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ABSTRACT

Adult pink salmon were enumerated using acoustic devices at Mission, B.C., during 1987 to estimate within-river escapement and distribution. Two fixed-aspect arrays were established in near-shore areas of the river with surface-downlooking, bottom-uplooking and shallow side-scanning transducers. The central portion of the river was surveyed by a mobile transecting vessel. Pink salmon migrated upstream across the entire river but were more numerous along the shore. The estimate of salmon run size, after correction for the upstream and downstream orientation of the targets, was about 1 million fish. A subsequent estimate of 3.2 million pink salmon was made post-season, using data from a mark-recapture tagging study. To improve the in-season estimates of pink salmon escapement past Mission, it is important to resolve the discrepancy in pink salmon run size estimated by the two independent procedures.

INTRODUCTION

The Fraser River currently supports the largest odd-year pink salmon *(Oncorhynchus gorbuscha)* population in British Columbia. Between 1979 and 1987, odd-year pink salmon runs from the Fraser River averaged about 15 million fish (Henderson 1991). During odd-numbered years, Fraser River pink salmon can be the largest stock of Pacific salmon returning to the B.C. coast. Migration to the mouth of the Fraser River occurs via the northern (Johnstone Strait) and southern (Juan de Fuca Strait) approaches (Vernon et al. 1964).

The Pacific Salmon Commission (PSC) is responsible for the in-season management of Fraser River pink salmon fisheries within the Fraser River Panel Area. Effective real-time estimates of pink salmon escapement to the Fraser River would be useful for making in-season fishery management decisions. Since 1977, pink salmon populations have been acoustically monitored by a mobile transecting program at Mission, B.C., in the Fraser River (Figure 1). Initial results from this program suggested there were large discrepancies between the estimate from the acoustic monitoring program compared to mark-recapture spawning ground estimates. Inaccuracies of the acoustic monitoring program possibly relate to the tendency of pink salmon to migrate close to the shore and to boat avoidance behavior (Olsen et al. 1983).

Alternate approaches to mobile acoustic transecting for pink salmon were undertaken by the International Pacific Salmon Fisheries Commission (IPSFC) at Mission during 1979 and 1981. During 1979, preliminary experimentation with a bottom-mounted (fixed-aspect), uplooking transducer array suggested a shore orientation of adult pink salmon in this reach of the Fraser River. During 1981, stationary down-looking echosounding was undertaken by two boats randomly sampling discrete locations within the Fraser River over successive 30 minute intervals. This latter approach was also unsatisfactory due to logistic problems and non-agreement of results with mark-recapture estimates of spawning escapement. During 1986, the sockeye salmon run in the Fraser River was monitored by a fixed-aspect transducer array attached to the support structures of the Mission Railway Bridge (Levy et al 1991; Nealson and Murphy MS 1987).

Due to a concern that the bridge supports might influence pink salmon behavior, a method was devised during 1987 to install transducers independently of any solid support structures. Fixed-aspect transducer arrays were deployed in a non-intrusive manner either from surface floats or bottom mounts. Thus there were no large physical structures present in the river which could potentially modify salmon behavior. Two separate arrays were established to cover near-shore areas of the Fraser River at Mission (one array on each shore). The central portion of the river between the two near-shore transducer arrays was sampled acoustically by a mobile transecting vessel. Additionally, a second mobile acoustic transect vessel was operated at Haney, 20 km downstream of Mission, to provide an independent pink salmon population estimate. The purpose of the present report is to summarize the data collected by the 1987 hydroacoustic monitoring program, evaluate the effectiveness of the approach and make recommendations for future improvements.

STUDY AREA

The Fraser River is the most important salmon-producing river system on the Canadian west coast (Northcote and Larkin 1989) and is a major focus for fisheries research (Government of Canada 1990). The biology of the lower Fraser River (below Hope, B.C.), emphasizing fisheries aspects, was reviewed by Northcote (1974). There is a large amount of data concerning

