Fixed-Aspect Hydroacoustic Estimation of Fraser River Sockeye Salmon Abundance and Distribution at Mission, B.C., in 1986

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Correct citation for this publication:

Levy, D. A., P. A. Nealson and P. Cheng. 1991. Fixed-aspect hydroacoustic estimation of Fraser River sockeye salmon abundance and distribution at Mission, B.C., in 1986. Pacific Salmon Comm. Tech. Rep. No. 4: 30 p.

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ABSTRACT

Adult sockeye salmon in the Fraser River were enumerated at Mission, B.C., during 1986, by a fixed-aspect hydroacoustic system which was operated during the upstream migration period of the Adams River run. Twenty transducers were installed on the pier support structures of the Mission Railway Bridge and sampled on a fixed schedule covering twenty-four hours per day. Numerical estimates of daily fish numbers were scaled by test-fishing catches and the proportion of upstream-oriented fish targets to yield an estimate of the total run size of sockeye migrants. The estimate of total sockeye population size from the fixed-aspect system (n=2,875,000) compared favorably with the estimate from the Pacific Salmon Commission mobile hydroacoustic program (n=3,043,000) that operated at an adjacent site. However, when scaled by the daily upstream-orientation estimates, the total sockeye run at the fixed-aspect site decreased to 1,547,000 fish, 35% lower than the number of late-run sockeye estimated (post-season) to have migrated upstream past Mission during the survey period. Recommendations are provided to refine acoustic estimates of sockeye salmon within the Fraser River.

INTRODUCTION

Quantitative acoustic enumeration of migrating fish populations can be undertaken either by mobile surveys or fixed-aspect procedures. The former approach usually relies on the passage of a survey vessel, housing an acoustic system, across a pre-determined grid of transects. For salmon and other diadromous fish species which undertake predictable, directed migrations, quantitative assessment can also be undertaken by fixed-aspect acoustic methods. The latter approach relies on the movement of fish past an immobile transducer array situated on the migration path of the species of interest. In principle, a fixed-aspect enumeration system could be controlled from a remote location with rapid (near real-time) generation of quantitative population estimates. In practice, preliminary studies are required to evaluate the accuracy and cost-effectiveness of fixed-aspect systems for fish population enumeration.

A timely and accurate estimate of sockeye salmon *(Oncorhynchus nerka)* escapements for the dominant runs of the Fraser River is necessary for in-season sockeye salmon management by the Fraser River Panel of the Pacific Salmon Commission (PSC). Mobile hydroacoustic surveys in the Fraser River have been undertaken since 1976, to provide in-season estimates of the sockeye salmon populations that migrate past Mission, B.C., which is the upstream boundary of the commercial fishery. Due to navigational hazards in the Fraser River and field crew safety concerns, particularly at night, fixed-aspect hydroacoustic methods may be preferable to mobile survey methods for sockeye stock enumeration at Mission. During 1986, a dominant return year for the Adams River sockeye stock, the Pacific Salmon Commission contracted BioSonics (Seattle) to assess the suitability of the Mission Railway Bridge as a fixed-aspect location for enumerating large (millions of fish) sockeye runs in the Fraser River (Nealson and Murphy MS 1987). Subsequently, Levy Research Services was contracted to conduct additional analyses of the data set, synthesize the results and provide recommendations for future fixed-aspect enumeration programs. Results of these analyses are presented in this technical report.

STUDY AREA

The Fraser River is the largest Canadian river system on the Pacific coast and supports British Columbia's most abundant sockeye salmon population (Northcote and Larkin 1989). Salmon originating in the Fraser River and its tributaries contribute substantially to numerous Canadian and American salmon fisheries. A recent review of Fraser River salmon ecology and production was undertaken by Northcote and Burwash (1991).

The fixed-aspect study area was located at Mission, B.C., approximately 90 km upstream of the river mouth at Steveston (Figure 1) and adjacent to the site described by Cheng et al. (1991). The Mission Railway Bridge, a 550 m long Canadian Pacific Railway trestle spanning the Fraser River, serves as the upstream boundary of the commercial fishing area (Area 29). Sockeye migrating past this site "escape" to the Indian food fishery or to upstream spawning grounds. The vertical tidal amplitude in this reach of the Fraser River is about 1.5 m.

Transducers were fixed to the pier supports of the Mission Railway Bridge. The bridge is supported by eleven concrete piers and utilizes a 70 m long swing-span at the southern end to pass boat traffic. The bridge deck is approximately 10 m above the river surface and consists of wooden rail ties.
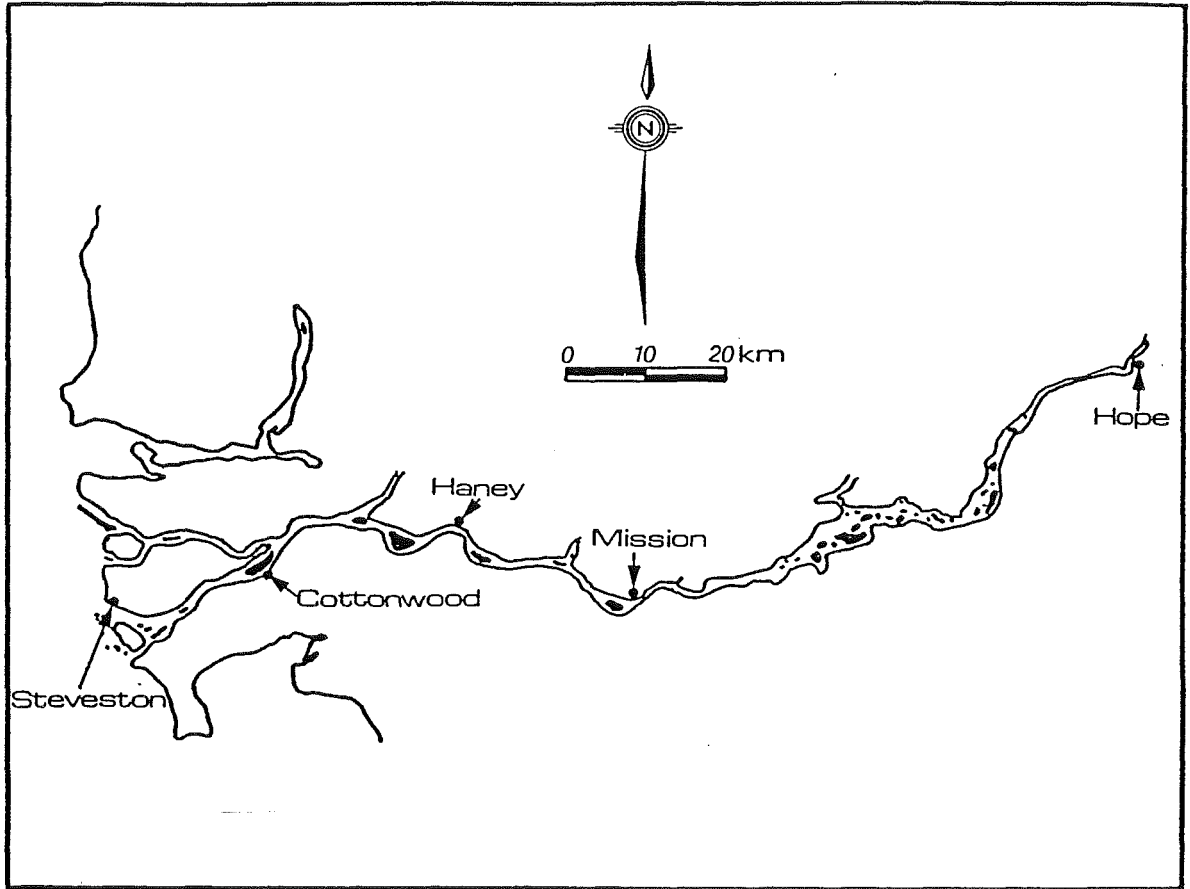
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Figure 1. Location of the Mission sampling site on the Fraser River.

METHODS

FIXED-ASPECT HYDROACOUSTIC SYSTEM

Twenty transducers were mounted on the Mission Railway Bridge on the upstream faces of the concrete piers and at the middle of the swing-span support bulkhead (Figure 2). The transducers were aimed slightly upstream of the adjacent pier and approximately perpendicular to the river flow, to establish an acoustic "screen" across the river. Two transducers aimed in opposite directions were installed on each of the nine center bridge piers. The two end piers had only one transducer each, aimed away from shore. Since these two piers were both within 3-7 m of the shoreline where water depths were less than 2 m, no significant fish passage likely occurred inshore of these locations.

The transducers were numbered from 1 to 20 beginning at the north bank (Figure 2A). Even-numbered transducers were oriented toward the north and odd-numbered ones toward the south. Transducers were mounted on the pier supports at 0.5-0.75 m depth (Figure 2B) relative to the mean low tide level (daily tidal fluctuations varied between 0.75-1.5 m amplitude at this location in the Fraser River). Each transducer was aimed across the river toward the upstream base of the adjacent pier (Figure 2C). Mobile acoustic transects undertaken in mid September, 1986, established the depth and bottom profile at each pier. Using this information, the appropriate vertical angle was calculated for aiming each transducer (between 80° and 85° in most cases, Figure 2B). After uniform vertical coverage was established across the bridge, each transducer was rotated 30° horizontally from the upstream edge of the span (Figure 2C) to permit the determination of fish swimming direction from the orientation of traces on echograms (Figure 3).

All transducers were of 15° nominal beam width. Actual beam widths measured during the calibration process varied between 16° and 18°. Each transducer and cable combination was calibrated at the BioSonics' facility in Seattle, so fish of a given size would be uniformly detectable at all sample locations. The output of the acoustic system was adjusted to establish a minimum threshold of fish detection. A detailed explanation of this procedure is provided by Cheng et al. (1991). At the Mission Bridge site for 1986, the system was configured to detect fish with a target strength between -40 db and -8 db. This eliminated observations of small-bodied, non-target fish, but detected larger targets such as upstream-oriented adult salmonids. Adult sockeye collected by purse seine in the Strait of Georgia just prior to the Mission Bridge study (Levy et al. 1991) indicated fish body lengths between 44 cm and 62 cm, corresponding to an ideal dorsal-aspect target strength of -30 db to -33 db (Love 1971). When measured from lateral-aspect, as at the Mission Site, the target strength of a 62 cm salmonid can exceed -20 db (Dahl 1982).

