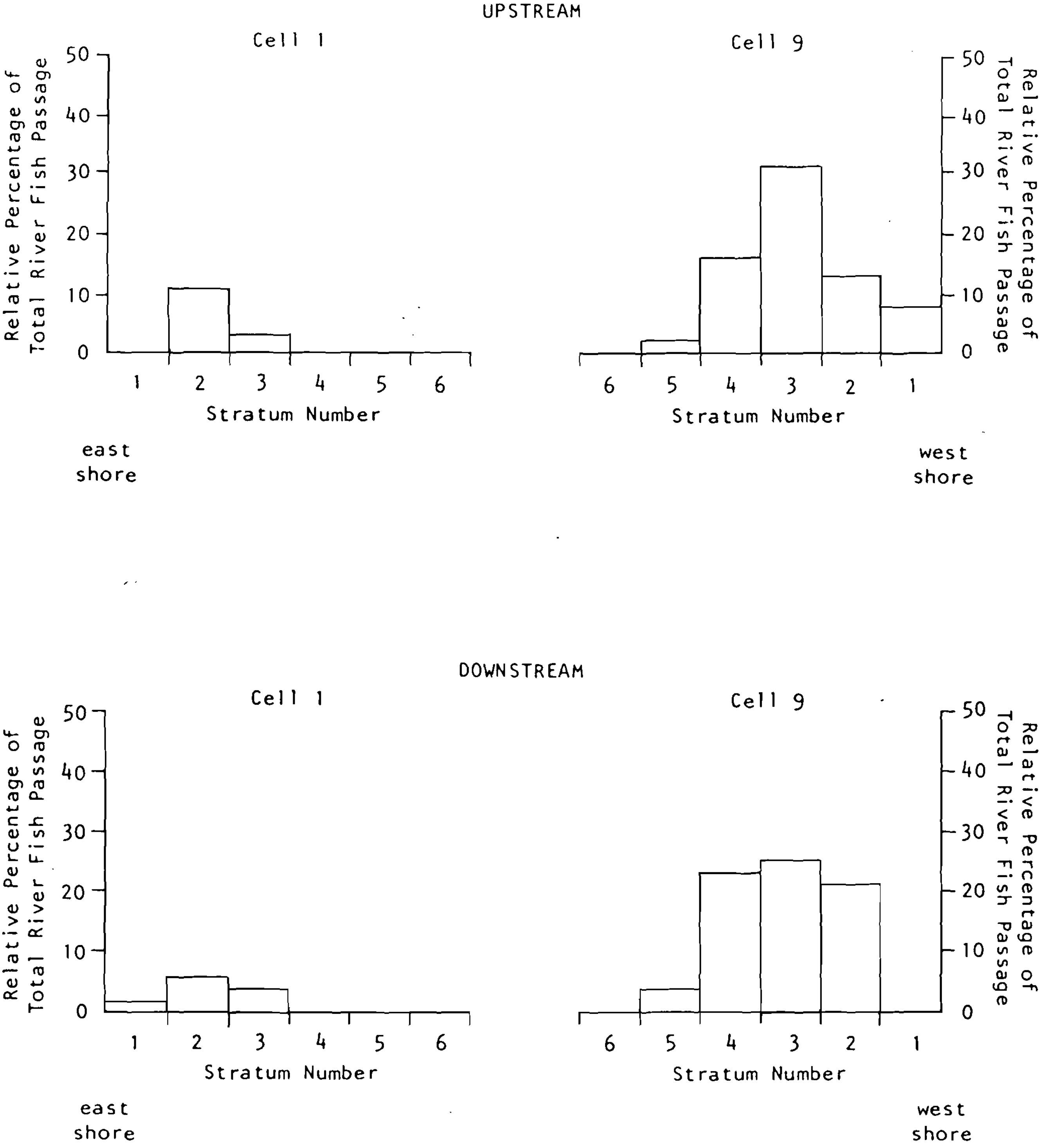


Figure M10. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period IV (August 4-8). Susitna River, 1985.

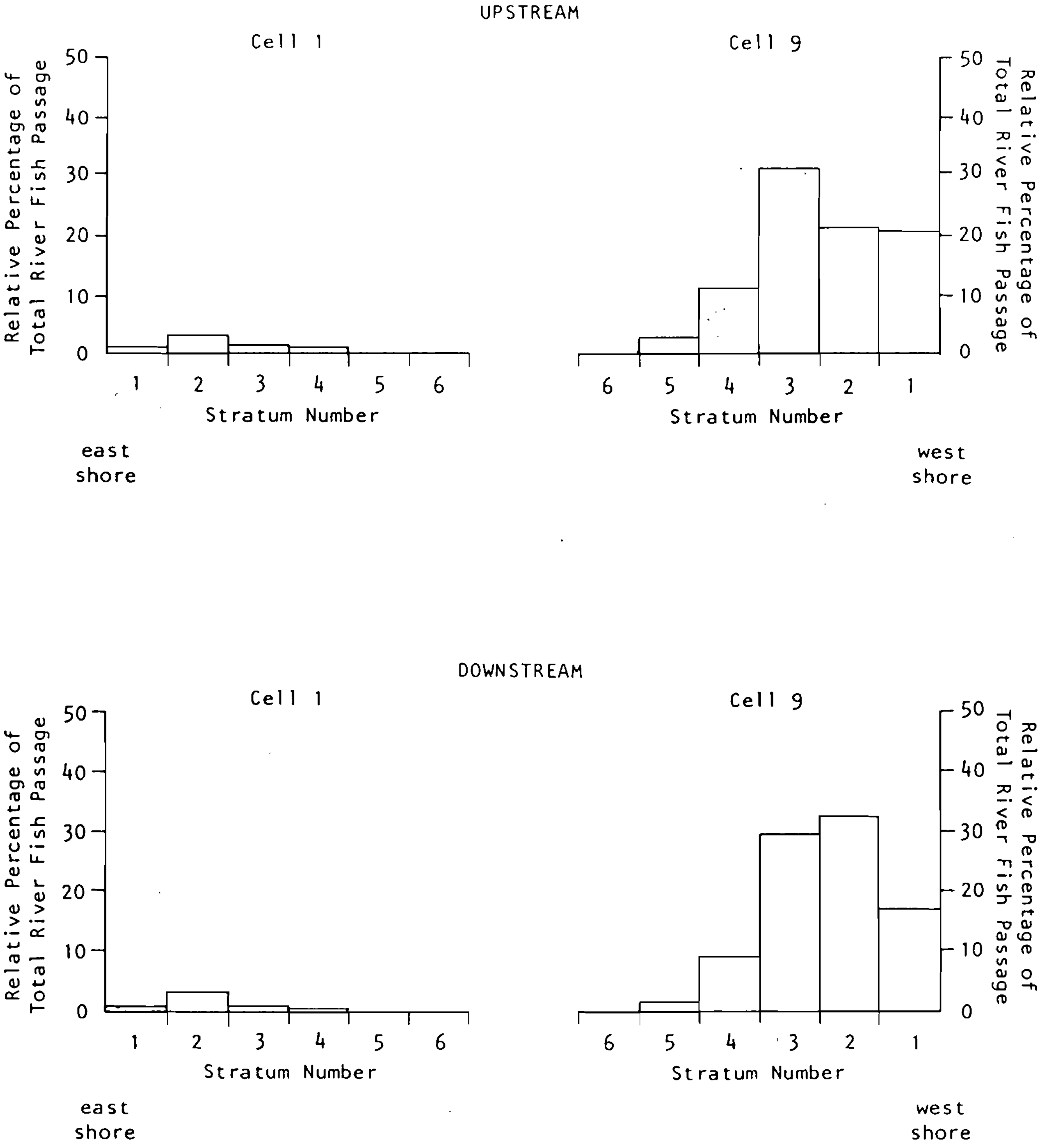


Figure M11. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Periods I and II (July 22-30). Susitna River, 1985.

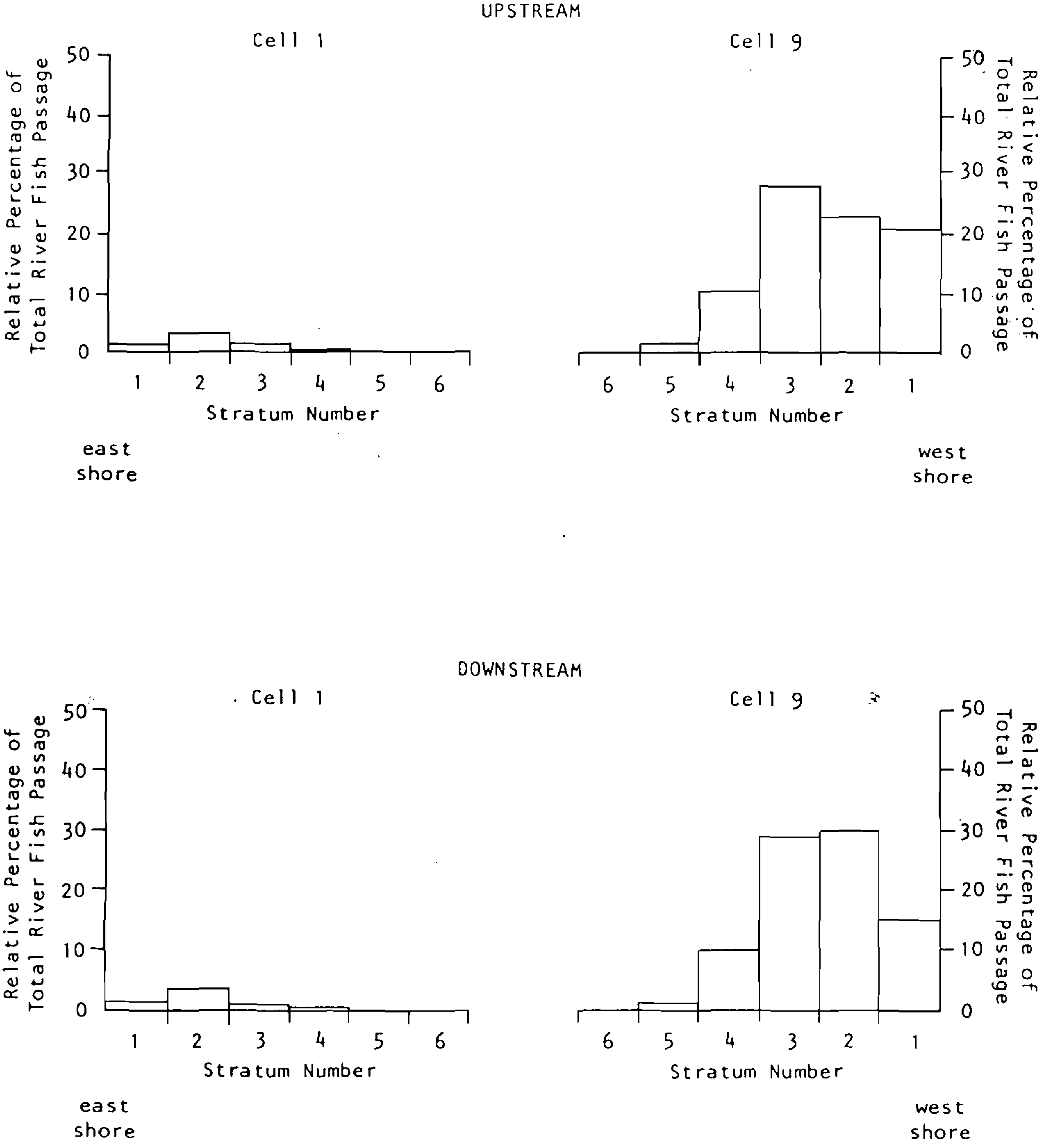


Figure M12. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

Appendix N: Mean Horizontal Distributions of Adult Salmon Across the River, Based on Distributions by Shift