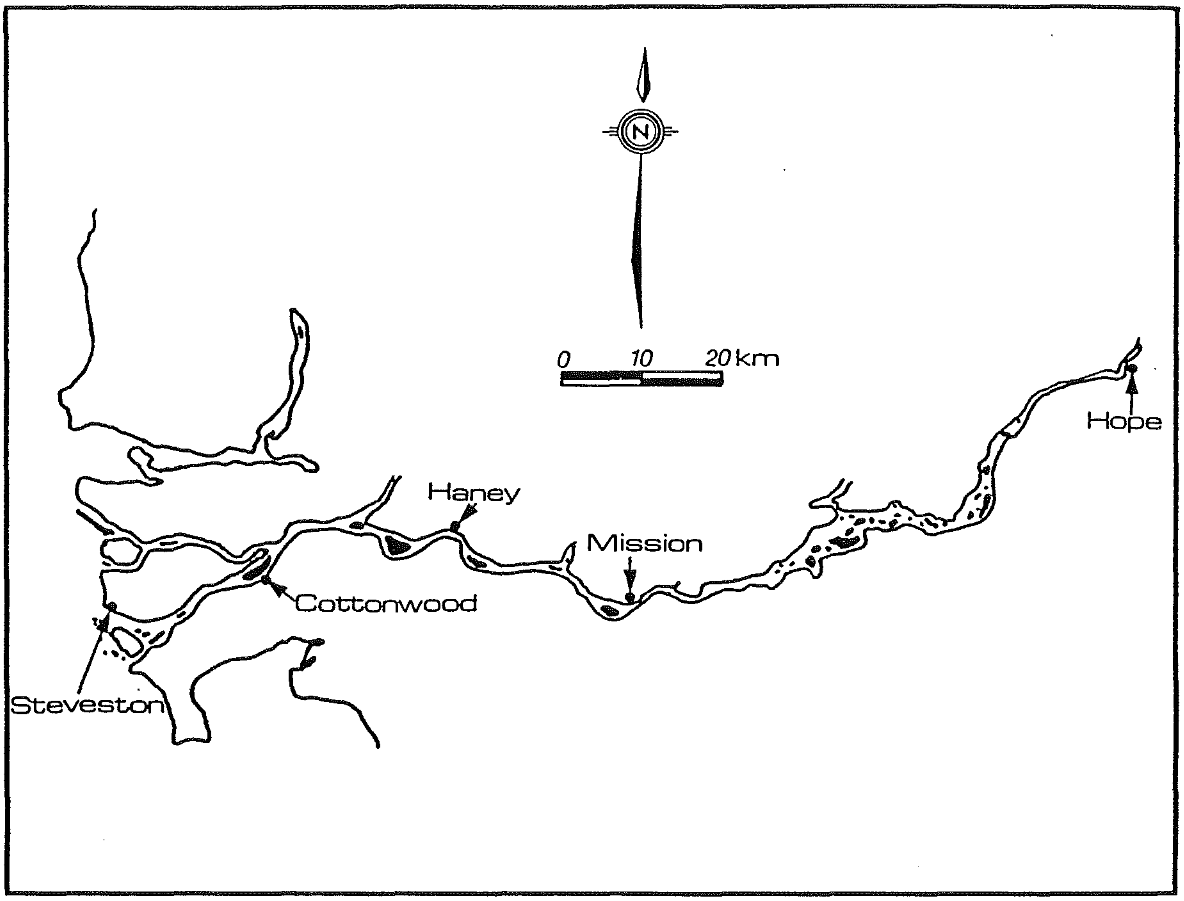


Figure 1. Location of sampling sites in the Fraser River at Mission, Haney and Cottonwood.

physical properties (e.g., flow) and water quality of the Fraser River, as well as much information concerning the ecology and production of its salmon populations.

Mission is located approximately 70 km upstream from Steveston near the Fraser delta mouth (Figure 1). The Fraser River carries a heavy sediment load, particularly during the freshet period between May and August of most years. The River is subject to tidal influence as far upstream as Mission, where tidal amplitudes can cover 1.5 m.

Due to its location in the lower river, Mission is a strategic site for numerical assessment of both juvenile and adult salmon. Most salmon populations spawn far upstream (hundreds of km) of the Mission site and migrating adults are thought to swim past Mission in a directed fashion. Mission is also the upstream boundary for commercial fishing. Most salmon which reach this point in the river will continue upstream to successfully spawn, provided they escape the in-river Indian food fishery. Accurate numerical estimates from Mission, therefore, provides information concerning pink salmon escapement to the Fraser River which can be used to adjust terminal area (in-river) commercial fisheries.

METHODS

FIXED-ASPECT HYDROACOUSTIC SYSTEM

Two BioSonics hydroacoustic systems were employed for fixed-aspect hydroacoustic studies at Mission during 1987, one on each bank of the river. Each system consisted of a 420 Khz Model 101 echosounder, a Model 151 multiplexer/ equalizer, a Model 111 chart recorder, and nine transducers and transducer cables. Hydroacoustic equipment was housed within a 2 x 3 m shed atop a 3 x 4 m raft anchored in shallow water (approximately 8 m from shore) adjacent to the transducer array. Power was supplied by 2100 W gasoline generators. Transducer beam widths (between 16° and 18°) were measured during calibration of the hydroacoustic equipment at the BioSonics (Seattle) facility in early September, 1987.

Each fixed-aspect system effectively sampled the section of the river from near-shore to a distance 84 m out from the river bank (Figure 2). Transducers were deployed from surface floats oriented towards the river bottom and fixed-to-bottom mounts oriented towards the water surface (Figure 3). One transducer in each array was deployed close to shore in a sidelooking mode of operation (Figure 4).

Downlooking and uplooking transducers were deployed in pairs. Surface-mounted transducers were suspended from steel gimbals attached to plywood-encased floats (1 m diameter) fixed in place by anchors (1 upstream, 1 downstream) and 35 m anchor ropes. Weights were suspended from the anchor ropes to dampen tidally-induced motion of the surface transducer. Bottom-mounted transducers were attached to steel gimbals fixed to tire rims which served as platform bases. Correct transducer position and orientation was obtained by a SCUBA diver who placed the tire rims along a marked lead-line perpendicular to shore. Transducer cables from bottom- and surface-mounted transducers, respectively, were routed to shore along the lead-line and along a buoyant surface line situated between the floats and outside the transducer sound beams. Figure 4 depicts the deployment of transducers for both the north and south transducer arrays, together with the respective cell widths covered by opposing transducer pairs.

