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

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DRAFT REPORT

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, and to begin developing a hydroacoustic technique for future enumeration of adult salmon in the Susitna River.

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 27.

Upstream and downstream moving fish had similar horizontal distributions across the river. For the total season, approximately 88% of the fish 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).

Along the west shore (cell 9) fish tended to be oriented near the bottom, the upstream moving fish more so than downstream fish. Horizontal and vertical distributions suggested that fish were oriented primarily toward low velocity water 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.

During the study period, 48% of the fish were moving upstream, and 52% downstream. This high incidence of downstream movement was probably due in large part to turbulence caused by water being forced around Petes Point, upstream of the study site. It also appears that 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 determined to have been moving upstream.

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.

The location of ensonified volumes relative to the surface and bottom could be better defined by experiments in the field using standard targets.

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 by about 20-30 ft (6-9 m).

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.

The factors that need to be addressed in order to develop a technique to reliably enumerate salmon in the river have been noted, and each has high potential. It is recommended that hydroacoustic monitoring of migrating adult salmon in the Susitna River be continued in 1986. Improvements to the technique applied in 1985 could be evaluated and implemented. Since a large pink salmon run and other factors could affect fish horizontal distributions, any fish enumeration strategy should incorporate plans to periodically examine the horizontal distributions of fish across the river.

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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 (ADFG) has in the past attempted to enumerate the Susitna River runs in-season. In the lower part of the 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, ADFG 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, and
2) vertical distribution of migrating adult salmon.

Secondary objectives were to:

3) estimate the acoustic size (target strength) of migrating adult salmon, and
4) begin developing a hydroacoustic technique for future enumeration of adult salmon in the Susitna River.

1.3 Site Description

The Susitna River lies northwest from 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 salmon (*Oncorhynchus keta*) and one of the primary producers of sockeye salmon (*O. nerka*) in the Upper Cook Inlet. Other salmon species occurring were pink (*O. gorbuscha*), silver (*O. kisutch*), and king (*O. tshawytscha*) salmon.

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) 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/s)).

Hydroacoustic sampling of migrating salmon took place for 25 d 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 not usually sampled. Shifts were numbered sequentially. A list of dates and times for each shift appears in Appendix A.

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. 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.

During the low water period, water velocities were measured on July 24 and August 6 with a Marsh-McBirney portable water current meter.

Concurrent with hydroacoustic sampling, ADFG conducted fish wheel sampling along the east bank at cell 1 (Figure 2). Gill net drift sampling also took place near the sample transect.

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 B.

Primary data were obtained by surface-mounted and side-mounted transducers attached to the boat (Figures 4 and 5). Where depth permitted, the surface-mounted transducer was deployed and oriented 30° downward and downstream. Side-mounted transducers in the two sample cells nearest shore (i.e., cells 1 and 9) and in cell 4 were aimed horizontally into the river and 45° downstream. In cells 1 and 9, transducers were positioned as near the shore as practical. In cell 4 the transducer was located near the shallowest area and aimed toward the middle of the river. In all the deepwater cells (cells 2, 3, and 5-8), a side-mounted transducer was aimed 45° downstream and near the surface.

At cell 9, a second horizontal 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 provided by a bottom-mounted transducer aimed 30° off vertical and downstream.

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 C.

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 then used to calculate fish acoustic size (i.e., target strength), as detailed in Appendix D.

Because the dual-beam transducers were aimed at either 30° or 45° downstream (for surface-mounted and side-mounted 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 determined the fish's direction of movement (i.e., either upstream or downstream). This procedure is detailed in Appendix E.

Occasionally, data tapes included spurious bottom returns. These tapes were processed separately. The individual fish traces from these samples were counted from the chart recorder echograms and then weighted as with all other data as described below.

Individual fish detections were sorted by direction of movement, weighted to compensate for beam spreading with range from the transducer, and used to calculate a mean fish flux (quantity of fish/time/area). Daily water levels were recorded (Appendix M) and used to estimate the cross-sectional area of individual strata within cells. Fish flux was multiplied by this area to give a passage rate (quantity of fish/time). Passage estimates were summed over strata to obtain the passage rate for a total cell. The total fish passage rates by cell were then divided by the sum of all cells' passage rates to obtain estimates of horizontal distribution across the river.

The data analysis procedure is explained in more detail in Appendix F.

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, 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, mean 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. 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 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 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 most variable when passage rates were lower.

All distributions were calculated separately for upstream and downstream migrating fish.

3.1.2 Results and Discussion

Run Timing

The run timing index is presented in Figure 6 and Table 1. 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 respectively lower rates in periods I, III, and IV.

The cumulative run timing index by shift for the whole season indicated that 91% of the adult salmon passed between July 24 and August 1. Fifty percent of the fish had passed by July 27 (Figure G1).

ADFG fish wheel catches for period I were comprised primarily of sockeye salmon, while the other periods yielded a mixture of sockeye, silver, pink, and chum salmon.

Horizontal Distributions Weighted for Fish Abundance

The horizontal distributions weighted for fish abundance are presented by period in Table 2. The distributions for periods I-IV combined appear in Figure 7. Other distributions weighted for abundance are presented by day and period in Appendix H.

All horizontal distributions weighted for fish abundance 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). All distributions indicate the vast majority of these fish occurred in the westernmost cell (cell 9). For the entire study period (periods I-IV), the weighted distributions show approximately 88% of all fish in cell 9, and approximately 7% and 5% in cells 1 and 4, respectively (Table 2). Percentages by period for cell 9 varied from 61-92%. For cells 1 and 4, percentages varied from 4-31% and 3-18%, respectively.

The weighted distributions over the season were nearly identical for upstream and downstream moving fish (Figure 7 and Table 2). 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% of river total).

Mean Horizontal Distributions from Distributions by Shift

The mean horizontal distributions by period appear in Appendix F. These distributions exhibited the same trends as those weighted for abundance, but with slight shifts away from cell 9 and toward cells 1 and 4. For the total season, approximately 16% 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 H and I for abundance-weighted and mean horizontal distributions, respectively.

Distributions within these two near-shore cells were heavily weighted toward shore, with some drop off in fish percentages in the 20-40 ft (6.1-12.2 m) sections nearest 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) (Figure 8 and Table 3). While the magnitudes of the percentages were smaller on the east bank, the fish were similarly shore-oriented.

In cell 9, there appeared to be a slightly stronger tendency for offshore orientation of downstream moving fish than for upstream moving fish.

Discussion

An examination of individual horizontal distributions by shift reveals much variability between percentages for cells 1, 4, and 9 (Table H1). High variability appears to correspond with relatively low passage rates (Figure 6, Table 1). When passage rates were relatively high, horizontal distributions were consistently weighted toward cell 9.

The horizontal distributions weighted for fish abundance were calculated from the total numbers of fish passing through each cell during a given period. It is believed that these distributions are most representative of fish within a given period.

The extremely shore-oriented distributions of migrating salmon can probably be attributed in large part to the low water velocities observed at these locations. The fish were probably not distributed so much toward the shore or shallow depths, but toward slower water velocities. The force of water flow poses the most resistance to their upstream progress. In an effort to conserve energy, the salmon apparently tended to take the route of least resistance. If one compares Figures 3 and 7, a correlation between high fish percentages and low water velocities appears. Most fish tended to be located where water velocities were < 0.5 fps (0.15 m/s).

Mean fish target velocities are shown in Appendix L. Estimated mean velocities throughout the season were 1.13 fps (0.35 m/s) and 1.07 fps (0.33 m/s) for upstream and downstream moving fish, respectively (Appendix K). Since most fish were located where velocities were approximately 0.5 fps (0.15 m/s) or less, swimming speeds of upstream moving fish averaged approximately 1.6 fps (0.49 m/s) or less. 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 N), they would have had to expend much more energy.

The reasons for the much higher proportion of fish along the west shore compared to the east shore are unknown. These results suggest that these fish were predominantly destined for the Yentna River system, and that Susitna River system runs upstream were considerably smaller. However, the extent of crossover from the west side to the east side of the river further upstream is unknown.

As the within-cell distributions show, there was a drop in fish numbers nearest shore. This drop can in part be attributed to shallower depths near-shore, and thus a smaller cross-sectional area with which to accommodate fish passage. It is also likely that some fish nearest the transducer passed undetected. Non-detection could be due to the small sample volume nearest the transducers, or to the fish being bottom-oriented (Section 3.2). Throughout the course of data collection and analysis, several improvements to the hydroacoustic applications of this study were suggested to greatly improve the probability of detecting these fish (Section 3.4).

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 will be in 1986 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 analyses were 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 side-mounted, horizontally aimed transducers which monitored the shallow, near-shore areas.

Twice on July 28, during relatively high fish passage, a side-mounted transducer was aimed alternately near the surface and near the bottom. Fish detections were counted by direction of movement, and relative percentages of fish numbers between the two strata were calculated.

3.2.2 Results and Discussion

Results from counts of fish monitored in each stratum showed that 17% of the fish were located in the upper portion of the water column, and 83% in the bottom portion (Table 4).

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.

It is probable 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 N).

It is also conceivable that salmon actively swimming upstream tended to be more bottom oriented than those moving downstream. Unlike upstream moving fish, downstream 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 strengths (acoustic sizes) were calculated for individual fish as detailed in Appendix D. Mean target strengths were calculated for each of the six periods, and converted to approximate total fish lengths, as explained in Appendix D.

3.3.2 Results and Discussion

Mean target strengths and corresponding fish lengths appear in Table 5. Target strength frequency distributions for the total study period appear in Figure 9, and distributions by individual period appear in Appendix J.

The mean target strengths for the season were -35.4 dB and -34.4 dB (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) for upstream and downstream migrating fish.

ADFG fishwheel catches indicated that primarily sockeye salmon passed in the first period, and that other periods contained a mixture of salmon species.

3.4 Objective 4: Development of the hydroacoustic technique for enumeration of migrating adult salmon in the Susitna River

During data collection in the field and data analysis in the laboratory, refinements to the sampling technique were noted that would enhance hydroacoustic monitoring of adult salmon in the Susitna River. Related findings and suggested improvements are presented below.

3.4.1 Improved Sampling Near the Bottom

An important improvement would be to sample more thoroughly near the bottom. Most fish were located near the bottom (Section 3.2), upstream moving fish more so than downstream fish. The following applications should greatly improve detection of these fish.

Improved Siting

Other sites on the river may be more conducive to hydroacoustic monitoring. The most desirable near-shore sites would have a smooth bottom profile, a soft substrate, a minimum of turbulence, and an initial rapid drop in depth from shore. The west shore just below Petes Point (cell 9) exhibited a high proportion of downstream moving fish (52%) (Table L4), probably due to the high water velocities and turbulence caused by the river being sharply diverted around the point. Similar trends were observed at cells 1 and 4 (Tables L2 and L3). A significant correlation between river water level and the relative percentage of downstream traveling fish was found ($r=0.439$, $N=36$, $p<0.01$) (Figures L1 and L2).

From July 30 to August 8, supplemental monitoring was conducted 10 times at a site along the west shore approximately 600 ft (183 m) upstream from Petes Point (Figure 2). Here, 79% of the detected fish were moving upstream. Moving the west shore sample site to this area could provide improved monitoring of upstream moving salmon.

Use of Elliptical Transducers

Dual-beam transducers with elliptical beam patterns are available with a 3° x 7° narrow beam and 10° x 21° wide beam. (Circular-beam transducers of 6° and 15° were used in 1985.) The elliptical transducers would sample better near the bottom and at close ranges to the transducer. Fish at these locations would be in the broader acoustic beam for a longer time, resulting in more detections per fish.

Use of Two Transducers in Tandem

The near-shore areas would be more efficiently sampled by multiplexing between two transducers, one sampling near the surface and the other sampling near the bottom. Multiple transducers could also be strategically aimed to compensate for irregular bottom profiles.

Shallower Downstream Aiming Angles

The data from the side-mounted, 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 D2). By aiming transducers downstream 15-30°, the strength of signal returns can be increased by approximately 3-6 dB (50-100%), compared to a 45° aiming angle (Appendix D). This added signal-to-noise ratio would allow closer aiming of transducers to the bottom, thereby improving the probability of detecting fish near the bottom.

Better Defined Sample Volume

The actual sample volume, and its proximity to the bottom and surface, can best be defined under field conditions by actual experimentation. 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. Before the salmon arrive, acoustic measurements can be made using standard targets. In this way, other improvements can be evaluated in their ability to enhance monitoring near the bottom.

More Stable Work Platform

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

3.4.2 Other Improvements to Sampling Technique

Weir Salmon Away from Shore

There were no large differences in upstream and downstream fish target velocities (Appendix K). This suggests that there should be no disparity in hydroacoustic detectability between the two groups. Also, all velocities were slow enough to allow ample ensonifications at all but extremely close ranges.

Migrating adult salmon were visually observed very close to the west shore, in water as little as 6-12 inches (15-30 cm) deep. In an effort to better sample these fish, a weir could be placed near shore immediately downstream of the sample site to deflect fish approximately 20-30 ft (6-9 m) into the river. This approach could greatly improve the probability of detecting fish normally passing through the first two sections of cells 1 and 9.

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 technique is flexible enough to permit rapid altering of sampling strategies to compensate for these changes.

4.0 CONCLUSIONS AND RECOMMENDATIONS

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 adult salmon passed. Fifty percent had passed by July 27.

3. Upstream and downstream moving fish had similar horizontal distributions across the river.

4. During the study period, approximately 88% of the fish passed through the cell nearest the west shore (cell 9), 7% through the cell nearest the east shore (cell 1), and 5% through a shallow cell near the middle of the river (cell 4).

5. During the study period, 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). This trend of shoreward orientation was also observed along the east shore (cell 1).

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

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

8. During the 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 turbulence caused by water being forced around Petes Point upstream of the sample site.

10. It also 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 noted which would improve monitoring of the near-bottom and near-shore fishes. The flexibility of this technique lends itself to timely evaluation and implementation of these improvements.

11. At a more hydraulically stable test site upstream of Petes Point, 79% of the monitored fish were determined to have been moving upstream.

12. 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.

13. 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.

14. The location of ensonified volumes relative to the surface and bottom could be estimated by experiments in the field using standard targets.

15. A stable work platform is essential for reliable aiming of acoustic beams. A stable boat or semi-permanent bottom mount for transducers would greatly benefit monitoring near the bottom.

16. Monitoring of the fish nearest the west shore would be enhanced by weiring fish out away from shore 20-30 ft (6-9 m). A weir on the east shore could also improve detectability.

17. Any sampling strategy in even numbered years will need to be flexible enough to deal with very large densities of pink salmon. Since a large pink run and other factors could affect fish horizontal distributions, any fish 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 tasks.

18. 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 real-time basis.

19. Experience gained in 1985 has confirmed the ability of fixed-location hydroacoustics to monitor salmon in the Susitna River. The factors that need to be addressed in order to develop a technique to reliably enumerate salmon in the river have been noted, and each has high potential. It is recommended that hydroacoustic monitoring of migrating adult salmon in the Susitna River be continued in 1986. Improvements to the technique applied in 1985 could be evaluated and implemented. The data collection crew should arrive at least one week prior to commencement of actual sampling in order to search for better sampling sites, test elliptical transducers, test semi-permanent transducer mounts, and perform standard target measurements to better define sample volumes.

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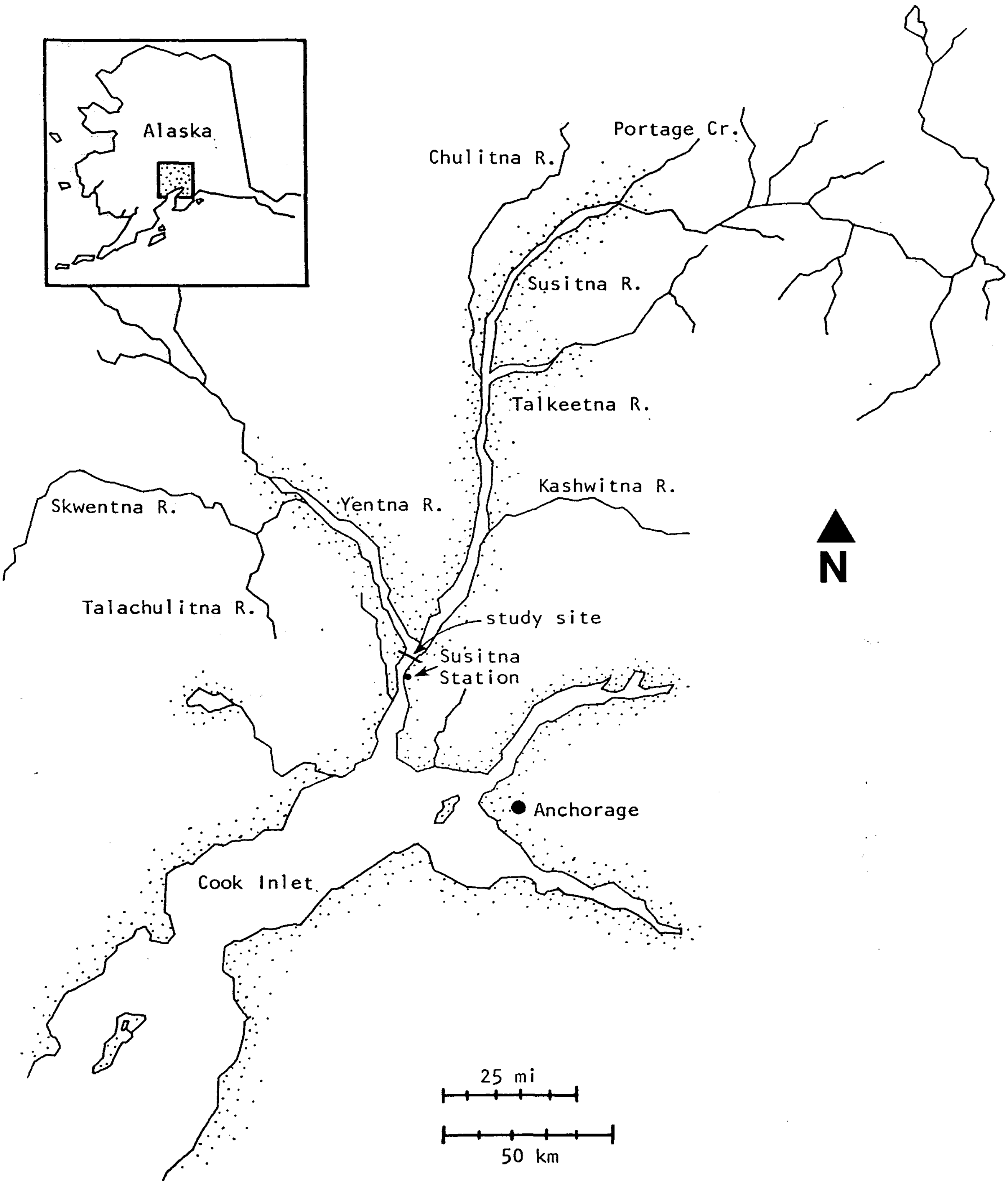


Figure 1. Susitna River drainage, showing Susitna Station and the 1985 study site location.

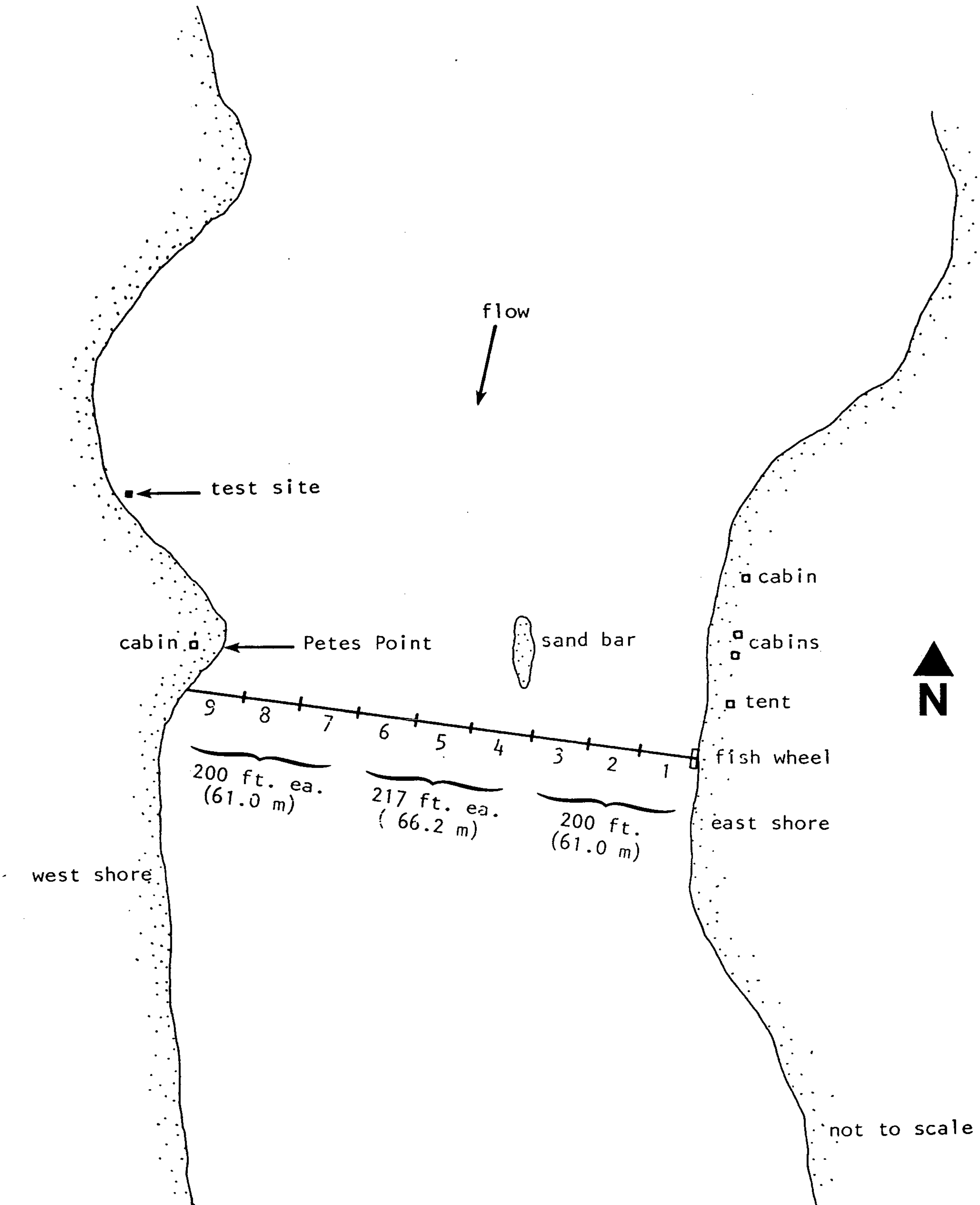


Figure 2. Study site, sample transect, and sample cell locations at RM 28. Susitna River, 1985.