Two separate hydroacoustic systems were deployed at the Mission Railway Bridge. Each system consisted of a Biosonics Model 101 Echo Sounder, a BioSonics Model 151 Multiplexer/Equalizer, a BioSonics Model 111 Thermal Chart Recorder and a Hitachi Model V-422 Oscilloscope. Two systems were required since the Model 151 Multiplexer/Equalizer can accommodate a maximum of sixteen transducers and twenty were required for complete coverage of the river. Transducer cables were routed along the railing on the upstream side of the bridge. Cables that crossed the swing-span of the bridge (Locations 16-20 on Figure 2A) were fitted with connectors which could be quickly uncoupled when the bridge was opened to allow boat traffic to pass.
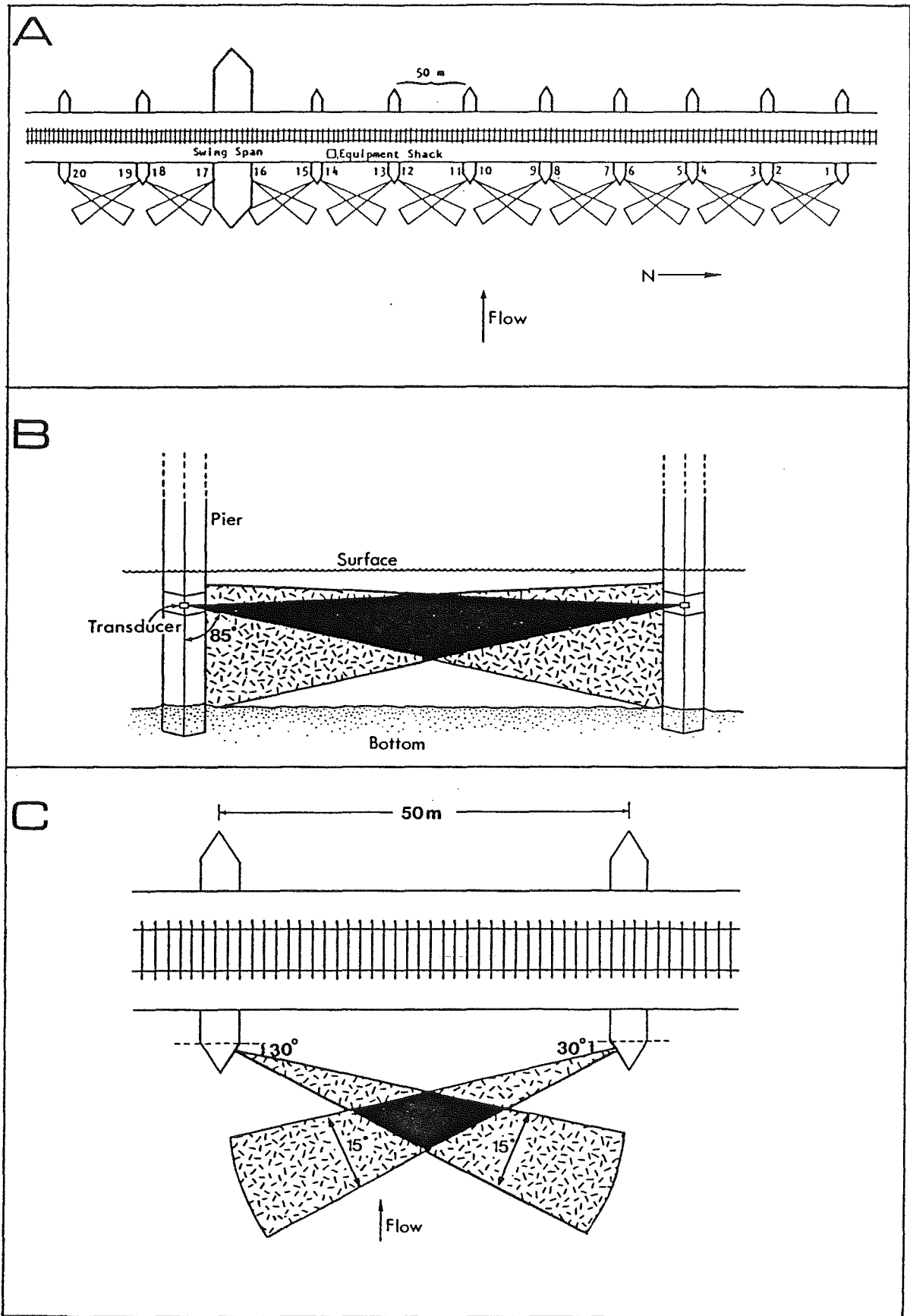
Figure 2. Location and orientation of transducers mounted on the Mission Railway Bridge: A) plan view, B) frontal view and C) top view.
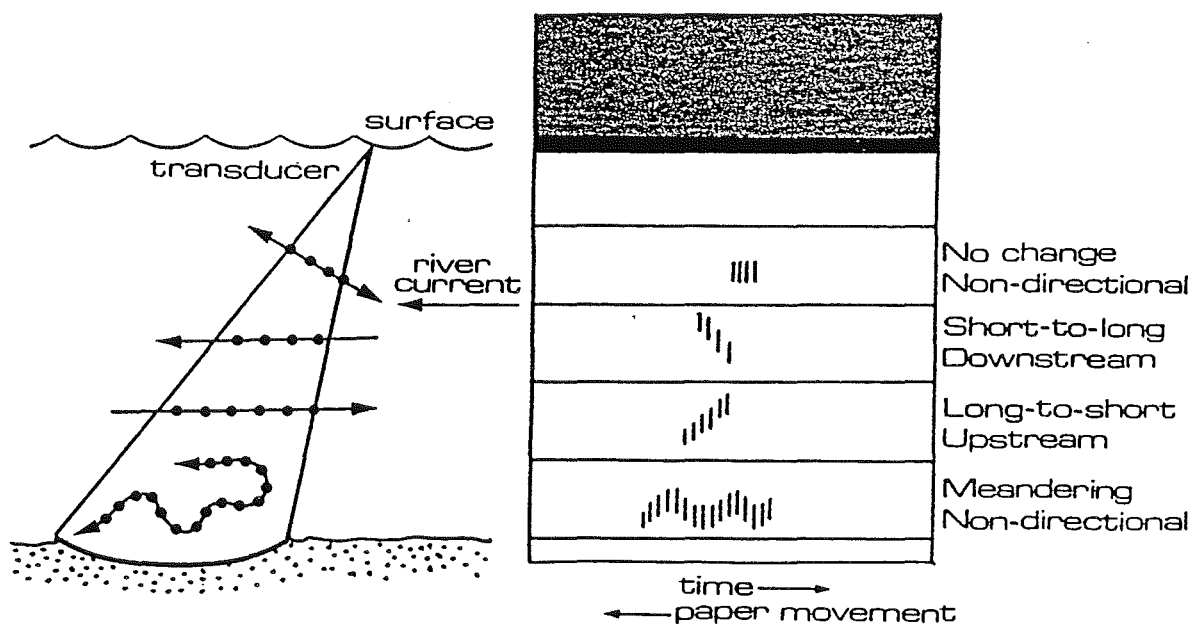
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Figure 3. Classification of echo targets in the sonic field of an angled transducer as downstream, upstream or non-directional depending on the target orientation.

Transducers were interrogated sequentially, beginning at the north bank of the river, at a rate of 10 pulses per second for consecutive periods of 3-4 minutes per hour, twenty-four hours per day. Between September 19-22, only transducer locations 1-15 were sampled due to a delay in the equipment installation. Installation of transducers 16-20 was completed on September 23 and all twenty sample locations were monitored from that date until the end of the study on October 4. To account for the passage of adult sockeye through locations 16-20 during the first four days of the study, horizontal distribution data collected during September 23-27 were averaged and applied as a correction factor to the data collected between September 19-22. Since 87.6% of the total daily fish passage was enumerated at transducer locations 1-15 on the former dates, estimates of total daily fish numbers were increased by 14% for September 19-22, to account for the zone of the river that was initially not sampled.

The multiplexer was programmed to sample each transducer on a fixed schedule of once every hour. The first system sampled transducers 1-15 sequentially over the course of an hour. The second system sampled the remaining five transducers, 16-20, during the first 20 minutes of each hour. This allowed the latter system to be shut down during bridge openings without interfering with the sampling of transducers 1-15. The end of each sequence was marked on the echogram by an output from the multiplexer noting location, time and number of sound pulses for the sample. Horizontal lines were printed on the echograms at 5 m range intervals, which corresponded to 1 m vertical depth intervals due to the vertical aiming angles (Figure 2B) that were employed.

At the completion of each transducer sequence, the technician tallied the number of fish traces on the echogram in each 5 m range stratum and recorded the number of detections on a data logging form. A completed log sheet for an hour of sampling was in the form of a matrix, with range strata in rows and transducer numbers in columns. These data were then entered into a LOTUS 1-2-3 spreadsheet (on microcomputer) to calculate an estimate of fish passage for each hour of sampling. Daily fish target frequencies were estimated by summing the twenty-four hourly estimates made from 5 a.m. to 5 a.m. the following day.

Hourly fish population estimates were derived from the fish target frequency observations by applying expansion factors to account for differences between the actual area sampled and the total cross-sectional area of the inter-pier section of the river, and the actual time sampled during each hour. The horizontal cross-section of the acoustic beam formed an ellipse, so the expansion factor contained the formula of the ellipse at the mid-point of each 5 m range strata. This elliptical sample area was expanded to the width between the piers to account for the areas not sampled by the acoustic system. Time was expanded from the number of seconds actually sampled to a one hour period. The entire expansion was calculated as follows:

$$W = \frac{F \, E}{\left(\dfrac{2R \, \tan(\theta/2)}{\cos V} \right)} \frac{3600}{S}$$

where W is the weighted number of fish per area per hour, F is the observed number of fish in a range stratum, E is the expansion width (m), R is the mid-point of the stratum range (m), θ is the beam width of the transducer, V is the vertical aiming angle of the axis of the transducer beam referenced to 0° (i.e., straight down), 3,600 is the number of seconds in an hour and S is the number of seconds sampled.

The following example illustrates the weighting procedure. Assume one fish (F) is detected in the 5 m range (R) at sample location 5, where the width between spans is 50 m (E), sample time is 4 min (S), transducer beam width is 16° (θ) and the beam axis is 83° (V) off vertical. The width of the beam at 5 m is:

$$\frac{2R \tan(\theta/2)}{\cos V} = \frac{2\ (5)\ \tan(16°/2)}{\cos 83°} = 11.5\ m$$

At a range of 5 m, 23% $(11.5/E = 11.5/50)$ of the inter-pier area is sampled. Therefore, the observed fish count (one fish) is extrapolated by a factor of 4.35 $(E/11.5 = 50/11.5)$ to estimate the passage of salmon across the entire span area (4.35 fish) in a four minute period. This estimate converts to about 65 fish per hour.

One fish observed at 5 m range at sample location 5 was, therefore, equivalent to a weighted hourly passage estimate of 65 fish. Since most inter-pier locations were sampled by two transducers, the mean of the range-weighted values for the two adjacent transducers was used to estimate the total fish passage for a particular inter-pier section of the river. By summing these computed mean values, an hourly estimate of total fish passage past the bridge was generated. These estimates of hourly fish passage were grouped to estimate daily fish passage and later processed to determine the horizontal and vertical distributions of fish in the river.

The estimates of daily fish passage were adjusted to account for the presence of fish moving perpendicular to the flow of the river and downstream at the Mission Railway Bridge site. The two transducer locations showing the highest fish passage (locations 13 and 14) were examined three times daily (at 07:00, 15:00 and 23:00) to record the direction of fish movement as shown on Figure 3. Fish direction was classified in one of three vector categories: upstream, downstream and non-directional (no net change in range from the transducer). Data were combined across sampling locations and sampling times to obtain the percentage of net upstream-oriented fish. For the purpose of directional scaling, non-directional fish (an average of 10% of the targets categorized) were ignored and net upstream estimates were derived according to the daily percentage of upstream:downstream fish. This procedure for calculating net upstream orientation differs slightly from the method described by Cheng et al. (1991).

Due to the fixed-aspect sampling strategy adopted (each transducer was sampled once per hour on a fixed schedule) and the large diel effects observed on fish abundance estimates and directional preference, no variance calculations on the population estimates were undertaken. Instead, hourly estimates of salmon abundance were derived and summed over twenty-four hours to give a single point estimate of daily sockeye salmon abundance.

MOBILE HYDROACOUSTIC SYSTEM

Since 1976, the PSC and its predecessor, the International Pacific Salmon Fisheries Commission, have relied on a mobile hydroacoustic monitoring program to estimate the abundances of sockeye and pink salmon migrating past Mission, B.C., to be used for in-season management decisions. A mobile survey vessel undertakes continual (over the diel cycle) transects across the Fraser River at a site 1 km upstream of the Mission Railway Bridge. This latter method does not adjust for the orientation preference of migrating salmon. A description of the hydroacoustic hardware and the procedures used for field sampling and data analysis is provided by Cheng et al. (1991).