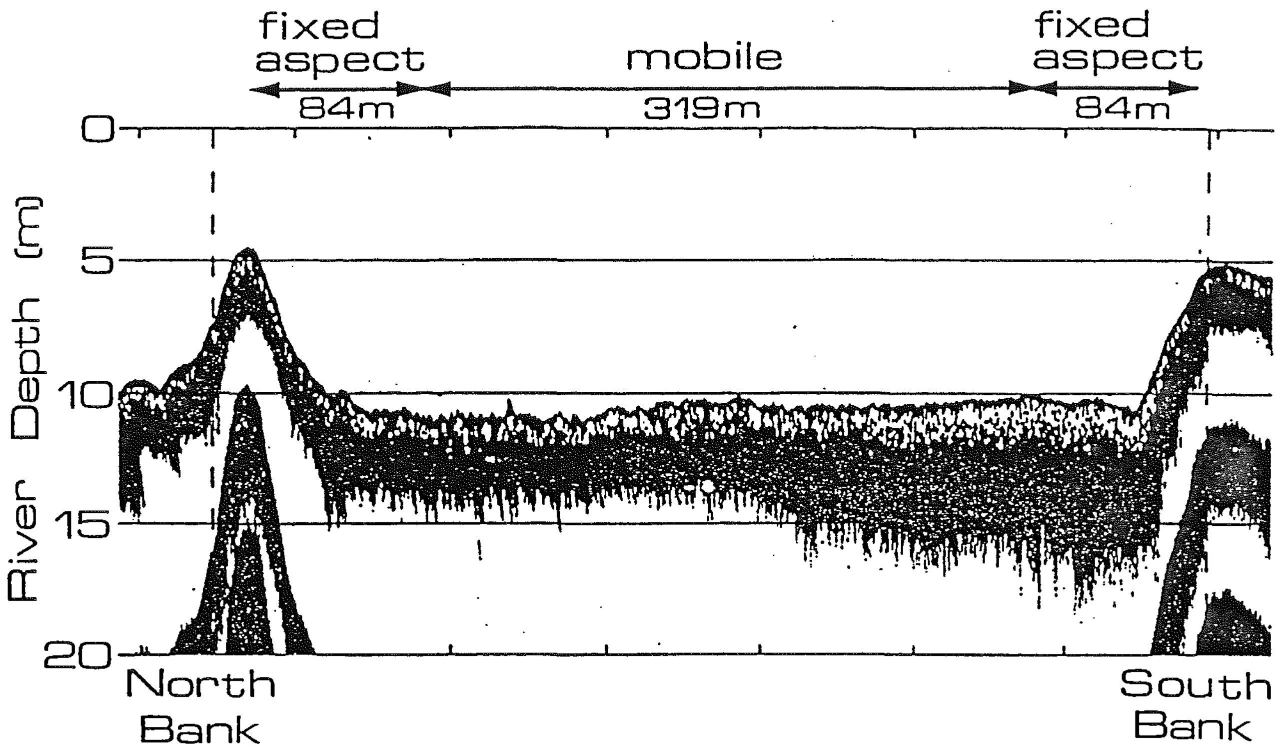


Figure 2. Echogram depicting the cross-section of the Fraser River at the Mission sampling site. The two steep-sided near-bank portions of the river were sampled by fixed-aspect arrays. The center section was sampled by a mobile survey vessel.

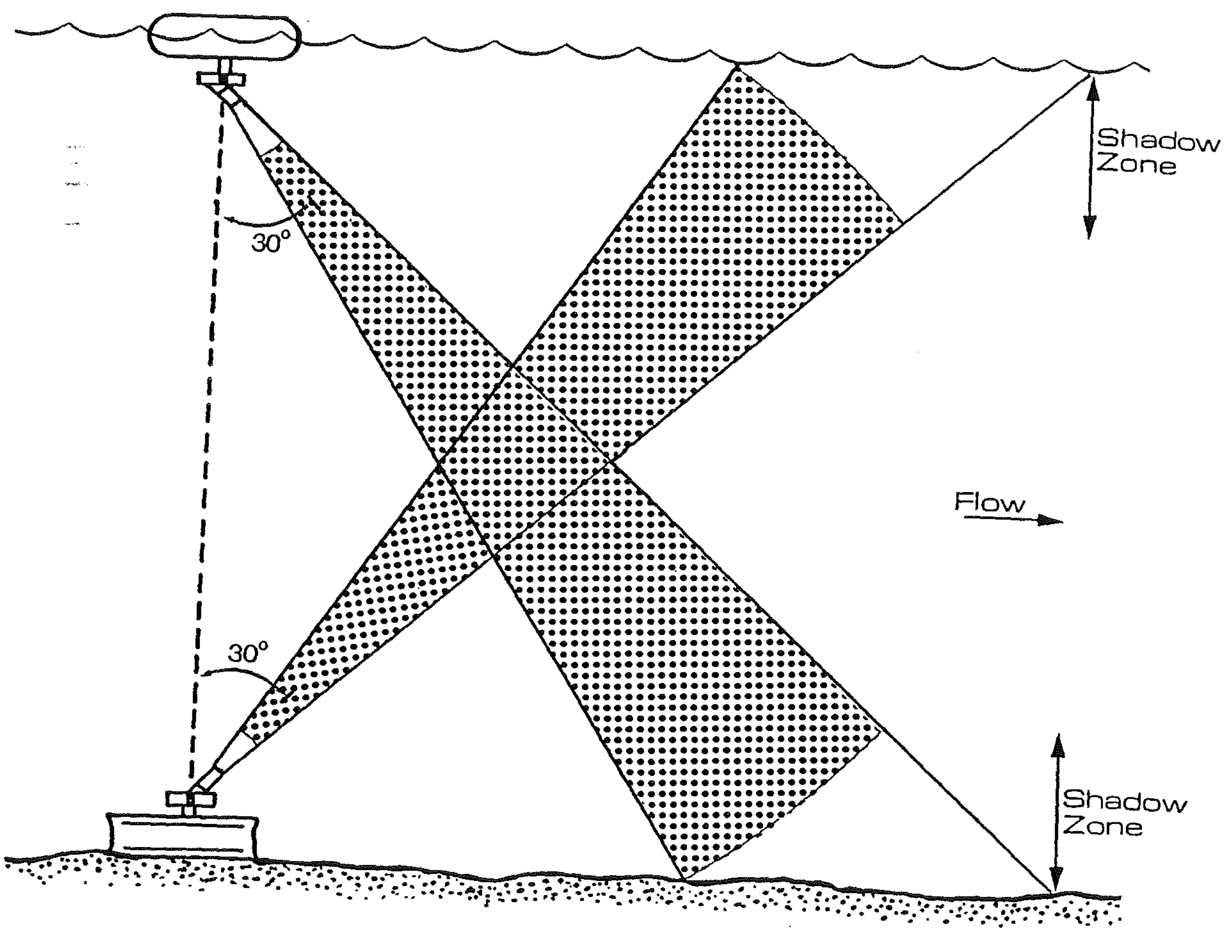


Figure 3. The orientation of uplooking and downlooking transducers deployed at Mission during 1987. The shaded regions depict the approximate portion of the water column sampled by each transducer.