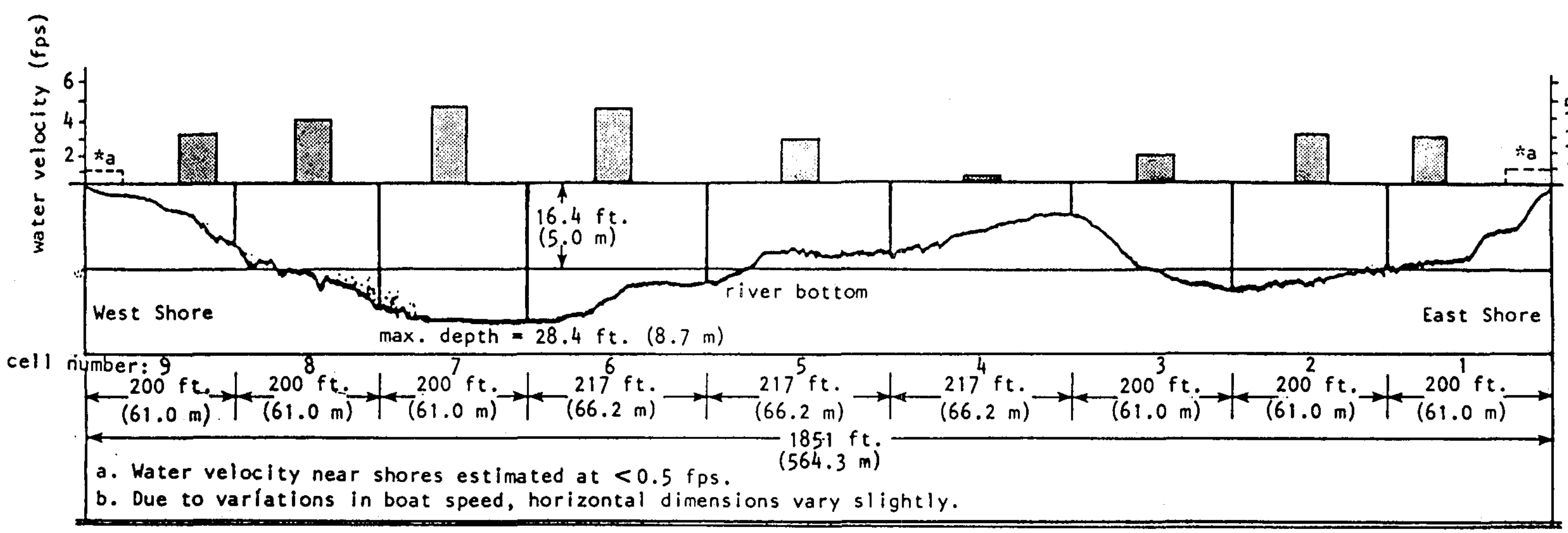


Figure 3. Sample cells and depth profile along the transect sampled hydroacoustically in 1985. Transect was recorded July 18. Transducer was 21 inches (53 cm) below the water surface. Susitna Station staff gauge was 0.9 feet (27 cm) above the lowest water level observed during the study (August 6). Susitna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

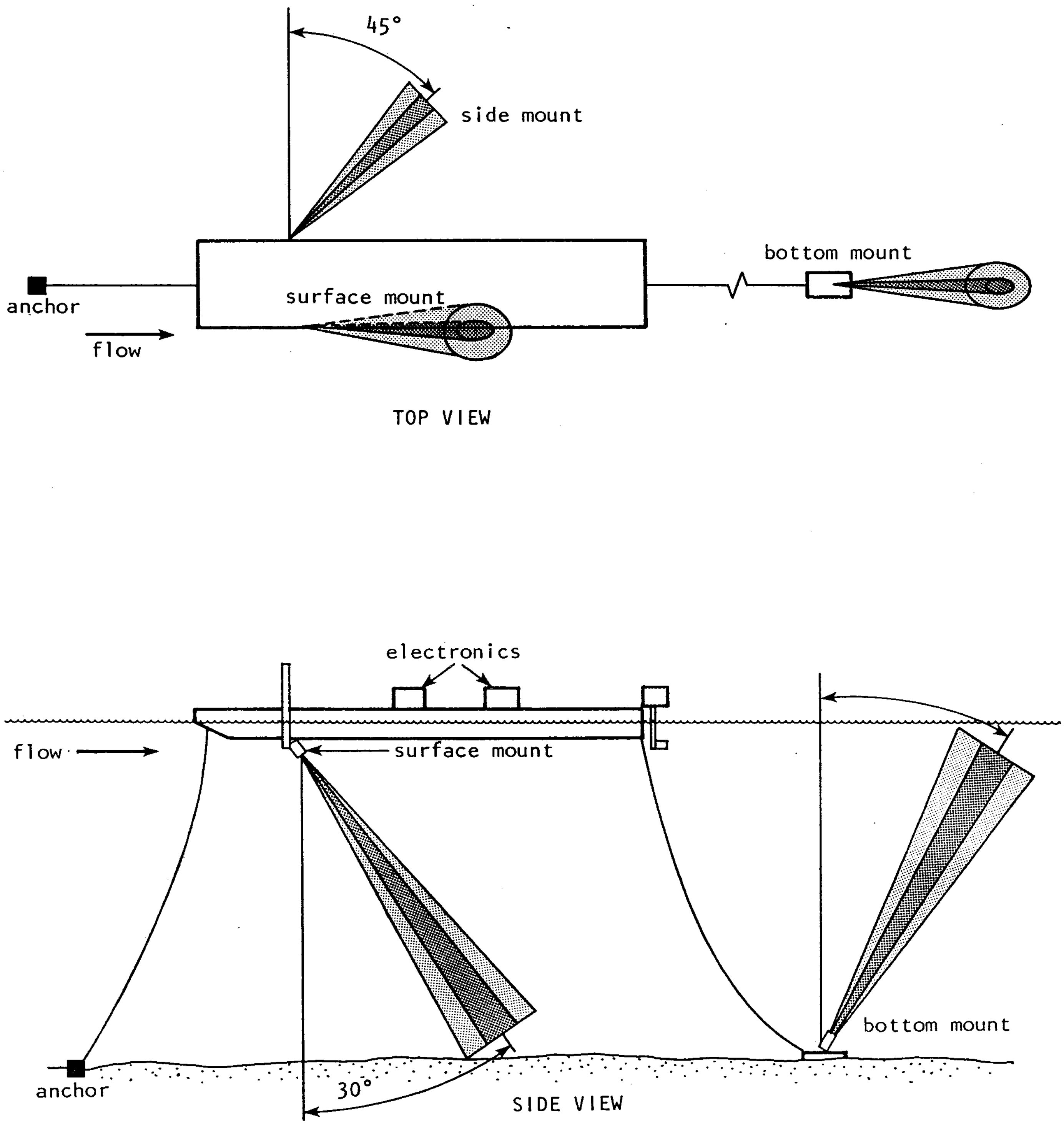


Figure 4. Location and orientation of transducers on sample boat. Susitna River, 1985.

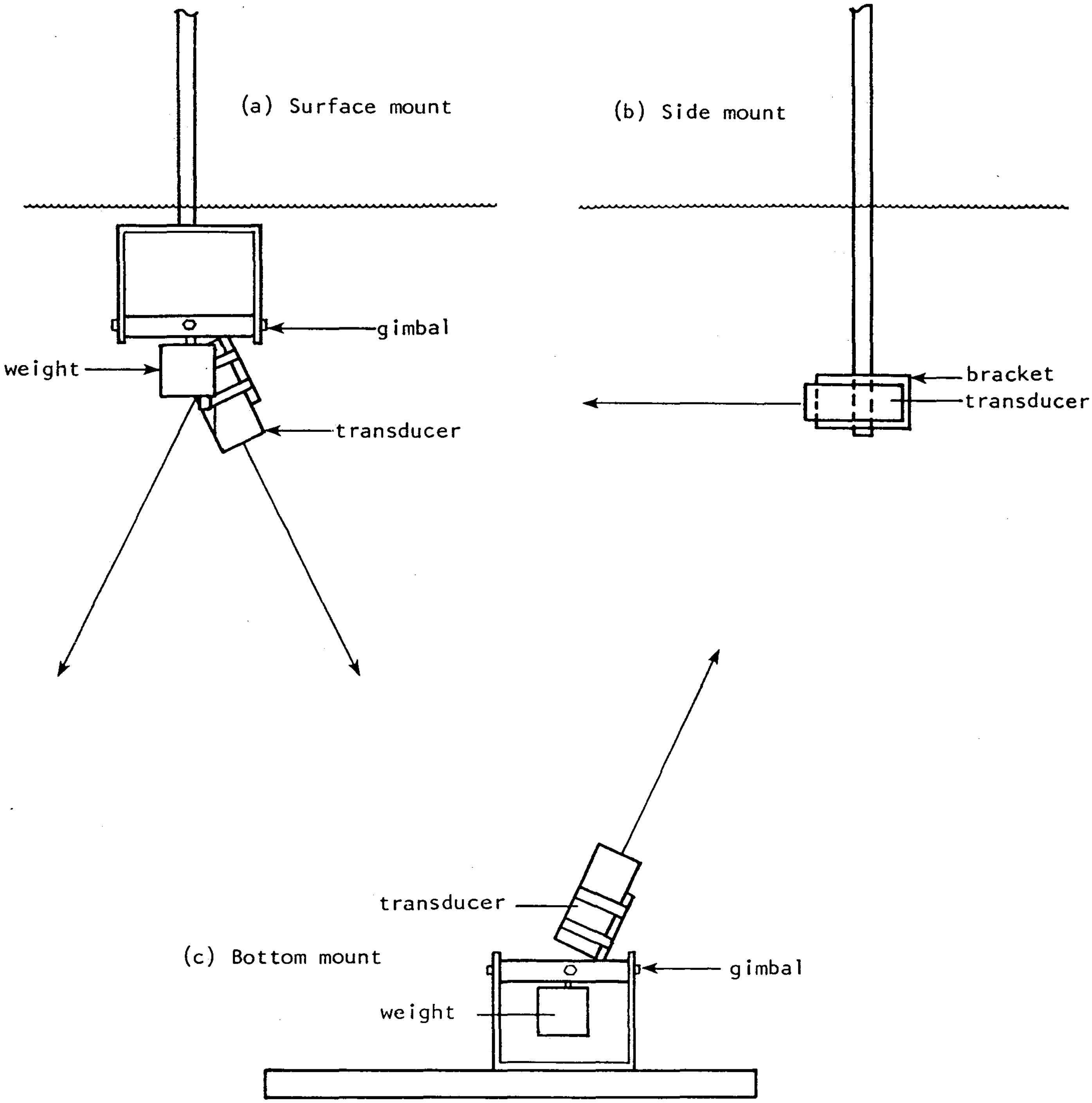


Figure 5. Transducer mounts. Susitna River, 1985.

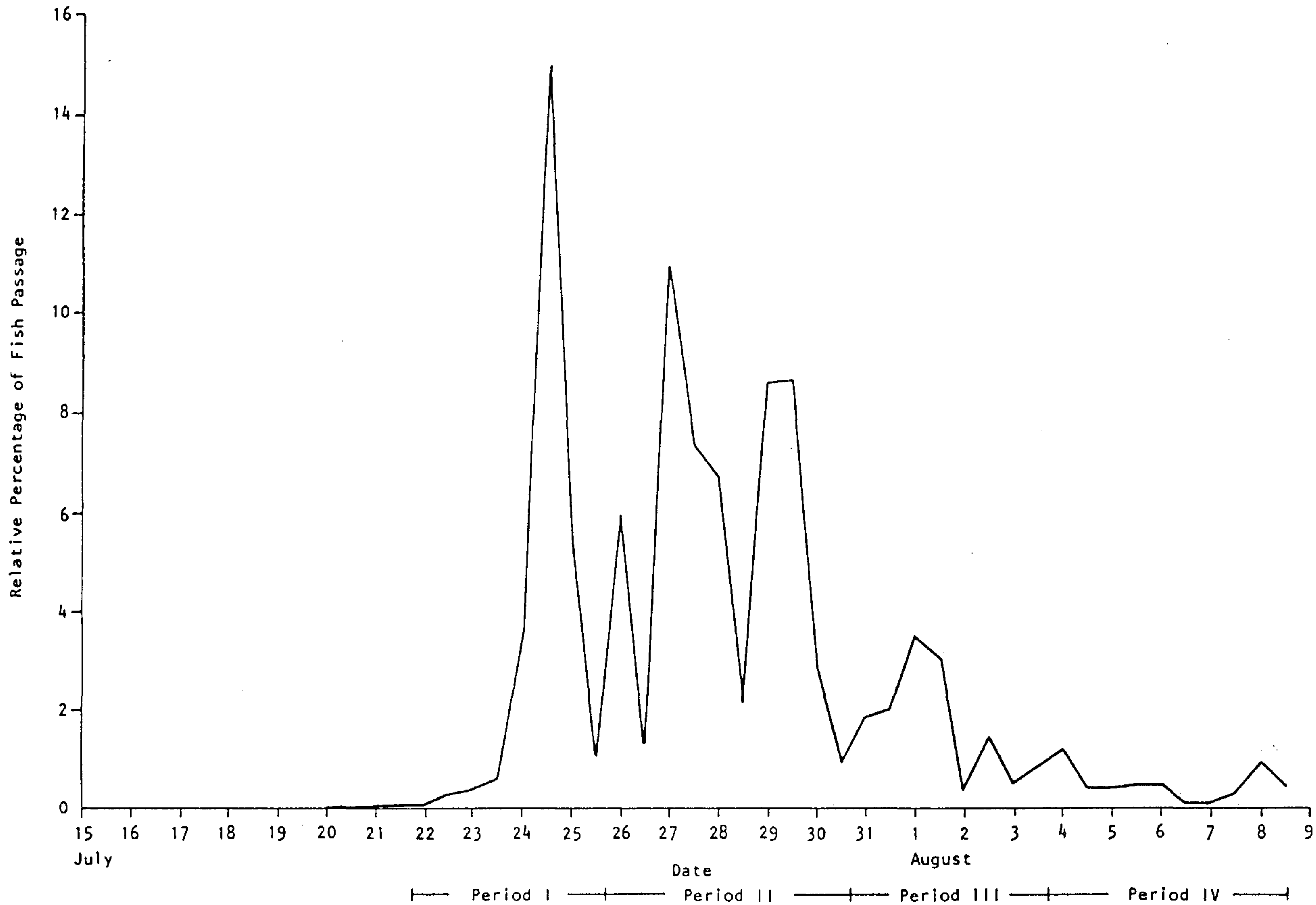
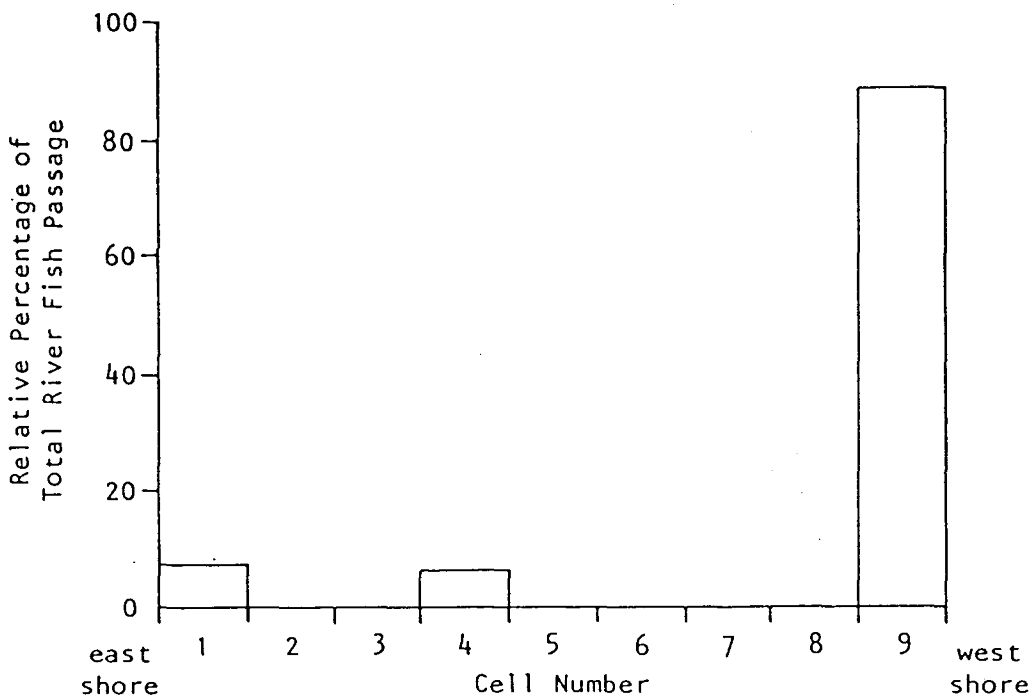


Figure 6. Run timing: relative percentage by 12 h of season total fish passage. Susitna River, 1985.

UPSTREAM



DOWNSTREAM

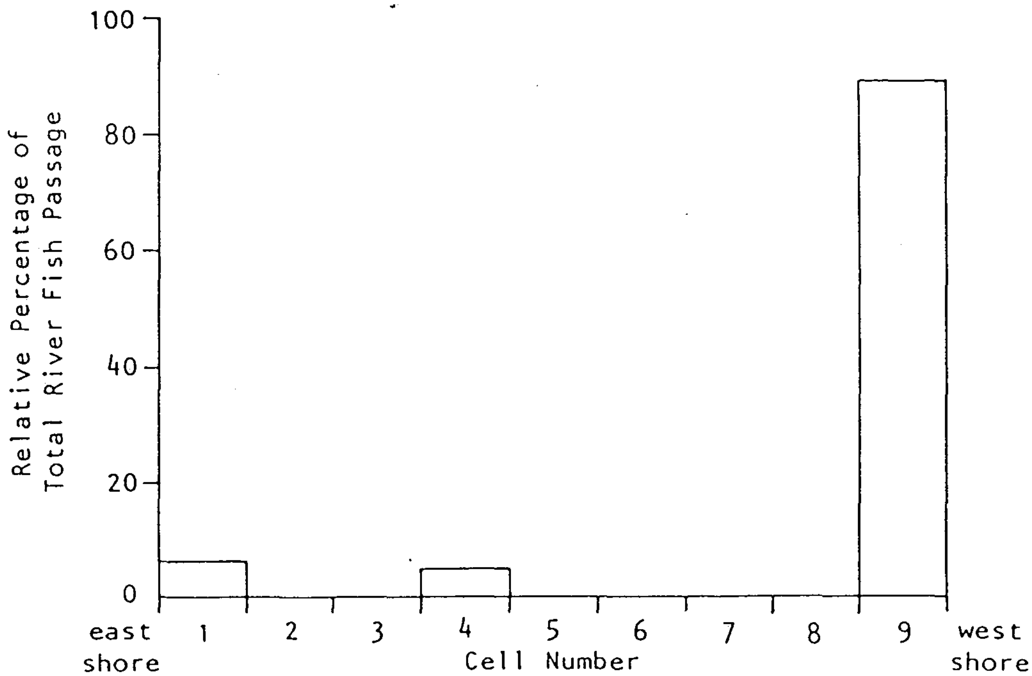


Figure 7. Horizontal distribution of adult salmon across the river, wieghted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

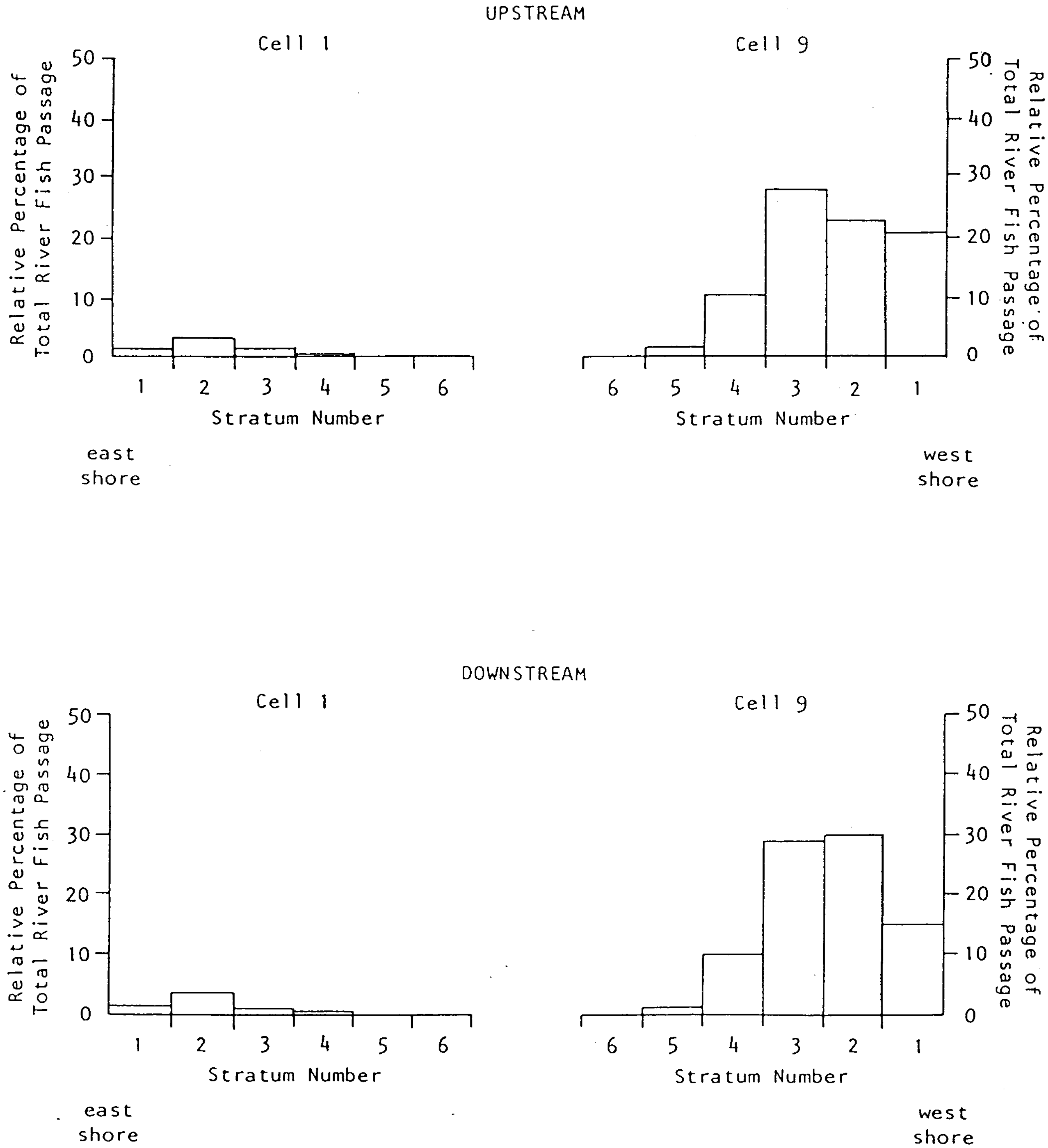


Figure 8. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

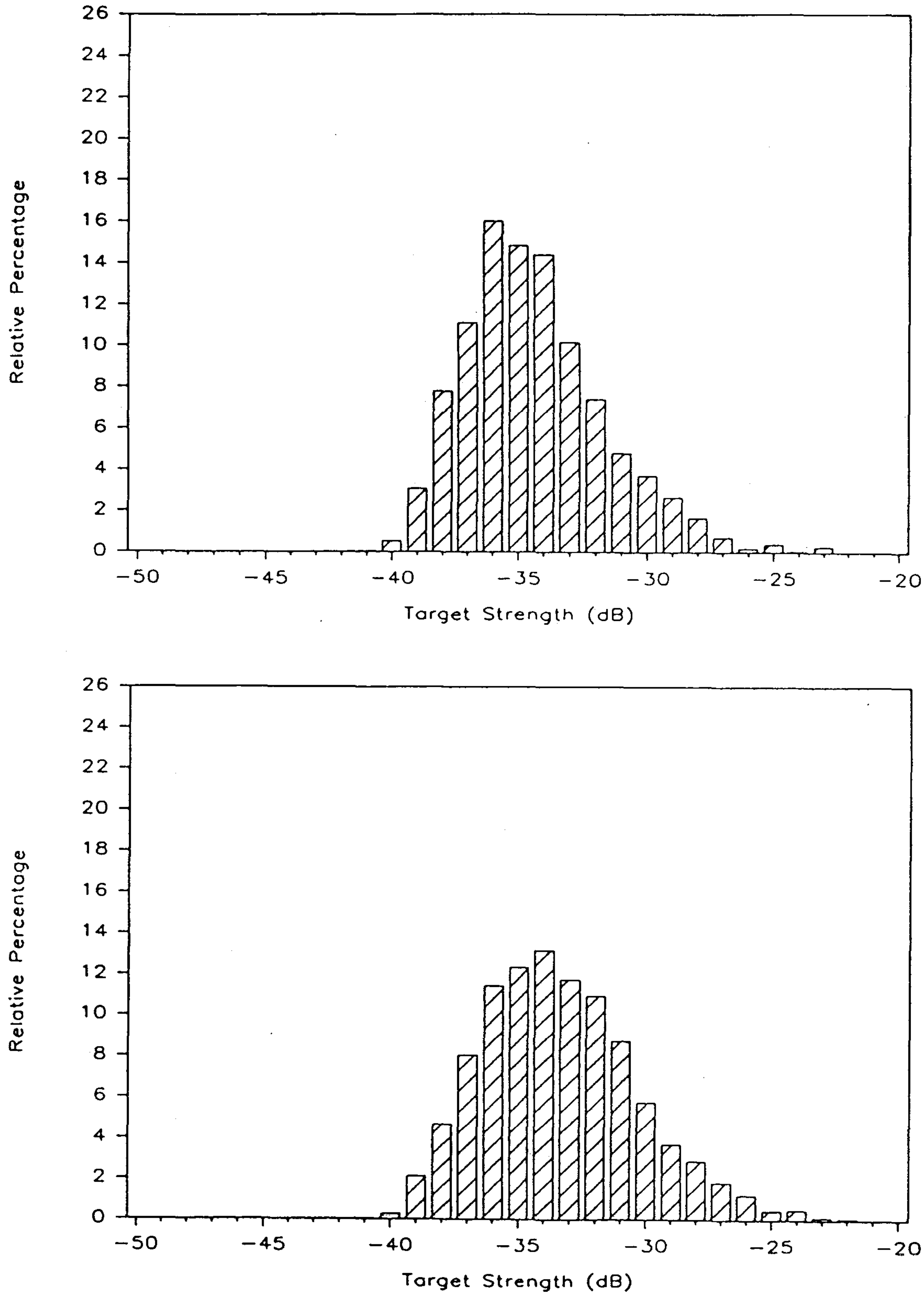


Figure 9. Acoustic size distribution of fish during Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table 1. Run timing of fish passage by 12h period (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
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

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

Period Number	Dates	Fish Direction	Relative Percentage of Fish: East Shore 1	2	3	Cell Number 4	5	6	7	8	West Shore 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	0.8	0	0	7.7	0	0	0	0	81.6	100.0
		Downstream	1.2	0	0	7.4	0	0	0	0	61.4	100.0
IV	8/4-8	Upstream	3.1	0	0	8.2	0	0	0	0	68.7	100.0
		Downstream	3.1	0	0	2.4	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

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

Period No.	Dates	Fish Direction	Relative Percentage of Fish: Cell 1 (East Shore) Section* 1	2	3	4	5	6	Sum	Cell 9 (West Shore) Section* 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.

Table 4. 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.

Table 5. 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.

APPENDIX A: Sample Times for Each Shift

SHIFT NUMBER	DAY/ NIGHT	START DATE	START HOUR	END DATE	END HOUR
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
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
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
33	N	7 30	2200	7 31	800
34	D	7 31	800	7 31	1800
35	N	7 31	2200	8 1	800

APPENDIX A, cont.

SHIFT NUMBER	DAY/ NIGHT	START DATE		START HOUR	END DATE		END HOUR
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
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 B: 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 B1. Table B1 lists specific manufacturers and model numbers of the electronic equipment used.