COTTONWOOD TEST FISHING

The fish population estimates described above included all fish which exceeded the acoustic threshold of -40 db. To account for non-sockeye fish targets, the numerical values were scaled by the percentage of sockeye within the river, as estimated by a gillnet test fishing program at Cottonwood (Figure 1). A commercial gillnet fisherman was contracted during the survey period to make gillnet drifts on a daily basis at a pre-determined location adjacent to Cottonwood bar. Chum, chinook and coho salmon were present in the Fraser River during the survey period, necessitating daily fish sampling for species identification purposes. The vessel fished a 133 mm mesh gillnet (knot-to-knot stretched measurement) of dimensions 30 m length by 60 meshes deep. The test fishing drifts (20 min duration) were conducted during the turn of the tide at low water. Catch results from Cottonwood were lagged by two days to account for the migration passage of salmon between the gillnet site and the fixed-aspect enumeration site at Mission.

RESULTS

SOCKEYE SALMON ABUNDANCE AND RUN TIMING

At the time of the fixed-aspect survey, sockeye were the most numerous adult salmonid present in the Fraser River, comprising the majority of the Cottonwood gillnet test catch until the end of September (Figure 4). In October, the percentage of sockeye in the test catch declined to low levels, reflecting the seasonal passage of the fish to their spawning grounds upstream of Mission.

Between 1.5 and 3 million sockeye were estimated to have passed Mission during 1986, depending upon the acoustic methodology and scaling procedures used (Table 1). There was good agreement between the mobile survey and fixed-aspect results; estimates for both enumeration methods tracked each other closely over the sampling period (Figure 5). Scaling by the estimates of upstream fish passage (Figure 6) reduced the fixed-aspect sockeye estimate by about 46% (Table 1, Figure 5).

Adult sockeye had a sharply peaked run-timing curve past Mission in 1986. The bulk of the run migrated past the enumeration site over a two-week period in the latter portion of September (Figure 5). Secondary peaks (September 24 and September 30 - October 1) were detected by both the fixed-aspect and mobile acoustic systems. The similar results obtained by the two independent systems suggests that both were sensitive to numerical changes in sockeye abundance.
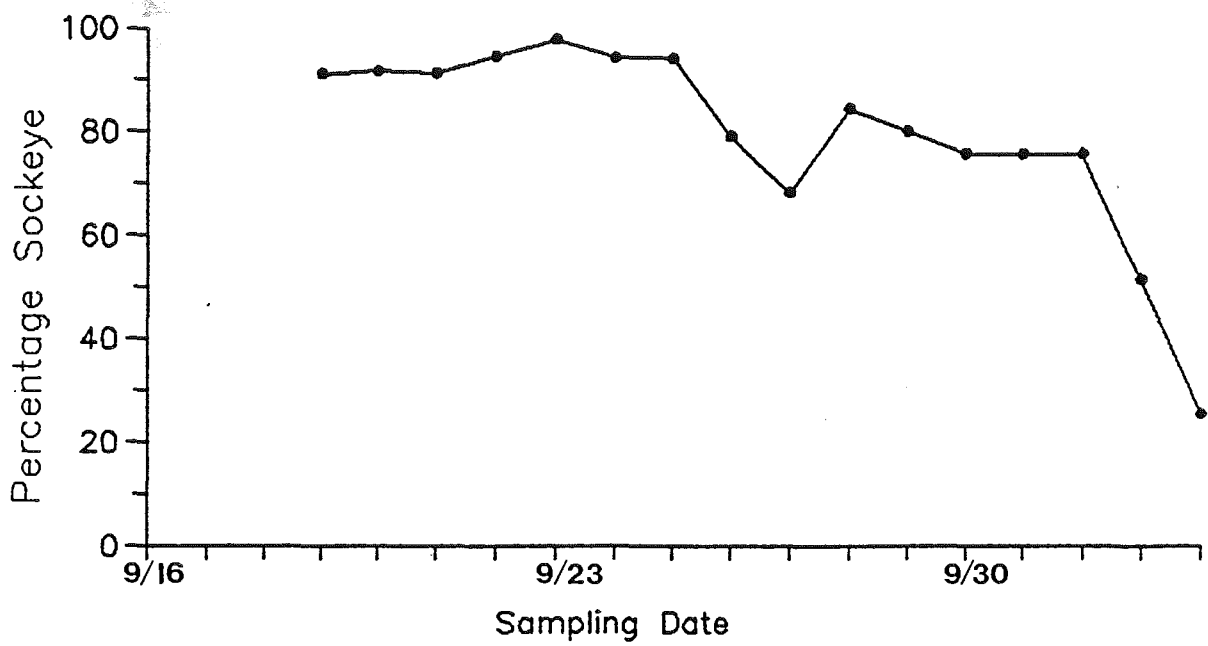
Figure 4. Daily percentages of adult sockeye in 1986 gillnet test fishing catches.

Table 1. Daily sockeye passage estimates for the Fraser River at Mission, B.C., between September 16 - October 4, 1986.

Date	Mobile Survey[1]	Fixed-Aspect[1]	Fixed-Aspect[2]
9/16	30,600	NS[3]	NS
9/17	67,400	NS	NS
9/18	135,800	NS	NS
9/19	185,100	179,900	120,000
9/20	333,700	274,500	153,800
9/21	469,400	375,700	200,800
9/22	554,000	565,000	300,800
9/23	416,400	352,700	162,100
9/24	472,400	370,300	210,300
9/25	280,100	249,000	132,000
9/26	108,700	178,300	100,500
9/27	69,600	93,400	44,200
9/28	21,900	49,500	25,400
9/29	10,300	26,400	8,900
9/30	39,700	47,900	37,300
10/1	40,500	48,800	29,000
10/2	24,300	33,100	13,300
10/3	11,600	18,000	4,700
10/4	6,000	13,000	4,000
Total (9/16-10/4)	3,277,500		
Total (9/19-10/4)	3,043,700	2,875,500	1,547,000

[1] Scaled by sockeye percentage
[2] Scaled by sockeye percentage and net upstream orientation
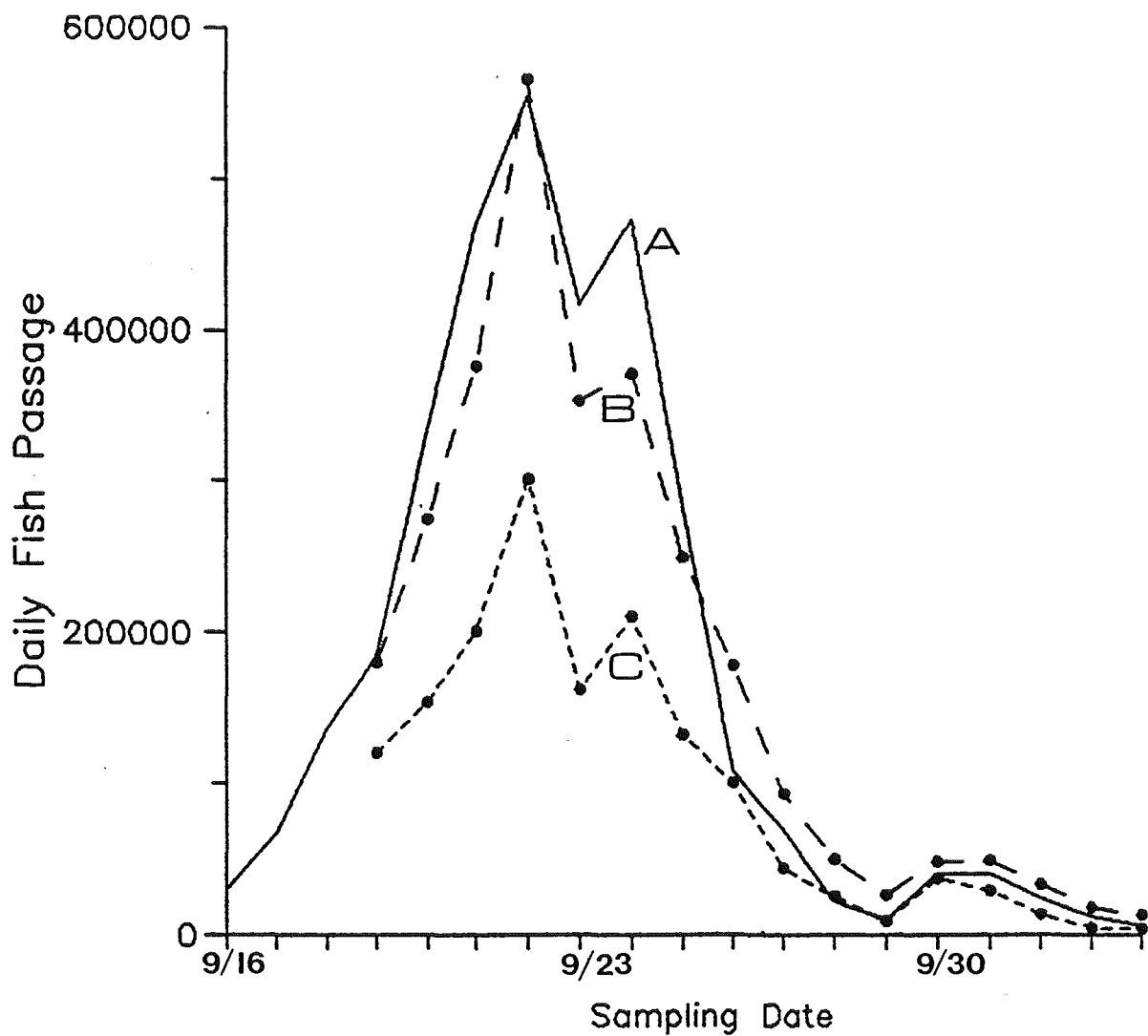[3] Not sampled