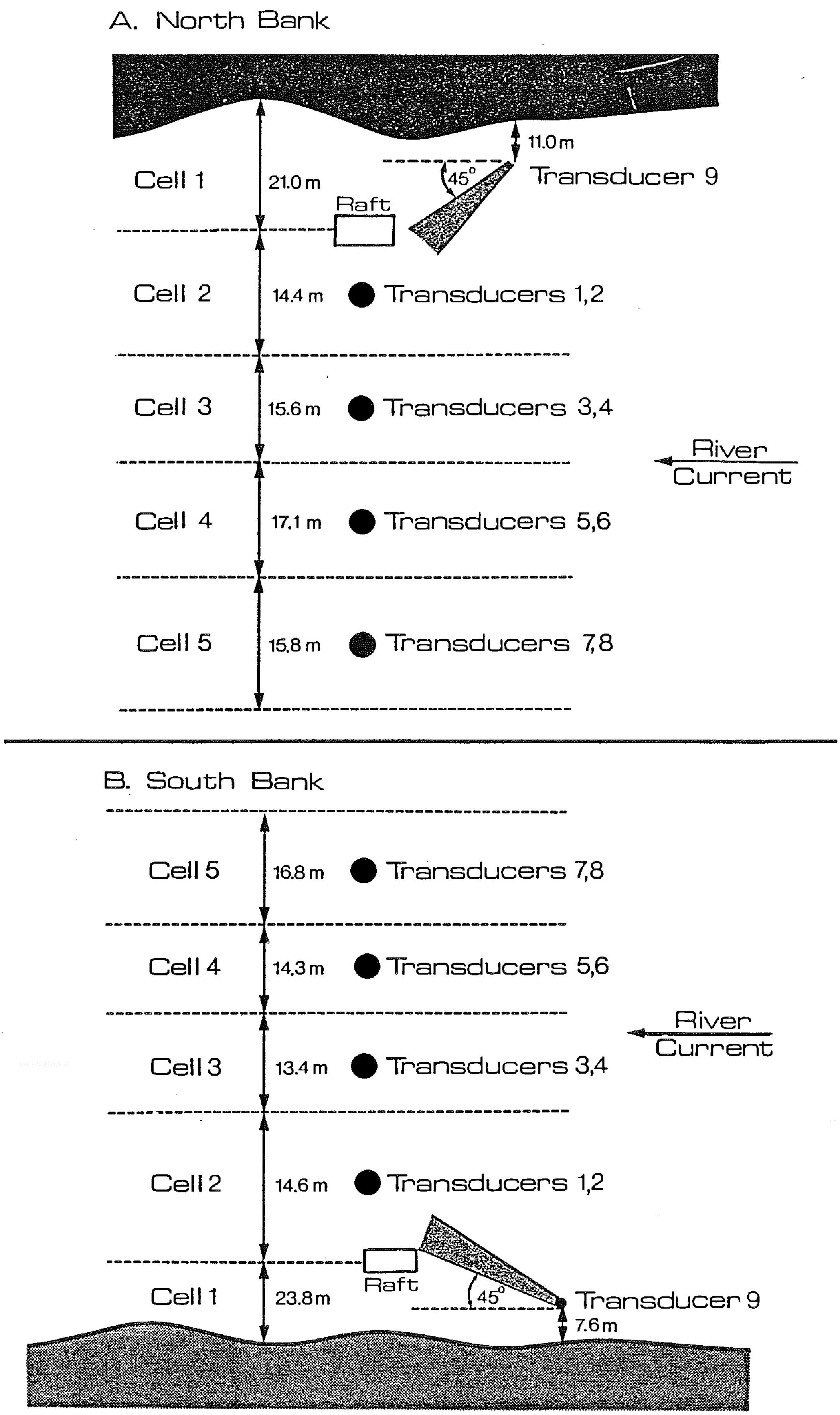


Figure 4. The location and geometry of fixed-aspect transducer arrays at Mission adjacent to the A) north bank and B) south bank of the Fraser River.

During the present study, aiming angles were established at 30° from vertical for both bottom- and surface-mounted transducers. Assuming a fish swimming velocity of 1 m per sec, a pulse rate of 10 pings per sec and near ideal surface and bottom conditions, this would create an effective shadow zone depth (Figure 3) of about 0.75 m adjacent to the surface and the bottom. Transducer attachment flanges on both bottom- and surface-mounted gimbals conformed to 30° angles so as to ensure consistent vertical aiming angles at the different sampling locations.

Calibration and echosounder operation

In order that fish be uniformly detectable at all sample locations, an on-axis fish target of a given size should return the same voltage signal out of the echosounder, independent of the particular transducer and transducer cable combination that it was detected on. Since each echosounder, transducer and transducer cable had slightly different transmission efficiencies and receiving sensitivities, acoustic returns from each transducer were amplified differently so as to equalize the sensitivity at all sample locations. This was accomplished with the multiplexer/equalizer device, in conjunction with information obtained during laboratory calibration measurements. Each transducer/cable combination was equalized using the following equation:

$$EQ = V_o - SL - G_1 - TS - RG - G_{tvg} + TL$$

where EQ is the equalizer gain setting in decibels (db), V_o is the signal output in db, SL is the transducer source level at a specified transmit power setting in db, G_1 is the through system gain at 1 m in db (with the echosounder receiver gain set at 0 db), TS is the target strength in db of the smallest target of interest (threshold), RG is the receiver gain setting in db, G_{tvg} is the time varied gain to compensate for beam spreading loss with increasing range, and TL is the transmission loss due to beam spreading and absorption with range (zero in fresh water).