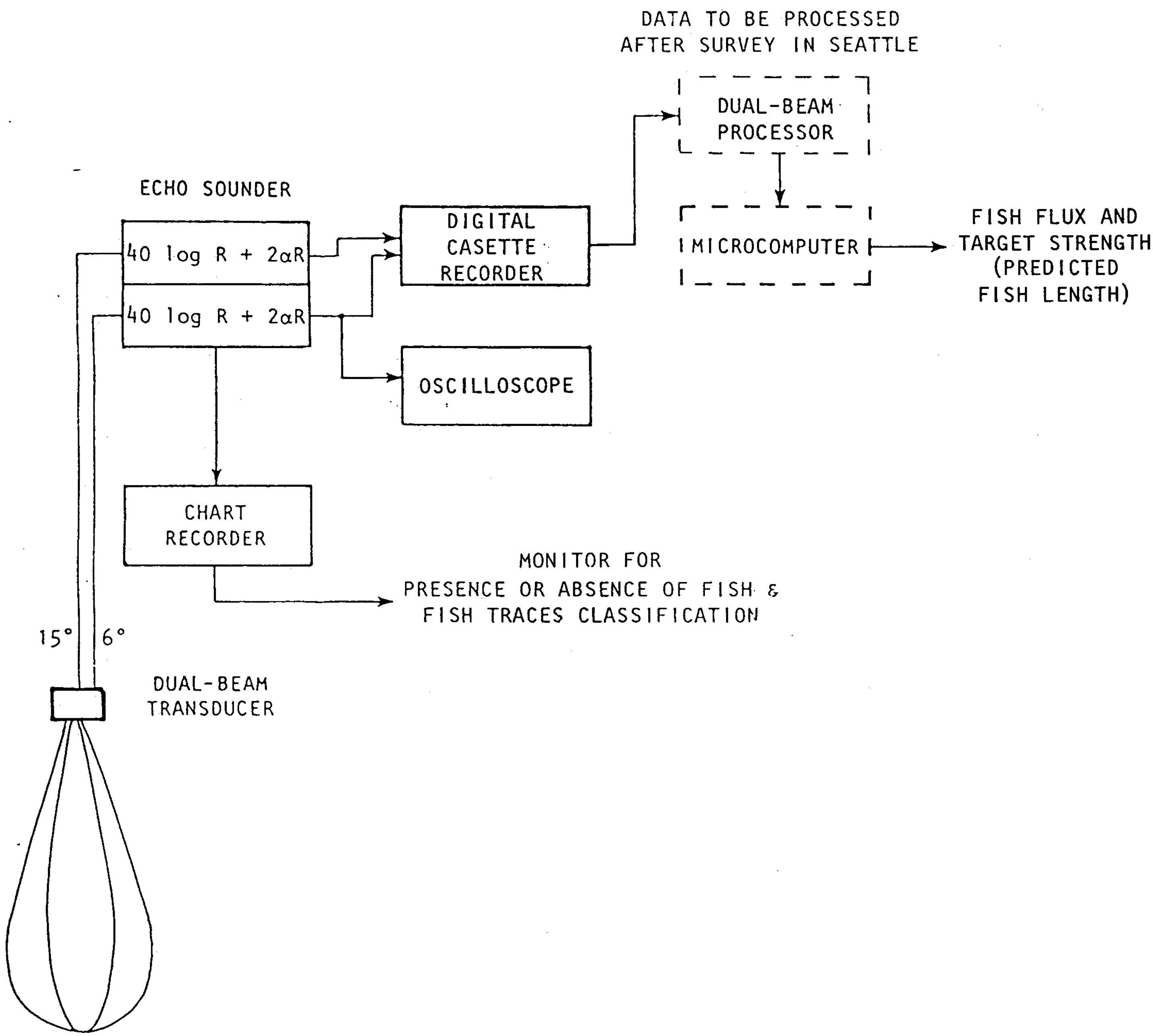


Figure B1. BioSonics dual-beam system for echo surveys.

Table B1. 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.

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.

Pulse rates were 10 pings/sec. This was sufficient to obtain ample ensonifications of fish to determine change-in-range (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).

APPENDIX C: Migrant Detection and Direction of Movement Criteria

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 D.

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). This redundancy criterion enhanced fish detectability in the presence of background interference, and for fixed-location studies 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 C1 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 C2).

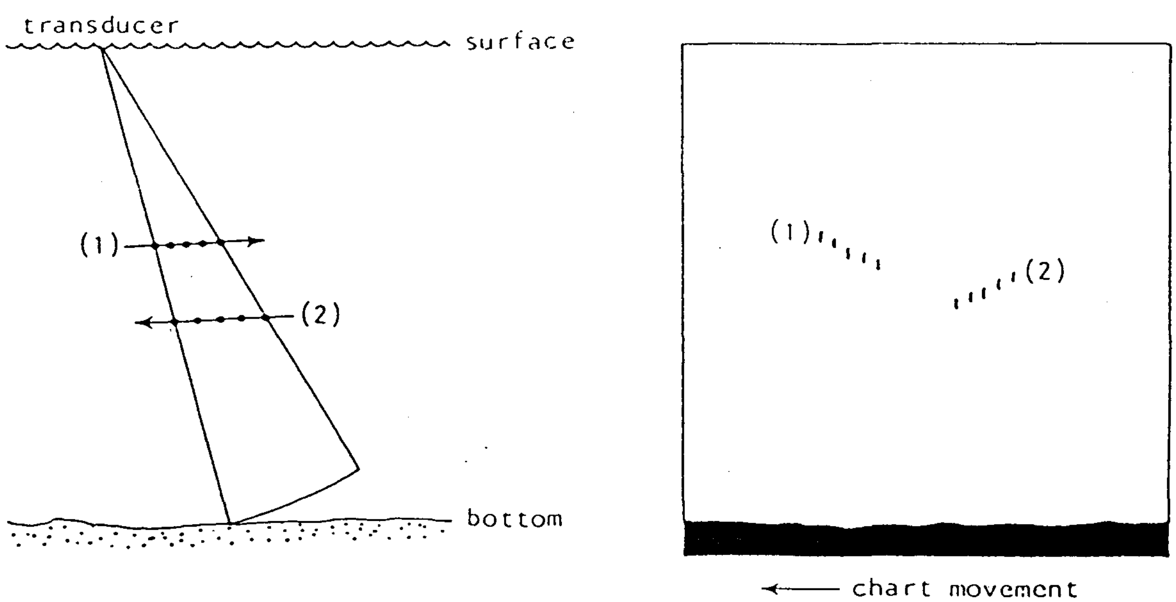


Figure C1. Fish movement through an oblique ensonified sphere resulting in change-in-range for fish traces on echogram.

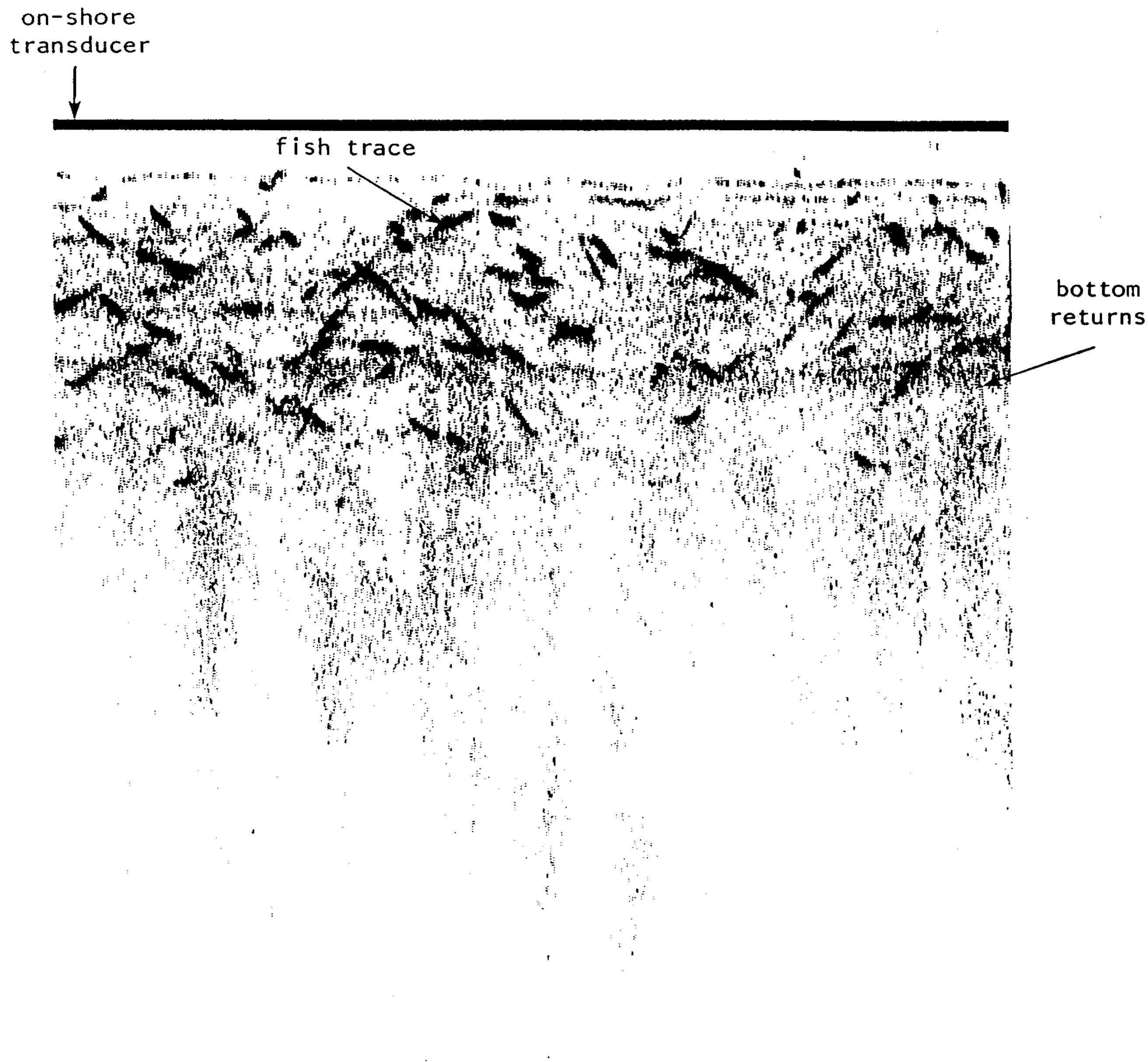


Figure C2. Echogram from side-mounted horizontal transducer, looking into the river and aimed 45° downstream. Susitna River, 1985.

APPENDIX D: 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:

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

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).

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

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

$b(\theta,\emptyset)$ 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 $b^2(\theta,\emptyset)$ 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 $(\theta,\emptyset)$ 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 C1). The narrow- and wide-beam squared voltage outputs are:

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

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

For simplicity of mathematics, assume that a dual-beam system is designed so that $b_w(\theta,\emptyset) = 1$ 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

[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 (see Section 6.2, Steps 8 and 9).

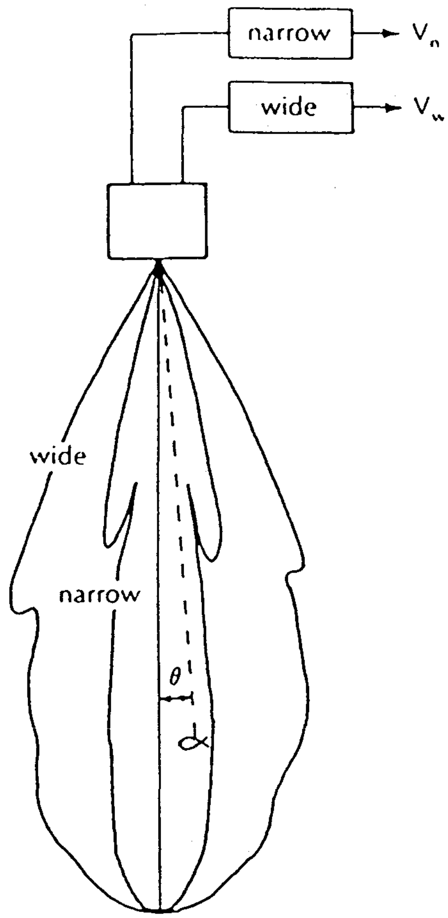


Figure D1. Beam patterns of narrow- and wide-transducer elements showing a fish within both beams.

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

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

Rearranging gives:

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

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

$$\sigma_{bs} = \frac{V_w^{\,2} \; k_n}{V_n^{\,2} \; k_w^{\,2}} \tag{7}$$

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 thresholding and beam width calculations.

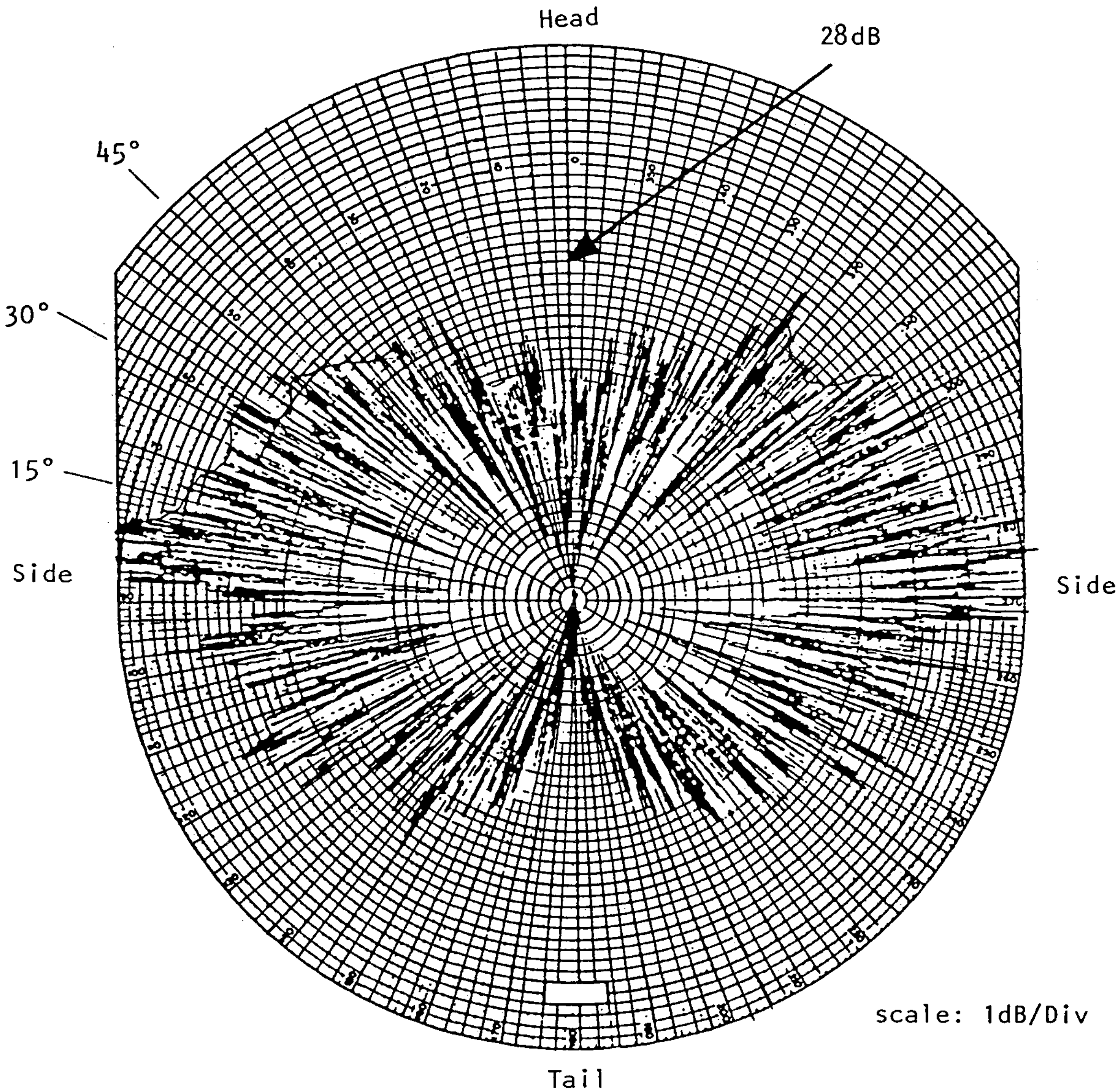
To adjust for the side aspect orientation, we relied on Dahl (1982) and Haslett (1977). A sample plot of target strength directivity for a 52 cm salmonid is presented in Figure D2. A corresponding smoothed plot for three salmonids (40, 52, and 61 cm) appears in Figure D3. These fish were near the size of Susitna River salmon (Table 5).

The mean difference between the dorsal and side aspect target strengths was 4 dB (Table D1). 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.

Table D1. 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 D2. Polar plot (420 kHz) of fish directivity in the yaw plane.

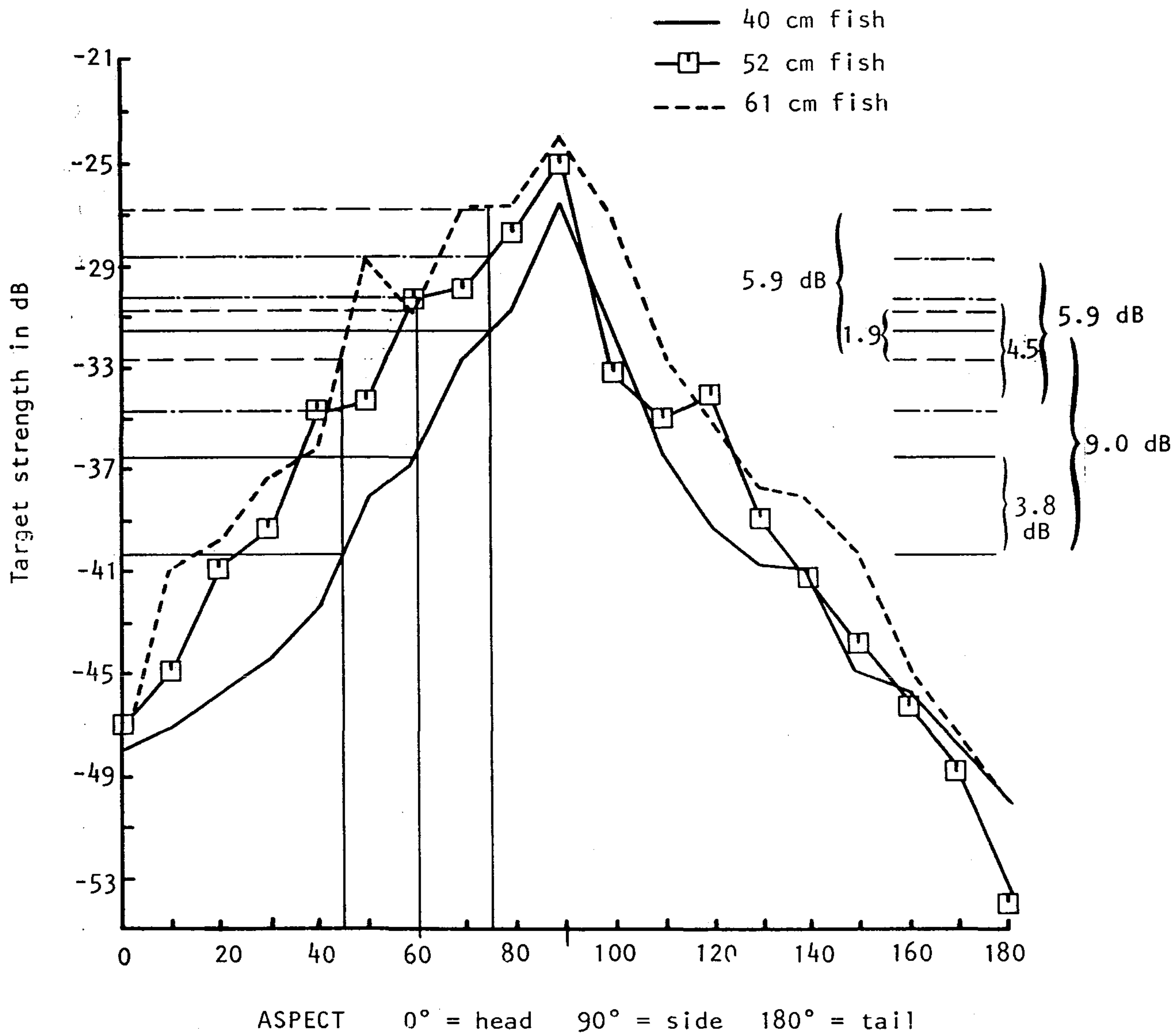


Figure D3. Plot of mean smoothed fish directivity (mean target strength in 10° increments (Dahl 1982).

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 D3 and Table D2 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 D2. Difference between side-aspect target strength at 15°, 30°, and 45° aiming angles, from Dahl (1982) (Susitna River 1985).

Fish Length (cm)	Aiming Angle* 15°	Aiming Angle* 30°	Aiming Angle* 45°	Target Strength Difference 45° to 30°	Target Strength Difference 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

APPENDIX E: Simultaneous Tracking of Fish Direction of Movement and Target Strength

As stated earlier, 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 fixed-aspect transducers operated at high pulse rates (this study used 10 pulses per second), each target usually had several echoes recorded during passage through the acoustic beam. Using 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 C). 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

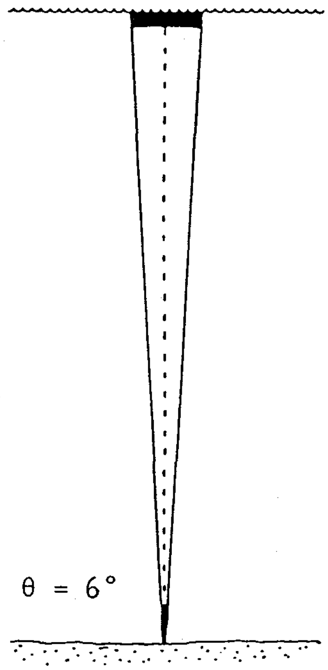
D = distance traveled through the beam.

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. TRACKER also simultaneously calculated fish passage rates for upstream and downstream moving fish.

APPENDIX F: Data Reduction and Analysis

Weighting Factor

The extrapolation of individual fish detections to a representation of all fish in the area first took into account the cone-like geometry of the acoustic beam produced by the transducer. Since the diameter of the ensonified sample volume increases in direct proportion to distance from the transducer, each fish detection was multiplied by a geometric weighting factor which decreases with range. Thus, a fish detected closer to the transducer is weighted more (to represent more fish) than a fish detected further away. All subsequent data analyses are based on these weighted fish detections. An example of how weighted fish detections are determined is shown in Figure F1.



Range (m)	Diameter of Beam	Weighting Factor [a]	Weighting Factor [b]
40	4.19	1.00	3.58
35	3.67	1.14	4.09
30	3.14	1.33	4.78
25	2.62	1.60	5.73
20	2.10	2.00	7.14
15	1.57	2.67	9.55
10	1.05	3.99	14.29
5	0.52	8.00	28.85
2	0.21	19.81	71.43

a) Relative to diameter at maximum range.

b) Relative to 15 m intake opening.

FIGURE F1. For quantitative studies based on echo counting, each fish detection is multiplied by a weighting factor to account for the cone shape of the acoustic sample volume. At range R, the weighting factor W(R) is the ratio of a normalization width N to the diameter of the beam D(R) at the range of detection:

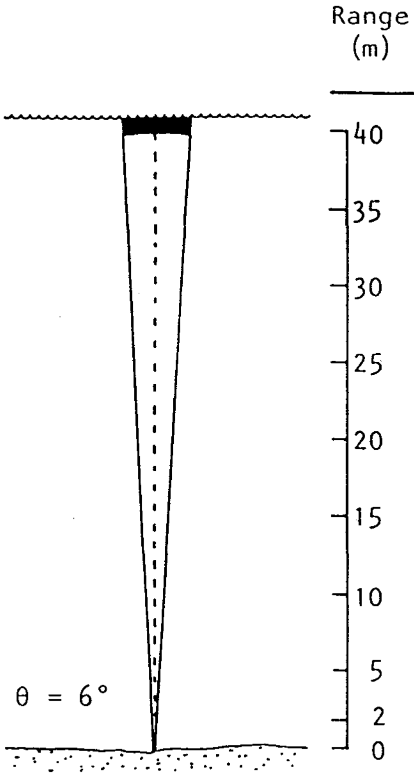
$$W(R) = \frac{N}{D(R)} = \frac{N}{2\ R\ \tan(\theta/2)}$$

For relative studies, the choice of normalization width is arbitrary, but it is frequently taken as the diameter of the beam at maximum range. For absolute estimates of fish passage through well-defined passage routes, the normalization width should be the width of the sample cell, in Susitna River's case.

The above figure illustrates how the weighting factor for a 6° transducer changes with range for two different normalization widths. The first column of numbers lists the diameters of the acoustic beam at various ranges. The second column lists the corresponding weighting factors normalized to the maximum diameter of the beam (in this case, 4.19 m). The third column lists the weighting factors normalized to a 15-m width.

Vertical Distribution

The vertical (depth) distribution of fish in the water column is a straightforward calculation from data obtained from either a bottom-mounted transducer, a surface-mounted transducer, or both. An example is provided in Figure F2. When the transducer is aimed at an angle to the surface, a vertical distribution can be developed by first converting ranges from the transducer to depths below the surface using the appropriate trigonometry.



	Average Weighting Factor	Number Fish Detections	Weighted Fish Detections	Vertical Distribution Percentage
	1.07	12	12.84	11.31
	1.24	23	28.52	25.13
	1.47	18	26.46	23.31
	1.80	10	18.00	15.86
	2.34	5	11.70	10.31
	3.33	3	10.00	8.81
	5.99	1	5.99	5.27
	13.90	0	0.00	0.00
TOTALS		72	113.51	100.00

FIGURE F2. This figure shows how a vertical distribution of fish is obtained from a bottom-mounted 6° transducer aimed straight up in 40 m of water. The first column of numbers shows the average relative weighting factor for each of the 5-m depth strata. The second column lists the numbers of single fish detections in each of the 5-m depth strata over a 12-hour period. The third column shows the results of multiplying these fish detections by the average weighting factors in the first columns. The fourth column shows the vertical distribution of fish expressed as percentages of total weighted fish detections in the water column.

Separate vertical distributions can be developed and compared for different time periods, environmental conditions, plant operating procedures, etc. The width of the depth strata are selected according to the study's objectives.

Horizontal Distributions

By summing weighted fish detections for the different directions of movement, one can calculate the flux of fish (quantity of fish/area/time) through a cross-sectional area. For a given aiming angle, the general direction of fish movement and the resulting flux values can be determined for two opposite directions.

Once total flux rates were calculated for each cell across the river, the horizontal distribution across the river was calculated as the relative percentage individual cells represented of the ground total flux rate for the whole river.

Horizontal distributions were calculated separately for upstream and downstream moving fish.

Horizontal distributions within cells 1 and 9 were calculated as explained above for vertical distributions. Since side-aspect transducers were used for these data, all dimensions are simply rotated 90°.

Fish Target Speed

Fish swimming speed is a physiological term referring to the estimated speed of the fish if the fish were exerting an equivalent effort in zero current. 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. Average fish target speeds were determined acoustically by dividing the average width of the beam at the range of detection by the average time in the beam based on the average number of detections by successive pings.