Figure 5. Sockeye abundance in the Fraser River as estimated by: A) mobile acoustic transects, B) the fixed-aspect acoustic system and C) the fixed-aspect acoustic system scaled by the percentage of net upstream-oriented fish targets (Figure 6).
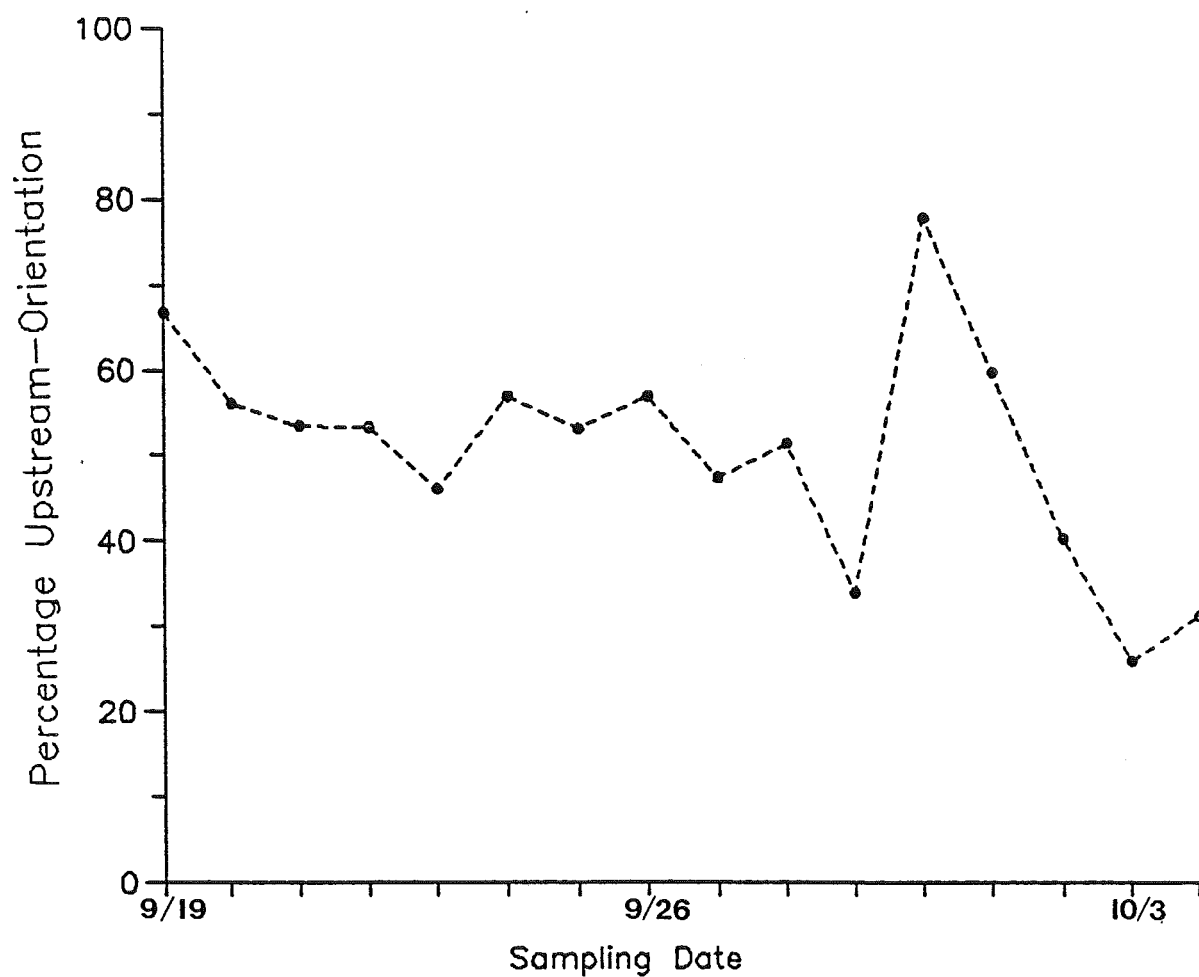
Figure 6. Daily percentage of net upstream-oriented fish targets in the Fraser River between September 19 - October 4, 1986.

HORIZONTAL DISTRIBUTION

The horizontal distribution of sockeye across the Fraser River was analyzed by comparing the numerical values obtained at each transducer location. Results were plotted as a percentage of the total daily escapement (Figure 7). Additionally, the daily results were averaged and summed to produce the distributions shown on Figure 8. Most of the fish migrated up the center of the River, between transducer locations 10-15 inclusive (Figures 7 and 8). These sampling sites accounted for 53% of the estimated fish passage up the Fraser River (Figure 8B).

Relatively high daily percentage values were also observed close to the south shore (transducer locations 20 and 18) during the latter half of the observation period (Figure 7). However, the daily passage of salmon was relatively low during this period (Figure 5), so the absolute number of fish passing these two locations amounted to only 7.5% of the estimated total sockeye run (Figure 8B).

VERTICAL DISTRIBUTION

The depth distribution of fish targets was calculated from fish target frequency observations (as a function of range from the transducer face) and the vertical aiming angle of the transducers. The results suggested a normal distribution of fish targets, with respect to depth, which was skewed towards slightly shallower depths over the study period (Figure 9A). Mean depths of sockeye ranged from slightly below 5 m at the beginning of the study, to slightly less than 4 m near the end (Figure 9B).

To estimate the directional tendency of fish within different depth strata, fish targets observed at transducer locations 1-15 on September 19-20 (90% sockeye - Figure 4) were classified into directional categories (Figure 3) and assigned a depth value. Of the total fish targets enumerated on these dates, 87% showed upstream orientation, 10% downstream and 3% non-directional. Most of the fish targets were situated in mid-water column depths (3-8 m), where a high proportion were oriented in an upstream direction (Figure 10). As the river depth at the Mission site is mostly between 6-9 m, the observations suggest a mid-water distribution of most sockeye, with a strong pattern of upstream migration.

DIEL PERIODICITY

Daily estimates of sockeye abundance (Figure 5) were generated from twenty-four successive hourly observations which were summed over the diel cycle. To analyze diel trends in sockeye abundance at Mission, the individual hourly estimates were plotted over the entire observation period. The results were expressed as a percentage of the daily escapement (Figure 11A), as well as in numerical counts (Figure 11B).