For the Mission 1987 study, a threshold target strength of -45 db was chosen as the smallest target of interest. Fish smaller than this target strength would return a voltage signal less than 200 mV and not be visible on the chart recorder (with a voltage threshold value of 200 mV). This target strength was chosen as a conservative estimate of the echo return produced by a 35 cm pink salmon ensonified (passing through the sound field) at a 30° off-dorsal aspect angle. The target strength of a 35 cm salmonid, which would be expected to produce a target strength of about -35 db in dorsal aspect (Love 1971), decreases considerably as one moves towards a head-on aspect. With a threshold target strength value of -45 db, observation of the smallest upstream migrant pink salmon would be possible and smaller resident fish species would be excluded from the target counts.

The following example illustrates how equalization values were calculated. For transducer 107 and the south shore echosounder, the following values were obtained during laboratory calibration:

$SL = 203.6$, $G_1 = -174.1$ (40 log R amplification)

Since $TS = -45$, $TL = 0$ (freshwater), $G_{tvg} = 0$, $RG = 0$, $V_o = 200$ mV (threshold) = (20 log 0.2) db = -13.98 db_v, the solution of the above equation for EQ gives:

$$EQ = (-13.98) - 203.6 - (-174.1) - (-45) - 0 - 0 + 0 = 1.52 \text{ db}$$

Thus with a receiver gain setting of 0 db and 1.5 db of additional gain input at the multiplexer/ equalizer, a -45 db target strength object observed at transducer 107 would produce a 200 mV return from this echosounder.

The Model 101 echosounder has a maximum signal output of approximately 10 volts, which is equal to +20 db. This gives a total dynamic range of 20 -(-14) or 34 db. Therefore, any fish targets between -45 db and -11 db target strength would have been detectable by the fixed-aspect hydroacoustic systems deployed at Mission during 1987.

Results of equalization gain calculations are shown in Table 1. For the south shore system most of the equalization values were negative, indicating that the signal out of the echosounder was over-amplified, resulting in increased detectability of small fish below -45 db. Therefore, to equalize these transducers, the receiver gain of the echosounder was reduced to -6 db and a further 6 db amplification was added to the equalization values as shown in Table 1. The north shore echosounder had somewhat lower receiving sensitivity characteristics and equalization values were positive for the 0 db receiver gain setting. The 0 db receiver gain setting was used for the north shore array, since it is preferable to apply amplification gain to the signal within the echosounder (as opposed to the multiplexer/ equalizer).

The transmit power for both echosounders was set at -3 db. Measurement of the source level during calibration (signal out of the transducer) at different transmit power values (signal to the transducer) indicated that a transmit power of -3 db would maximize the output signal without impacting the efficiency of the transducer.

A voltage threshold of 200 mV used on the chart recorders and in equalization calculations was determined by observing the background acoustic noise level at the echosounding sites (75-100 mV). Thus, the threshold value corresponded to roughly double the background noise level. Pulse width and band width were set at 0.4 msec and 5 kHz, respectively. Pulse repetition rate was set at 16 pings per sec, slightly less than the maximum of 18.5 pings per sec which could be adopted in a 10 m water column without interference due to surface and bottom reverberation.

Field data collection

The multiplexer was programmed to sample each of the nine transducers sequentially for 400 sec during each hour of operation. Fish target observations were recorded on chart recorder paper, which also logged the transducer location, time and number of pings in the sampling sequence. Lines depicting 2 m range intervals were output on the echograms so as to classify fish target location within the sound beam. A representative echogram from the Mission site is shown in Figure 5. The systems were operated continually over the twenty-four hour diel cycle between September 9 and October 10, 1987.

Following each day of operation, echograms were transported to the PSC office in Vancouver where they were enumerated in 2 m range strata by an experienced analyst. Because of the 30° (from vertical) aiming angle of the transducers, a direction of movement was assigned to each target according to the scheme shown on Figure 6. Depending on the angle of target orientation, fish were classified as either upstream, downstream or non-directional migrants (Figure 6).

Table 1. Equalization gain settings for fixed-aspect transducer arrays deployed at Mission during 1987.

Transducer number	Source level	G_1[a]	Equalization at Rec. gain 0 db	Equalization at Rec. gain +6 db
South array (Echosounder 101-83-028)				
1	208.1	-174.1	-3.0	3.0
2	203.6	-174.1	1.5	7.5
3	207.8	-175.7	-1.1	4.9
4	208.3	-173.2	-4.1	1.9
5	207.8	-175.6	-1.2	4.8
6	207.4	-174.9	-1.5	4.5
7	203.0	-176.3	4.3	10.3
8	208.0	-174.3	-2.7	3.3
9	207.4	-173.7	-2.7	3.3
North array (Echosounder 101-83-031)				
1	207.4	-182.9	6.5	12.5
2	207.1	-182.3	6.2	12.2
3	206.7	-184.6	8.9	14.9
4	207.1	-184.6	8.5	14.5
5	208.0	-182.0	5.0	11.0
6	207.4	-183.0	6.6	12.6
7	203.8	-181.7	8.9	14.9
8	204.1	-182.9	9.8	15.8
9	206.7	-177.3	1.6	7.6

[a] Through-system gain at 1 meter (in db) with the echosounder receiver gain set at 0 db.