Appendix G. Run Timing: Cumulative Percentage of Season Total Fish Passage, by 12 h

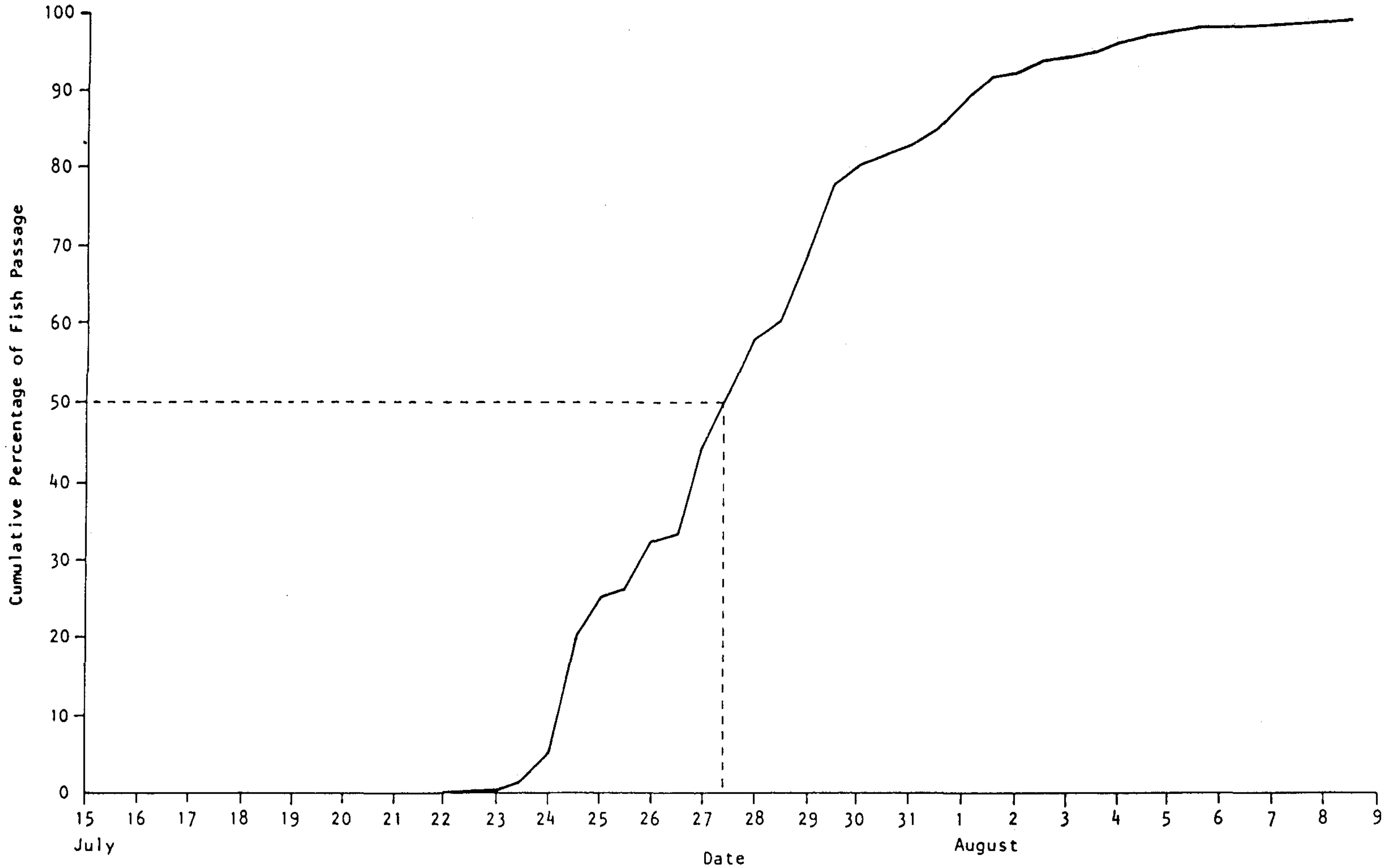


Figure G1. Run timing: cumulative percentage by 12 h of season total fish passage. Susitna River, 1985.

Appendix H. Horizontal Distributions of Adult Salmon Across the River, Weighted for Fish Abundance

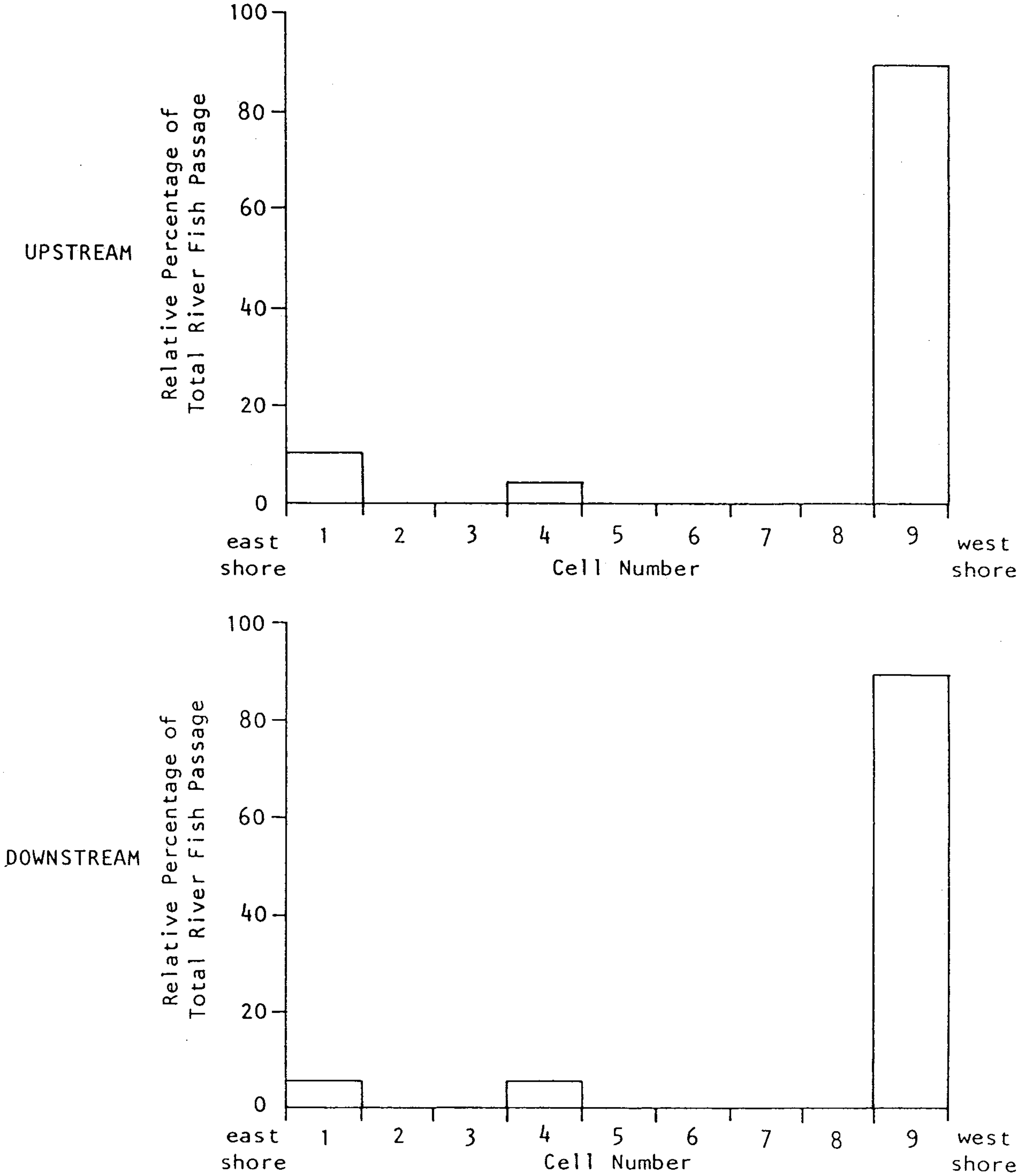


Figure H1. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period I (July 22-25). Susitna River, 1985.

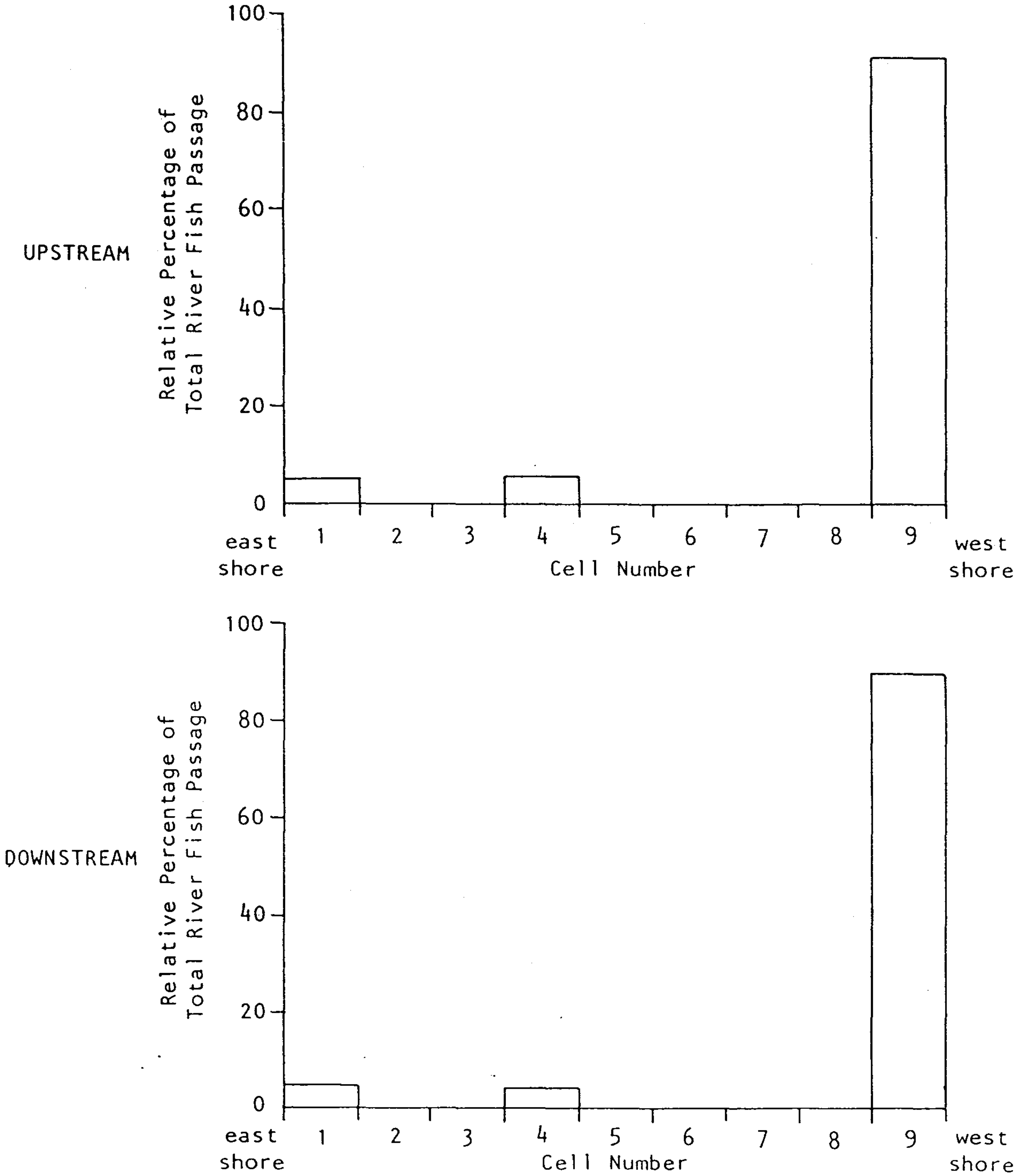


Figure H2. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period II (July 26-30). Susitna River, 1985.

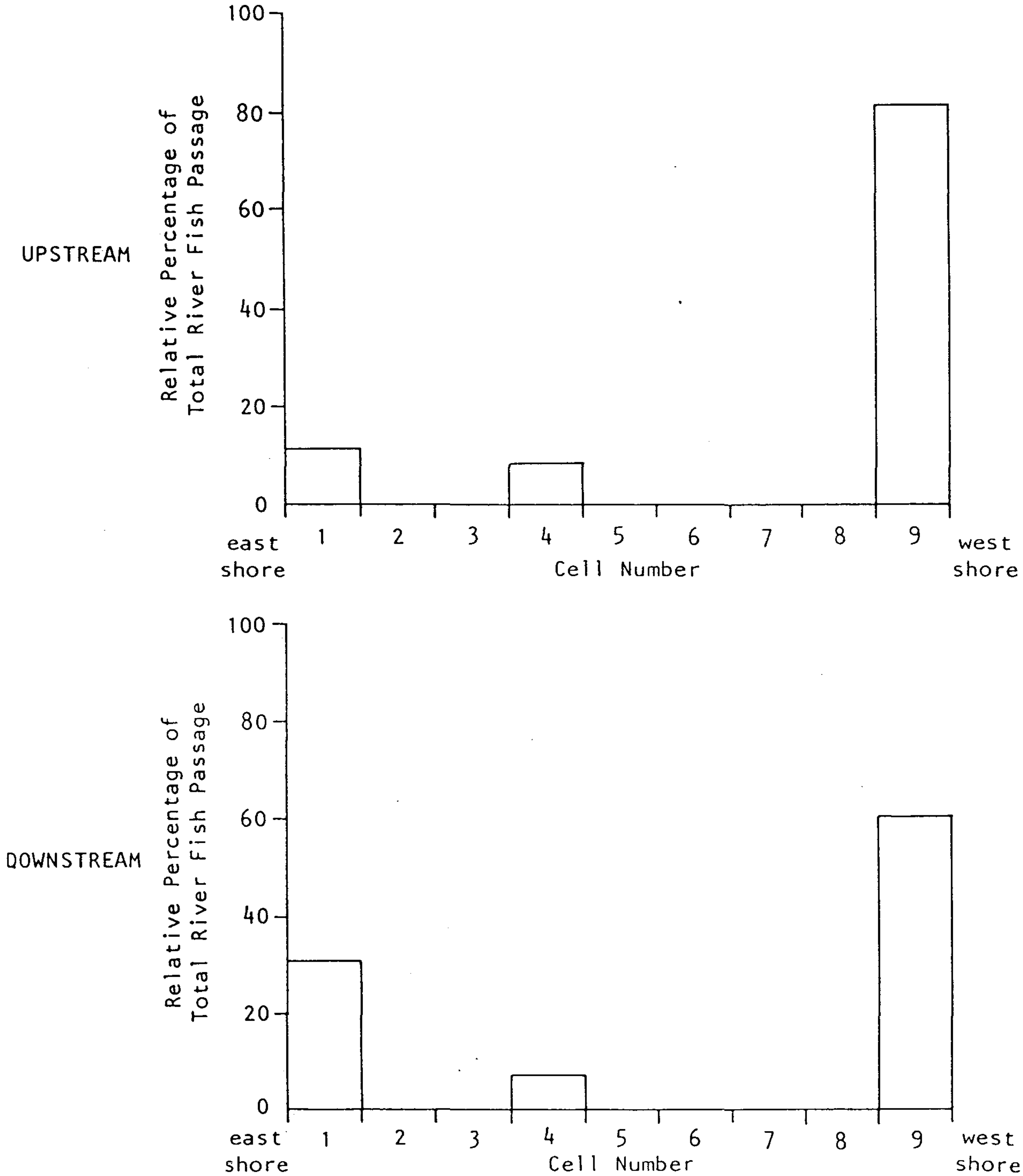
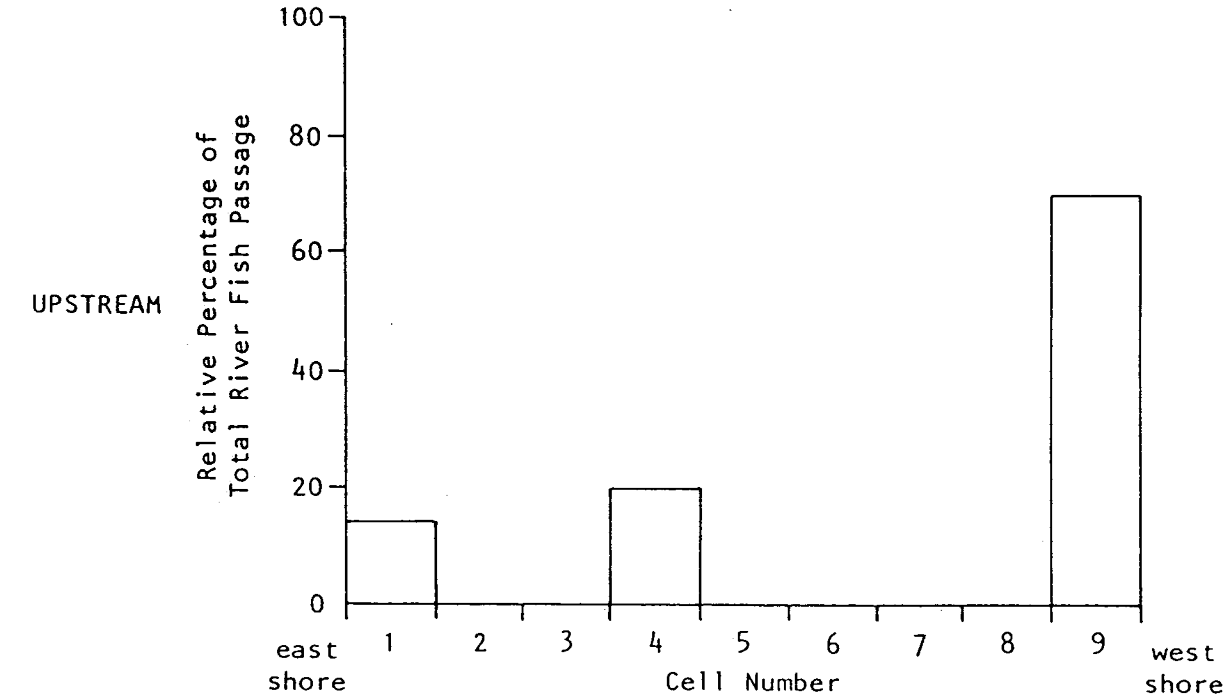


Figure H3. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period III (July 31 - August 3). Susitna River, 1985.



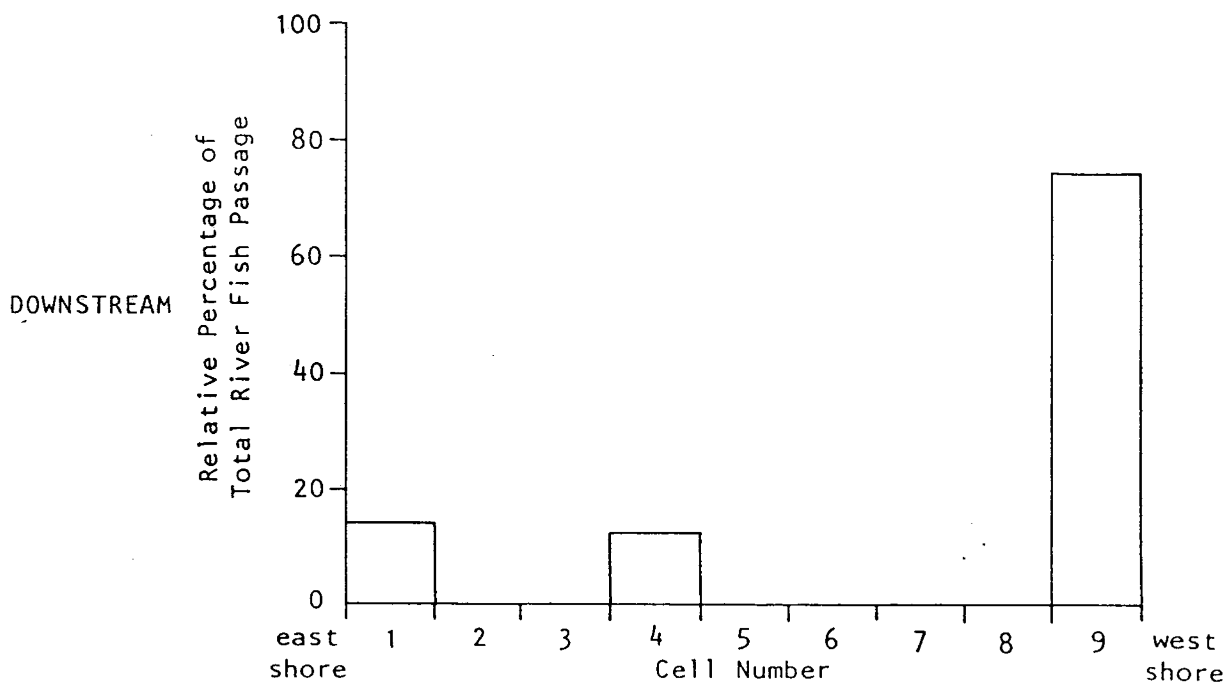


Figure H4. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Period IV (August 4-8). Susitna River, 1985.

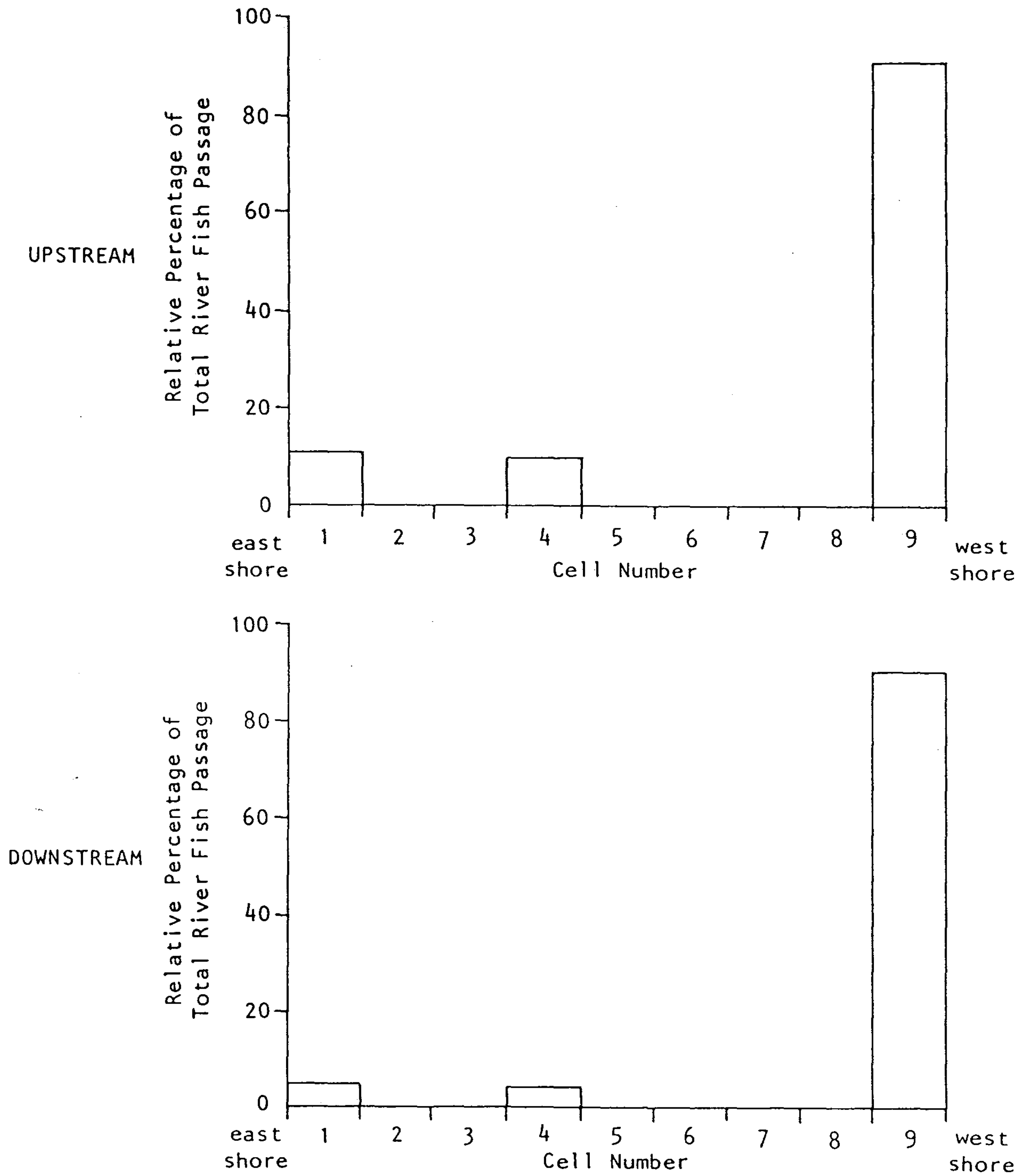


Figure H5. Horizontal distributions of adult salmon across the river, weighted for fish abundance, for Periods I and II (July 22-30). Susitna River, 1985.