Sockeye showed pronounced diel peaks in their migration past Mission which showed up as distinct pulses in the numerical values (Figure 11). The peak daily sockeye count in percentage terms was about 12% of the total daily count during the fifteen days of observation. Expressed in absolute terms, a relatively small number of observations accounted for a large fraction of the total sockeye population enumerated by the fixed-aspect system. Out of the 2,700,000 total
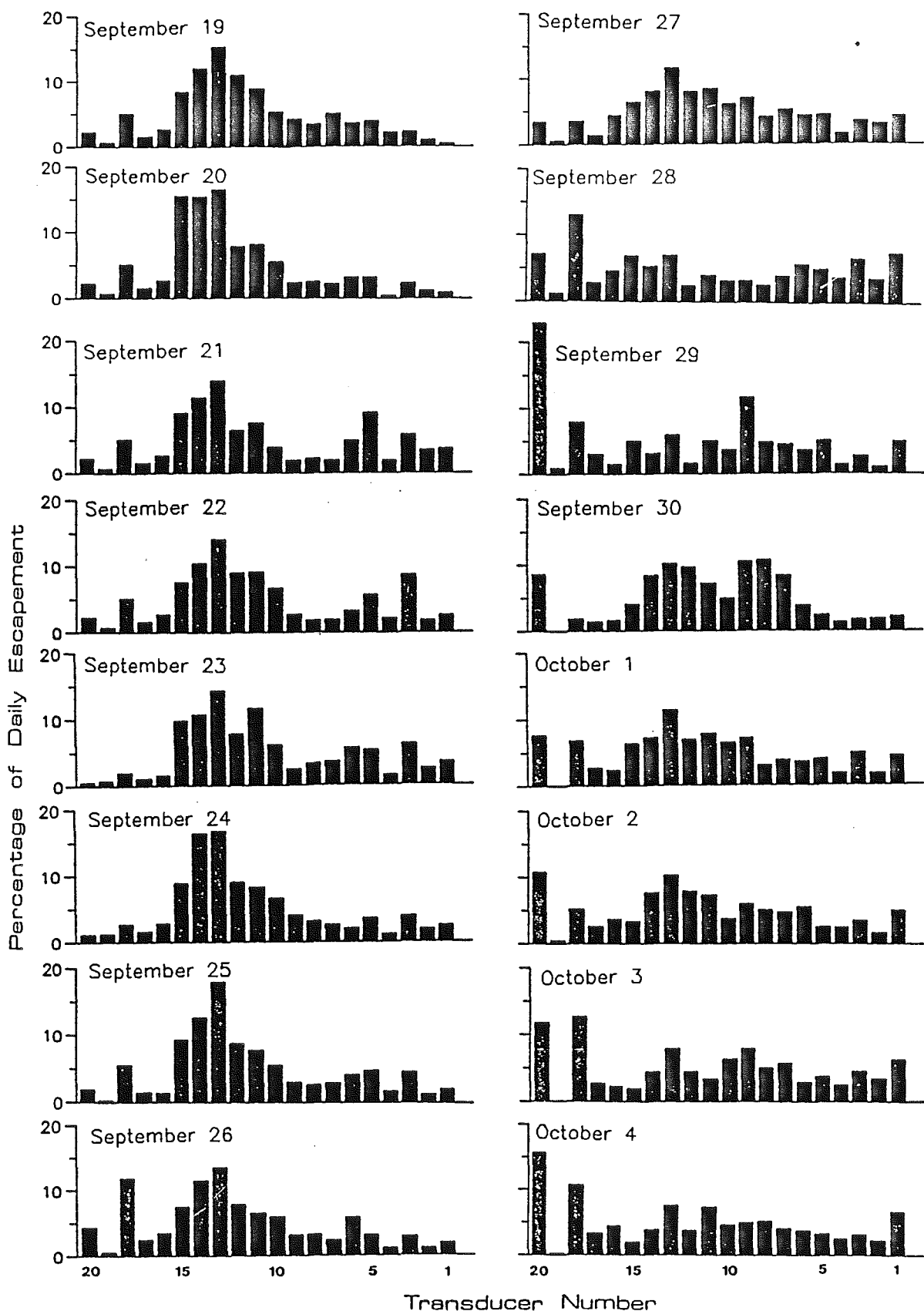
Figure 7. Horizontal distribution of sockeye salmon across the Fraser River between September 19 - October 4, 1986. Location of transducers is shown on Figure 2A.
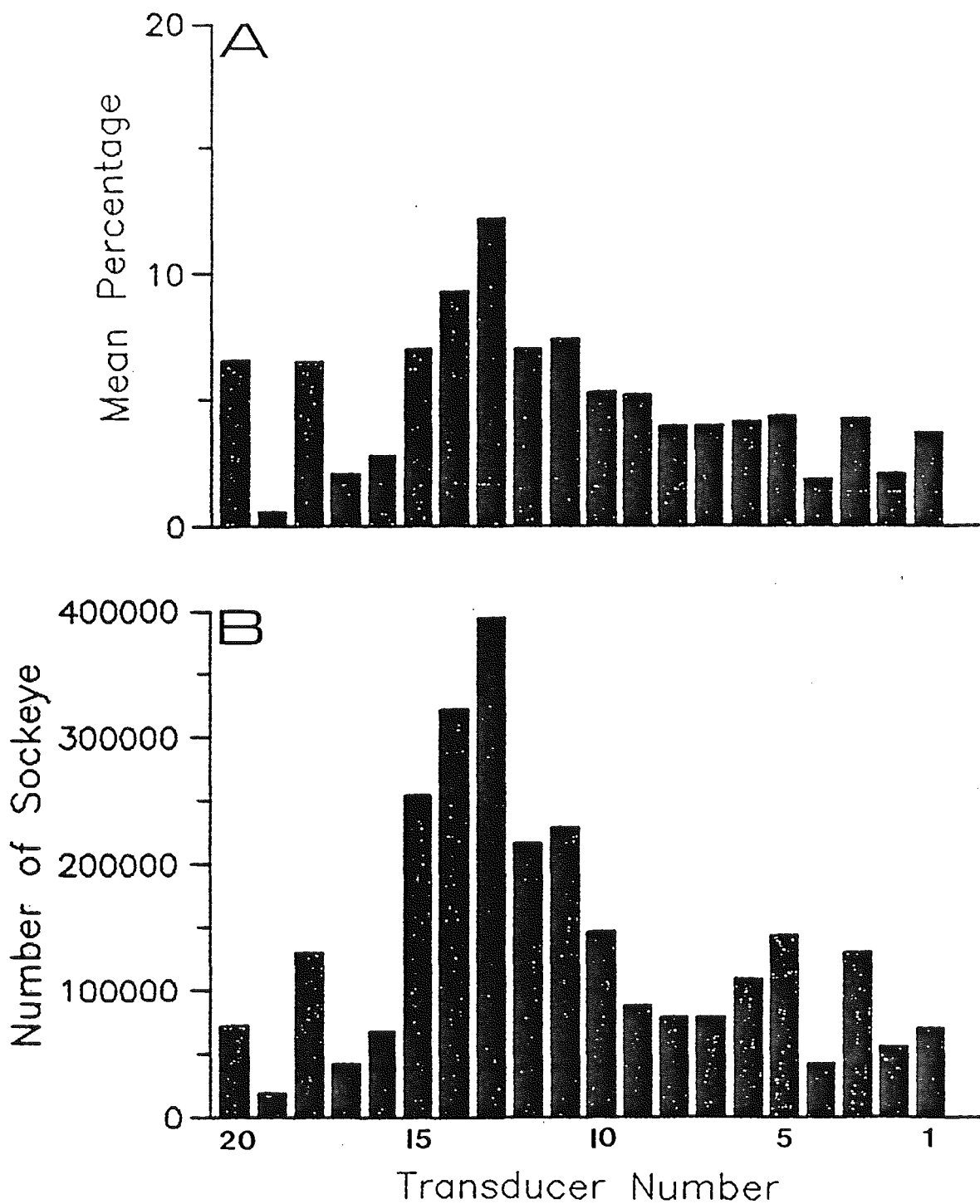
Figure 8. Cumulative distribution of sockeye salmon across the Fraser River between September 19 - October 4, 1986, expressed as: A) mean percent and B) total number of sockeye.
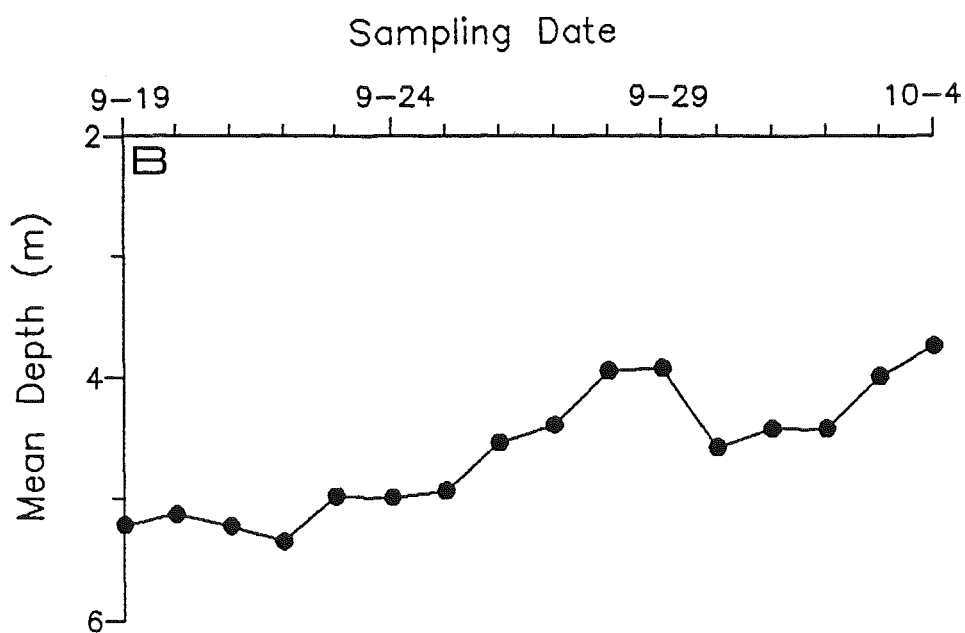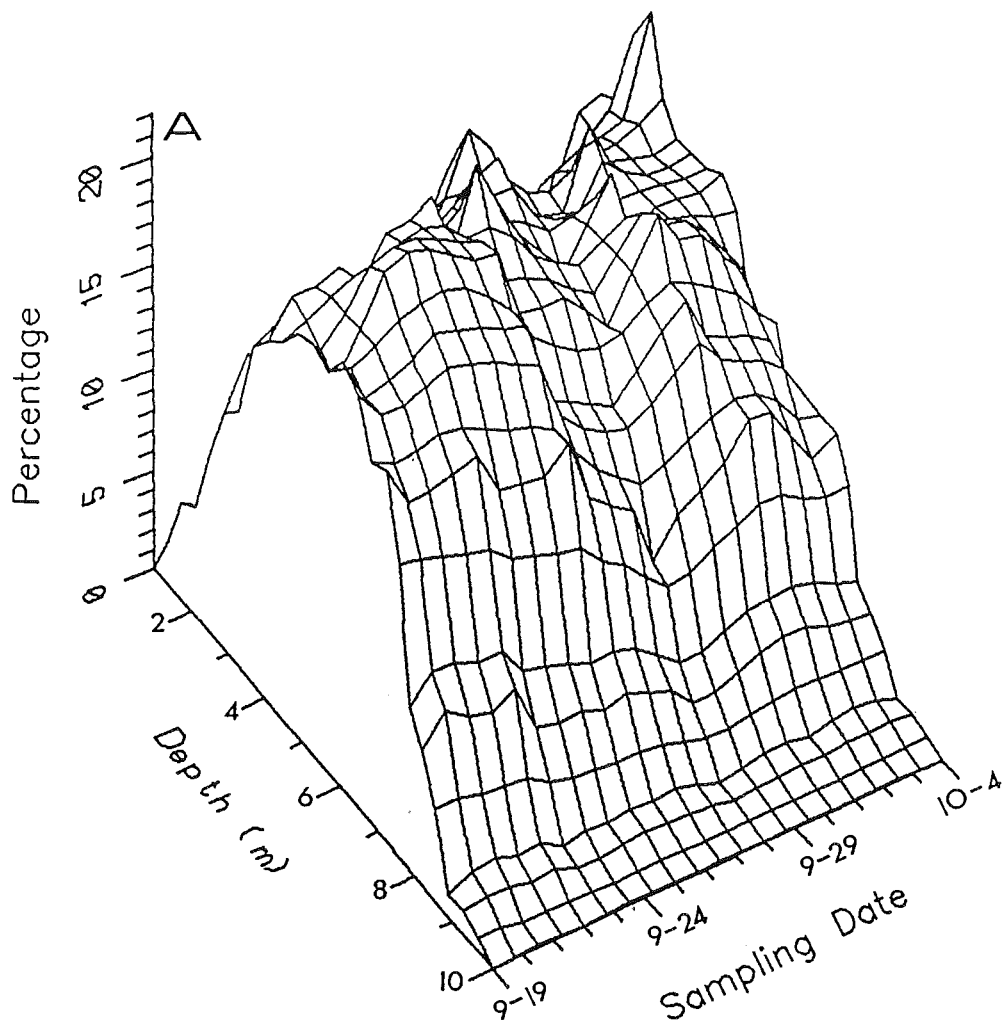
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Figure 9. A) Daily vertical distribution and B) mean depth of sockeye salmon in the Fraser River at Mission, B.C., between September 19 - October 4, 1986.
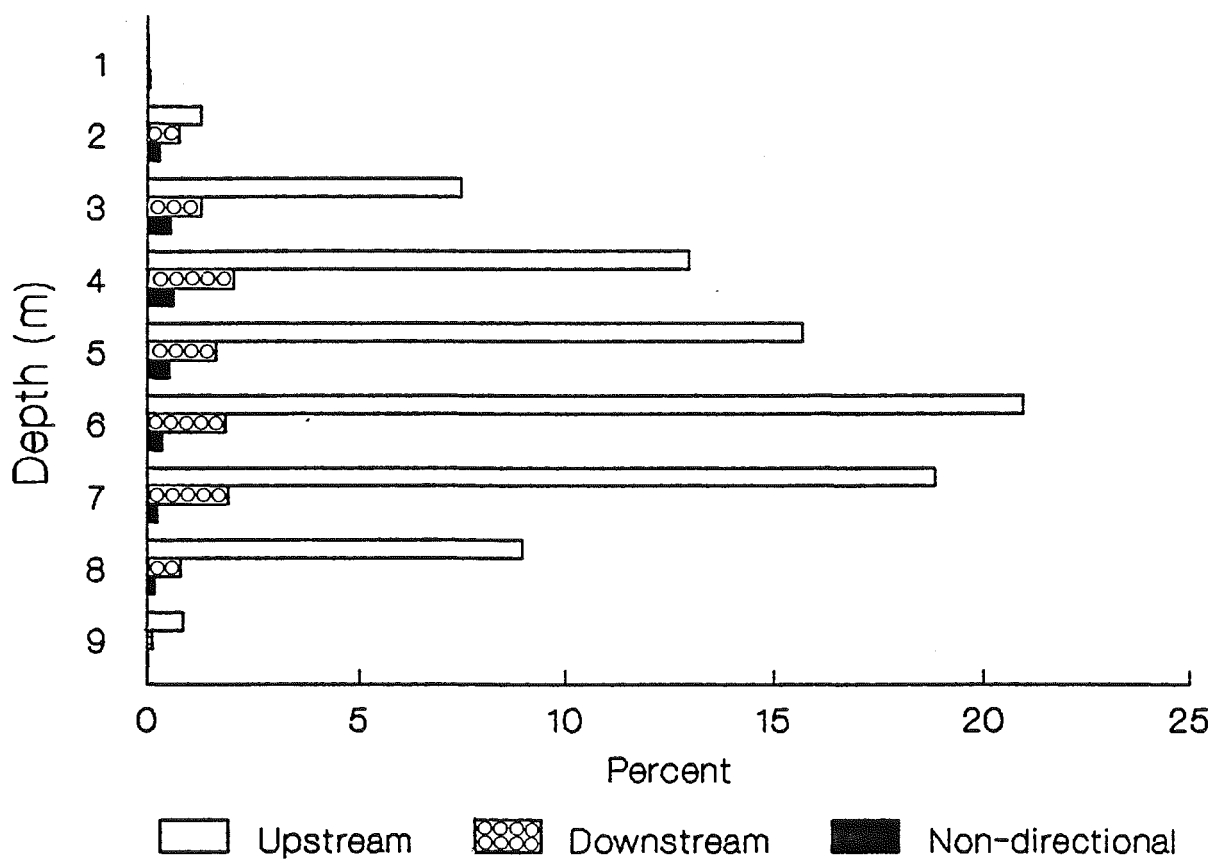
Figure 10. Percentage of fish targets showing upstream, downstream and non-directional orientation in different depth strata on September 19-20, 1986.
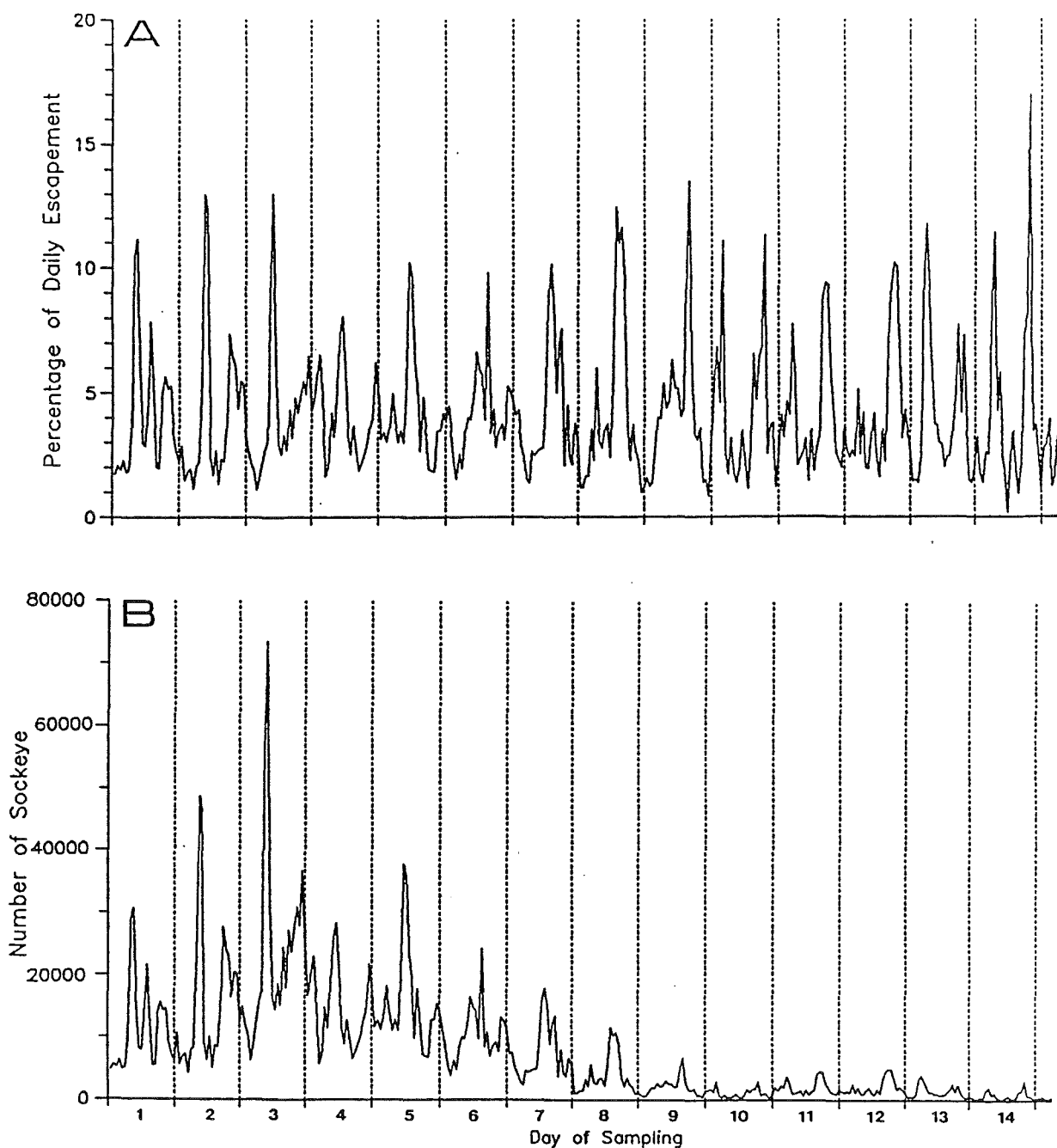
Figure 11. Diel variation in sockeye abundance from 01:00 to 24:00 (PDST) between September 19 - October 2, 1986, expressed as: A) percentage of the daily escapement and B) absolute number of sockeye enumerated (Day 1 = September 19).