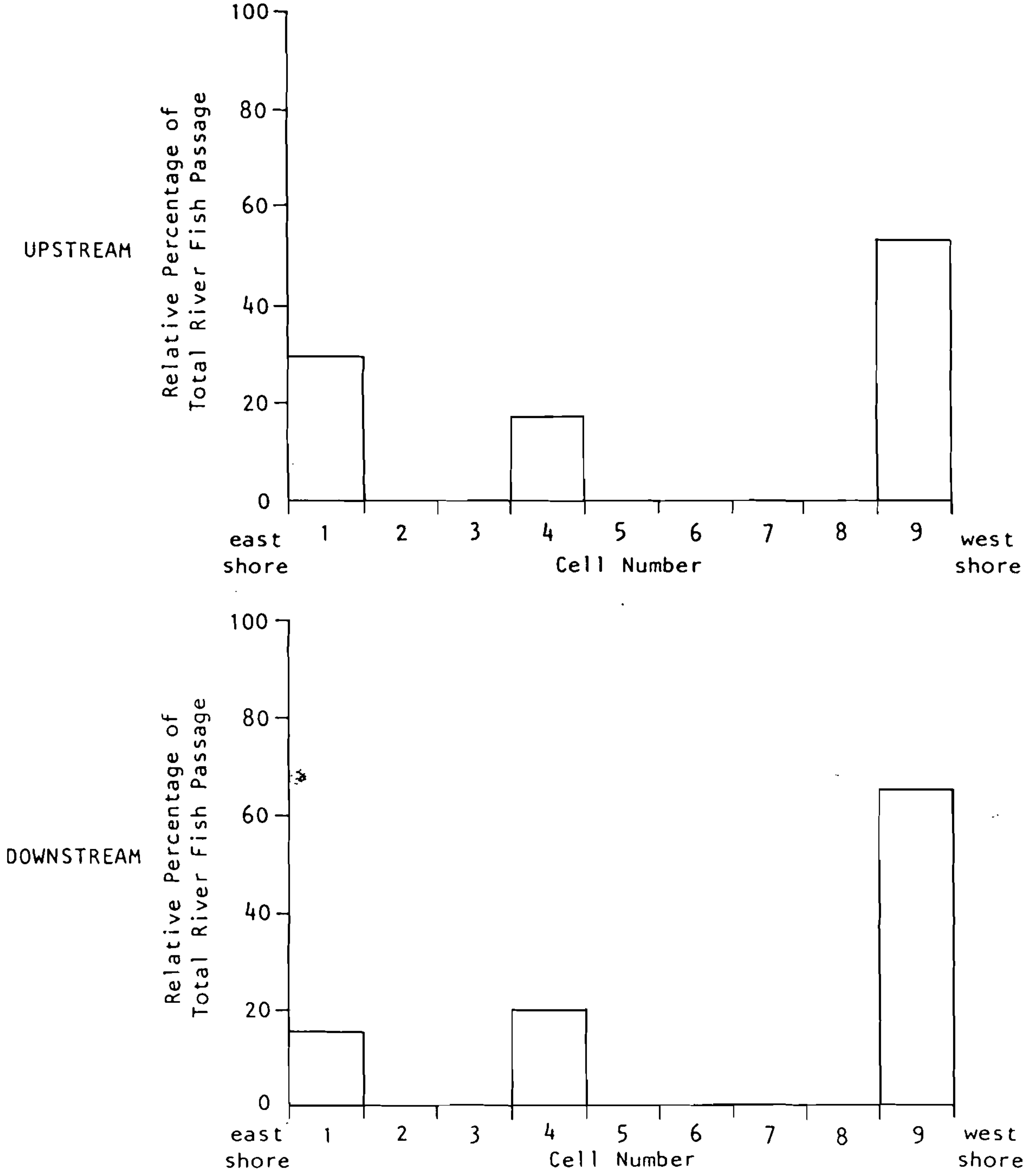


Figure N1. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period I (July 22-25). Susitna River, 1985.

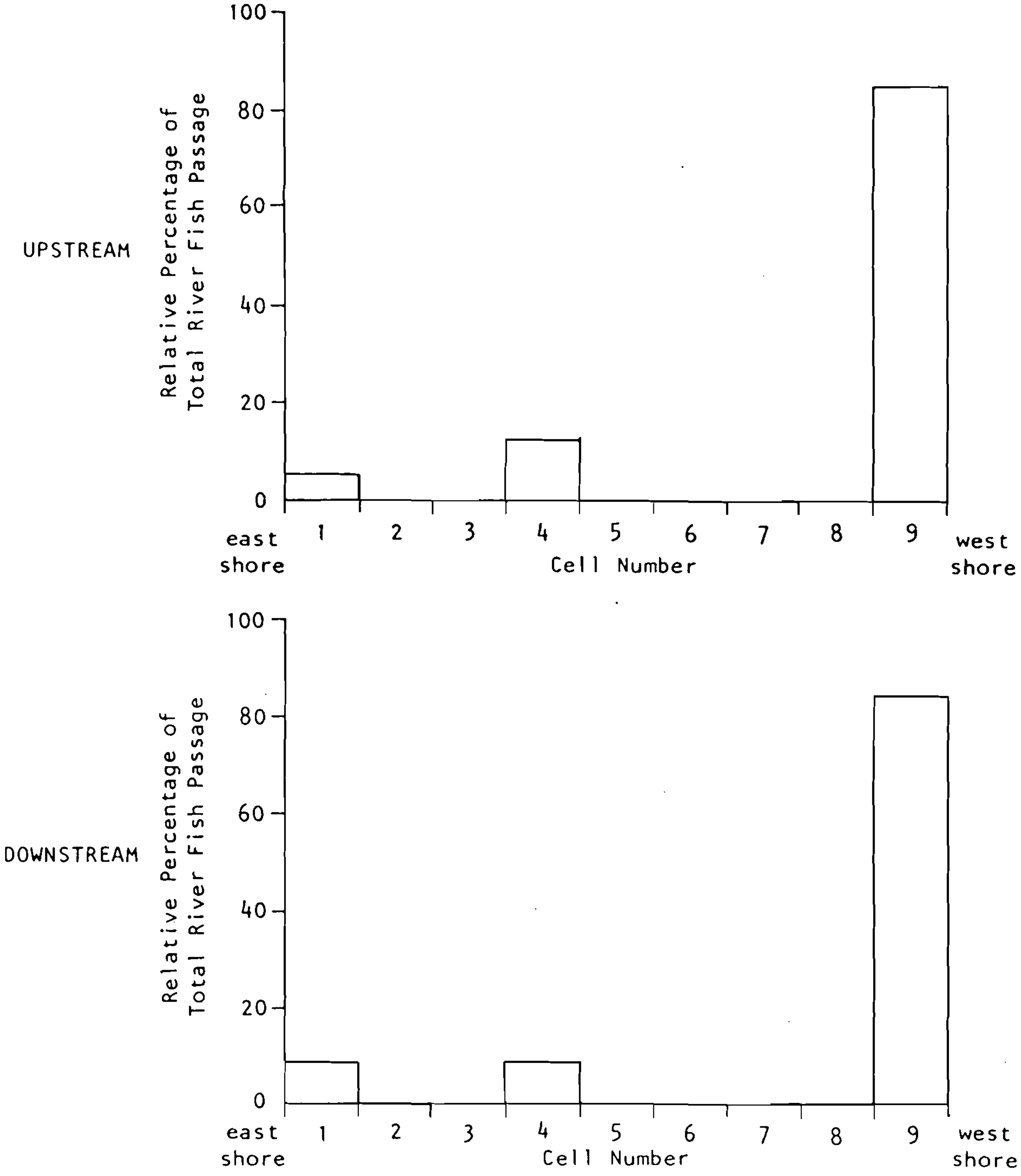


Figure N2. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period II (July 26-10). Susitna River, 1985.

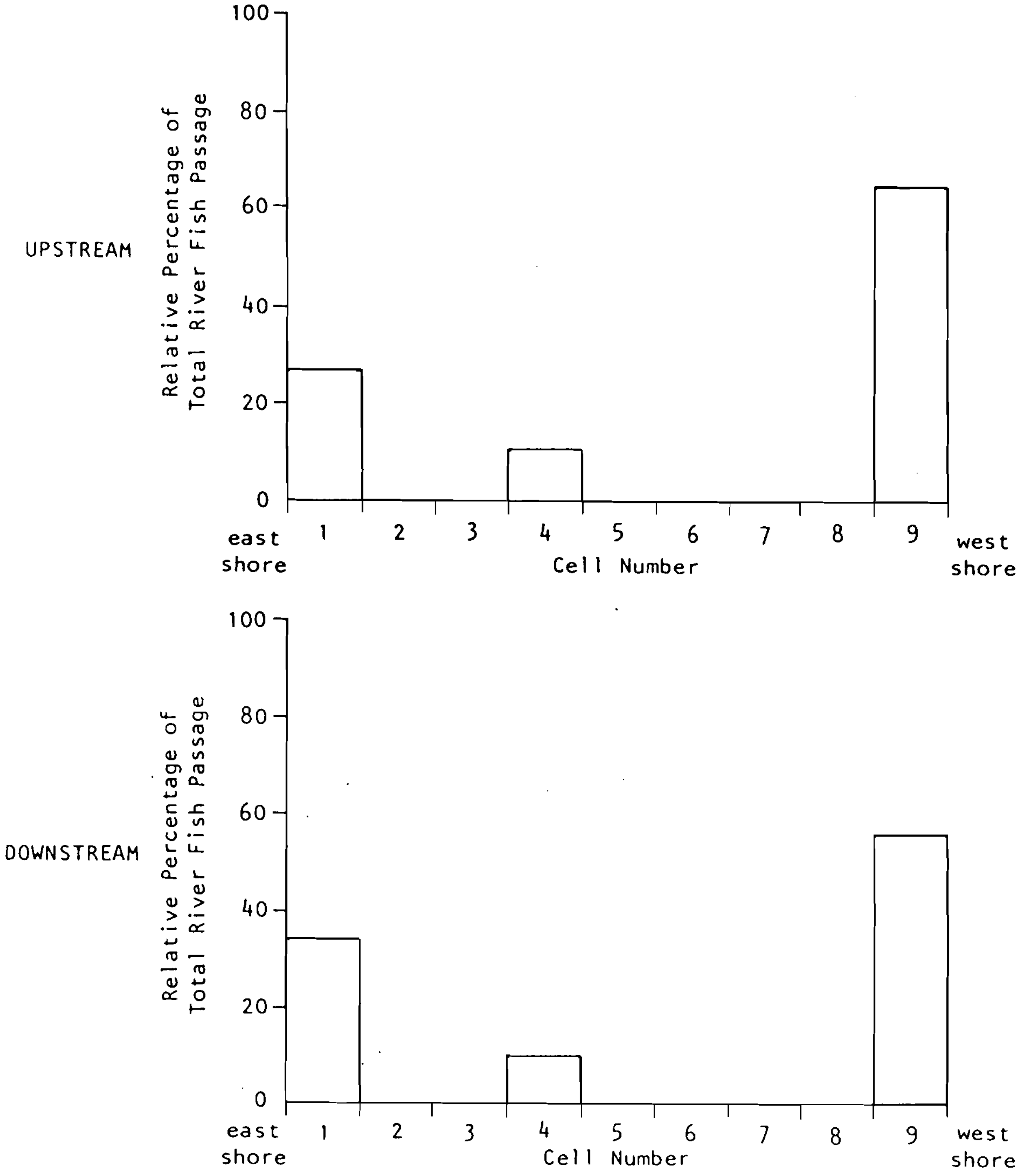


Figure N3. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period III (July 31 - August 3). Susitna River, 1985.

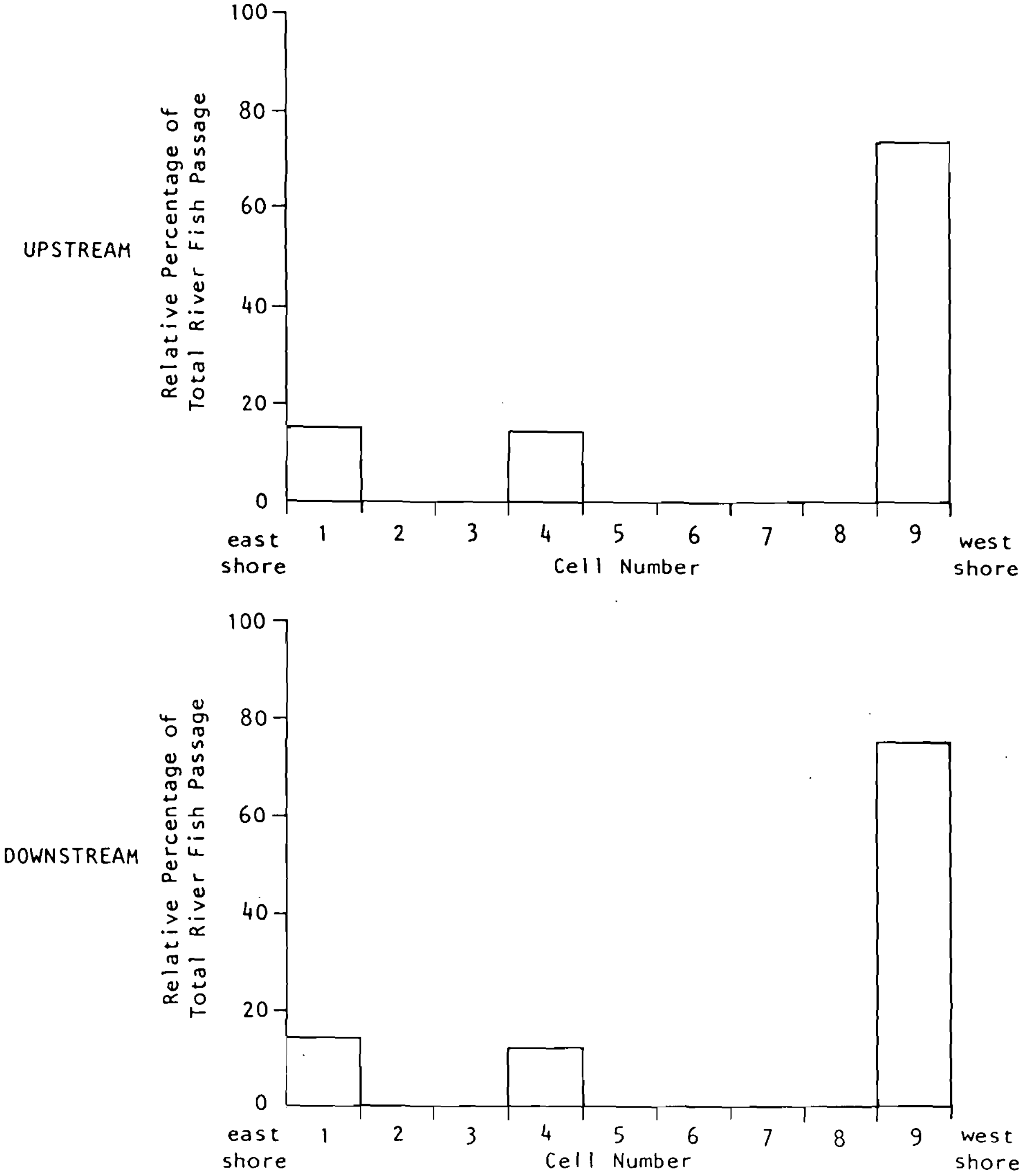


Figure N4. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period IV (August 4-8) Susitna River, 1985.