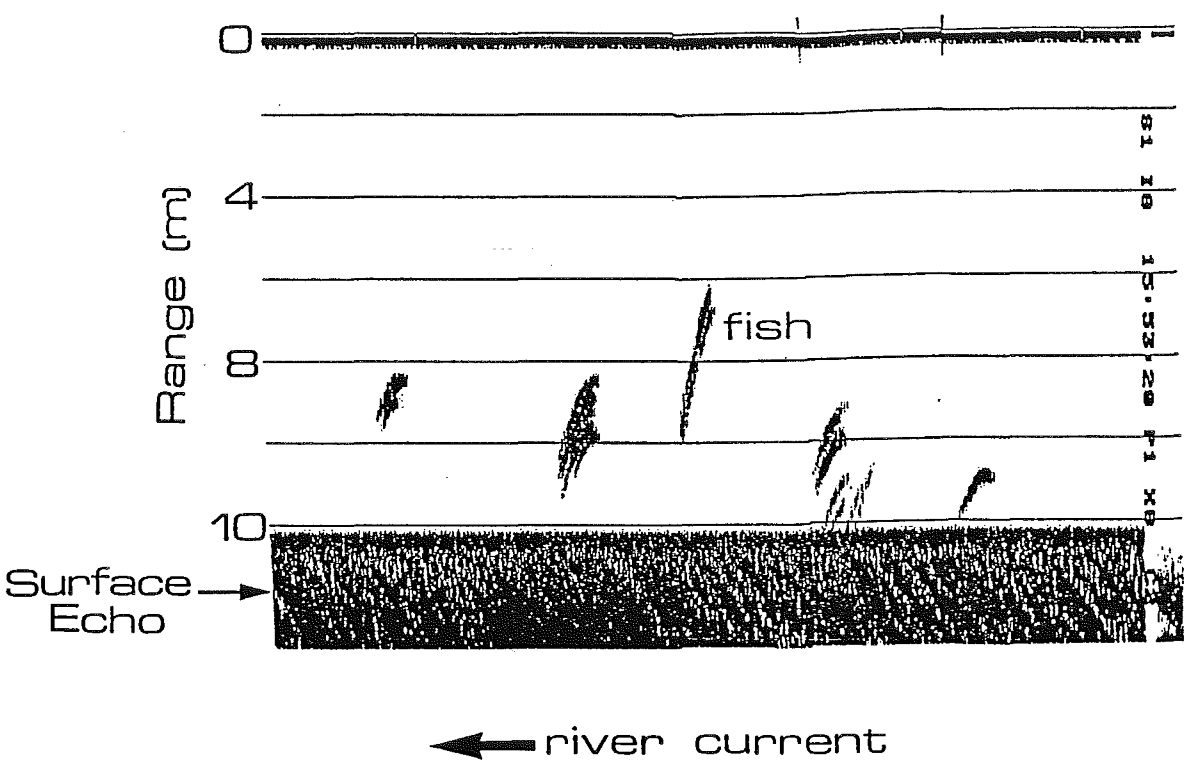


Figure 5. Representative echogram from an uplooking transducer indicating an upstream target orientation within the sound field.

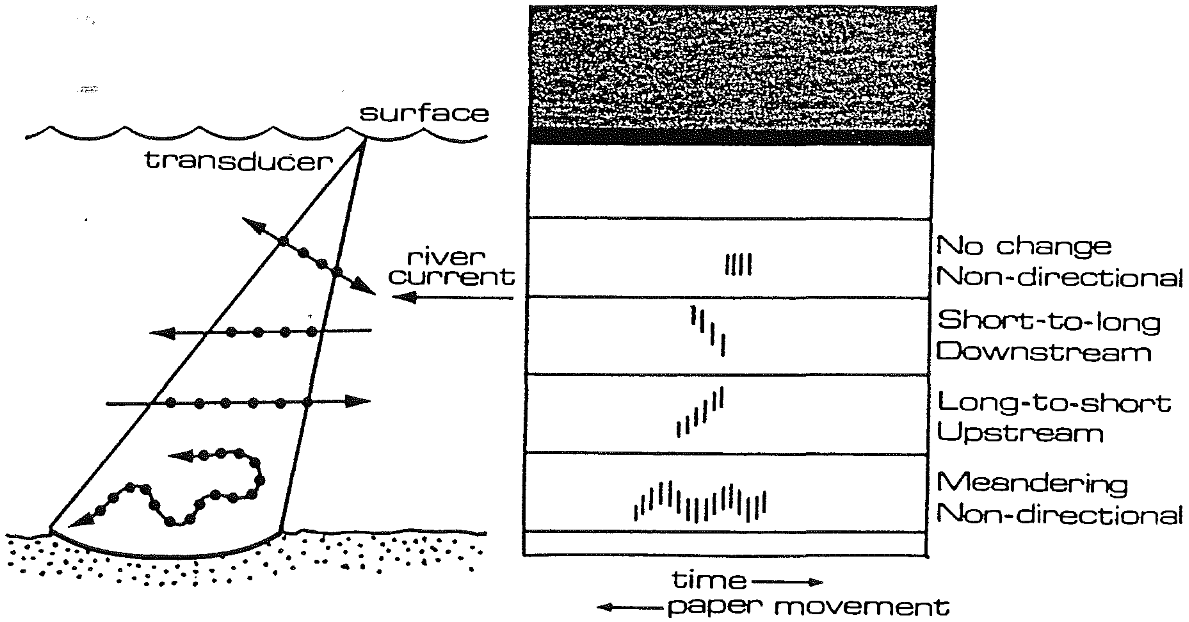


Figure 6. Classification of echo targets in an angled transducer sound field as downstream, upstream or non-directional depending on target orientation within the sound field.

Data analysis

Target count data were entered into LOTUS spreadsheets to compute the hourly fish passage across each transducer array. Daily totals were compiled by summing the hourly estimates between 05:00 a.m. to 05:00 a.m. the following day. Raw count data were expanded to account for the difference between the actual area of the transducer beam and time sampled (400 sec), and the cross-sectional area of the sampling cell (Figure 4) and the entire hour. The following expansion formula was utilized:

$$W = \frac{FE}{2R\tan(\theta/2)} \frac{3600}{S} 0.5$$

where W is the number of weighted fish per cell per hour, F is the observed number of fish targets within a range stratum, E is the cell width (m), R is the range from the transducer face (m), θ is the beam width of the transducer, and S is the number of seconds that the transducer was sampling during the hourly time block. Multiplication of the weighting factor formula by 0.5 was required to average the two values obtained by the surface downlooking and bottom uplooking transducers.

For the two sidelooking transducers (one adjacent to each shore, Figure 4), the area covered by the transducer was expanded to the cross-sectional area between the raft and the shore (Figure 4), producing areal expansion factors of 2.29 and 2.24 for the north and south sidelooking transducers, respectively. Temporal expansion was also applied to account for the fraction of the hour sampled (400 sec/hour) by the sidelooking transducers.