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sockeye enumerated, over 1,000,000 fish were enumerated by 33 hourly observations of greater than 20,000 sockeye per hour. The remaining 1,700,000 fish were enumerated during the 327 hours of observation when the migration rate was below 20,000 sockeye/hour.

There were variable patterns in the diel timing and frequency of the peaks in sockeye migration past Mission (Figure 11). Over the first five days of observation, there was at least one peak detected during mid-morning hours, with a secondary peak during dusk-early evening periods. Between day 6 and 9, the dusk-early evening peak became more prominent. Thereafter, between day 10 and 14, bi-modal sockeye abundance peaks were evident. During the latter period, the absolute sockeye abundance was low (Figure 11B). Because of these shifts in the diel timing of the migration peaks, the diel timing curve for the entire period (Figure 12) was smoothed out when the data were averaged (Figure 12A) and two modest crepuscular peaks were evident. The latter were much less extreme than the individual daily peak observations (Figure 11).

Diel variations were also evident in the percentage of upstream-oriented targets (Figure 13). On ten of the sixteen days of observation, the lowest percentage of upstream migrants occurred at mid-day (15:00), suggesting more active upstream migration during crepuscular periods. During October 2 and 3, the converse was true: a higher frequency of upstream-oriented fish targets occurred during the mid-day period. This was probably due to a change in the diel migration behaviour of sockeye, since sockeye were present at Mission on these two dates (Figure 4), albeit at low levels of absolute abundance (Figure 11B). Alternatively, the altered diel behavior may reflect the presence of other fish species in the vicinity of the Mission Railway Bridge.
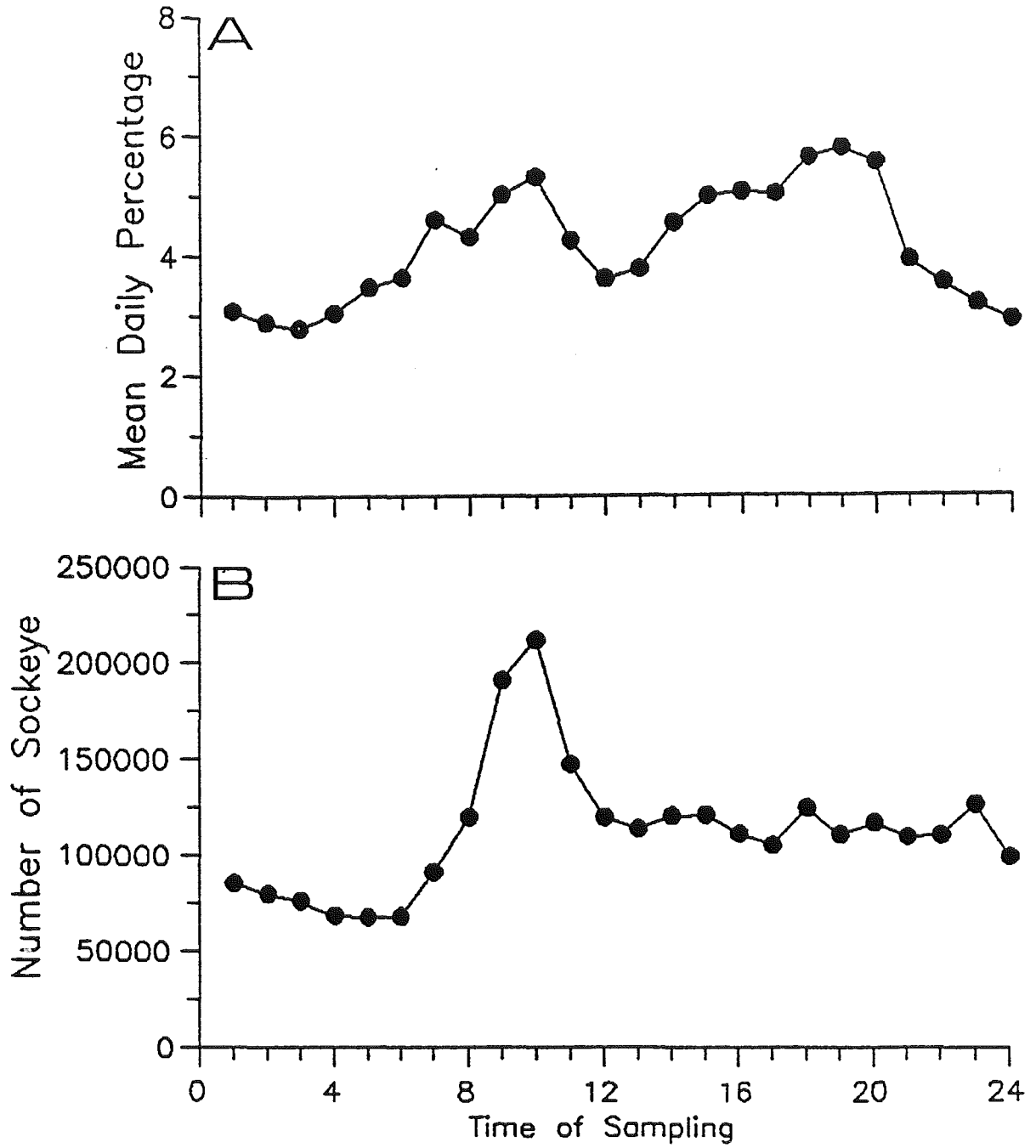
Figure 12. Diel pattern of sockeye abundance between September 19 - October 4, 1986, shown as: A) mean percent and B) number of sockeye.
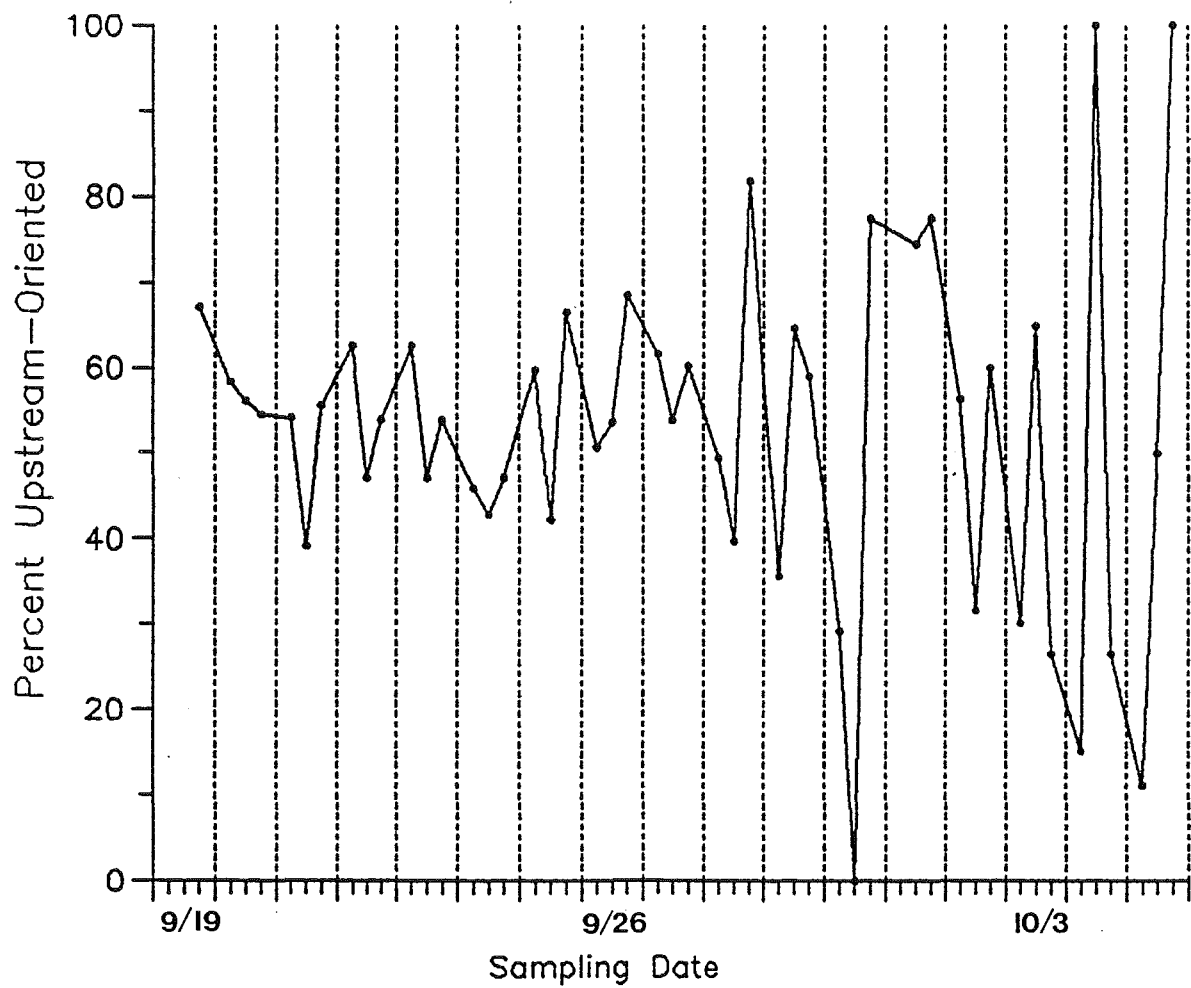
Figure 13. Percentage of net upstream-oriented fish targets measured at 07:00, 15:00 and 23:00 (PDST) each day between September 19 - October 4, 1986.