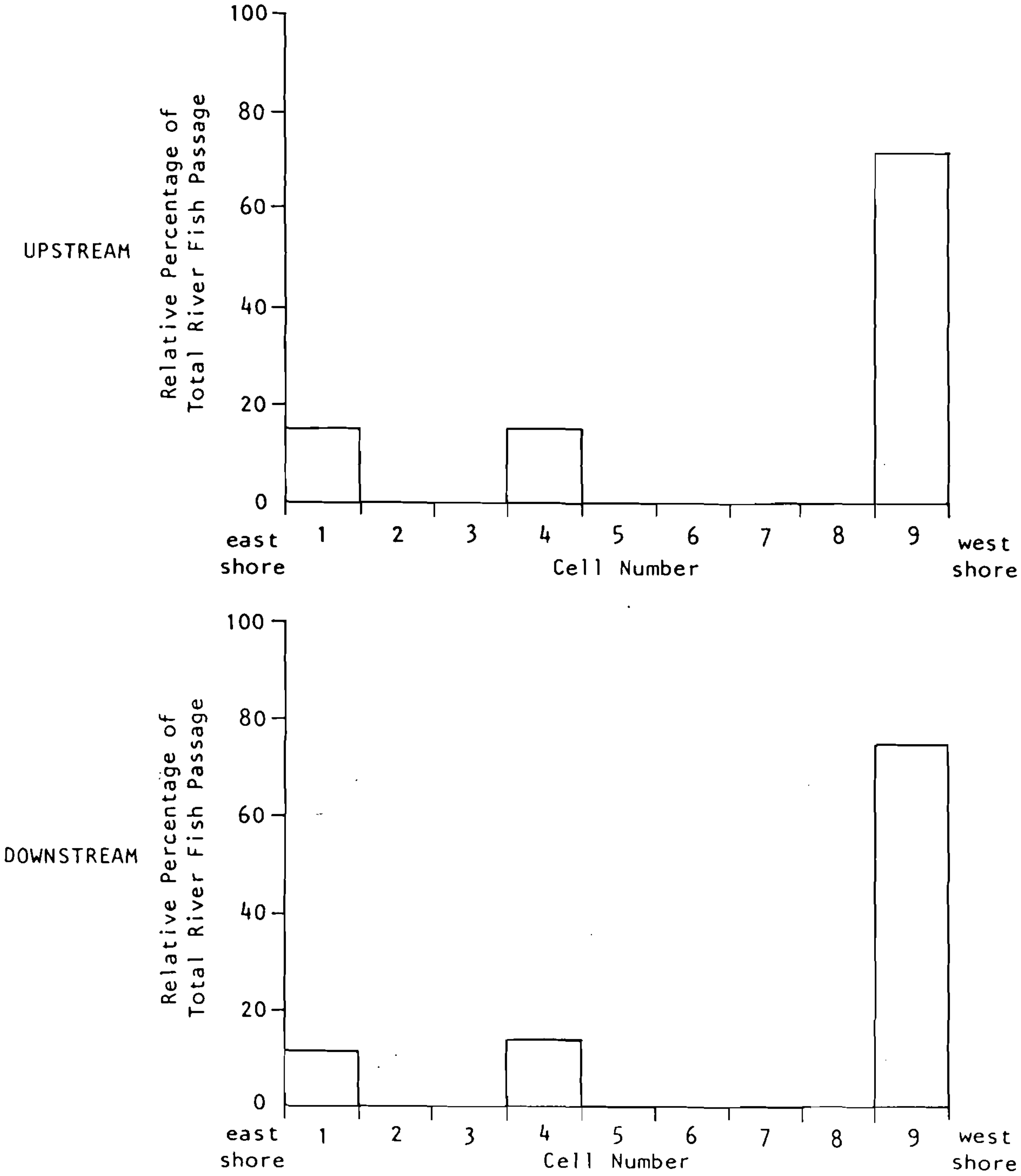


Figure N5. Mean horizotnal distributions of adult salmon across the river, based on distributions by shift, for Periods I and II (July 22-30). Susitna River, 1985.

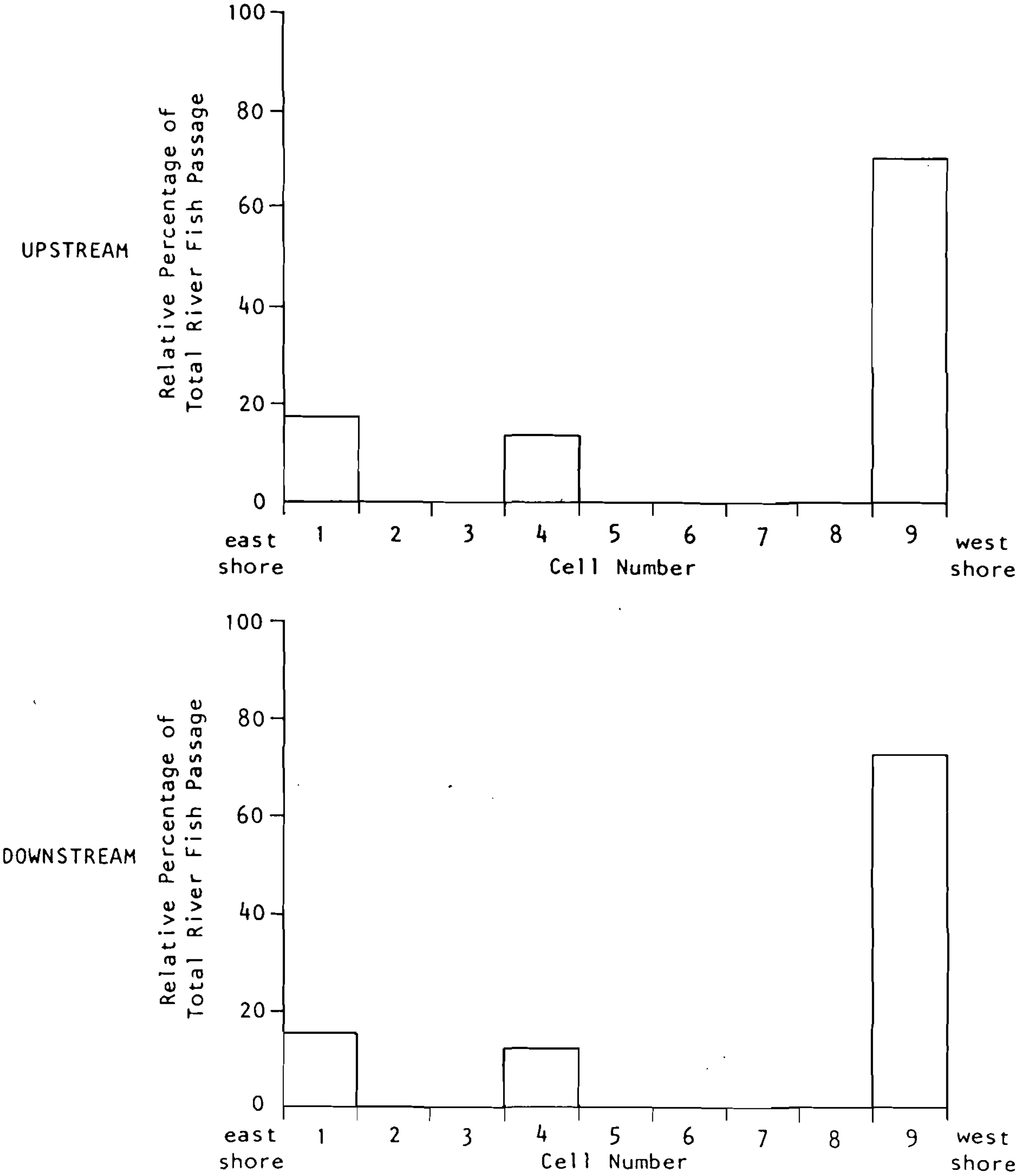


Figure N6. Mean horizontal distribuions of adult salmon across the river, based on distributions by shift, for Periods I-IV, (July 22 - August 8). Susitna River, 1985.