Directional data were analyzed in order to estimate the percentage of upstream migrating fish targets, according to the formula:

$$\textit{Percent Upstream} = \frac{T_{up} + T_{non} - T_{down}}{T_{up} + T_{non} + T_{down}} 100$$

where T_{up}, T_{down} and T_{non} are the total numbers of upstream, downstream and non-directional fish targets, respectively. Non-directional fish targets were thus enumerated as upstream migrant fish for the purpose of the present analysis. Total hourly target counts were scaled by the percentage of upstream targets to estimate the net upstream fish passage.

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 daily point estimate of pink salmon abundance.

MOBILE HYDROACOUSTIC SYSTEM

The PSC and its predecessor, the IPSFC, have since 1976 relied on a mobile hydroacoustic monitoring program to estimate sockeye and pink salmon runs migrating past Mission, B.C., to provide in-season stock size information for management decision-making. Mobile sampling during 1987 was undertaken in conjunction with the fixed-aspect enumeration program. The mobile transects were undertaken in the 319 m central portion of the Fraser River at Mission (Figure 2) to enumerate pink salmon that migrated in deeper water between the two fixed-aspect arrays. (Navigational concerns precluded the deployment of a fixed-aspect hydroacoustic array across the entire river). A second mobile echosounding program (to replace the routinely scheduled program at Mission) was undertaken at Haney, 20 km downstream of Mission (Figure 1). Procedures adopted for the Haney program and the Mission center mobile program were identical and are outlined below.

Field data collection

Mobile transects were undertaken aboard 5 m vessels operating at 1 m/sec. At Mission, a 50 kHz Furuno Model FE-606 echosounder, together with a 42° circular beam transducer was operated at 40 Log R time-varied gain. The transducer was housed in a pipe mount fixed amidships. A 20 m depth scale was used during all transects, producing an associated chart paper speed of 0.167 mm/sec. At Haney, the mobile system was comprised of a 420 kHz BioSonics Model 101 echosounder operated at 40 Log R time-varied gain, together with a Model 111 Thermal Chart Recorder (0-20 m depth range). Receiver gain and pulse rate were fixed at -12 db and 15.3 pps, respectively. The Model 111 Chart Recorder was set at 1/32 mm/ping, producing a chart paper speed of 0.478 mm/sec.

Transects were undertaken continuously over the twenty-four hour diel cycle starting on September 8 and extending to October 10 at Mission and October 18 at Haney.

Data analysis

Fish targets were enumerated from echograms in 2 m depth bins and expanded to a fish population estimate using an empirically-derived factor. The expansion procedure was analogous to the duration-in-beam method (Thorne 1988) for estimating the effective sampling volume of an acoustic system. At regular intervals (nine times per day) during the present study, the transect vessel was anchored and stationary acoustic measurements were undertaken. Since the chart recorder speed was fixed, the echo width (proportional to passage time) of individual salmon through the sonic beam defined the effective beam width of the acoustic system at a particular depth level in the water column. The following expansion formula was used:

$$N = \sum_{i=1}^{K} \left[\left(\frac{Targets}{Volume} \right) (Area) (Speed\ of\ Travel) \right]$$

$$= \sum_{i=1}^{K} \left[\left(\frac{t_i}{A_i\, BW_i} \right) A_i \left(\sum_{j=1}^{M_i} \frac{\frac{86{,}400\ (0.8)\ BW_i}{TW_{ij}}}{P_s\, M_i} \right) \right]$$

$$= \sum_{i=1}^{K} t_i \left[\frac{69{,}120\ P_s}{\frac{\sum_{j=1}^{M_i} TW_{ij}}{M_i}} \right]$$

where N is the population estimate for a twenty-four hour period for all depth strata, K is the number of depth strata, t_i is the mean number of targets in depth stratum i from mobile transects, A_i is the cross-sectional area (m^2) of stratum i, BW_i is the mean beam width (m) of stratum i, M_i is the number of targets in stratum i from stationary measurements, TW_{ij} is the measured width (mm) of target j in stratum i, and P_s is the chart speed (mm/sec). The 86,400 term is a conversion factor (sec/day), while the 0.8 term is the average chord length through a circle (average swimming distance of salmon through the sonic field).

COTTONWOOD TEST FISHING

A commercial gillnet vessel was contracted during the survey period to make standard gillnet drifts on a daily basis at a predetermined location adjacent to Cottonwood bar (Figure 1). Sockeye, chum, chinook and coho salmon were also migrating up the Fraser River at the same time as pink salmon, necessitating daily fish sampling for estimation of species composition. The vessel fished a 133 mm mesh gillnet (corner-to-corner stretched measurement) of dimensions 183 m by 60 meshes deep. Test drifts (15-30 min duration) were conducted by fishing a predetermined location at Cottonwood during the turn of the tide at low water.

RESULTS

PINK SALMON ABUNDANCE AND RUN TIMING

Estimates for the number of pink salmon migrating upstream past Mission (Table 2, Figure 7) were obtained by scaling the total fish numbers by the estimated daily upstream movement and the daily percentage of pink salmon in the Fraser River as determined in the Cottonwood gillnet sets (Figure 8). The net upstream movement, measured independently in the north and south transducer arrays (Figure 9), was seasonally coherent and showed two broad peaks (highest value was 69.9% for fish targets moving upstream through the north array on September 26). The mean value for the proportion of upstream-oriented fish targets in the north and south transducer arrays was used to scale the fish counts from the center mobile section (Table 2).