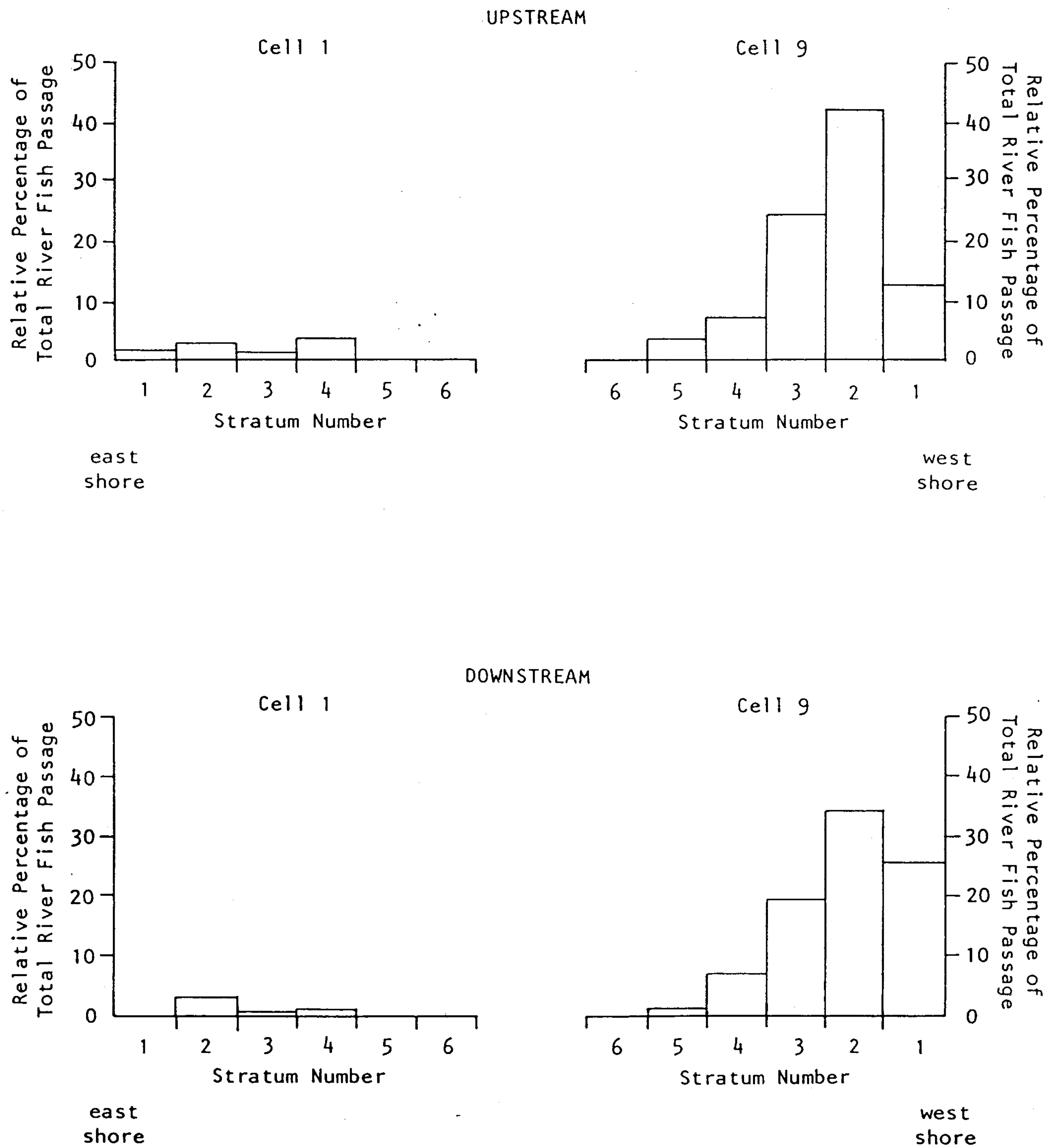


Figure H6. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period I (July 22-25). Susitna River, 1985.

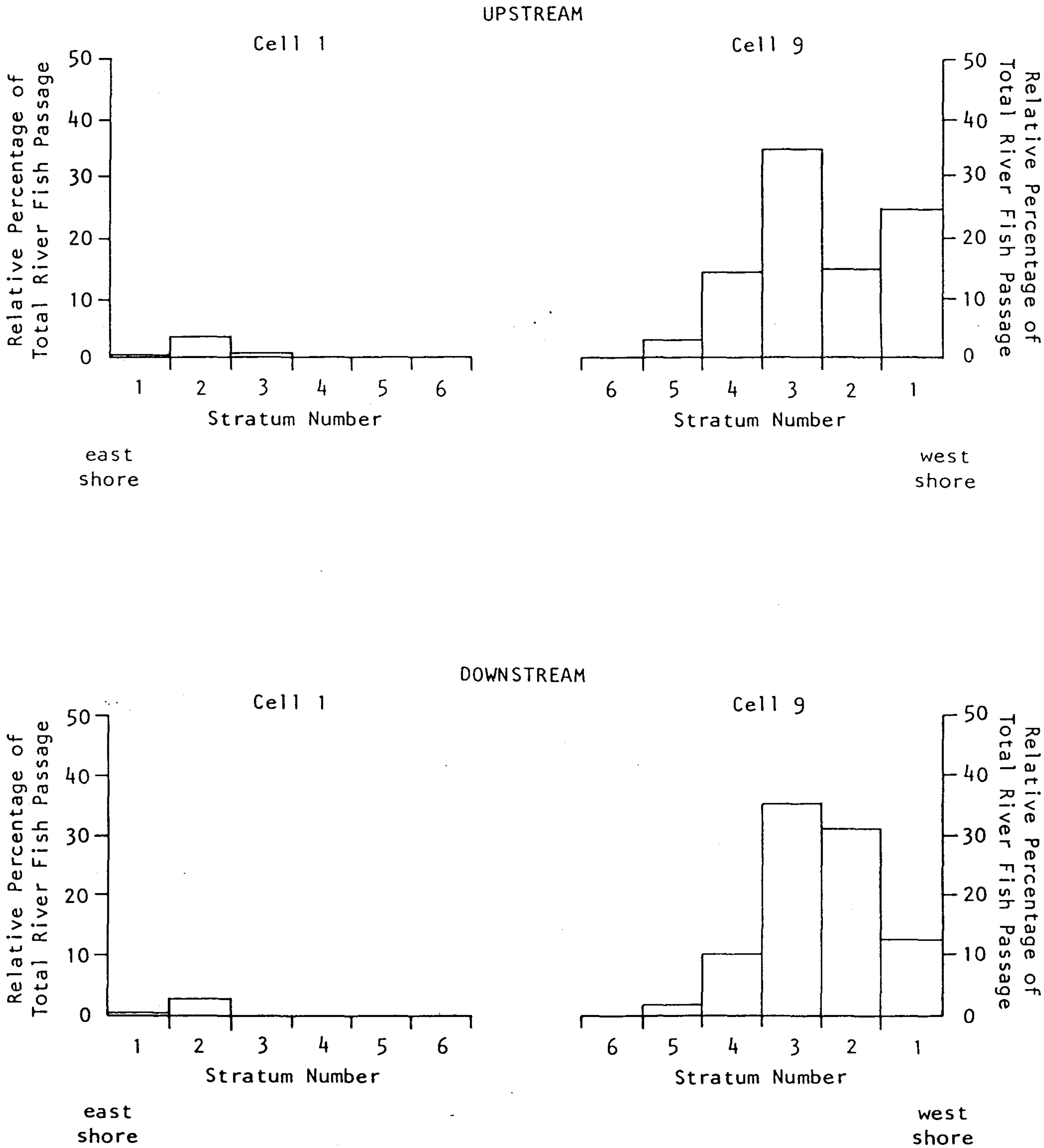


Figure H7. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period II (July 26-30). Susitna River, 1985.

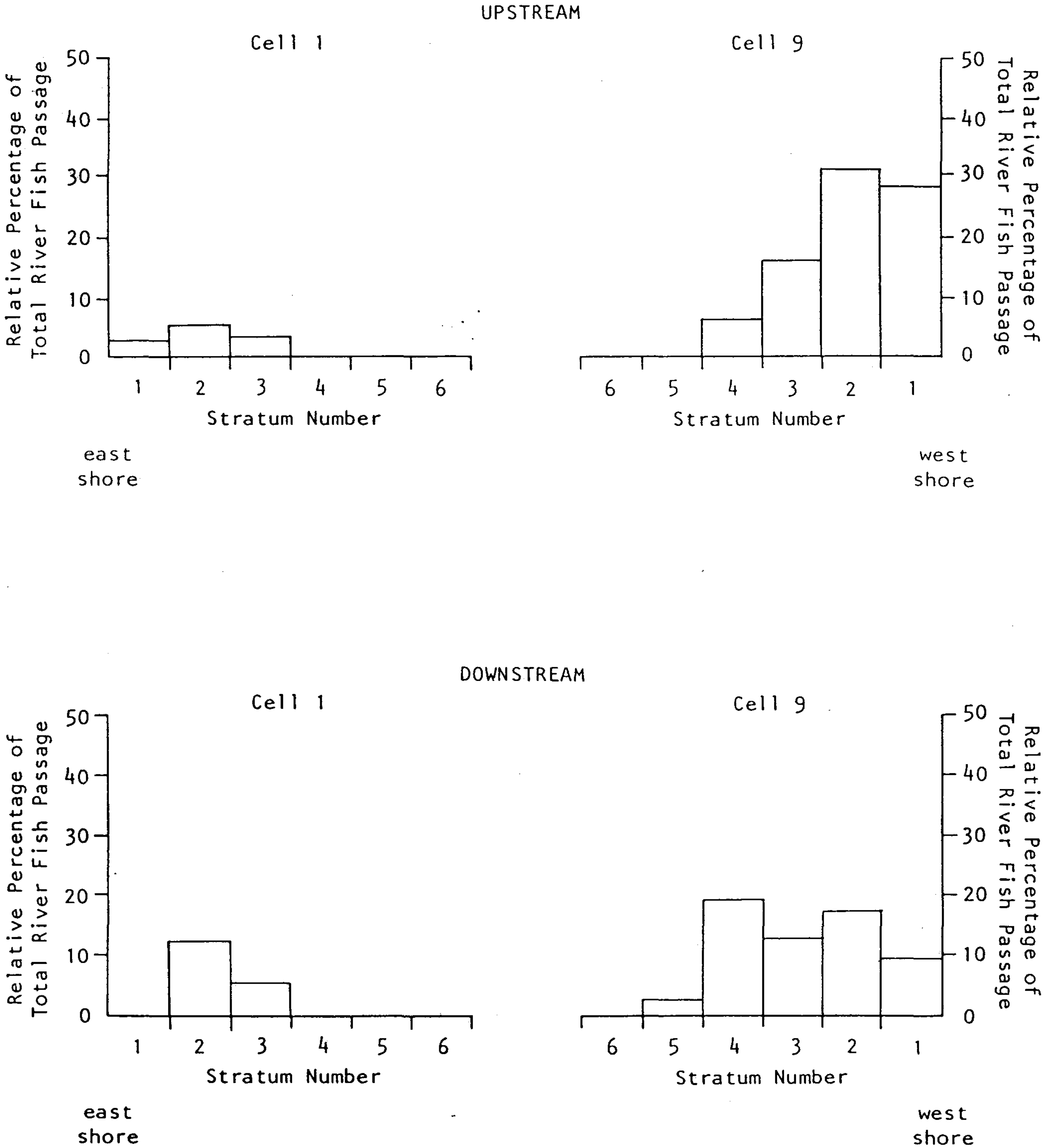


Figure H8. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period III (July 31 - August 3). Susitna River, 1985.

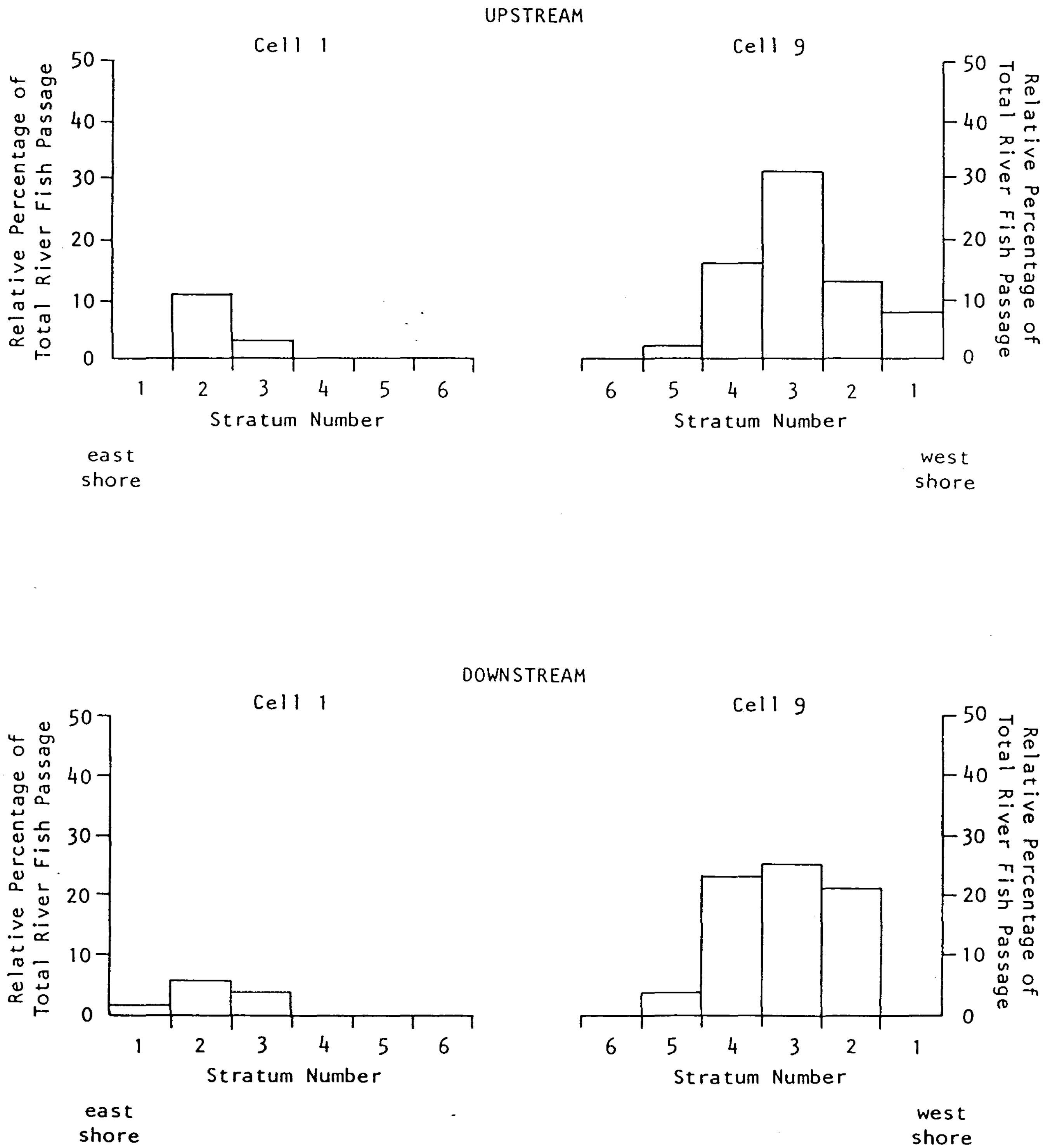


Figure H9. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Period IV (August 4-8). Susitna River, 1985.

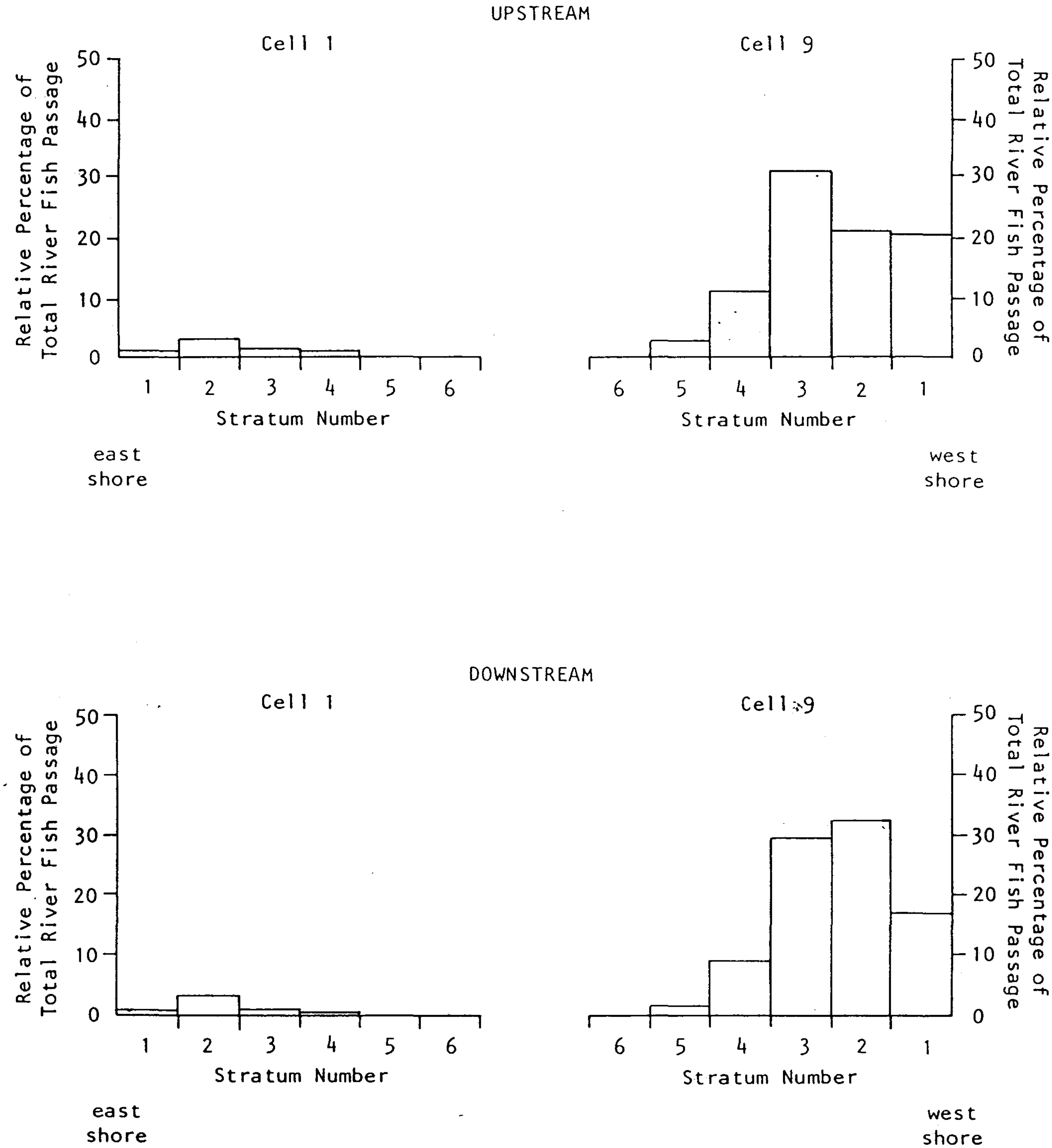


Figure H10. Horizontal distributions within Cells 1 and 9, weighted for fish abundance, for Periods I and II (July 22-30). Susitna River, 1985.

Table H1. Summary of horizontal distributions of upstream migrating adult salmon, by shift (Susitna River 1985).

Date	Shift Number	1	2	3	4	5	6	7	8	9	Total
		Relative Percentage across River by Cell									
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 H2. Summary of horizontal distributions of downstream 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	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 H3. 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 H4. 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 I. Mean Horizontal Distributions of Adult Salmon Across the River, Based on Distributions by Shift

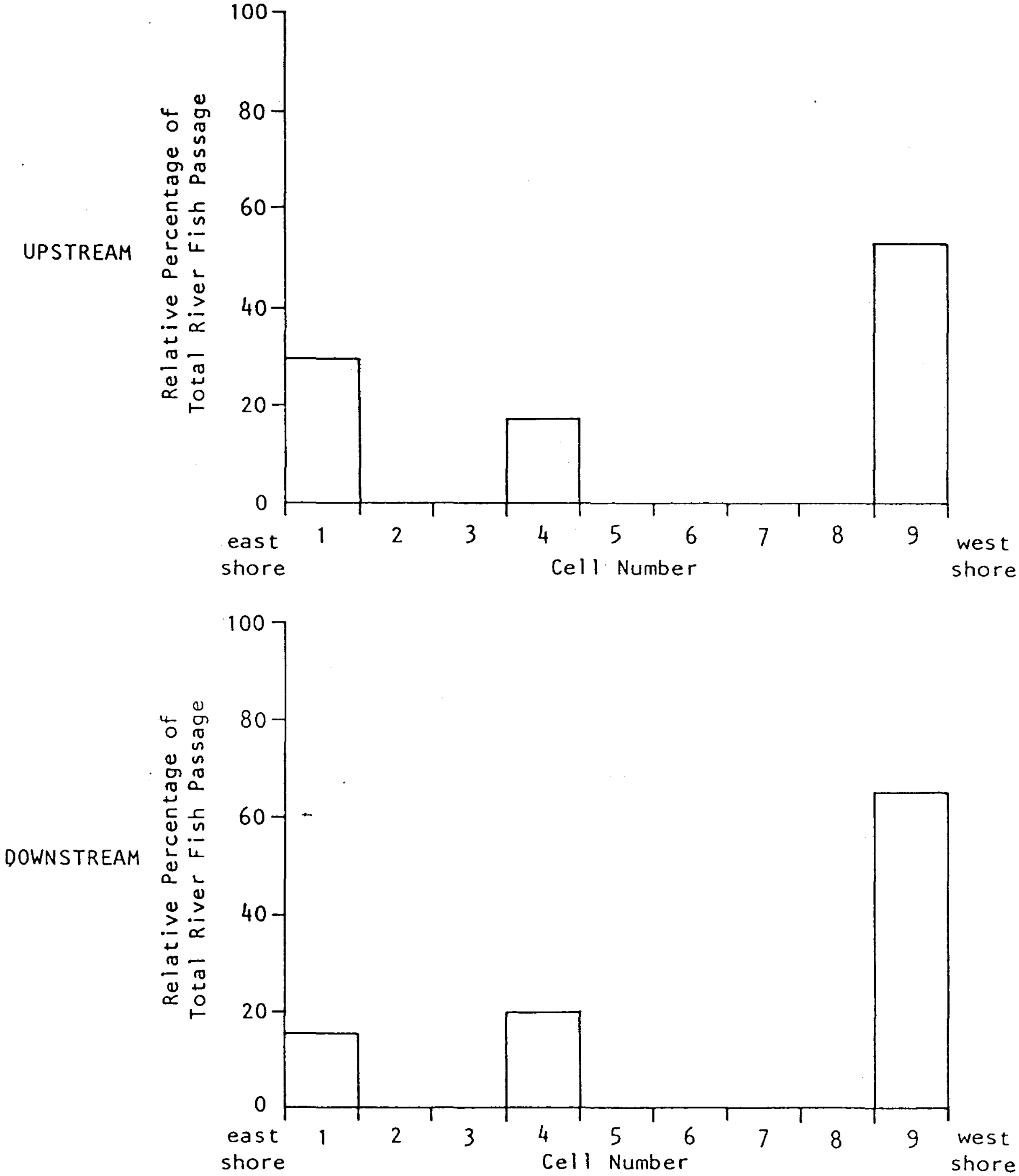


Figure I1. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period I (July 22-25). Susitna River, 1985.

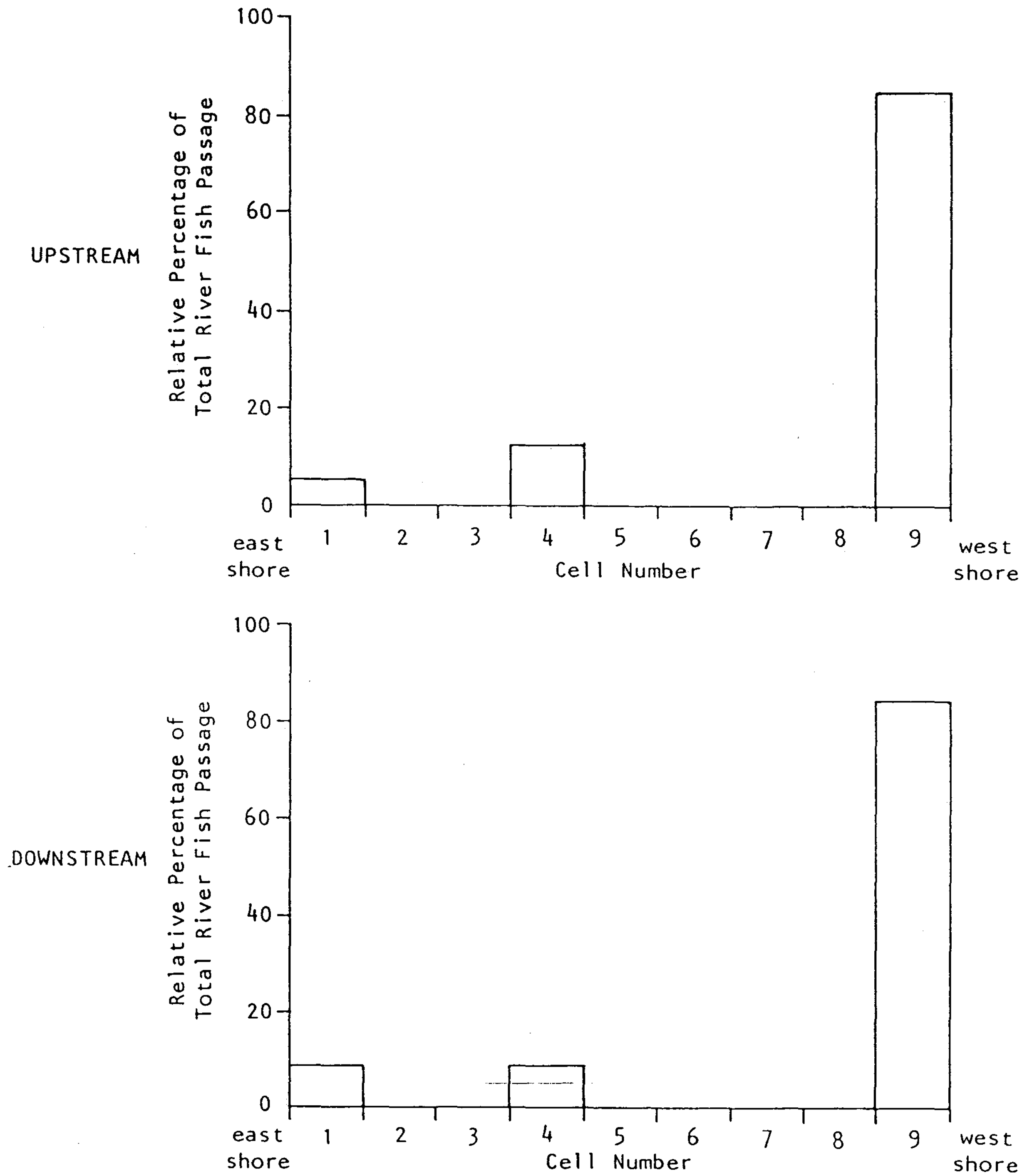


Figure I2. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period II (July 26-10). Susitna River, 1985.