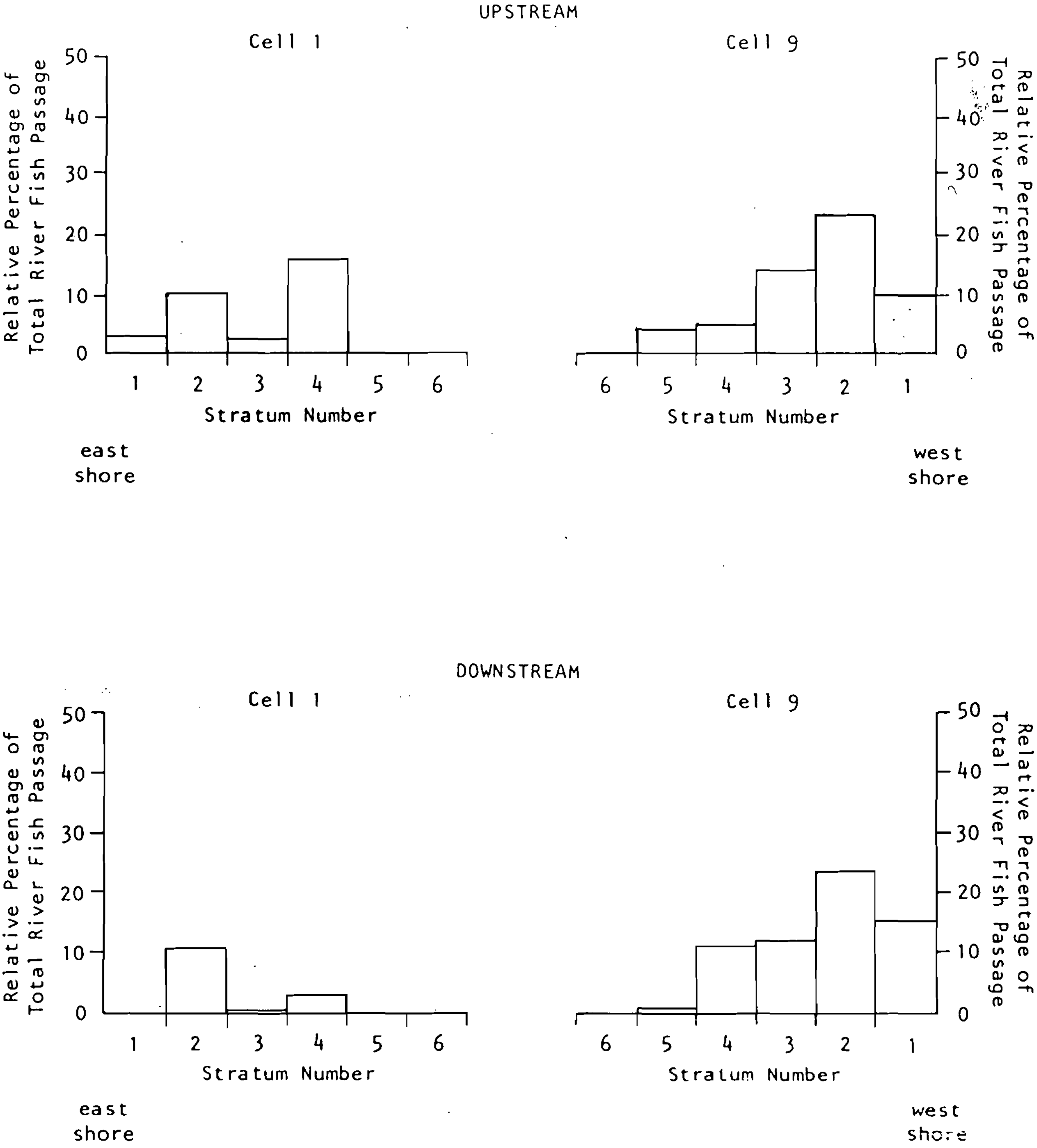
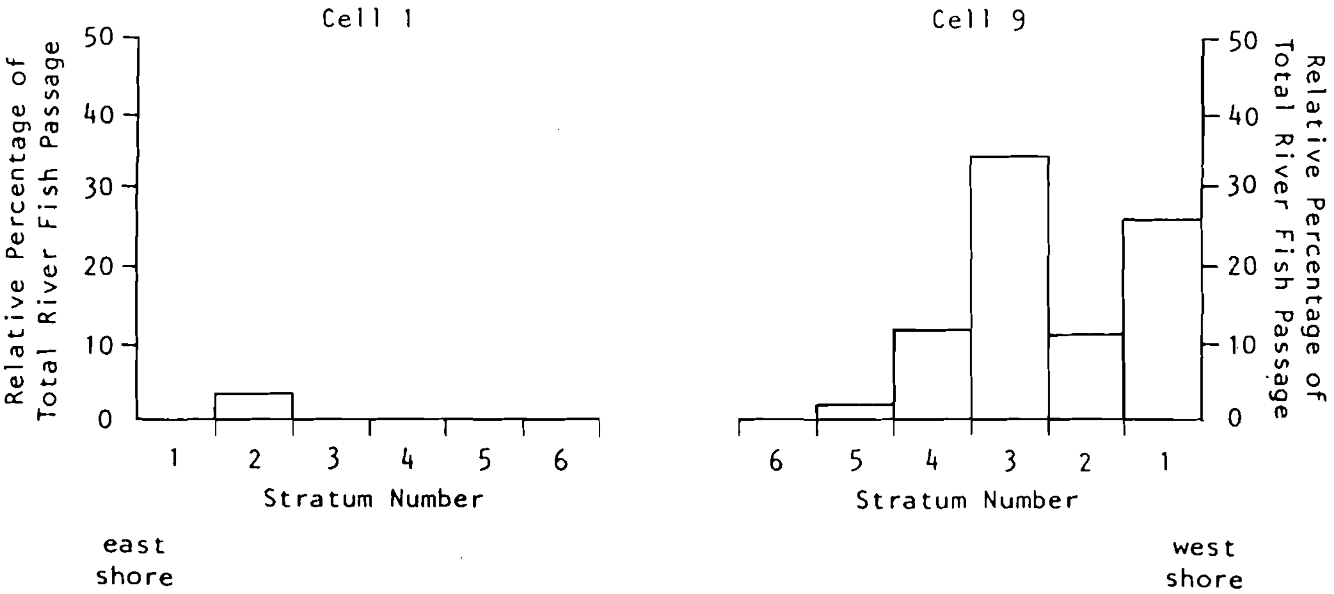


Figure N7. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period I (July 22-25). Susitna River, 1985.

UPSTREAM



DOWNSTREAM

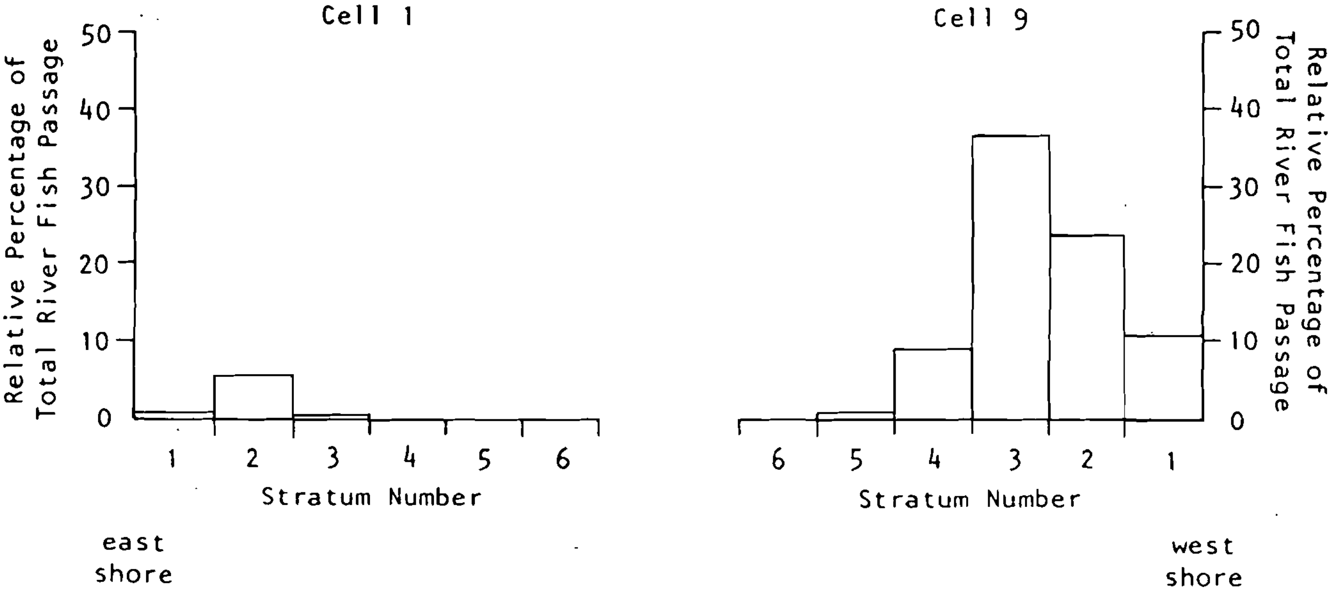


Figure N8. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period II (July 26-30). Susitna River, 1985.

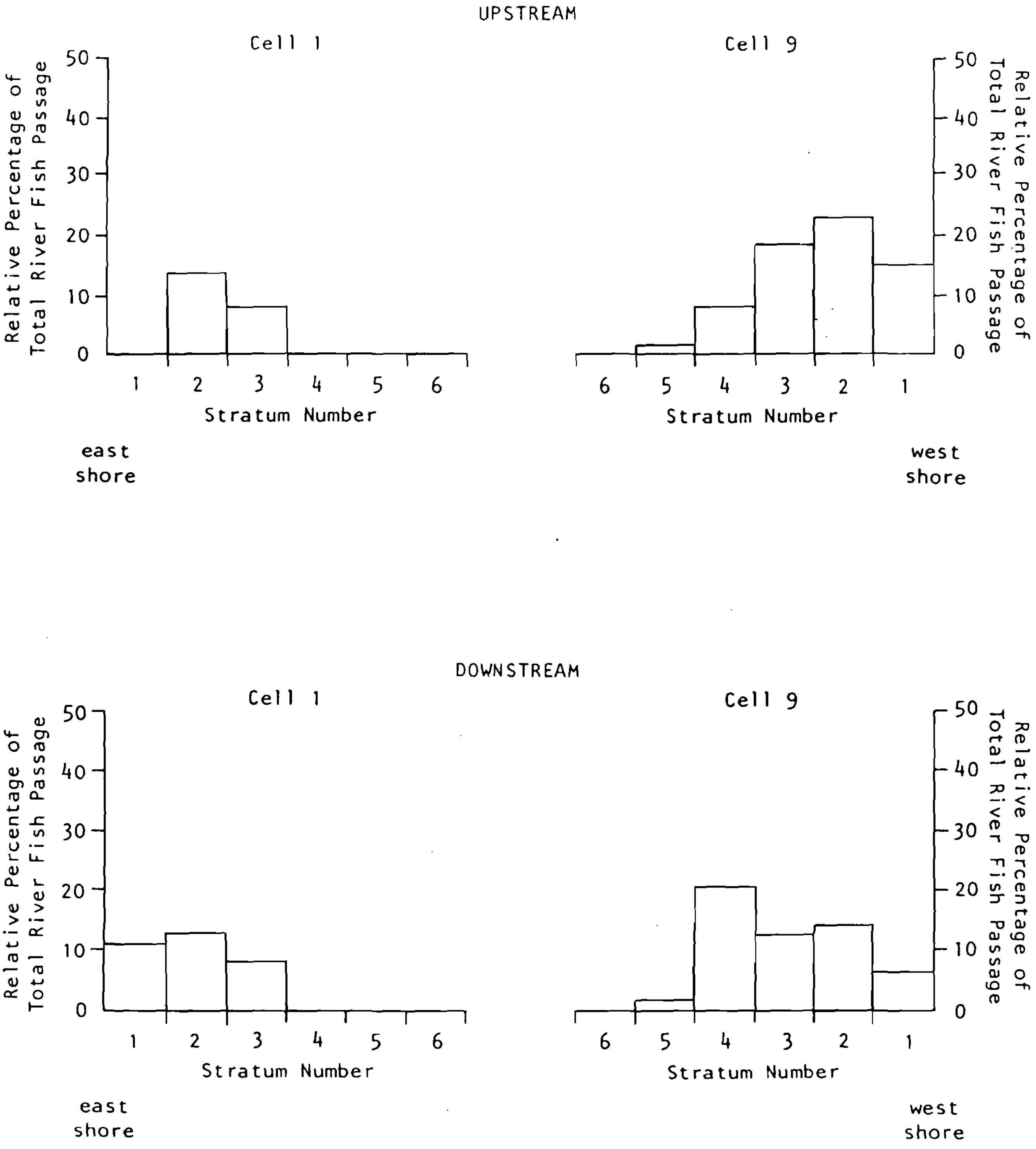


Figure N9. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period III (July 31 - August 3). Susitna River, 1985.

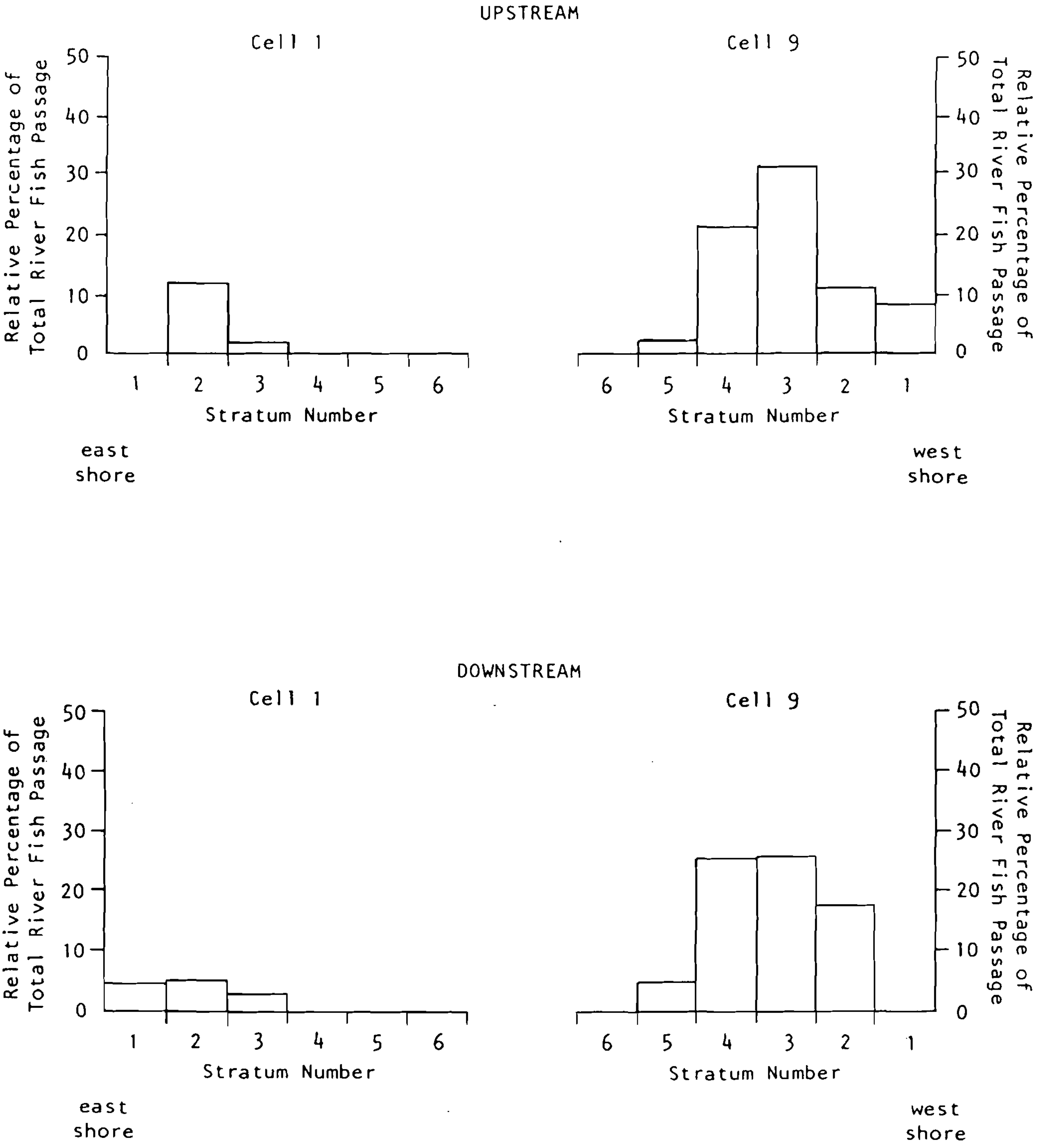


Figure N10. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period IV (August 4-8). Susitna River, 1985.