DISCUSSION

The acoustically-derived sockeye population estimate from Mission Bridge can be compared with the estimated late-run sockeye escapement to the Fraser River. During 1986, the gross escapement (sum of the fish enumerated on the spawning grounds plus the Indian food fishery catches) of late-run (mostly Adams River) sockeye was 3,004,000 fish (Pacific Salmon Commission 1988). A fraction of these late-run fish migrated upstream past Mission prior to, as well as after, the September 19 - October 4 fixed-aspect survey period. The proportion of sockeye enumerated by the mobile acoustic survey program prior to (August 6 - September 18) and after (October 5 - October 13) the fixed-aspect survey period was estimated as 18% and 3% of the total late-run, respectively. Therefore, it is likely that 2,373,000 (0.79 x 3,004,000) late-run sockeye migrated past Mission between September 19 - October 4.

The total number of sockeye enumerated by the fixed-aspect acoustic program was 2,875,000 fish (Table 1). However, when corrected for net upstream orientation, the number of sockeye enumerated by the fixed-aspect system was 1,547,000 (Table 1), 800,000 less than the adjusted post-season escapement estimate. Assuming the post-season estimate is accurate, the fixed-aspect method substantially underestimated the size of the sockeye run.

The post-season escapement value is derived from a Petersen mark-recapture procedure which depends on a number of assumptions (Krebs 1989) that are rarely satisfied during field programs (e.g., equal distribution of tagged and non-tagged animals at the recovery site). The accuracy of sockeye spawning escapement estimates was analyzed by Simpson (1984), who compared Petersen mark-recapture estimates with fence count values. In all cases examined (n = 13, including four estimates of large sockeye returns to Babine Lake), mark-recapture methods overestimated the sockeye population size by an average of 21%, compared to the fence count estimate. If the 1986 mark-recapture procedures biased the escapement estimate in a similar direction, this would diminish the discrepancy between the fixed-aspect acoustic estimate and the mark-recapture estimate. However, until studies are specifically designed to provide absolute sockeye population numbers for Fraser River tributaries (via fence counts), it will be difficult to critically evaluate spawning escapement discrepancies measured by independent assessment methods and to determine which method is most accurate. Resolution of this issue is important for the management of Fraser River sockeye over the long term.

In an acoustic study of pink salmon at Mission in 1987, species composition assignment errors were rejected as a cause of the discrepancy between pink salmon escapement estimates (obtained by Petersen mark-recapture studies on the spawning grounds) and acoustic enumeration results at the Mission Railway Bridge (Cheng et al. 1991). During the present study, sockeye (largely dominant-cycle Adams River sockeye) comprised a high proportion of the adult salmonid population in the Fraser River between September 19 and October 4, 1986 (Figure 4). The preponderance of sockeye compared to other salmon species makes it unlikely that errors in estimates of species composition were responsible for the observed discrepancy between the estimated spawning escapement to the Adams River and the adult sockeye population enumerated at Mission.

During 1986, good agreement was observed in the seasonal pattern of sockeye abundances measured independently by the fixed-aspect and mobile survey programs (Figure 5). This suggests that both procedures were equally capable of providing valid estimates of sockeye populations in the Fraser River. The sharp peaks in numerical abundances observed on a diel time scale (Figure 12) emphasize the importance of performing consistent twenty-four hour, round-the-clock acoustic

enumerations of sockeye salmon in the Fraser River. To accurately estimate the sockeye population, it is critical to sample effectively through the brief, diel migration windows that account for the bulk of the fish passage.

Consistent distribution patterns were observed by the fixed-aspect system during 1986: the bulk of the fish travelled near the center of the river and fairly deep in the riverine water column. In contrast, pink salmon in the Fraser River tend to be more shore oriented than sockeye (Cheng et al. 1991). During future acoustic assessments of sockeye within the Fraser River, if there are limitations on the acoustic sampling power imposed by multiplexer sequencing procedures, the central section of the river should be sampled more intensively than the shore zones to optimize the allocation of sampling effort (Jolly and Hampton 1991). Methods should also be developed to allocate sampling times for individual transducers on a random basis and so improve the statistical properties of the acoustic observations (Cheng et al. 1991).

During future acoustic assessments, it would also be desirable to refine directional scaling procedures, since the numerical estimates of sockeye abundance are directly proportional to the estimated net upstream movement. Considerable diel variation in net upstream orientation was observed (Figure 13), so values from the three daily sampling periods were averaged (Figure 6) in order to scale the estimated total number of sockeye targets. The upstream orientation preference of sockeye salmon probably varies predictably over the diel cycle and may also be affected by local current patterns, horizontal position and other factors. Ideally, measurements of upstream orientation preference should be undertaken continuously over the diel cycle and at different vertical and horizontal positions within the river. Such measurements could be undertaken by tracking individual fish through adjacent transducer beams or by undertaking independent telemetric studies.

Dual beam results (Appendix 1) provide a descriptive bench mark for estimating the side-aspect target strengths of sockeye salmon within the Fraser River. However, the use of target strength alone as a fish species discriminator (based on fish size-target strength relationships) may not be feasible due to body size and target strength overlaps of sockeye salmon with other co-migrating salmonids (e.g., coho, chinook and pink salmon). Other approaches, including the use of acoustic signal classification techniques (e.g., Rose and Leggett 1988), may offer better discrimination between salmonid species in the Fraser River. It may also be desirable to refine test fishing procedures to better estimate the relative abundance of different fish species during acoustic enumeration programs. Use of gillnets with a single mesh size may bias Fraser River fish species composition estimates due to gillnet selectivity effects. Gillnet test drifts undertaken immediately adjacent (upstream) to the Mission Railway Bridge with variable mesh gillnets, may improve daily estimates of the proportion of sockeye in the Fraser River fish population.

The Mission Railway Bridge is a strategic location for fixed-aspect acoustic enumeration of Fraser River salmon populations. The site is upstream of the commercial fishing boundary and provides a convenient support structure for transducer deployment. During 1986, a major fraction of the sockeye salmon at Mission showed an upstream orientation and were favorably distributed within the water column for enumeration by fixed-aspect transducers located immediately beneath the river surface. In the short term, it is feasible with existing technology to automate echo counting and target tracking and to generate reliable estimates of sockeye abundance for in-season fishery management. Over the long term, it may be possible to link the Mission echosounding site to the Pacific Salmon Commission offices in downtown Vancouver via modem and to develop a remote system (Thorne 1988) for controlling the echosounding and transducer multiplexing. Such a system could provide accurate, near real-time estimates of sockeye salmon population size in the Fraser River.

RECOMMENDATIONS

1. The Mission Railway Bridge is a convenient acoustic sampling location and fixed-aspect support structure for enumerating sockeye salmon populations in the Fraser River. During future fixed-aspect field trials, the traditional PSC mobile survey should be undertaken to further test the numerical agreement between these independent methods.

2. Uncertainties in the accuracy of sockeye spawning escapement estimates (generated from mark-recapture statistics) preclude the use of such estimates to verify the results of acoustic enumeration programs. Consideration should be given to undertaking fixed-aspect acoustic enumeration of a large sockeye population downstream of an existing counting weir (e.g., within the Skeena River downstream of the Babine counting fence). Alternatively, an accurate counting weir should be established on a Fraser River tributary with a large sockeye population to ground-truth the acoustic results and the mark-recapture estimates of spawning escapement.

3. During future fixed-aspect enumerations, acoustic sampling effort should be allocated in proportion to the observed horizontal distribution patterns of sockeye across the Fraser River. During the present study, roughly half of the sockeye were enumerated in the central portion of the river between transducer locations 10-15. Thus, half of the acoustic sampling effort should be allocated to these transducer locations.

4. An improved statistical design would allocate transducer sampling times on a random basis (within pre-determined temporal strata). Transducer sampling times should also be replicated within temporal strata to generate unbiased variance estimates and 95% confidence limits around the sockeye population estimate.

5. In future work, measurements of fish orientation direction (upstream/downstream) should be made continuously over the diel cycle, at several sampling locations, to refine the numerical estimate of sockeye abundance.

6. In future fixed-aspect enumeration programs, there should be sufficient time to optimize transducer aiming angles and verify uniform acoustic coverage across the river. Transducers should be in place at least one week before the start of the sockeye run. Tests should be undertaken with standard targets of known target strength in order to verify the effective sampling volume of each transducer.

7. The transducer mounting locations on the upstream side of the pier noses on the Mission Railway Bridge supports were effective during 1986, although it was difficult to adjust the vertical and horizontal aiming angles when required. A V-shaped bracket and collar arrangement, with a removable and adjustable transducer mount, is recommended for future fixed-aspect studies at this location.

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APPENDIX - TARGET STRENGTH RESULTS

Estimates of fish target strength, a measure of the echo-reflecting power of individual fish, are required during quantitative hydroacoustic surveys for measuring the effective beam dimensions of an acoustic system and for scaling echo integration results. Since target strength is related statistically to fish size (Love 1971), it may be possible to derive fish size information from target strength measurements, provided these measurements are not confounded by attitude (Buerkle 1987) or other effects. Such information could be used for fish species discrimination purposes if individual species have unique target strength values. The dual-beam system (Traynor and Ehrenberg 1979; Ehrenberg 1983) was specifically developed for obtaining fish target strength estimates *in situ*. Recent applications of dual-beam procedures to estimate the target strength of aquatic organisms during acoustic surveys include Burczynski and Johnson (1986), Jefferts et al. (1987), Greene et al. (1988) and Levy (1991).

Dual-beam data were collected with a BioSonics Model 105 dual beam echosounder operating at 420 kHz. Acoustic returns were monitored with an oscilloscope and chart recorder and stored on a digital tape recorder. The system was installed in a small power boat, with the transducer fixed in place immediately beneath the water surface by means of a pipe mount clamped to the gunwale of the boat. Power was supplied from a heavy gauge extension cord from the Railway Bridge or an 800 W gasoline generator.

Two different transducer deployments were used adjacent to the Mission Bridge site. The primary configuration was a standard, vertically-downlooking deployment to measure dorsal-aspect target strengths of adult sockeye. Data were collected either in a stationary mode of operation with the boat moored to the Mission Railway Bridge, or else in a mobile, transecting mode across the River adjacent to the Mission Highway Bridge. The second configuration involved aiming the transducer 20 degrees upstream. Data obtained from this deployment were analyzed with the BioSonics NTRACKER program which assigns a depth, direction and target strength to individual fish.

Because of a strong influence of target attitude on measured target strength (Buerkle 1987), target strength measurements obtained by the different deployments are not directly comparable. Target strength values obtained within an angled transducer beam are lower than those from a downlooking aspect. The advantage of the former deployment is that directional information can be derived from change-in-range measurements (Figure 3).