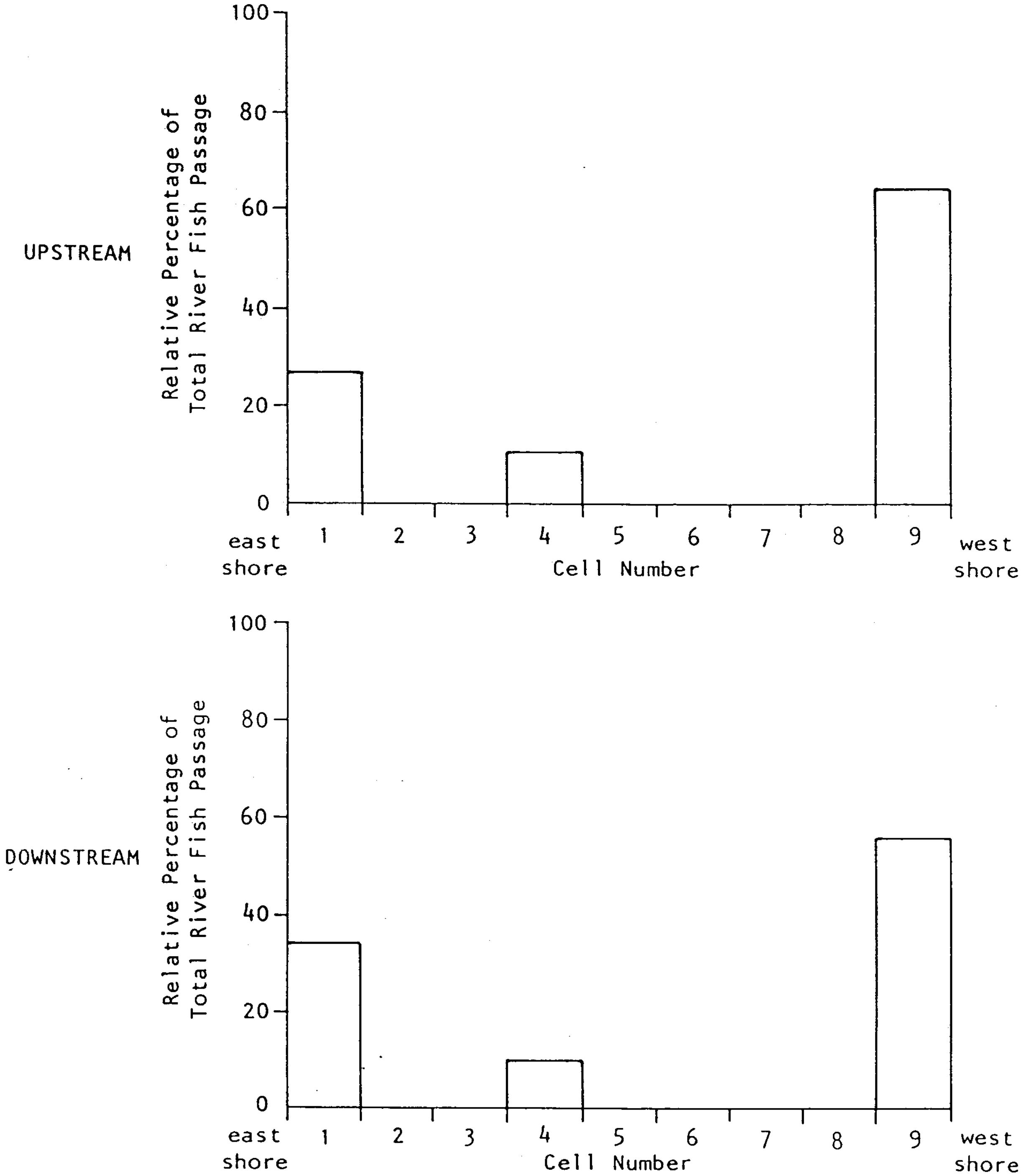


Figure I3. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period III (July 31 - August 3). Susitna River, 1985.

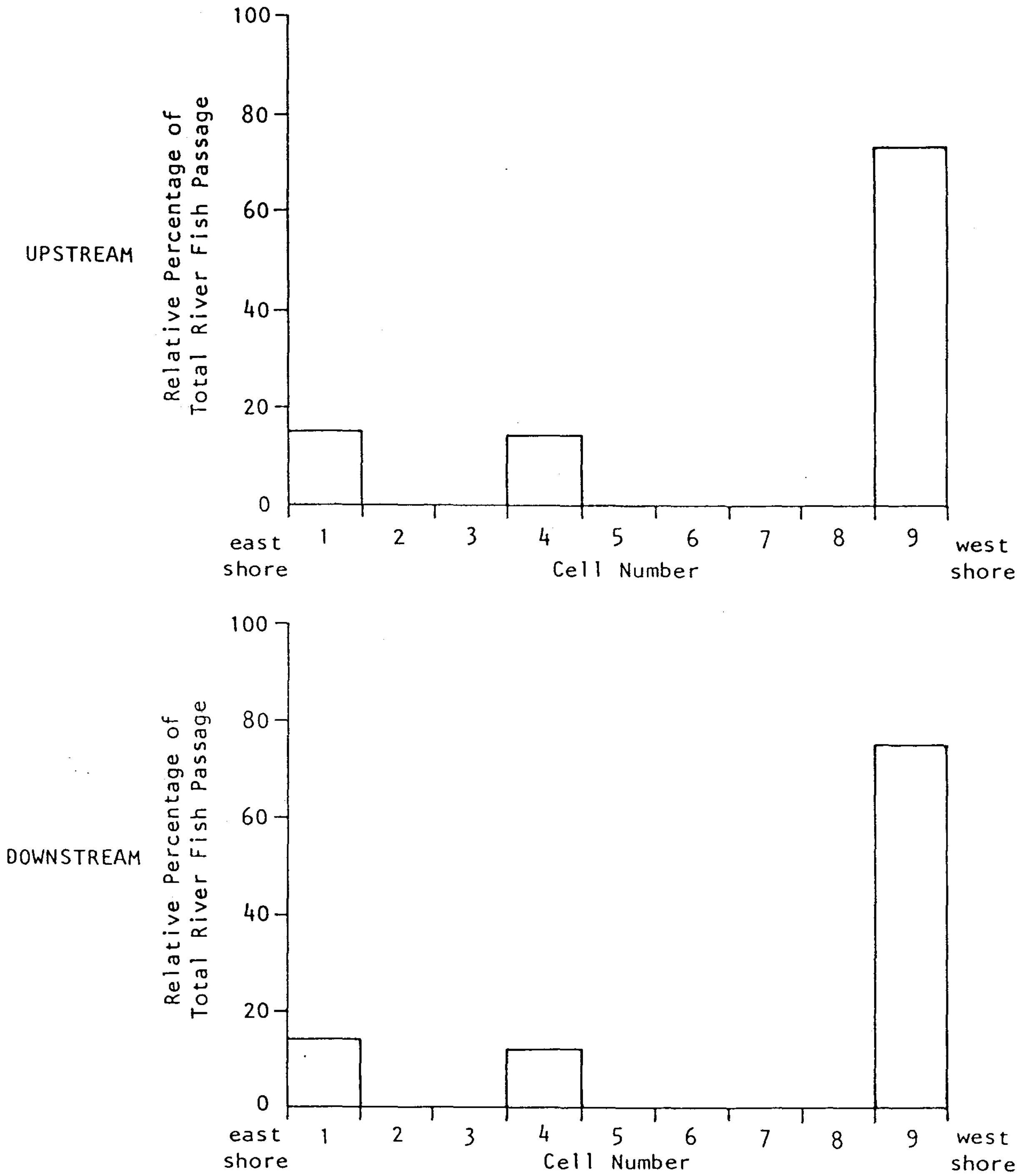


Figure I4. Mean horizontal distributions of adult salmon across the river, based on distributions by shift, for Period IV (August 4-8) Susitna River, 1985.

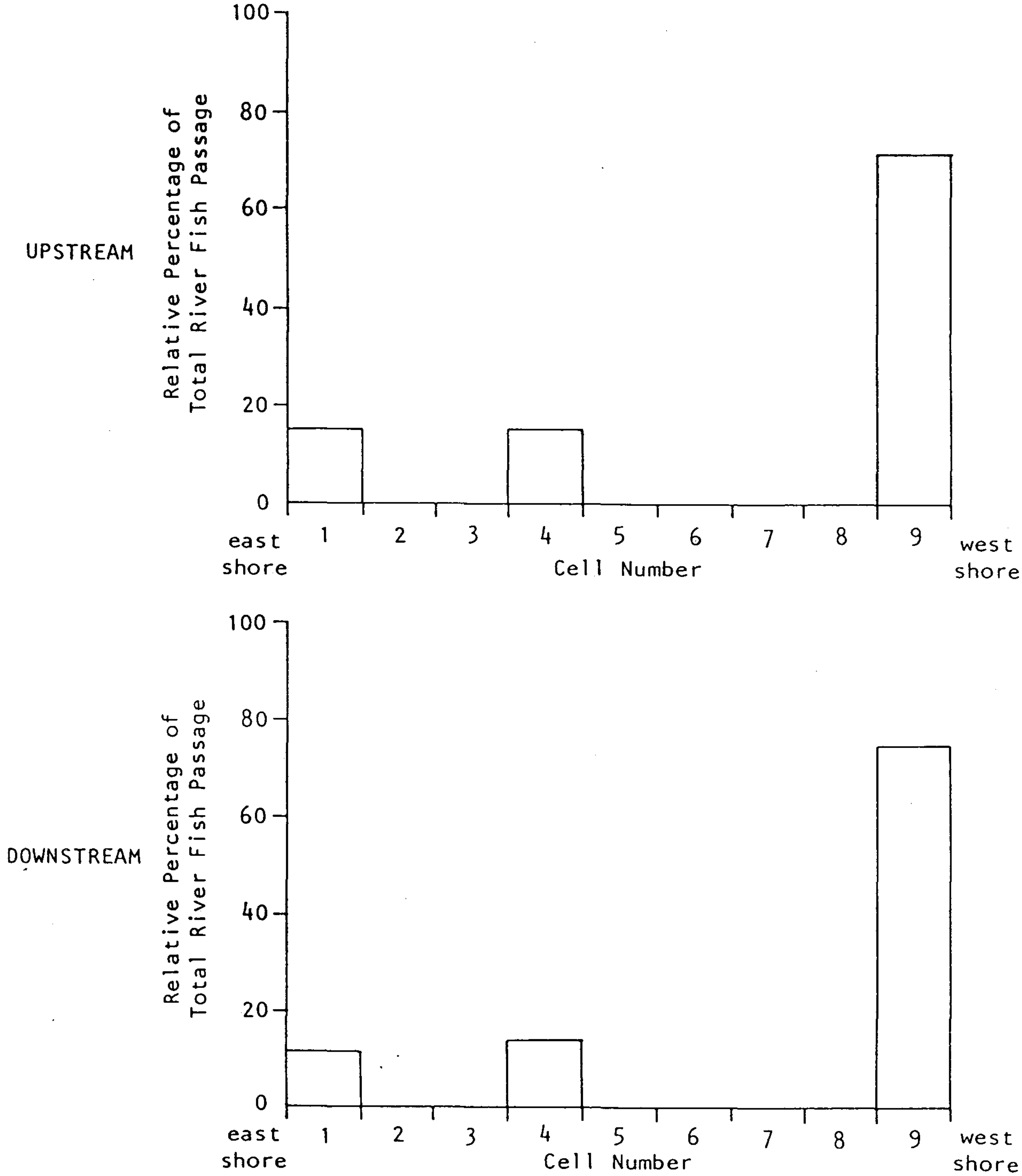


Figure I5. Mean horizotnal distributions of adult salmon across the river, based on distributions by shift, for Periods I and II (July 22-30). Susitna River, 1985.

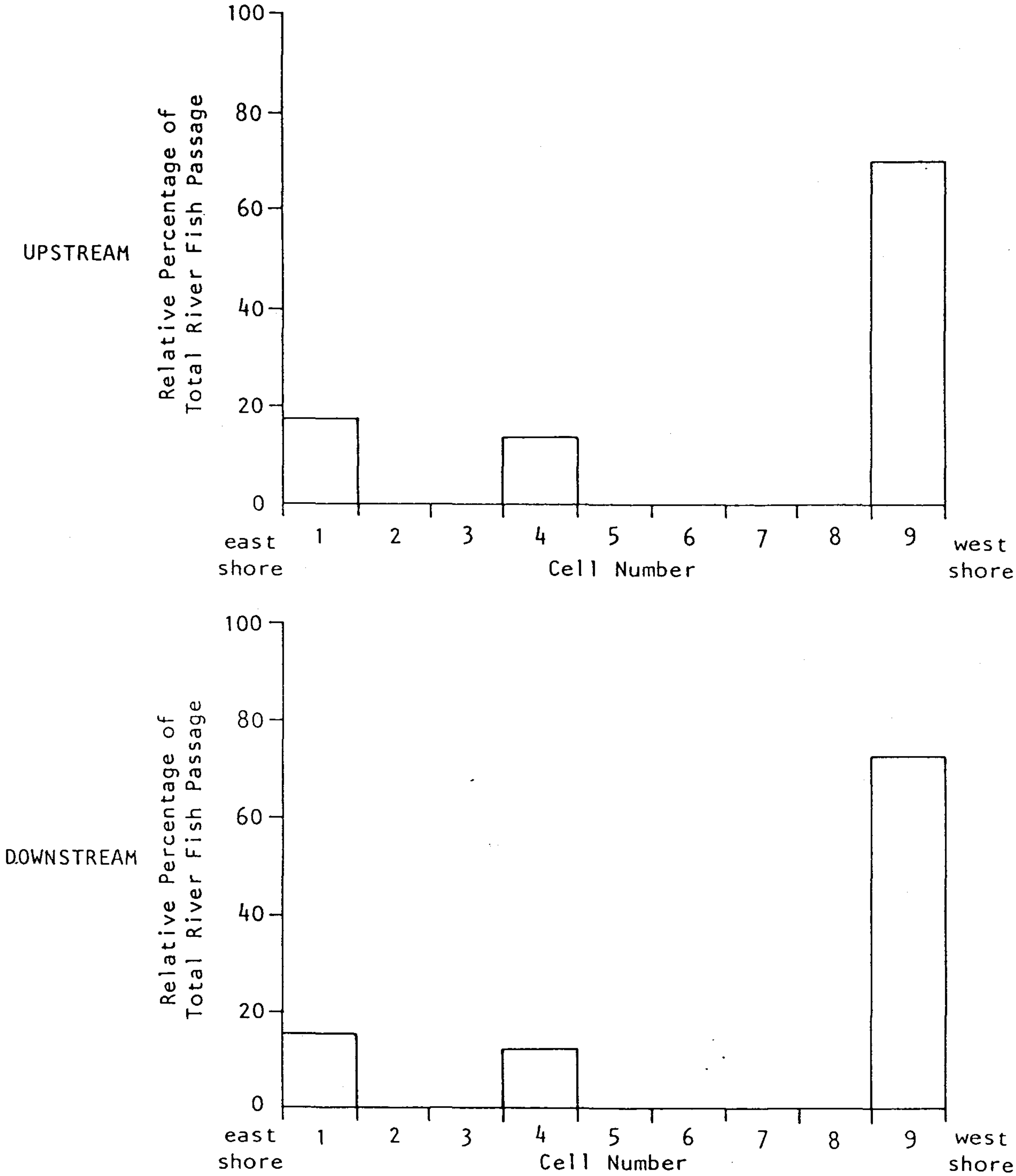


Figure I6. Mean horizontal distribuions of adult salmon across the river, based on distributions by shift, for Periods I-IV, (July 22 - August 8). Susitna River, 1985.

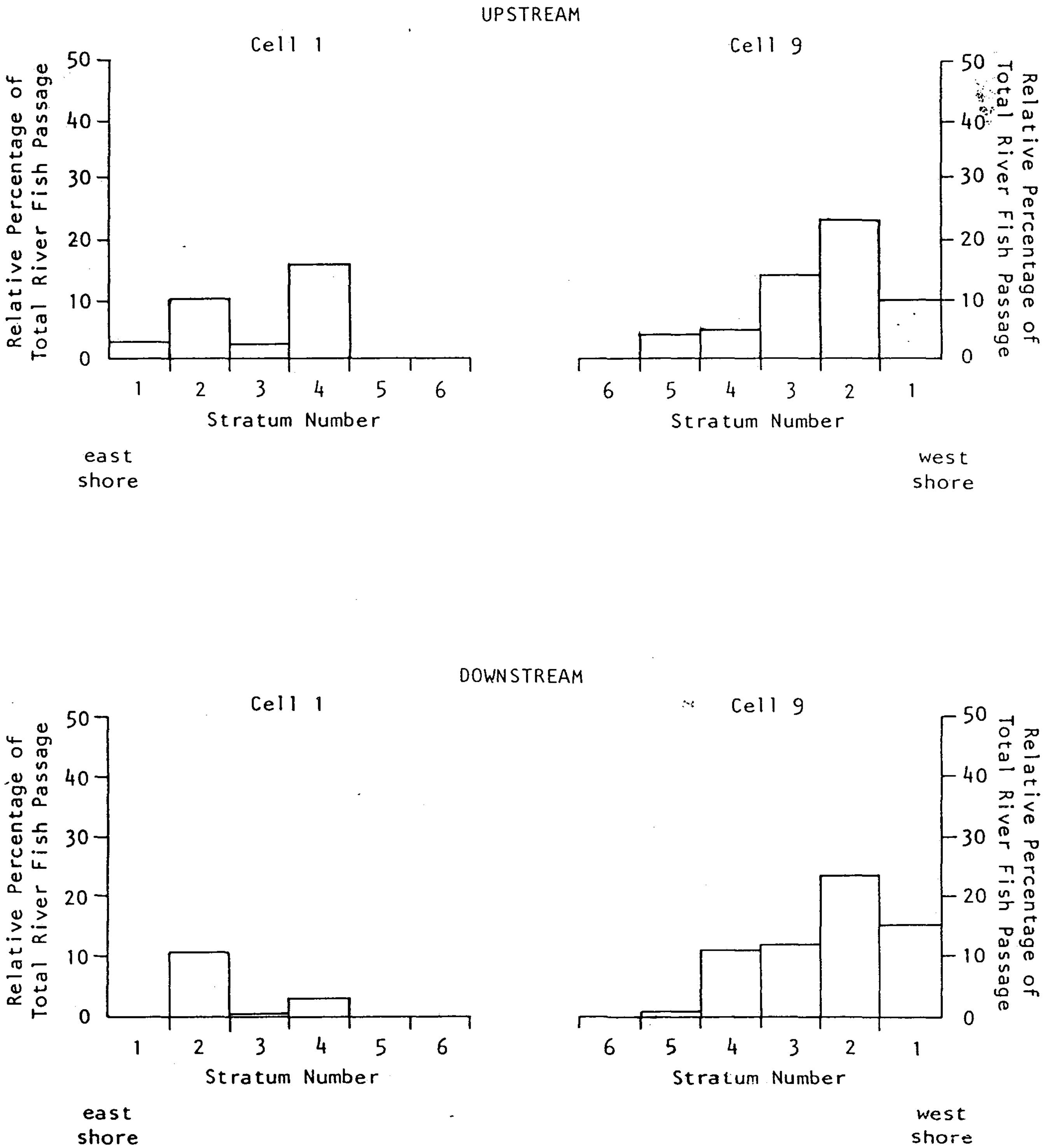


Figure I7. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period I (July 22-25). Susitna River, 1985.

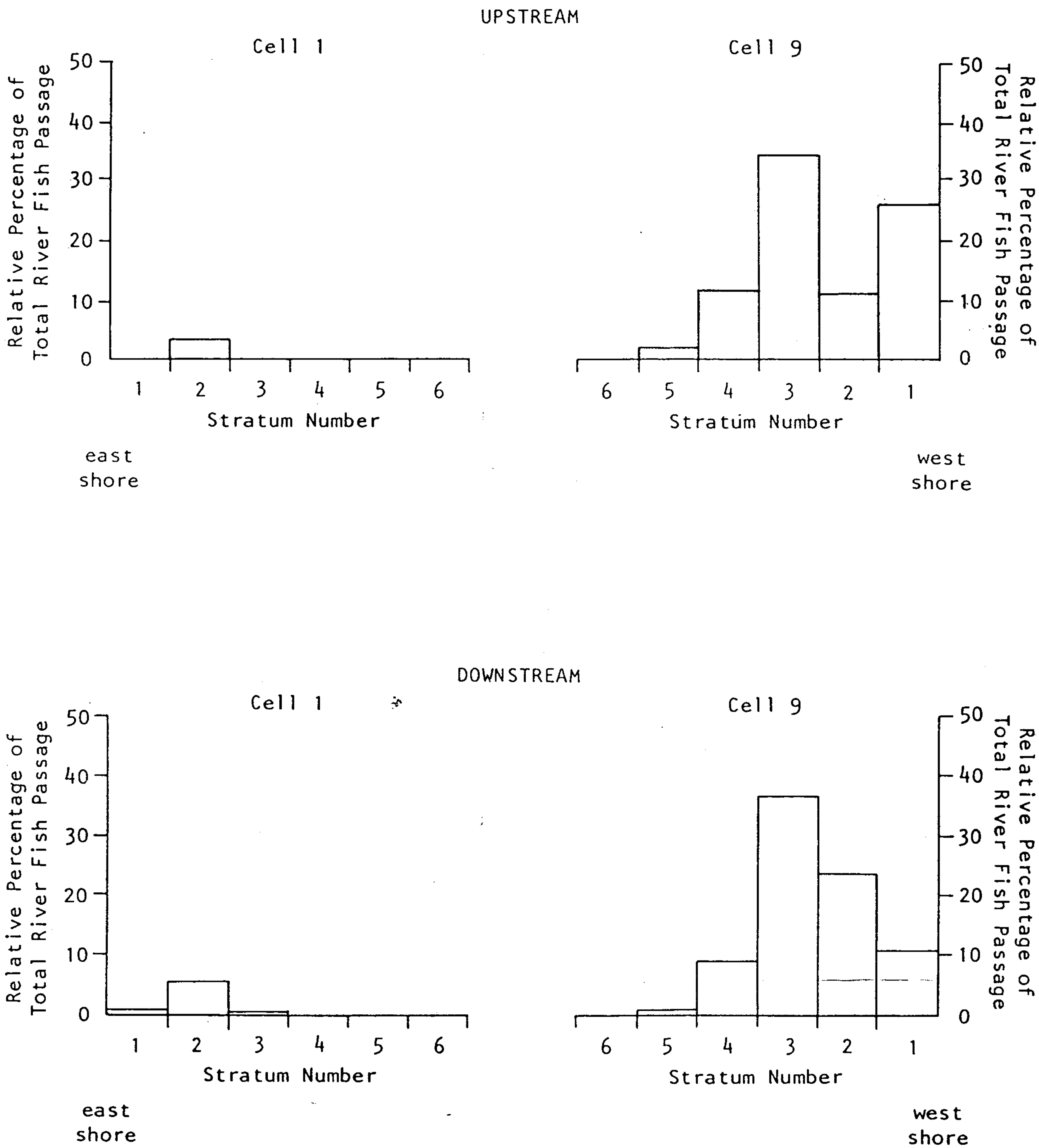


Figure I8. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period II (July 26-30). Susitna River, 1985.

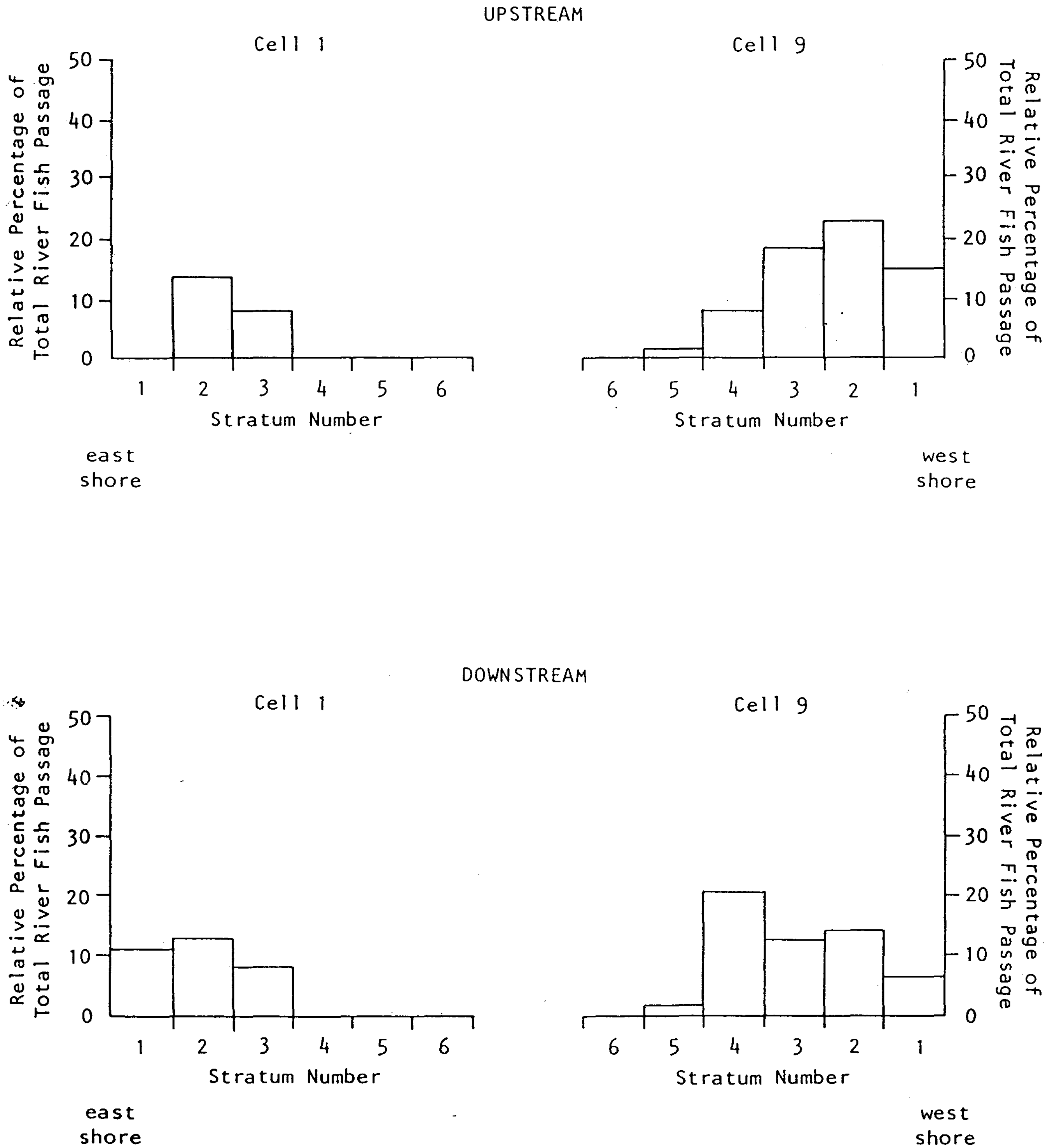


Figure I9. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period III (July 31 - August 3). Susitna River, 1985.