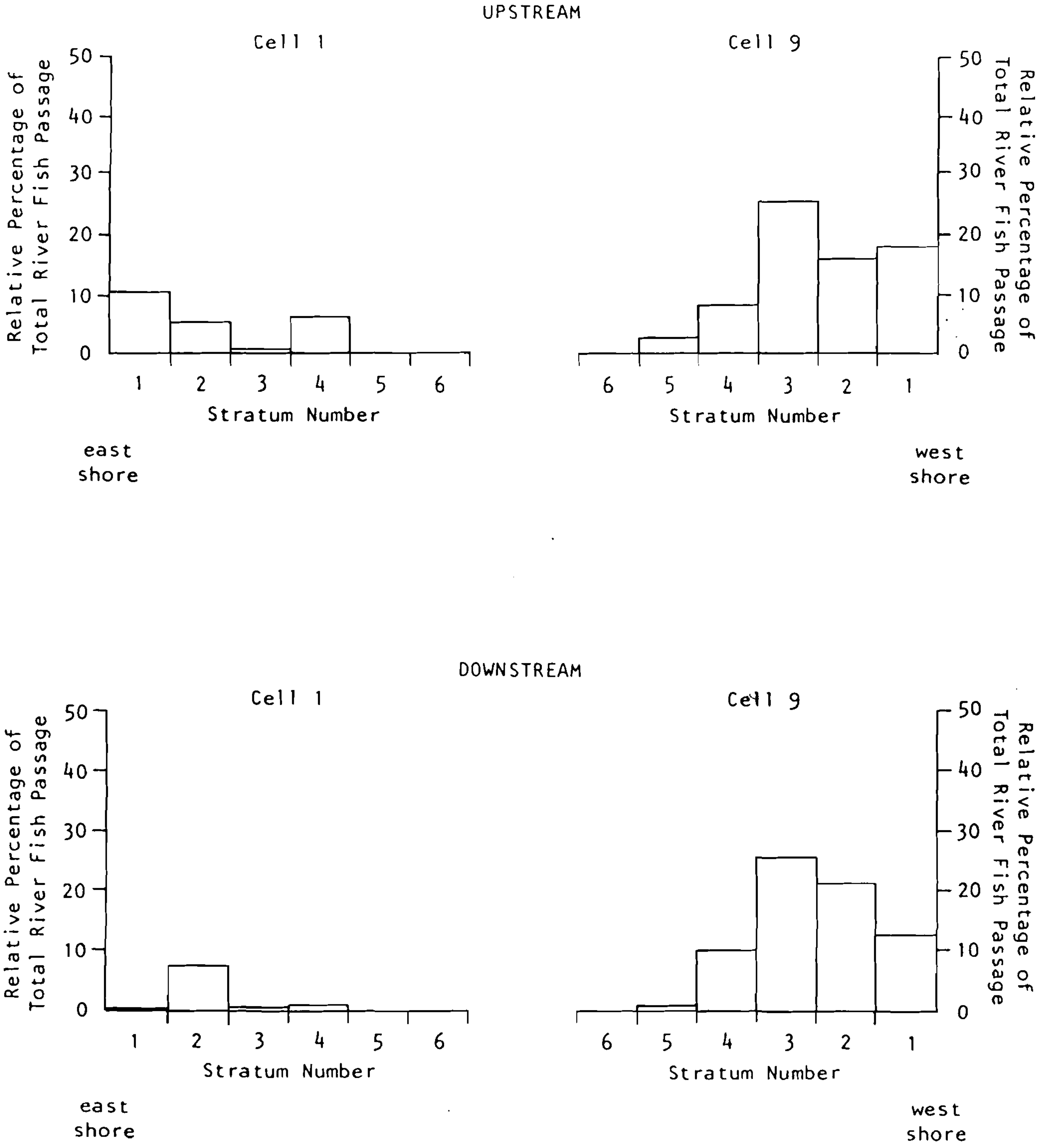


Figure N11. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Periods I and II (July 22-30). Susitna River, 1985.

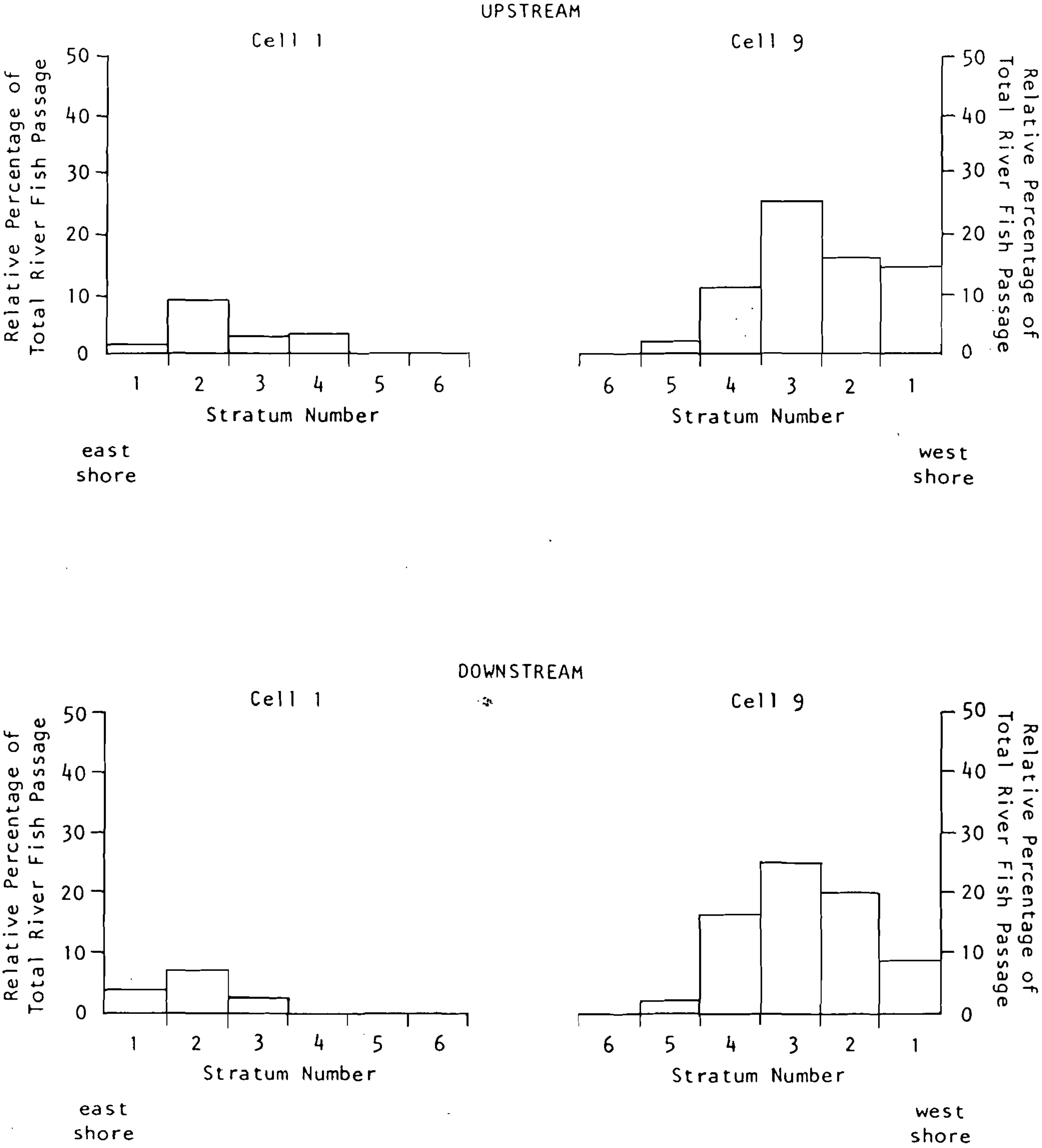


Figure N12. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table N1. Summary of mean horizontal distributions of adult salmon across the river, based on distributions by shift (Susitna River 1985).

Period		Fish	Relative Percentage Across River by Cell*									
Number	Dates	Direction	1	2	3	4	5	6	7	8	9	Total
I	7/22-25	Upstream	29.9/13.3	0	0	17.3/10.8	0	0	0	0	52.8/15.5	100.0
		Downstream	16.0/5.3	0	0	20.1/9.6	0	0	0	0	63.9/9.7	100.0
II	7/26-30	Upstream	3.9/1.3	0	0	11.9/4.8	0	0	0	0	84.2/4.9	100.0
		Downstream	8.6/2.7	0	0	8.4/3.1	0	0	0	0	83.0/5.7	100.0
III	7/31-8/3	Upstream	26.3/9.2	0	0	10.0/3.8	0	0	0	0	63.7/10.7	100.0
		Downstream	34.0/11.0	0	0	9.8/3.7	0	0	0	0	56.2/11.7	100.0
IV	8/4-8	Upstream	14.3/5.2	0	0	13.3/4.7	0	0	0	0	72.4/6.9	100.0
		Downstream	13.3/5.1	0	0	12.0/5.7	0	0	0	0	74.7/6.5	100.0
I-II	7/22-30	Upstream	14.6/6.2	0	0	14.1/5.1	0	0	0	0	71.3/7.7	100.0
		Downstream	11.9/2.8	0	0	13.6/4.7	0	0	0	0	74.5/5.7	100.0
I-IV	7/22-8/8	Upstream	17.2/3.9	0	0	12.9/2.9	0	0	0	0	69.9/4.8	100.0
		Downstream	15.2/2.9	0	0	12.3/2.9	0	0	0	0	72.5/4.0	100.0

* Relative percentage across the river/standard error.
Note that means and standard errors were calculated by period from untransformed data. If further statistical manipulations are anticipated they should be calculated on transformed data. Some form of an arcsin transformation would be most appropriate (Zar 1974).

Table N2. Summary of mean horizontal distributions of adult salmon across the river, based on distributions by shift (Susitna River 1985).

Period		Fish*	Relative Percentage Across the Cell, by Section**						
Number	Dates	Dir.	1	2	3	4	5	6	SUM
					Cell 1				
I	7/22-25	U	2.4/1.53	9.4/3.61	2.1/1.51	15.9/10.4	0	0	29.9/13.34
		D	0.2/0.13	11.6/4.13	1.2/0.50	3.0/1.71	0	0	16.0/5.33
II	7/26-30	U	0.1/0.09	3.2/1.17	0.6/0.40	0	0	0	3.9/1.28
		D	1.5/1.07	5.9/2.42	0.9/0.31	0.3/0.28	0	0	8.6/2.70
III	7/31-8/3	U	5.6/2.95	13.4/5.10	7.3/3.20	0	0	0	26.3/9.25
		D	11.8/6.41	13.8/6.28	8.4/3.55	0	0	0	34.0/11.02
IV	8/4-8	U	0	11.7/5.02	2.6/1.42	0	0	0	14.3/5.23
		D	4.9/4.92	5.0/2.11	3.3/1.70	0	0	0	13.3/5.07
I-II	7/22-30	U	1.1/0.67	5.8/1.75	1.3/0.66	6.6/4.51	0	0	14.6/6.18
		D	0.9/0.60	8.4/2.31	1.0/0.27	1.5/0.82	0	0	11.9/2.85
I-IV	7/22-8/8	U	1.8/0.80	9.2/2.04	3.0/0.95	3.2/2.33	0	0	17.2/3.94
		D	4.1/2.00	7.7/1.70	2.6/0.90	0.8/0.40	0	0	15.2/2.95

* Direction of fish movement, upstream or downstream.