Target strength data (individual downlooking measurements) are shown in Figure 14. The following are the mean target strength values for the three days of observation:

Date	Sample Time	Mean TS (db)	Sample Size (echoes)	Standard Deviation
9/29	1530-2130 h	-35.8	3211	11.1
9/30	1430-2300 h	-46.5	903	7.6
10/1	1600-2300 h	-43.0	6973	6.3

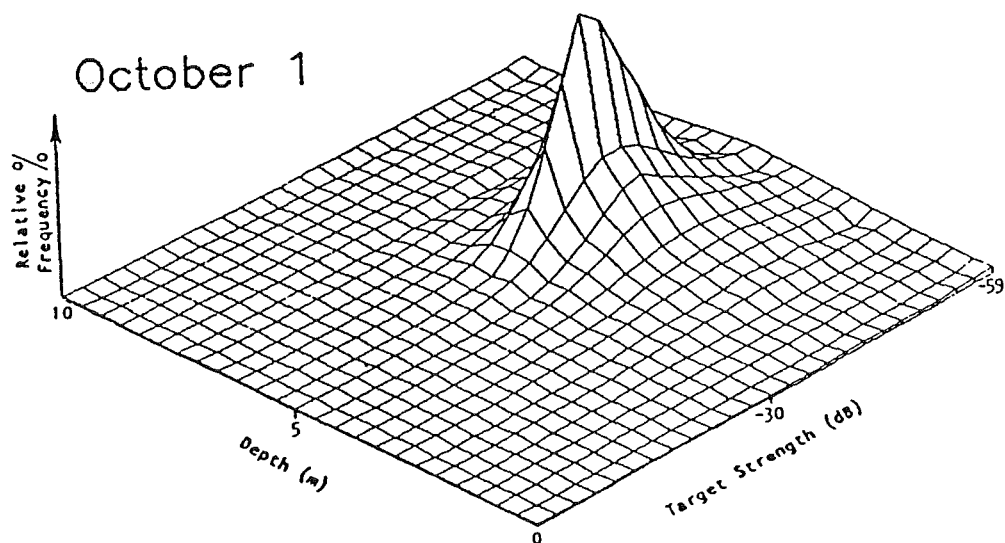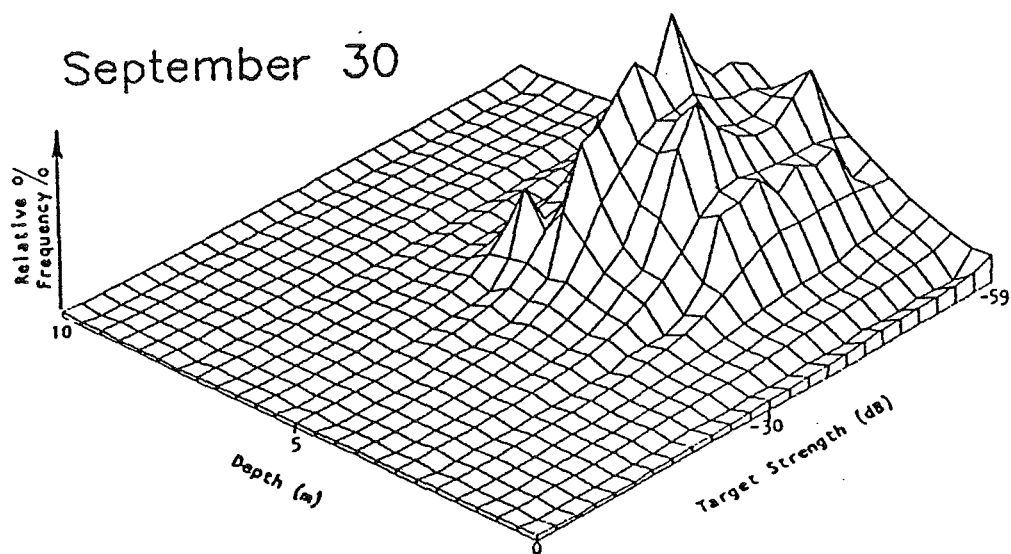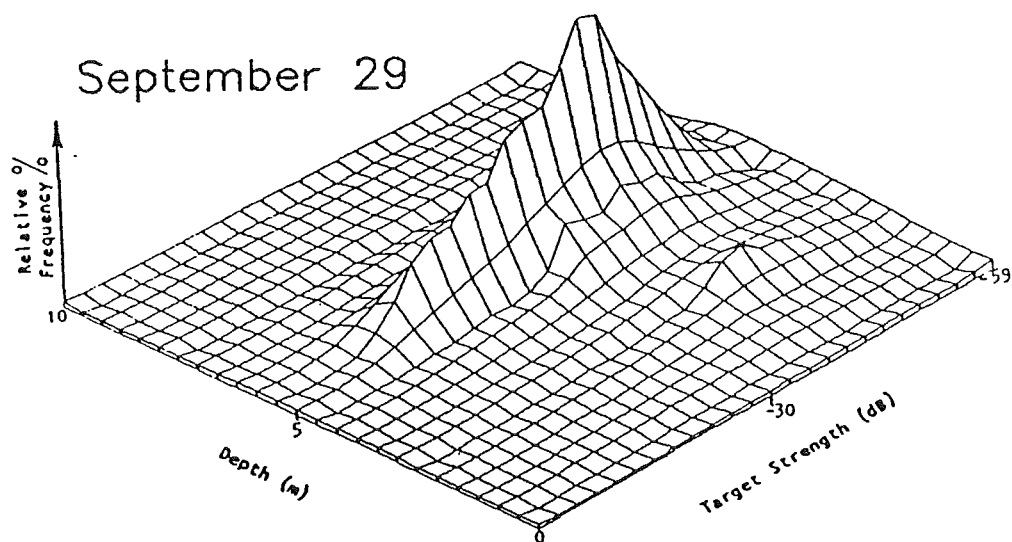Most of the targets were located at depths of 5 m or shallower (Figure 14).

Figure 14. Frequency distributions of target strength by depth, obtained at Mission Bridge on September 29 (15:30 - 21:30), September 30 (14:30 - 23:00) and October 1 (16:00 - 23:00).

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Target strength values for each of the three days varied markedly (Figure 14). Values on September 29 peaked at -41 db and showed a secondary peak at -30 db. On September 30, target strengths peaked at -43 db with several substantial smaller peaks at higher values (-31 db). Data for October 1 were distributed as a single mode with a peak at -41 db. Even in this case, there was a wide range in the estimated values (-25 to -60 db).

The tracked dual-beam information was analyzed to estimate the proportion of adult sockeye in the observed riverine fish population. Each fish target in the NTRACKER frequency distribution was weighted by the midpoint of the range strata in which it was detected, to remove the effect of beam spread and to equalize the detectability at all ranges. Fish closer than 3 m to the transducer were excluded from the distributions, since the two elements within the dual-beam transducer were located side-by-side and not precisely aligned in the near field. The proportion of fish targets between -36 db and -42 db target strength (expected values for adult sockeye salmon) was then estimated to provide an index of the adult sockeye population within the total population.

Observed target strength distributions obtained by the NTRACKER program are shown in Figure 15. The proportion of targets between -36 db and -42 db was 53%, 44% and 83% on September 29, September 30 and October 1, respectively (Figure 15). The percentage of sockeye captured in Cottonwood gillnet test sets during this period was approximately 80% (Figure 4). However, due to gillnet size-selectivity effects, it is unlikely that gillnets sampled the Fraser River fish population in a representative fashion. The target strength results (Figure 15) suggest the presence of numerous small fish targets (-45 db to -60 db) which would be detected by riverine acoustic devices.

The high variance in measured target strength values created a wide spread in the measured target strength distributions (Figures 14 and 15). This variation effectively reduced the utility of target strength as a fish species discriminator, particularly when relative fish sizes do not differ greatly. In future work, other measurable attributes of acoustic signals (e.g., Rose and Leggett 1988) should be examined to determine whether there are unique signal characteristics produced by adult sockeye salmon within the Fraser River.
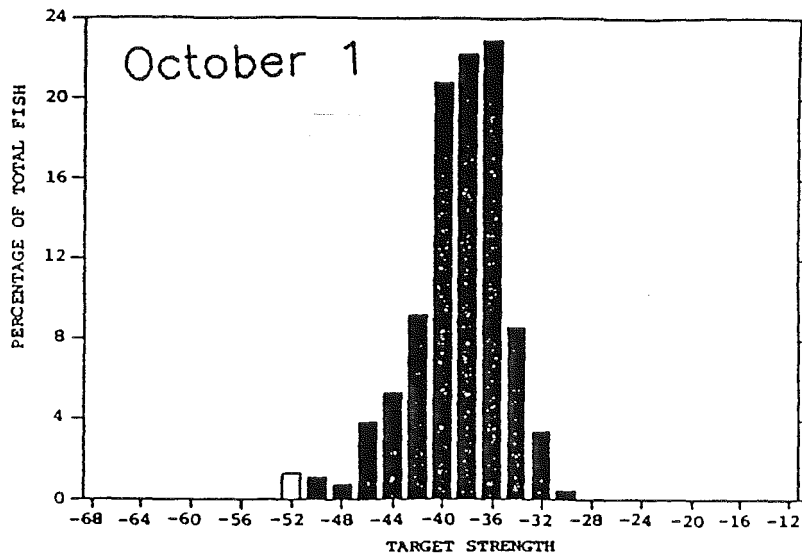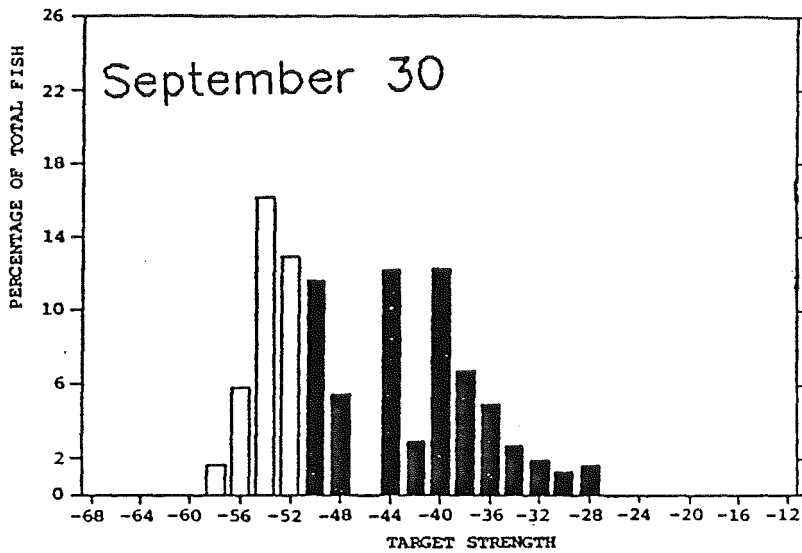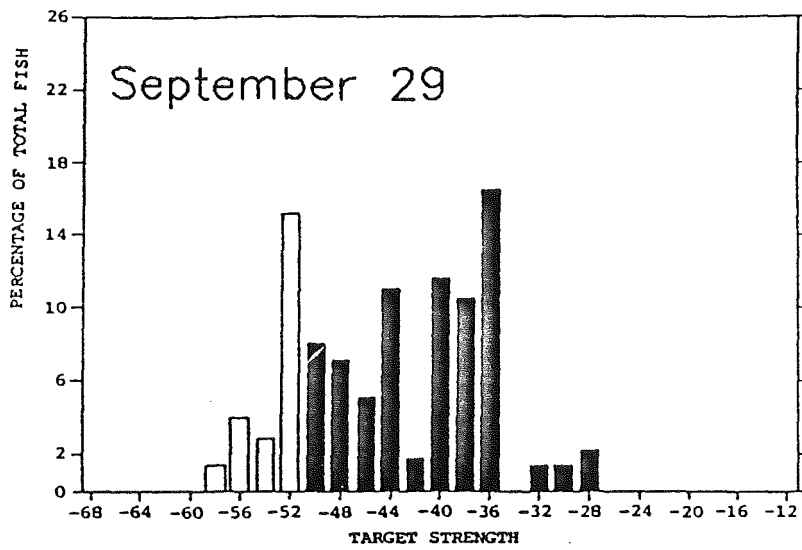
Figure 15. NTRACKER target strength frequency distributions on September 29, September 30 and October 1. Black histograms represent fish large enough to be detectable by the fixed-aspect (single beam) acoustic system.