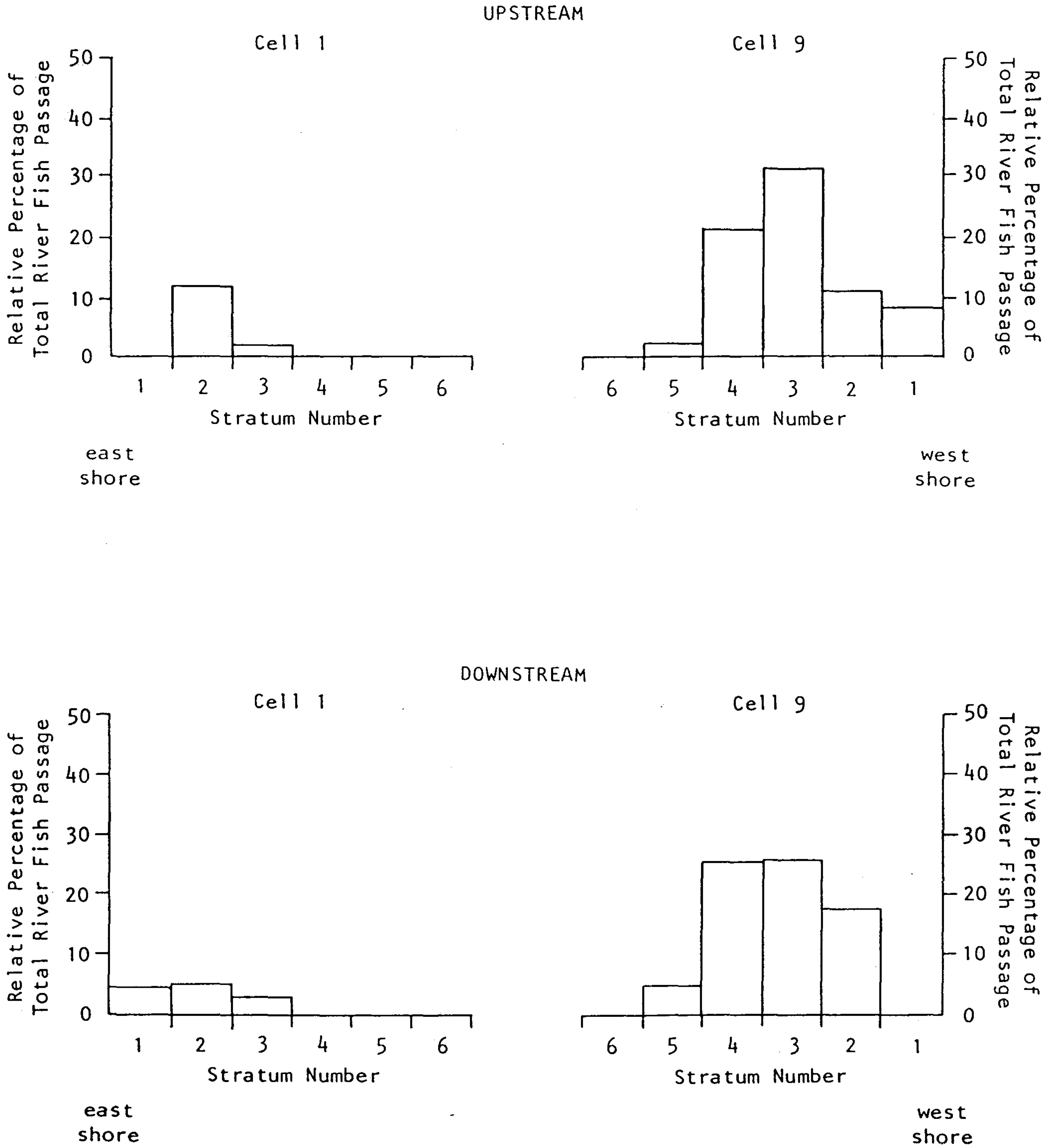


Figure I10. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Period IV (August 4-8). Susitna River, 1985.

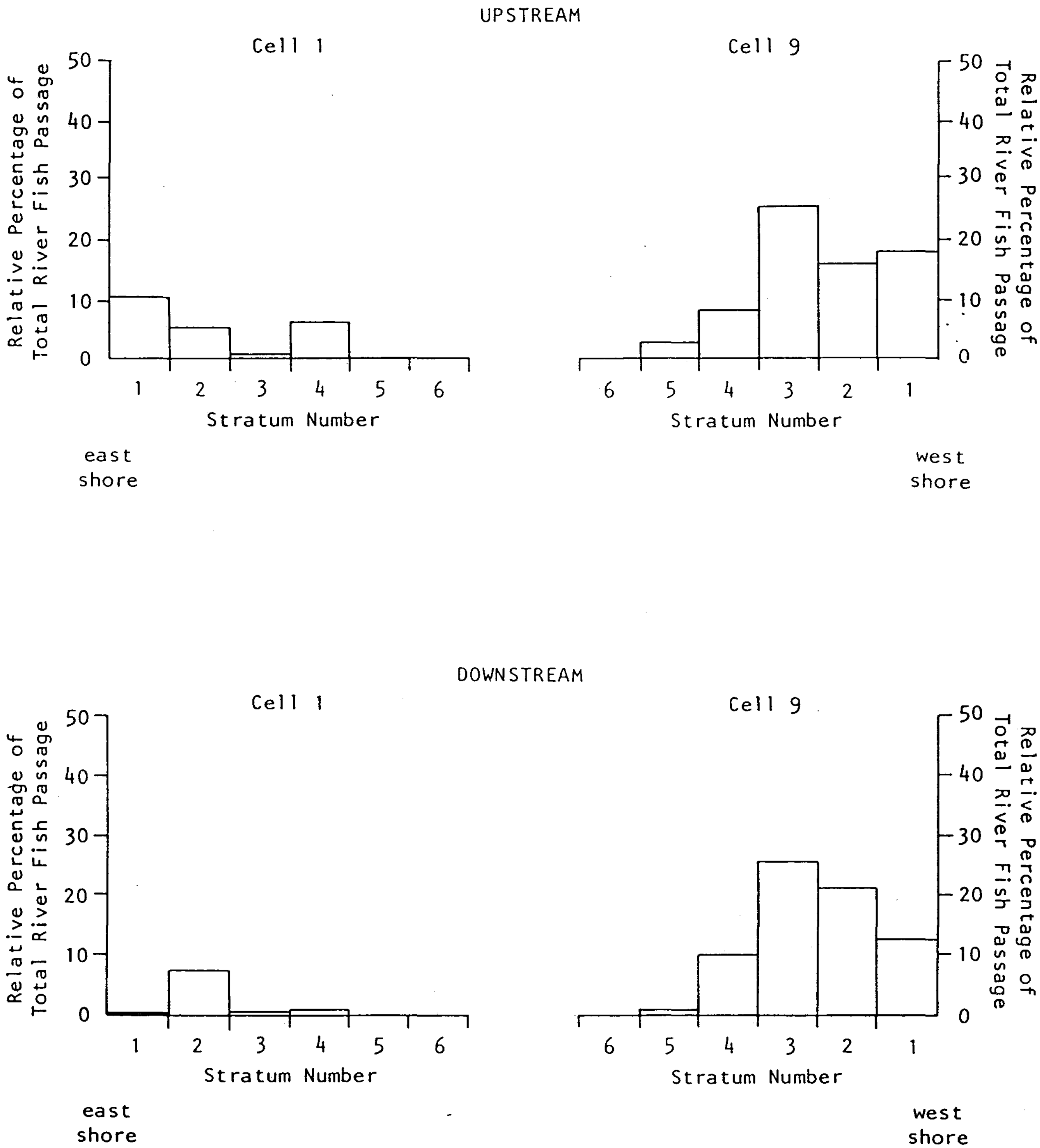


Figure I11. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Periods I and II (July 22-30). Susitna River, 1985.

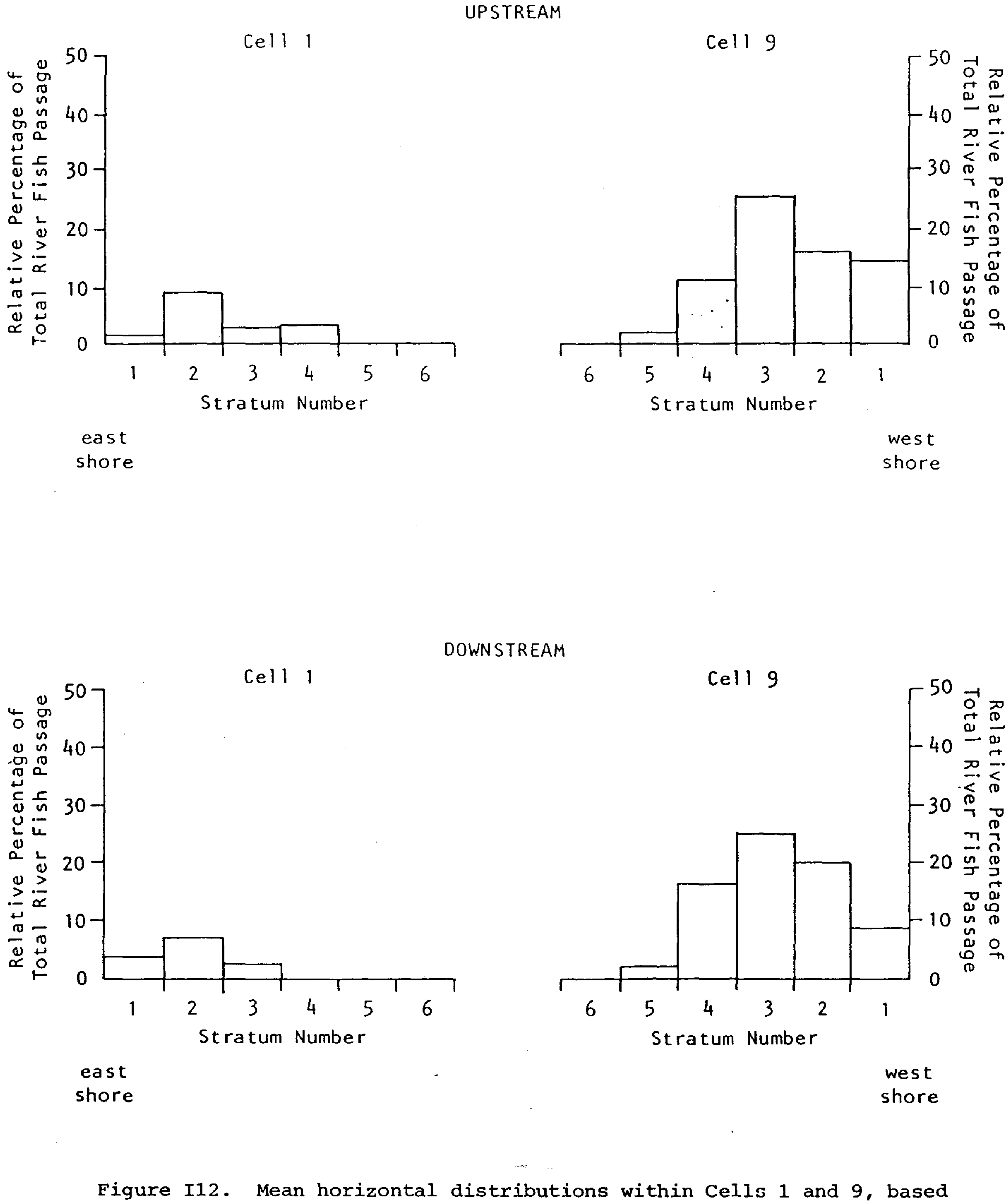


Figure I12. Mean horizontal distributions within Cells 1 and 9, based on distributions by shift, for Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table I1. Summary of mean horizontal distributions of adult salmon across the river, based on distributions by shift (Susitna River 1985).

Period Number	Dates	Fish Direction	Relative Percentage Across River by Cell* 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 I2. Summary of mean horizontal distributions of adult salmon across the river, based on distributions by shift (Susitna River 1985).

Period Number	Dates	Fish* 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

Column heading over sections 1–6: Relative Percentage Across the Cell, by Section**

* 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).

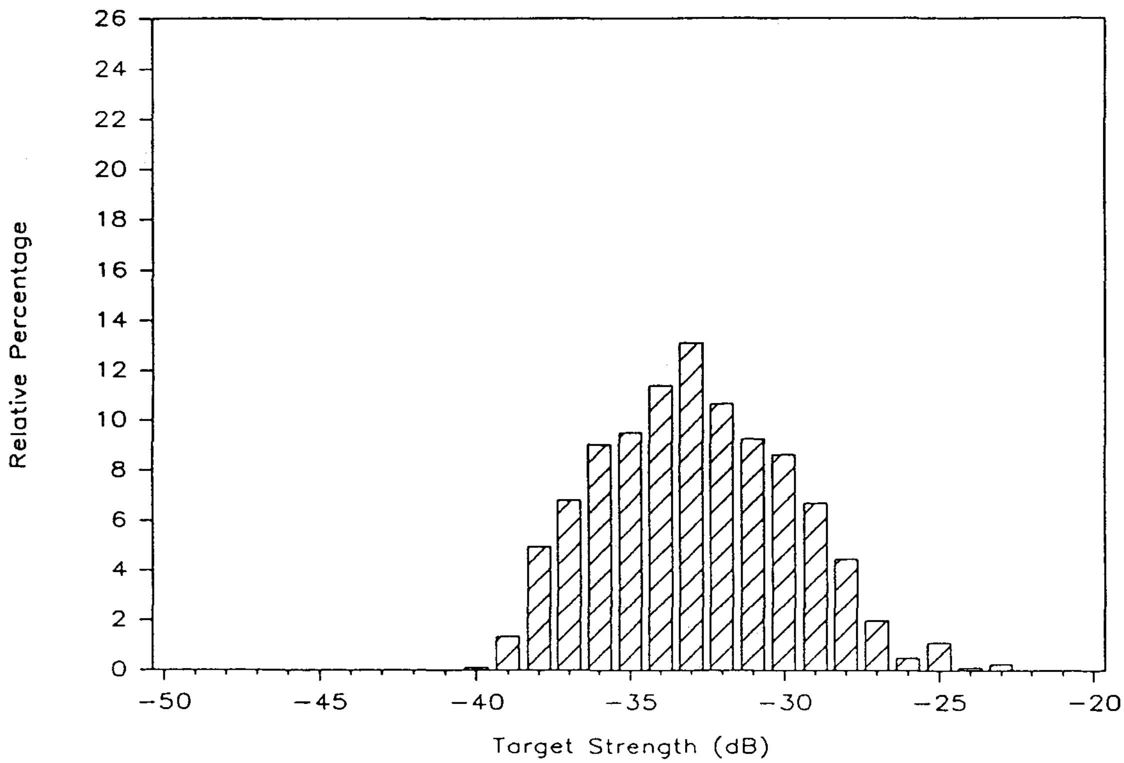
Table I2, cont.

Period Number	Dates	Fish* Dir.	1	2	3	4	5	6	SUM
			Relative Percentage Across the Cell, by Section**						
					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 J. Acoustic Size of Fish



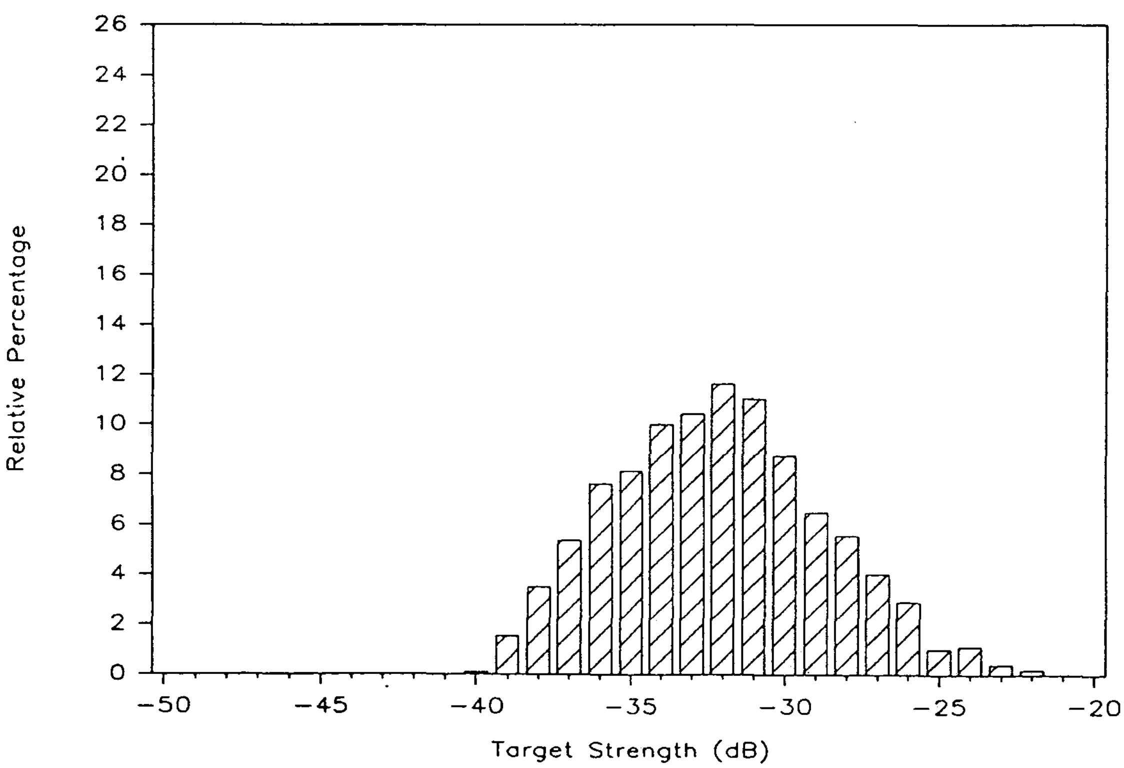


Figure J1. Acoustic size distribution of fish during Period I (July 22-25). Susitna River, 1985.

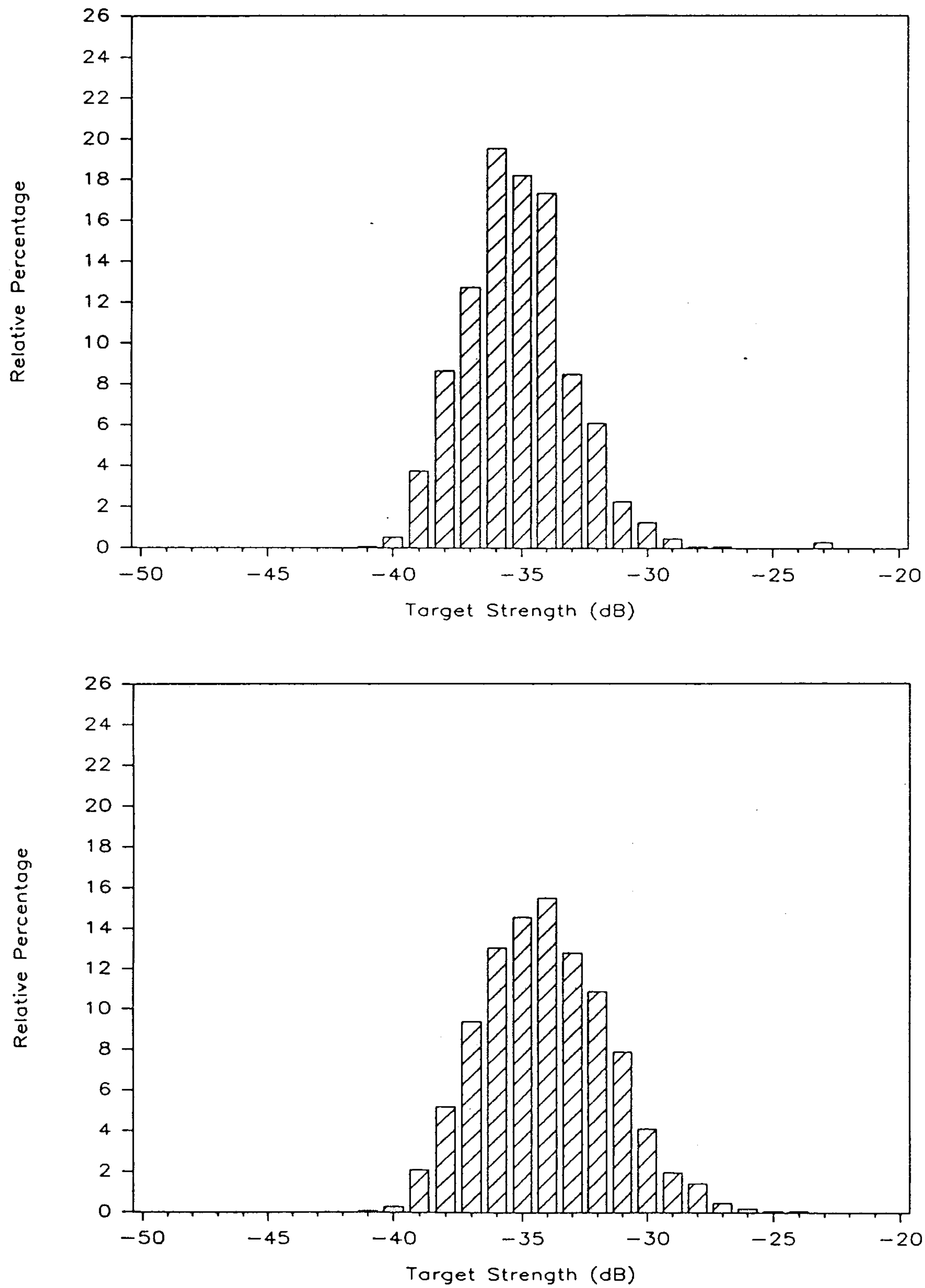
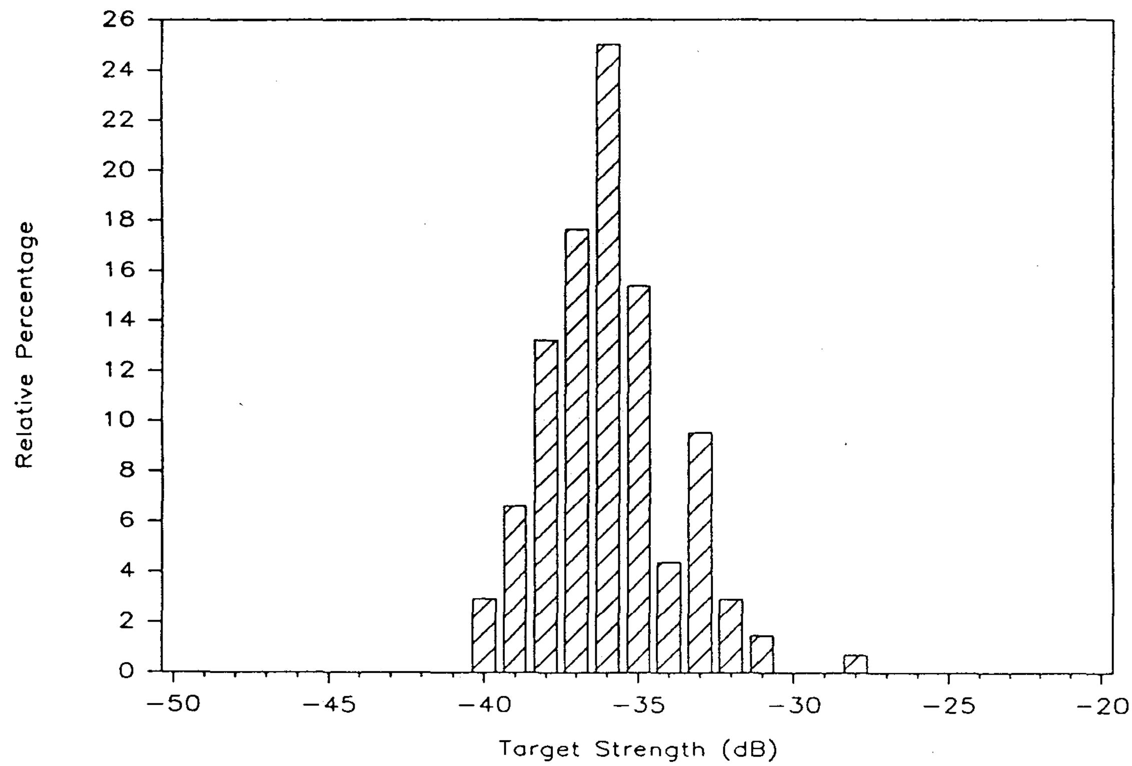


Figure J2. Acoustic size distribution of fish during Period II (July 26-30). Susitna River, 1985.