** Relative percentage across the river/standard error.
Note that means and standard errors were calculated by period from untransformed data. If further statistical manipulations are anticipated they should be calculated on transformed data. Some form of an arcsin transformation would be most appropriate (Zar 1974).

Table N2, cont.

Period		Fish*	Relative Percentage Across the Cell, by Section**						
Number	Dates	Dir.	1	2	3	4	5	6	SUM
						Cell 9			
I	7/22-25	U	9.0/4.67	22.8/8.21	13.2/5.65	4.7/3.35	3.2/1.75	0	52.8/15.46
		D	15.2/5.20	23.4/5.70	12.2/5.41	11.5/3.74	1.6/1.01	0	63.9/9.67
II	7/26-30	U	25.5/2.94	10.8/3.89	34.2/3.92	11.6/2.39	2.1/0.59	0	84.2/4.89
		D	11.3/1.50	23.8/5.9	36.8/4.92	9.3/1.95	1.8/0.38	0	83.0/5.72
III	7/31-8/3	U	14.2/10.56	22.6/10.74	17.5/9.27	7.6/1.70	1.8/1.17	0	63.7/10.75
		D	6.9/5.70	14.4/7.14	12.5/3.41	20.3/4.64	2.1/0.79	0	56.2/11.72
IV	8/4-8	U	8.0/0.99	10.5/6.14	30.8/6.03	20.9/5.28	2.4/1.78	0	72.4/6.95
		D	0	18.0/7.00	25.9/4.76	25.8/6.17	5.0/2.52	0	74.7/6.55
I-II	7/22-30	U	18.7/3.23	15.8/4.19	25.5/4.09	8.7/2.08	2.6/0.78	0	71.3/7.73
		D	13.0/2.42	23.6/4.01	25.9/4.62	10.3/1.94	1.8/0.48	0	74.5/5.66
I-IV	7/22-8/8	U	14.6/2.88	15.8/3.59	25.2/3.36	11.9/2.04	2.3/0.67	0	69.9/4.81
		D	8.1/1.92	20.0/3.18	25.1/3.25	16.6/2.46	2.7/0.75	0	72.5/4.05

* Direction of fish movement, upstream or downstream.

** Relative percentage across the river/standard error. Note that means and standard errors were calculated by period from untransformed data. If further statistical manipulations are anticipated they should be calculated on transformed data. Some form of an arcsin transformation would be most appropriate (Zar 1974).

Appendix P: Relative Percentage of Upstream- Vs. Downstream-Moving Adult Salmon

Table P1. Relative percentage of upstream and downstream movement of adult salmon by shift, for the whole river (Susitna River 1985).

Date	Shift Number	Relative Percentage Upstream	Downstream	Total
July 22	15	0.0	100.0	100.0
	16	39.2	60.8	100.0
23	17	34.9	65.1	100.0
	18	6.6	93.4	100.0
24	19	40.0	60.0	100.0
	20	40.6	59.4	100.0
25	21	46.5	53.5	100.0
	22	36.3	63.7	100.0
26	23	39.1	60.9	100.0
	24	56.7	43.3	100.0
27	25	42.2	57.8	100.0
	26	44.3	55.7	100.0
28	27	41.8	58.2	100.0
	28	43.6	56.4	100.0
29	29	53.6	46.4	100.0
	30	57.9	42.1	100.0
30	31	42.9	57.1	100.0
	32	45.9	54.1	100.0
31	33	52.8	47.2	100.0
	34	70.5	29.5	100.0
August 1	35	79.0	21.0	100.0
	36	69.8	30.2	100.0
2	37	39.6	60.4	100.0
	38	62.6	37.4	100.0
3	39	41.2	58.8	100.0
	40	50.8	49.2	100.0
4	41	62.7	37.3	100.0
	42	70.6	29.4	100.0
5	43	49.8	50.2	100.0
	44	43.1	56.9	100.0
6	45	40.8	59.2	100.0
	46	43.0	57.0	100.0
7	47	35.3	64.7	100.0
	48	9.2	90.8	100.0
8	49	48.5	51.5	100.0
	50	28.2	71.8	100.0
	Mean (by Shift)	44.7	55.3	100.0
	Mean (Weighted by Fish Abundance)	47.9	52.1	100.0

Table P2. Relative percentage of upstream and downstream movement of adult salmon by shift at cell 1 (Susitna River 1985).

Date	Shift Number	Relative Percentage Upstream	Downstream	Total
July 22	15	0.0	0.0	0.0
	16	59.4	40.6	100.0
23	17	42.1	57.9	100.0
	18	0.0	100.0	100.0
24	19	61.7	38.3	100.0
	20	50.8	49.2	100.0
25	21	47.7	52.3	100.0
	22	55.4	44.6	100.0
26	23	16.6	83.4	100.0
	24	28.7	71.3	100.0
27	25	100.0	0.0	100.0
	26	64.3	35.7	100.0
28	27	61.9	38.1	100.0
	28	22.9	77.1	100.0
29	29	43.5	56.5	100.0
	30	45.6	54.4	100.0
30	31	0.0	100.0	100.0
	32	0.0	100.0	100.0
31	33	54.0	46.0	100.0
	34	47.2	52.8	100.0
August 1	35	62.4	37.6	100.0
	36	57.1	42.9	100.0
2	37	75.6	24.4	100.0
	38	23.9	76.1	100.0
3	39	100.0	0.0	100.0
	40	41.4	58.6	100.0
4	41	52.1	47.9	100.0
	42	56.9	43.1	100.0
5	43	0.0	100.0	100.0
	44	40.5	59.5	100.0
6	45	39.8	60.2	100.0
	46	100.0	0.0	100.0
7	47	0.0	0.0	0.0
	48	0.0	0.0	0.0
8	49	50.0	50.0	100.0
	50	0.0	0.0	0.0
	Mean (by Shift)	46.9	53.1	100.0
	Mean (Weighted by Fish Abundance)	47.6	52.4	100.0

Table P3. Relative percentage of upstream and downstream movement of adult salmon by shift at cell 4 (Susitna River 1985).

Date	Shift Number	Relative Percentage Upstream	Downstream	Total
July 22	15	0.0	100.0	100.0
	16	0.0	0.0	0.0
23	17	0.0	0.0	0.0
	18	12.2	87.8	100.0
24	19	12.5	87.5	100.0
	20	28.9	71.1	100.0
25	21	25.3	74.7	100.0
	22	39.2	60.8	100.0
26	23	77.1	22.9	100.0
	24	67.3	32.7	100.0
27	25	100.0	0.0	100.0
	26	60.6	39.4	100.0
28	27	0.0	100.0	100.0
	28	42.5	57.5	100.0
29	29	28.3	71.7	100.0
	30	51.8	48.2	100.0
30	31	64.7	35.3	100.0
	32	56.9	43.1	100.0
31	33	0.0	100.0	100.0
	34	42.4	57.6	100.0
August 1	35	33.3	66.7	100.0
	36	90.5	9.5	100.0
2	37	21.5	78.5	100.0
	38	67.8	32.2	100.0
3	39	0.0	0.0	0.0
	40	79.9	20.1	100.0
4	41	67.6	32.4	100.0
	42	0.0	0.0	0.0
5	43	0.0	0.0	0.0
	44	0.0	100.0	100.0
6	45	59.6	40.4	100.0
	46	100.0	0.0	100.0
7	47	21.3	78.7	100.0
	48	0.0	0.0	0.0
8	49	33.6	66.4	100.0
	50	100.0	0.0	100.0
	Mean (by Shift)	46.2	53.8	100.0
	Mean (Weighted by Fish Abundance)	51.7	48.3	100.0

Table P4. Relative percentage of upstream and downstream movement of adult salmon by shift at cell 9 (Susitna River 1985).

Date	Shift Number	Relative Percentage		Total
		Upstream	Downstream	
July 22	15	0.0	100.0	100.0
	16	0.0	100.0	100.0
23	17	32.4	67.6	100.0
	18	6.1	93.9	100.0
24	19	35.6	64.4	100.0
	20	40.6	59.4	100.0
25	21	46.7	53.3	100.0
	22	0.0	100.0	100.0
26	23	39.7	60.3	100.0
	24	59.5	40.5	100.0
27	25	41.6	58.4	100.0
	26	42.2	57.8	100.0
28	27	41.8	58.2	100.0
	28	45.9	54.1	100.0
29	29	54.3	45.7	100.0
	30	58.8	41.2	100.0
30	31	41.1	58.9	100.0
	32	49.5	50.5	100.0
31	33	54.4	45.6	100.0
	34	78.0	22.0	100.0
August 1	35	80.6	19.4	100.0
	36	67.5	32.5	100.0
2	37	25.0	75.0	100.0
	38	79.8	20.2	100.0
3	39	20.8	79.2	100.0
	40	54.9	45.1	100.0
4	41	60.1	39.9	100.0
	42	77.5	22.5	100.0
5	43	53.1	46.9	100.0
	44	49.4	50.6	100.0
6	45	38.1	61.9	100.0
	46	15.7	84.3	100.0
7	47	45.9	54.1	100.0
	48	9.3	90.7	100.0
8	49	49.9	50.1	100.0
	50	24.7	75.3	100.0
	Mean (by Shift)	42.2	57.8	100.0
	Mean (Weighted by Fish Abundance)	47.7	52.3	100.0

Appendix Q: Mean Fish Target Velocities

		Target Velocity by Cell*		
Period	Direction**	Cell 1	Cell 4	Cell 9
I	U	3.2 (0.96)/19	3.1 (0.95)/27	1.2 (0.37)/762
7/22-25	D	1.9 (0.58)/26	1.7 (0.53)/67	1.1 (0.34)/876
II	U	1.7 (0.51)/42	2.0 (0.60)/46	1.1 (0.34)/1172
7/26-30	D	1.5 (0.45)/53	1.4 (0.44)/52	1.0 (0.31)/1365
III	U	2.4 (0.72)/8	2.0 (0.60)/19	1.5 (0.45)/91
7/31-8/3	D	1.1 (0.35)/2	1.5 (0.45)/22	1.2 (0.37)/75
IV	U	2.8 (0.87)/9	2.0 (0.62)/13	1.7 (0.51)/65
8/4-8	D	3.4 (1.05)/9	1.2 (0.37)/14	1.3 (0.41)/74
I-II	U	2.1 (0.65)/61	2.4 (0.73)/73	1.1 (0.35)1934
7/22-30	D	1.6 (0.49)/79	1.6 (0.49)/119	1.1 (0.32)/2241
I-IV	U	2.2 (0.69)/78	2.3 (0.69)/105	1.2 (0.35)/2090
7/22-8/3	D	1.8 (0.55)/90	1.5 (0.47)/155	1.1 (0.33)/2390

* Velocity in fps (m/sec)/N.

** Direction of fish movement: U = upstream; D = downstream.

APPENDIX R: Individual Samples for Vertical Distribution of Fish over Two Strata in Cell 9 on July 28

Stratum	Relative Percentage of Fish Upstream	Downstream	Total
		0128 h (N=38)	
	Vertical Distribution by Direction of Fish Movement		
1 Surface	10.5	26.7	17.6
2 Bottom	89.5	73.3	82.4
	-----	-----	-----
Total	100.0	100.0	100.0
	Fish Movement by Direction within Surface Stratum		
1 Surface	33.3	66.7	100.0
	Fish Movement by Direction within Bottom Stratum		
2 Bottom	60.7	39.3	100.0
		1111 h (N=58)	
	Vertical Distribution by Direction of Fish Movement		
1 Surface	15.4	15.6	15.5
2 Bottom	84.6	84.4	84.5
	-----	-----	-----
Total	100.0	100.0	100.0
	Fish Movement by Direction within Surface Stratum		
1 Surface	44.4	55.6	100.0
	Fish Movement by Direction within Bottom Stratum		
2 Bottom	44.9	55.1	100.0

Appendix S: Acoustic Size of Fish

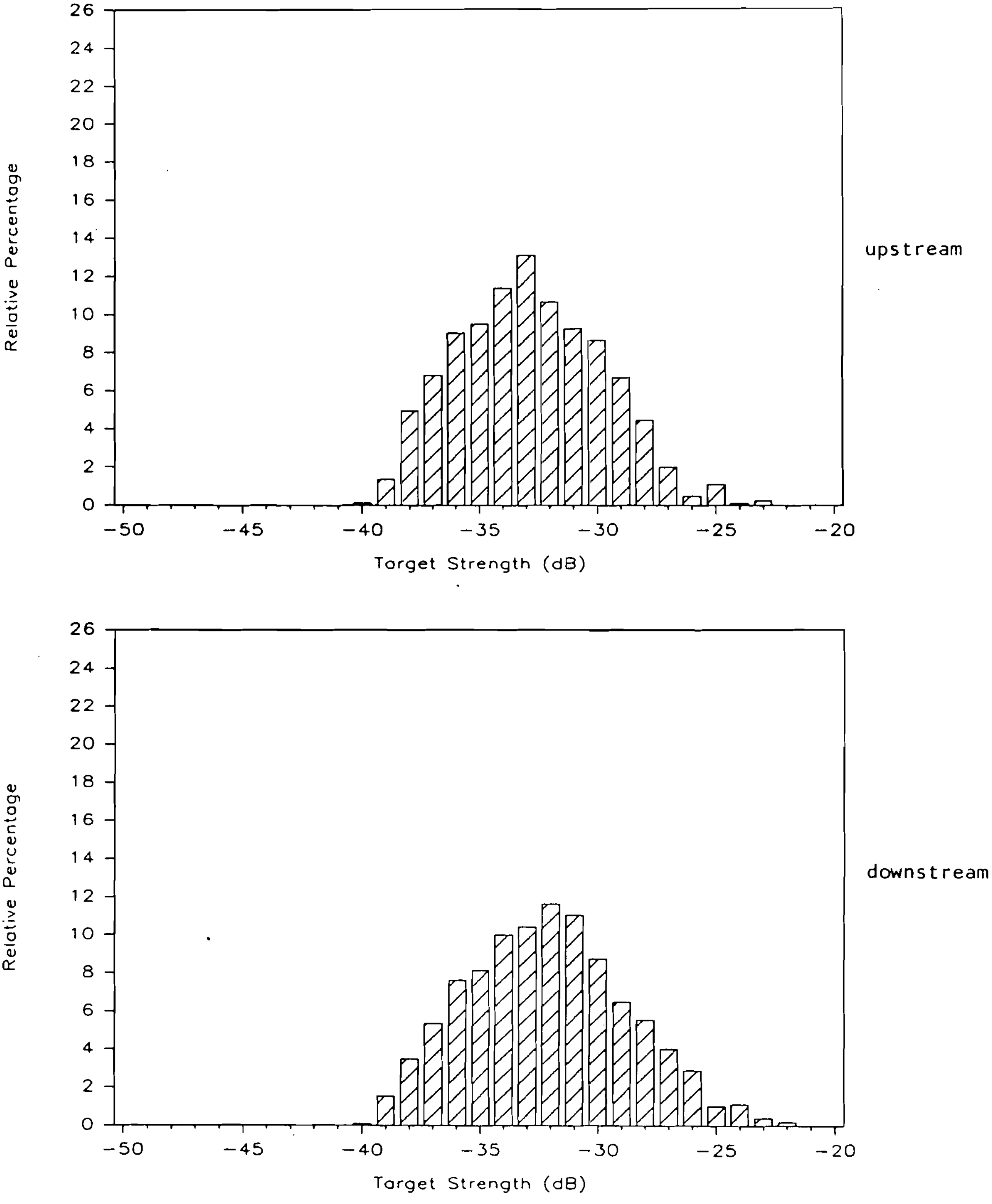


Figure S1. Acoustic size distribution of fish during Period I (July 22-25). Susitna River, 1985.

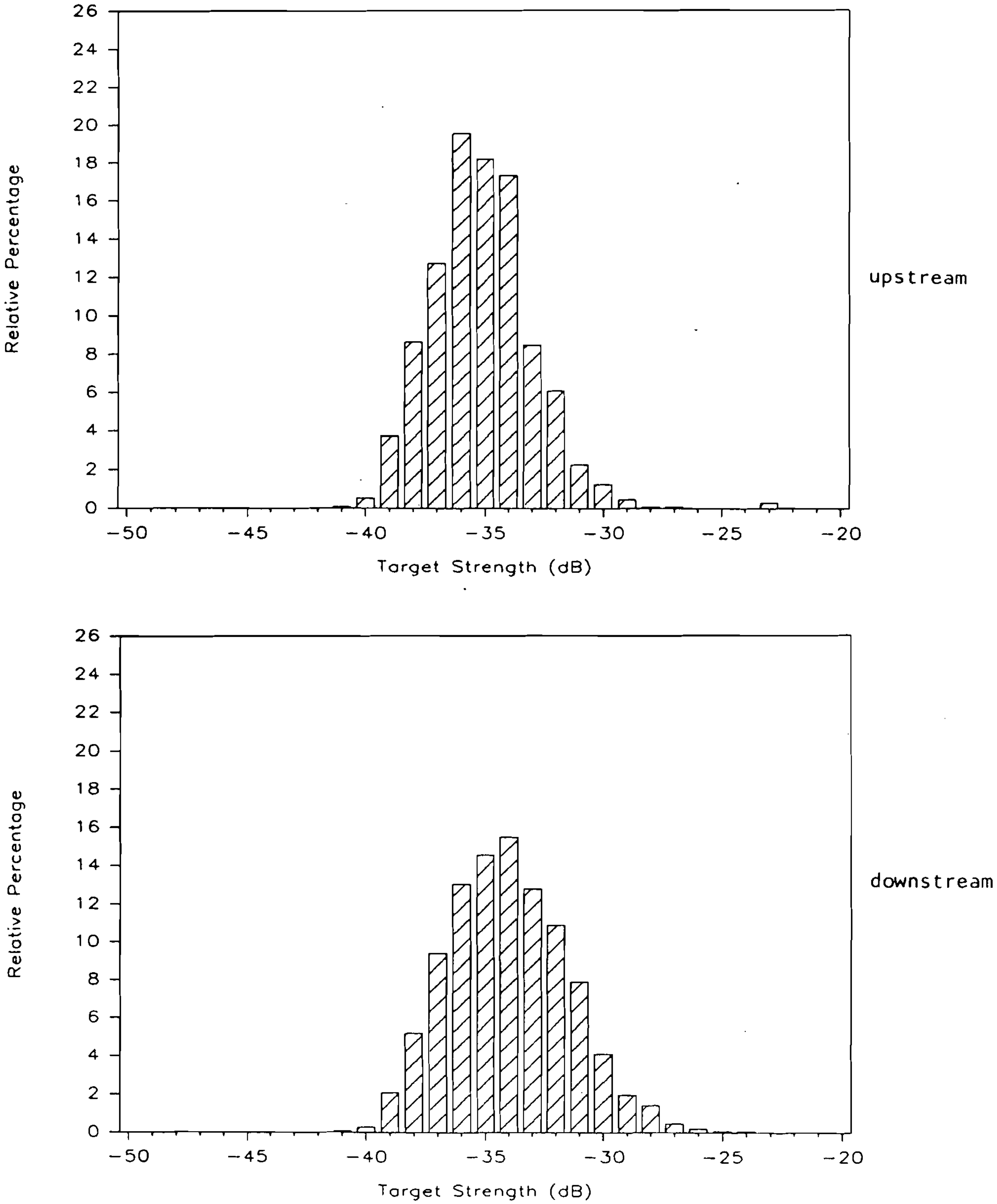


Figure S2. Acoustic size distribution of fish during Period II (July 26-30). Susitna River, 1985.

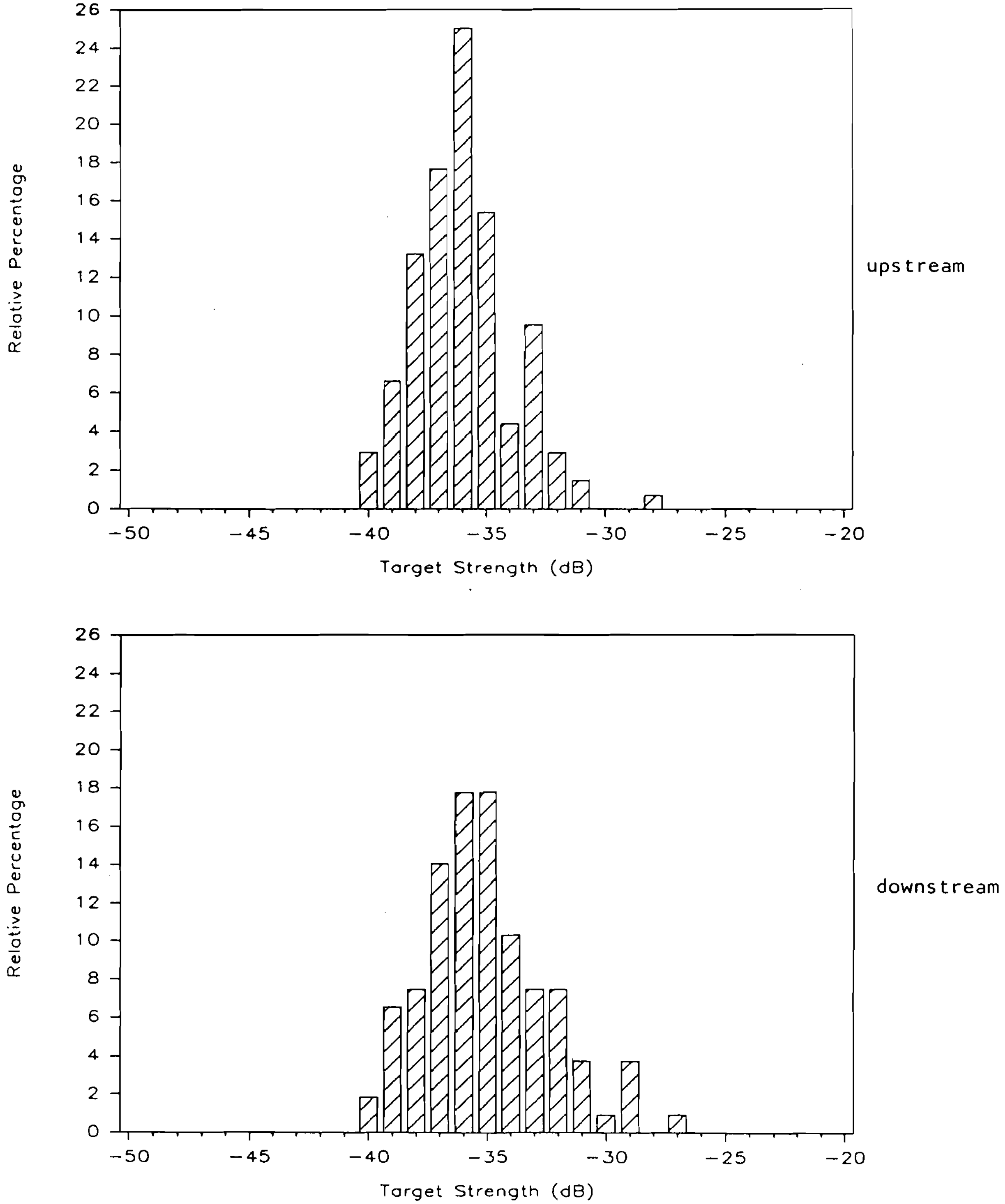


Figure S3. Acoustic size distribution of fish during Period III (July 31 - August 3). Susitna River, 1985.