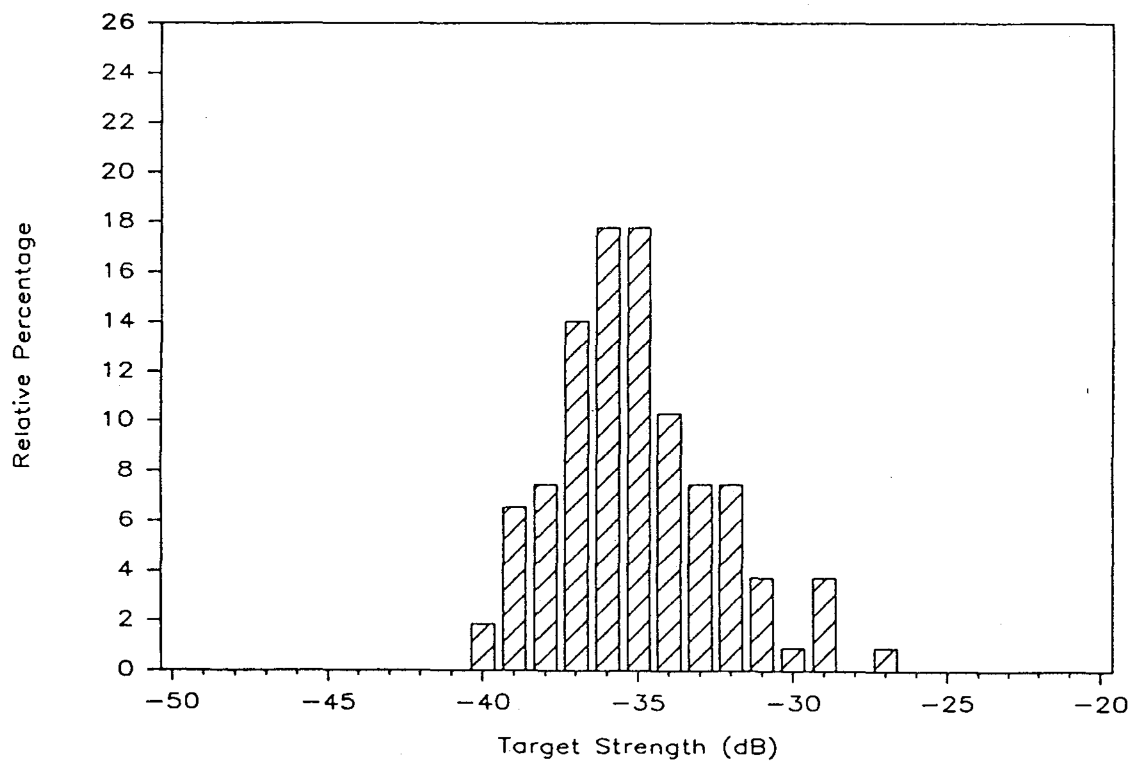


Figure J3. Acoustic size distribution of fish during Period III (July 31 - August 3). Susitna River, 1985.

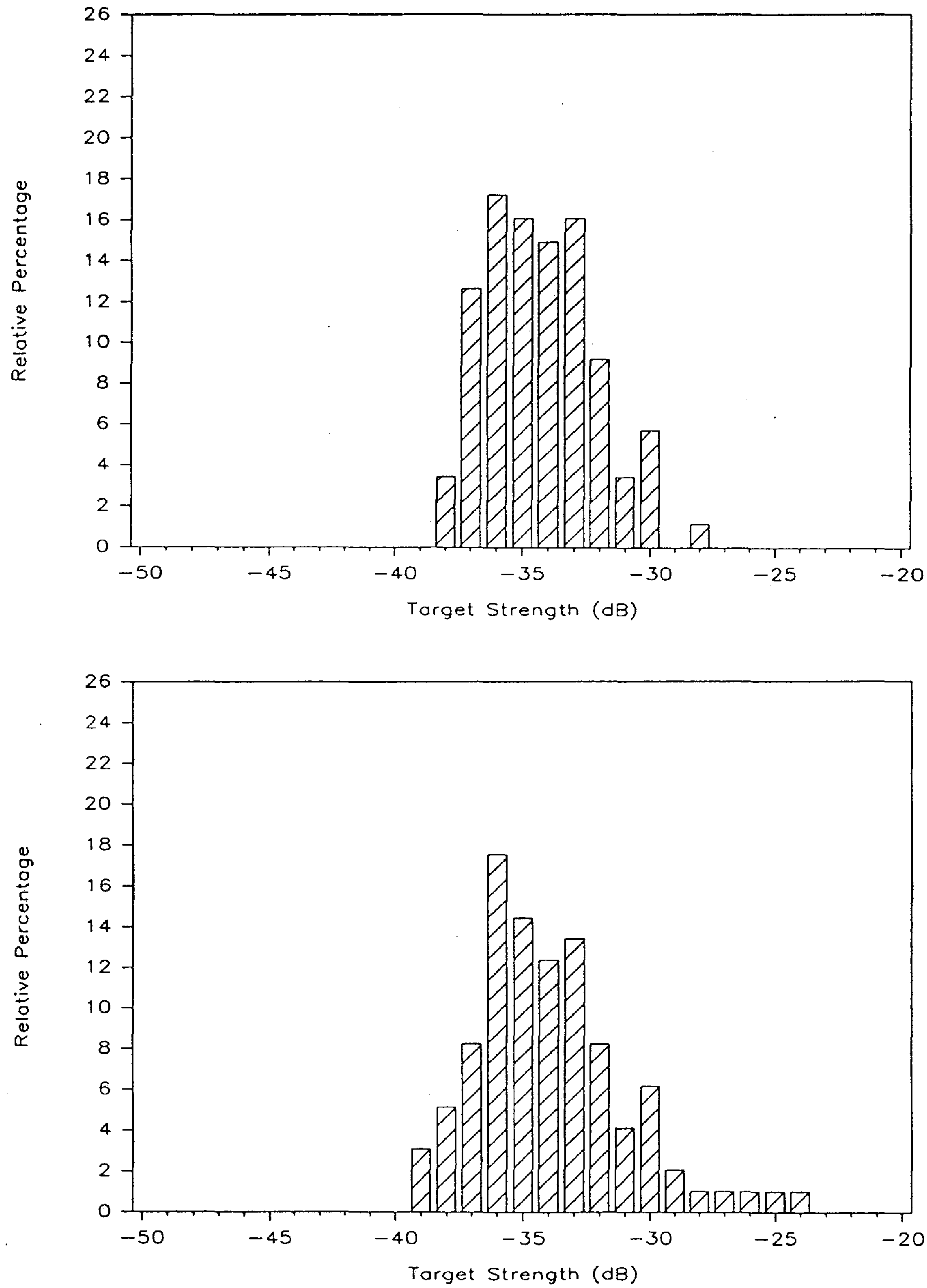


Figure J4. Acoustic size distribution of fish during Period IV (August 4-8). Susitna River, 1985.

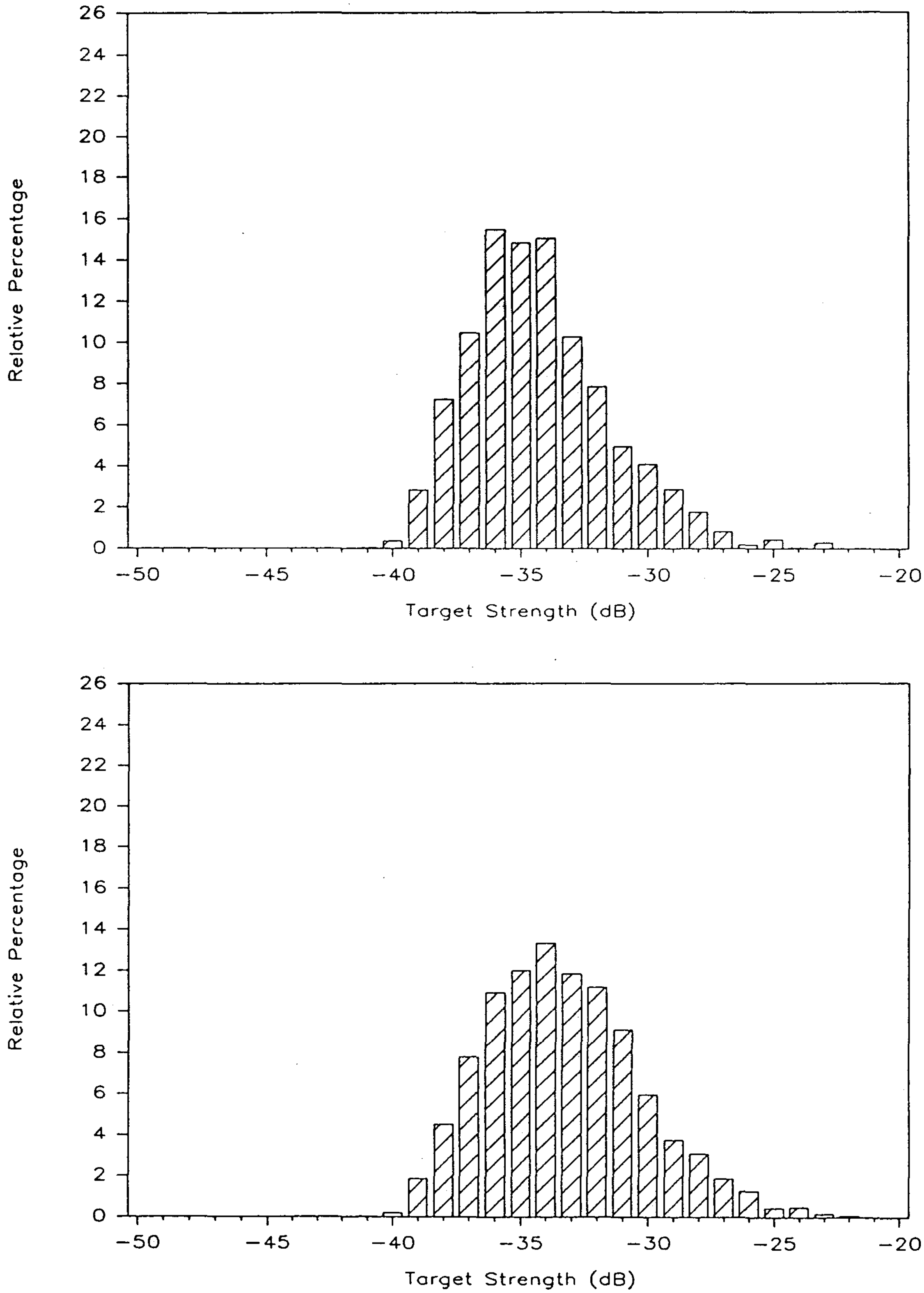
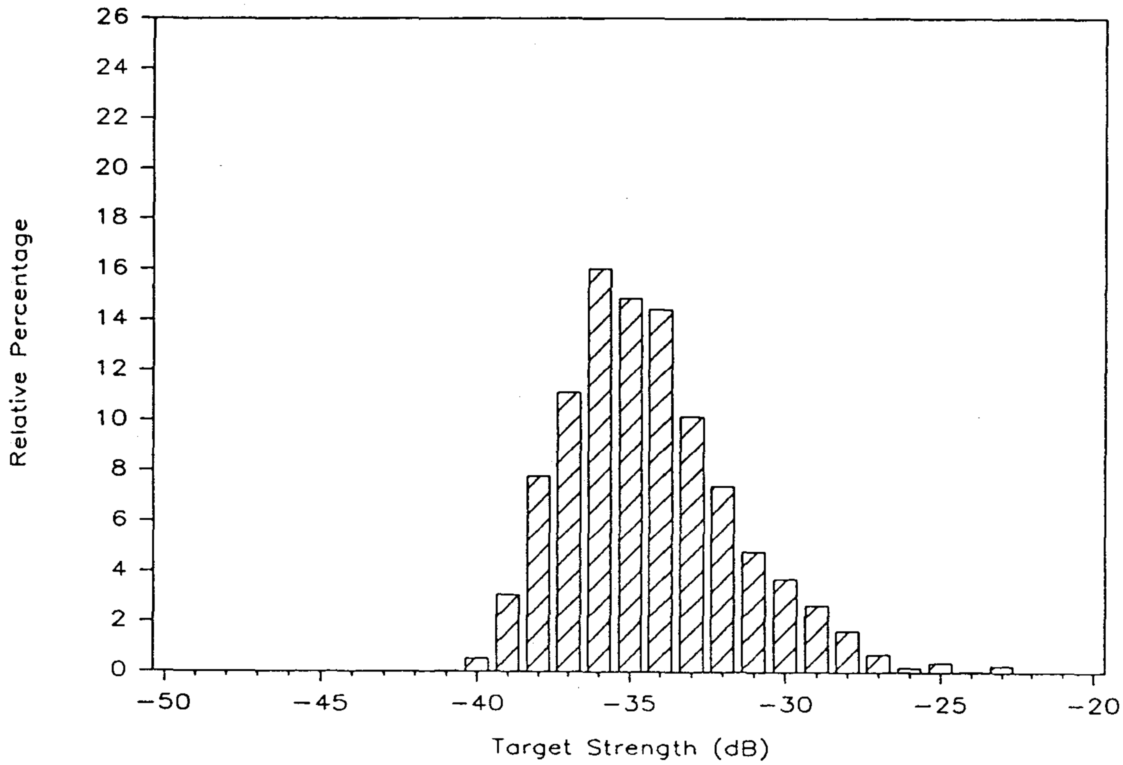


Figure J5. Acoustic size distribution of fish during Periods I and II (July 22-30). Susitna River, 1985.



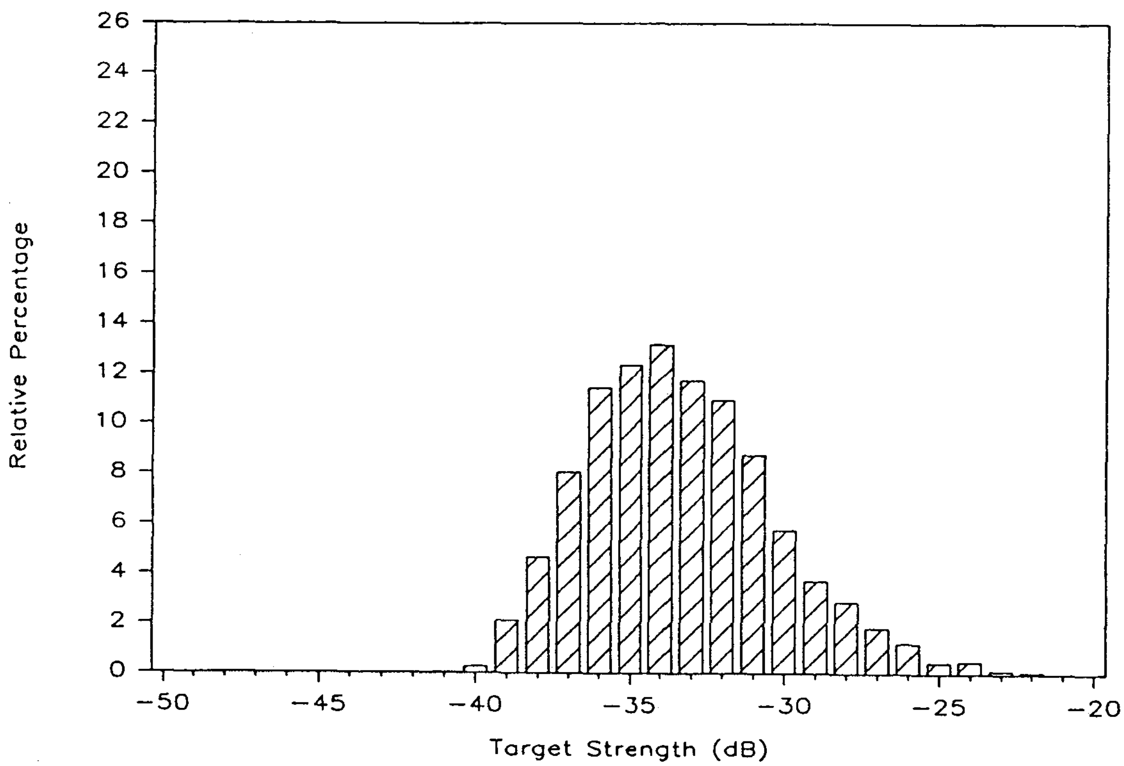


Figure J6. Acoustic size distribution of fish during Periods I-IV (July 22 - August 8). Susitna River, 1985.

Table J1. Target strength frequency distributions by period (Susitna River 1985).

UPSTREAM TS	BLOCK1	BLOCK2	BLOCK3	BLOCK4	BLOCKS I-II	BLOCKS 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 J1, cont.

DOWNSTREAM TS	BLOCK1	BLOCK2	BLOCK3	BLOCK4	BLOCKS I-II	BLOCKS 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

Appendix K. Mean Fish Target Velocities

Period	Dates	Upstream Velocity in fps (m/s)	N	Downstream Velocity in fps (m/s)	N
I	July 22-25	1.06 (0.32)	808	1.07 (0.33)	969
II	July 26-30	1.11 (0.34)	1279	1.03 (0.32)	1479
III	July 31-August 3	1.44 (0.44)	136	1.13 (0.34)	107
IV	August 4-8	1.47 (0.77)	87	1.16 (0.35)	97
I-II	July 22-30	1.11 (0.34)	2087	1.06 (0.32)	2448
I-IV	July 22-August 8	1.13 (0.35)	2310	1.07 (0.33)	2652

Appendix L. Relative Percentage of Upstream Vs. Downstream Moving Adult Salmon

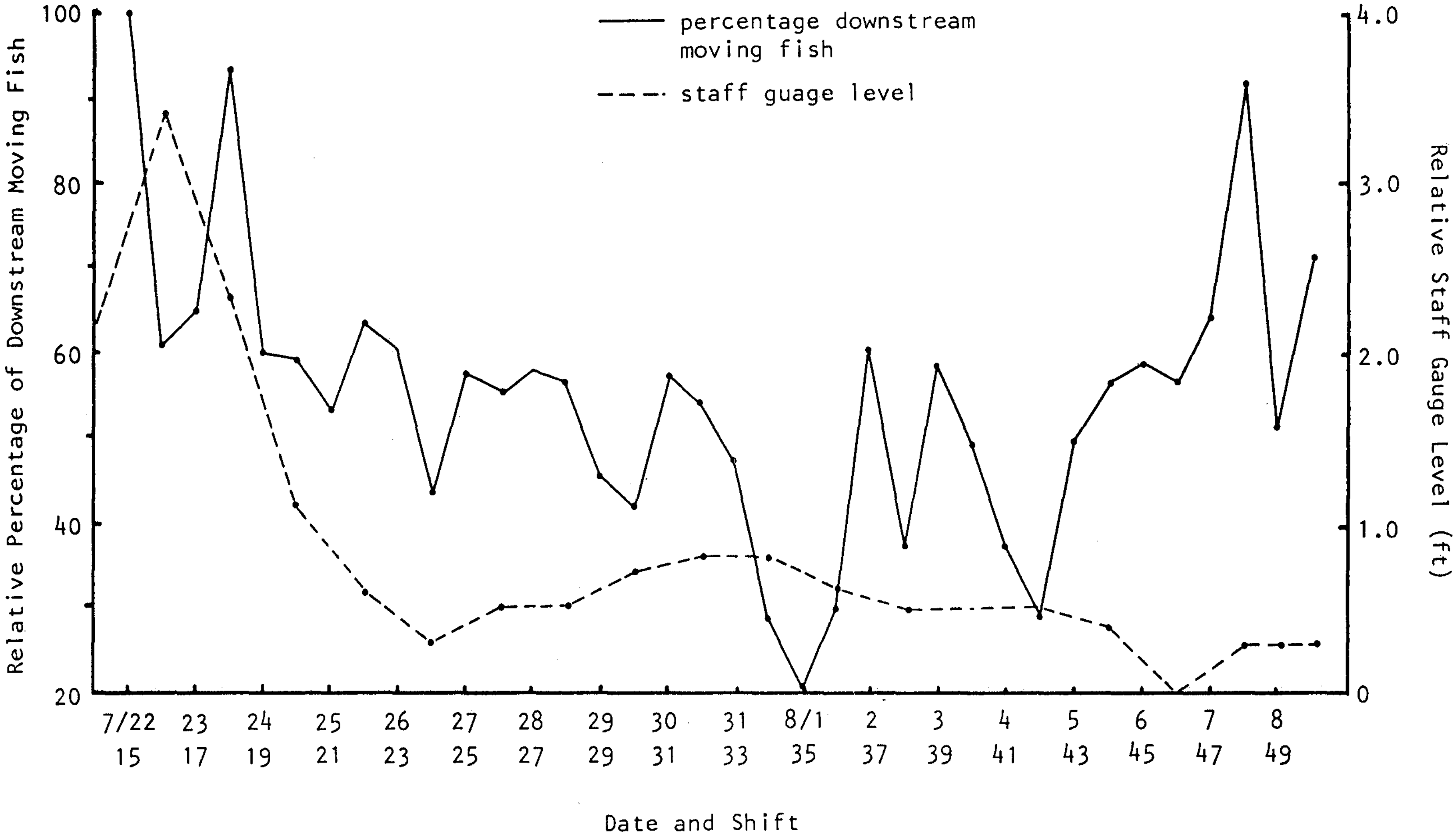


Figure L1. Relative percentage of downstream-moving fish and relative staff gauge level vs. date and shift. Susitna River, 1985.

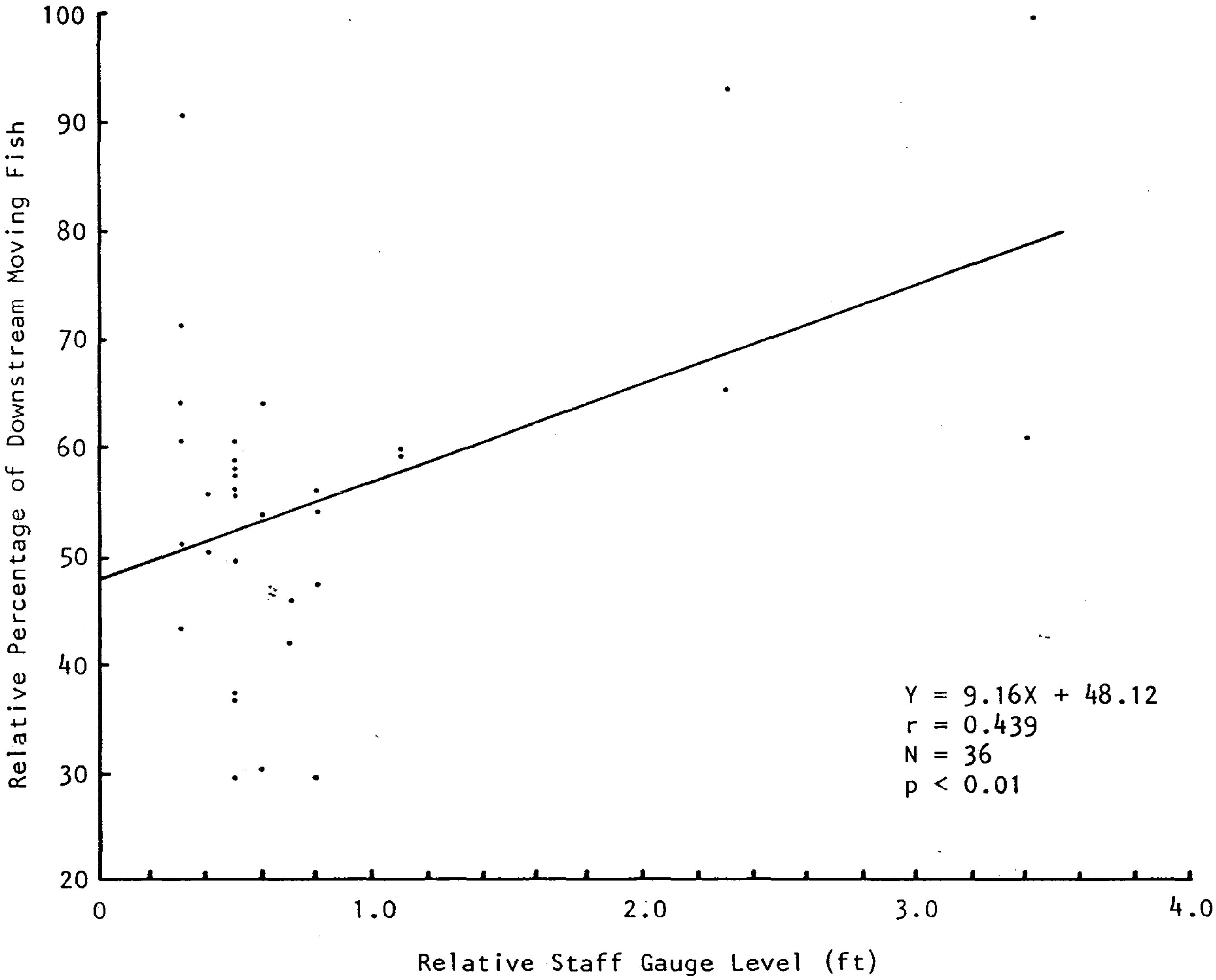


Figure L2. Regression of relative staff gauge level vs. relative percentage of downstream-moving fish. Susitna River, 1985.

Table L1. Relative percentage of upstream and downstream movement of adult salmon by shift, for the whole river (Susitna River 1985).

Date	Shift No.	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 L2. 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
(Weighted by Fish Abundance)	Mean	47.6	52.4	100.0

Table L3. 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 L4. Relative percentage of upstream and downstream movement of adult salmon by shift at cell 9 (Susitna River 1985).

Date	Shift Number	Relative Percentage Upstream	Relative Percentage Downstream	Total
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 M. Water Levels, Based on Daily Susitna Station Staff Gauge Readings

	Date	Water Level (feet) (Relative to 8/8 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.

Appendix N. Mean Water Velocity Profile and Depths During Low Water Period.

Cell	Depth Range* ft (m)	Surface	Velocity in fps Percentage of Total Depth** 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.