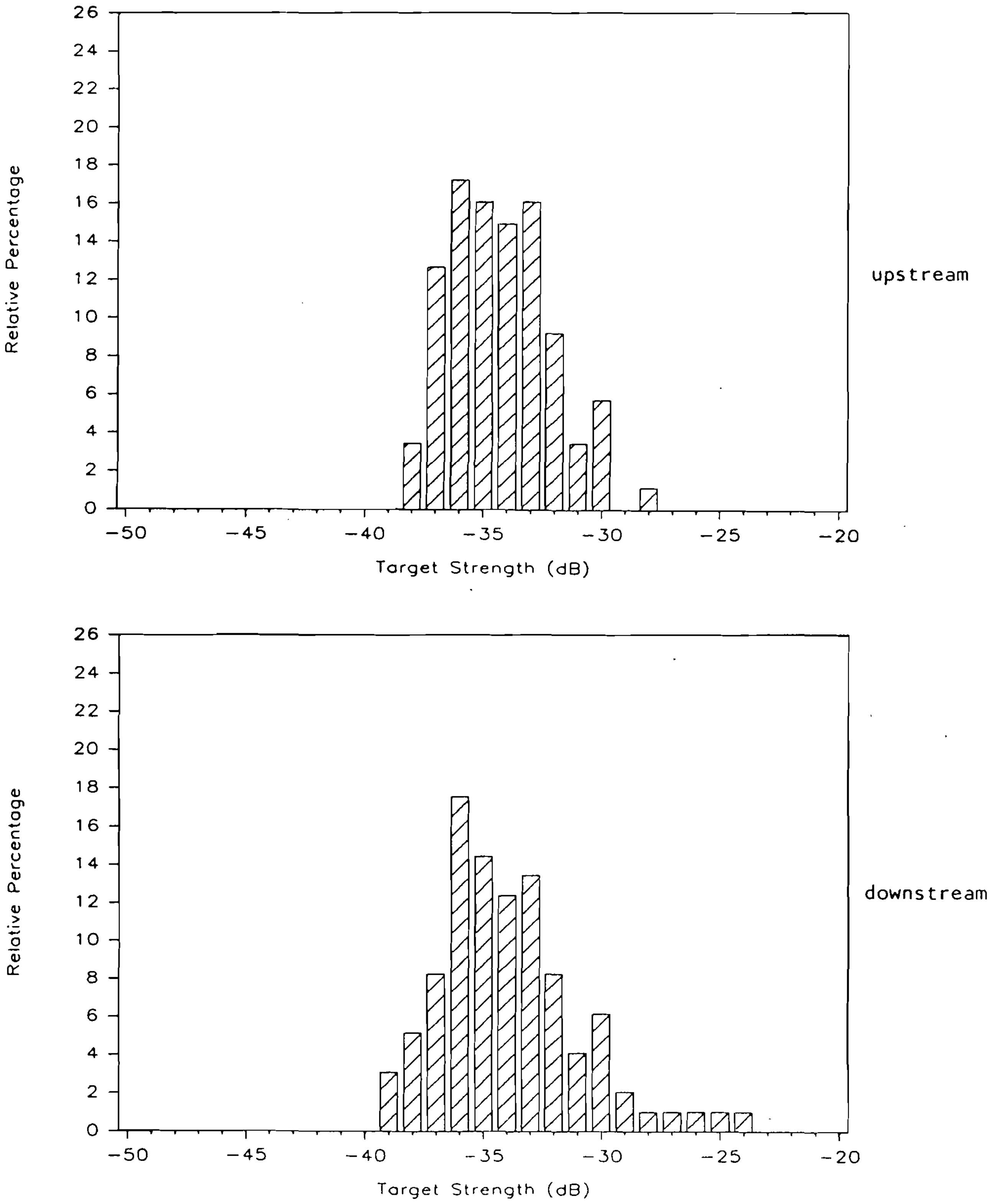


Figure S4. Acoustic size distribution of fish during Period IV (August 4-8). Susitna River, 1985.

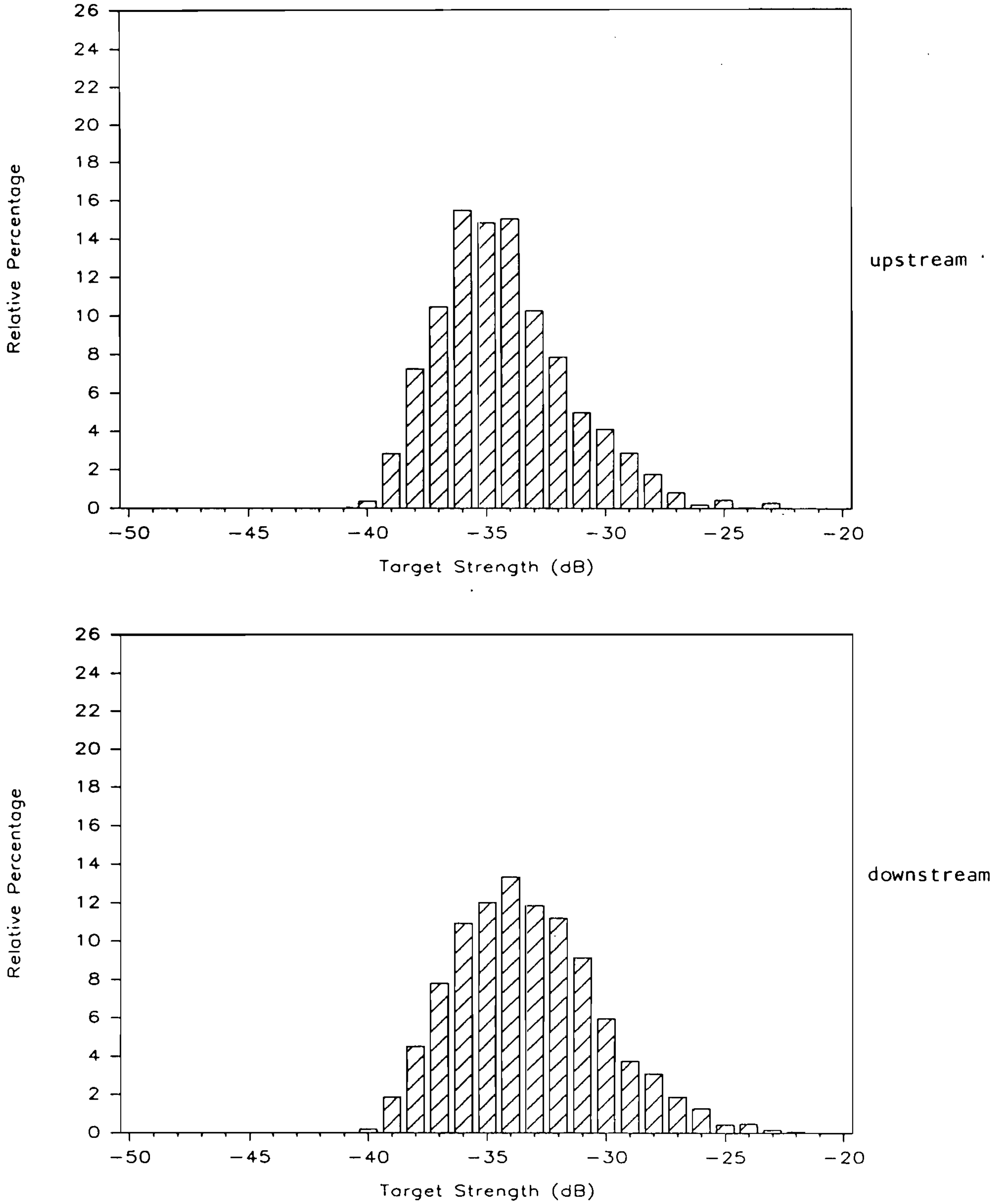


Figure S5. Acoustic size distribution of fish during Periods I and II (July 22-30). Susitna River, 1985.

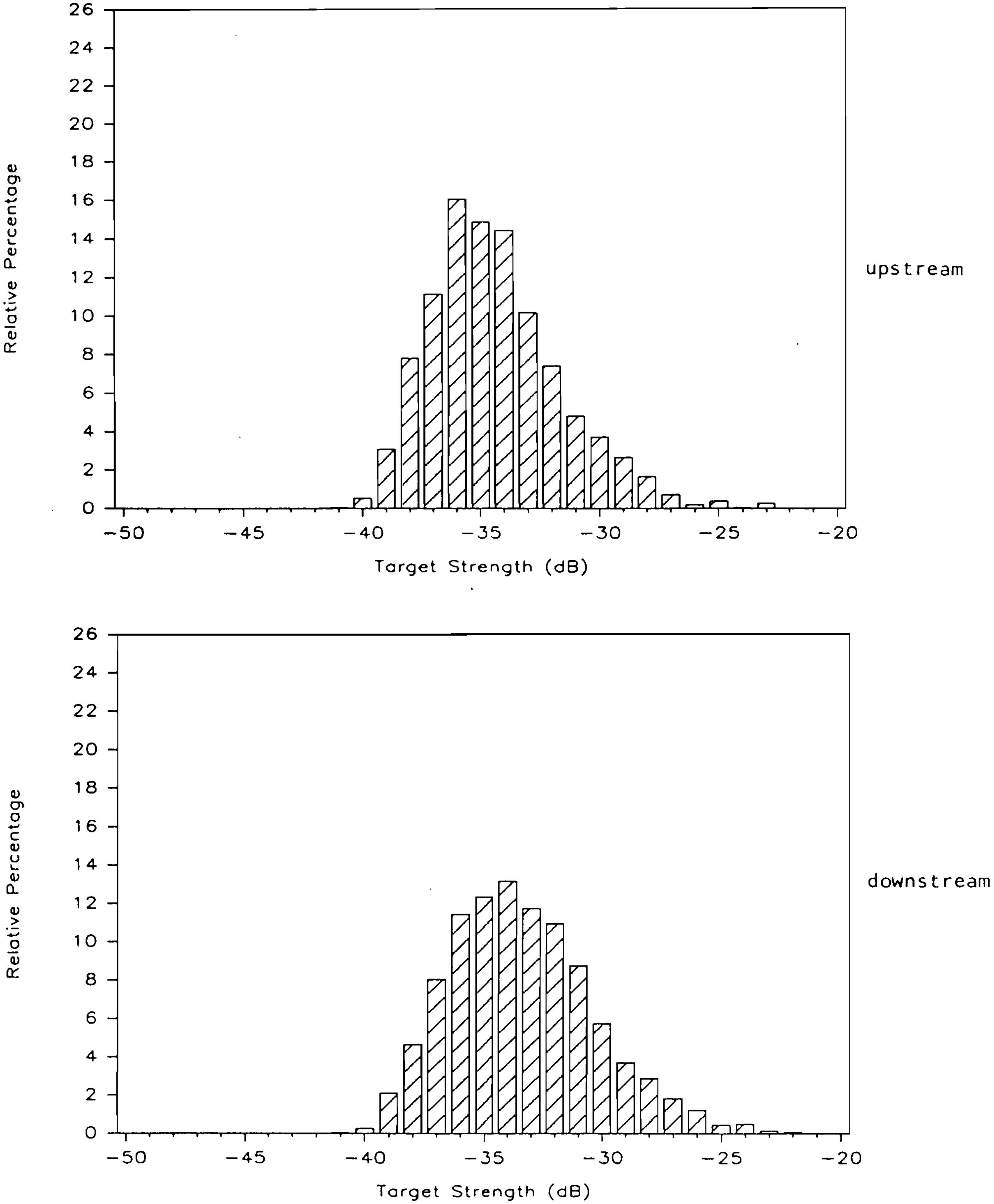


Figure S6. Acoustic size distribution of fish during Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table S1. Target strength frequency distributions by period for upstream moving fish (Susitna River 1985).

TS	Period	Period	Period	Period	Period I-II	Period I-IV
-20	0	0	0	0	0	0
-21	0	0	0	0	0	0
-22	0	0	0	0	0	0
-23	2	4	0	0	6	6
-24	1	0	0	0	1	1
-25	9	0	0	0	9	9
-26	4	0	0	0	4	4
-27	16	1	0	0	17	17
-28	36	1	1	0	37	38
-29	54	6	0	1	60	61
-30	70	16	0	0	86	86
-31	75	29	2	5	104	111
-32	86	78	4	3	164	171
-33	106	109	13	8	215	236
-34	92	222	6	14	314	334
-35	77	233	21	13	310	344
-36	73	250	34	14	323	371
-37	55	163	24	15	218	257
-38	40	111	18	11	151	180
-39	11	48	9	3	59	71
-40	1	7	4	0	8	12
-41	0	1	0	0	1	1
-42	0	0	0	0	0	0
-43	0	0	0	0	0	0
-44	0	0	0	0	0	0
-45	0	0	0	0	0	0
-46	0	0	0	0	0	0
-47	0	0	0	0	0	0
-48	0	0	0	0	0	0
-49	0	0	0	0	0	0
-50	0	0	0	0	0	0
SUM	808	1279	136	87	2087	2310

Table S2. Target strength frequency distributions by period for downstream-moving fish (Susitna River 1985).

TS	Period	Period	Period	Period	Period I-II	Period I-IV
-20	0	0	0	0	0	0
-21	0	0	0	0	0	0
-22	2	0	0	0	2	2
-23	4	0	0	0	4	4
-24	11	1	0	1	12	13
-25	10	1	0	1	11	12
-26	28	3	0	1	31	32
-27	39	7	1	1	46	48
-28	54	21	0	1	75	76
-29	63	29	4	2	92	98
-30	85	61	1	6	146	153
-31	107	117	4	4	224	232
-32	113	161	8	8	274	290
-33	101	189	8	13	290	311
-34	97	229	11	12	326	349
-35	79	215	19	14	294	327
-36	74	193	19	17	267	303
-37	52	139	15	8	191	214
-38	34	77	8	5	111	124
-39	15	31	7	3	46	56
-40	1	4	2	0	5	7
-41	0	1	0	0	1	1
-42	0	0	0	0	0	0
-43	0	0	0	0	0	0
-44	0	0	0	0	0	0
-45	0	0	0	0	0	0
-46	0	0	0	0	0	0
-47	0	0	0	0	0	0
-48	0	0	0	0	0	0
-49	0	0	0	0	0	0
-50	0	0	0	0	0	0
SUM	969	1479	107	97	2448	2652