When corrected for upstream orientation and fish species composition, the total 1987 pink salmon run estimate at Mission was 970,000 fish (Table 2). The seasonal abundance curves for pink salmon were multi-modal and flat-shaped, with 6-8 minor peaks over the seasonal migration period in the north, south and center sections of the river (Figure 7). The latter peaks indicated that migration was somewhat discontinuous over time due to the passage of discrete "pulses" of upstream migrants past the enumeration sites. The daily percentage of pink salmon in the Fraser River, estimated in the Cottonwood gillnet sets (Figure 8), also showed a flat-shaped distribution with 4-5 minor peaks.

The pink salmon population was also monitored acoustically (mobile survey procedure) at Haney, 20 km downstream of Mission (Figure 1). When the results were scaled by the mean upstream orientation (estimated in the north and south transducer arrays at Mission) and the percentage of pink salmon in the river (estimated in the Cottonwood gillnet sets), a total of 650,000 upstream migrant pink salmon were enumerated past Haney during 1987 (Table 3). Comparison of the seasonal abundance curves at Mission and Haney (Figure 10) show a slightly higher pink salmon abundance measured at Mission than at Haney, particularly during the middle and latter portions of the migration period. Minor peaks in the seasonal run timing pattern occurred at Haney as well as at Mission (Figure 10), suggesting a pulsed upstream migration

Table 2. Number of pink salmon enumerated at Mission during 1987 by the north and south transducer arrays and the mobile transducer in the Fraser River.

	North Array			South Array			Center Mobile			Total	%	Net Upstream
Date	Total Fish	% Up	Net Up	Total Fish	% Up	Net Up	Total Fish	% Up	Net Up	Upstream Fish	Pink Salmon	Pink Salmon
09-Sep	24,100	27.0	6,500	24,900	46.8	11,700	42,900	36.9	15,800	34,000	57.5	19,500
10-Sep	21,000	25.3	5,300	31,400	49.9	15,700	41,600	37.6	15,600	36,600	66.5	24,300
11-Sep	16,900	21.0	3,500	31,000	26.1	8,100	33,000	23.6	7,800	19,400	67.7	13,100
12-Sep	9,600	11.3	1,100	7,200	17.2	1,200	12,800	14.3	1,800	4,100	52.2	2,100
13-Sep	17,300	16.7	2,900	18,000	9.9	1,800	9,800	13.3	1,300	6,000	0.0	0
14-Sep	16,600	18.0	3,000	17,700	31.1	5,500	28,900	24.6	7,100	15,600	52.0	8,100
15-Sep	22,600	22.4	5,100	23,800	23.0	5,500	47,900	22.7	10,900	21,500	92.2	19,800
16-Sep	45,700	32.7	14,900	46,400	32.4	15,000	69,700	32.5	22,700	52,600	76.4	40,200
17-Sep	48,000	21.2	10,200	52,200	48.0	25,100	57,000	34.6	19,700	55,000	82.5	45,400
18-Sep	30,600	17.2	5,300	51,000	58.4	29,800	54,100	37.8	20,400	55,500	78.4	43,500
19-Sep	26,600	40.5	10,800	29,100	57.5	16,700	63,600	49.0	31,200	58,700	70.6	41,400
20-Sep	42,700	44.8	19,100	53,800	53.8	28,900	102,000	49.3	50,300	98,300	88.9	87,300
21-Sep	35,200	36.5	12,900	49,000	54.2	26,500	105,000	45.3	47,600	87,000	58.6	51,000
22-Sep	28,700	52.8	15,200	32,200	58.3	18,800	70,500	55.6	39,200	73,200	72.8	53,300
23-Sep	25,600	55.7	14,300	36,900	51.0	18,800	83,000	53.4	44,300	77,400	49.4	38,300
24-Sep	40,600	54.3	22,000	48,100	66.7	32,100	93,900	60.5	56,800	110,900	51.3	56,900
25-Sep	28,400	42.3	12,000	39,600	63.8	25,300	77,600	53.1	41,200	78,500	55.3	43,400
26-Sep	41,600	69.9	29,100	37,600	48.5	18,200	110,900	59.2	65,600	112,900	33.4	37,700
27-Sep	45,800	52.9	24,200	24,900	43.9	10,900	106,100	48.4	51,400	86,500	76.4	66,000
28-Sep	31,900	32.4	10,300	21,100	-7.3	(1,500)	73,300	12.5	9,200	18,000	87.8	15,800
29-Sep	20,600	16.0	3,300	18,400	49.7	9,200	69,200	32.9	22,700	35,200	78.3	27,600
30-Sep	37,000	23.2	8,600	31,300	30.0	9,400	102,300	26.6	27,200	45,200	50.1	22,600
01-Oct	51,700	37.2	19,200	47,500	60.9	28,900	121,300	49.1	59,500	107,600	67.6	72,700
02-Oct	53,500	34.8	18,600	51,100	59.4	30,300	83,600	47.1	39,400	88,300	77.8	68,700
03-Oct	40,200	41.0	16,500	38,200	33.0	12,600	81,800	37.0	30,300	59,400	22.4	13,300
04-Oct	41,700	46.1	19,200	33,500	61.6	20,600	78,900	53.8	42,500	82,300	39.0	32,100
05-Oct	29,700	35.9	10,700	21,800	30.5	6,700	50,600	33.2	16,800	34,200	48.2	16,500
06-Oct	21,100	16.5	3,500	14,300	16.0	2,300	41,600	16.3	6,800	12,600	41.7	5,200
07-Oct	20,200	8.2	1,700	15,100	15.8	2,400	59,200	12.0	7,100	11,200	32.7	3,700
08-Oct	19,300	26.7	5,200	24,600	-16.1	(4,000)	54,400	5.3	2,900	4,100	11.1	500
09-Oct	16,800	13.1	2,200	16,100	3.2	500	58,000	8.2	4,700	7,400	1.1	100
10-Oct	16,400	18.9	3,100	24,800	-10.9	(2,700)	50,000	4.0	2,000	2,400	3.1	100
TOTAL	967,700		339,500	1,012,600		430,300	2,134,500		821,800	1,591,600		970,200

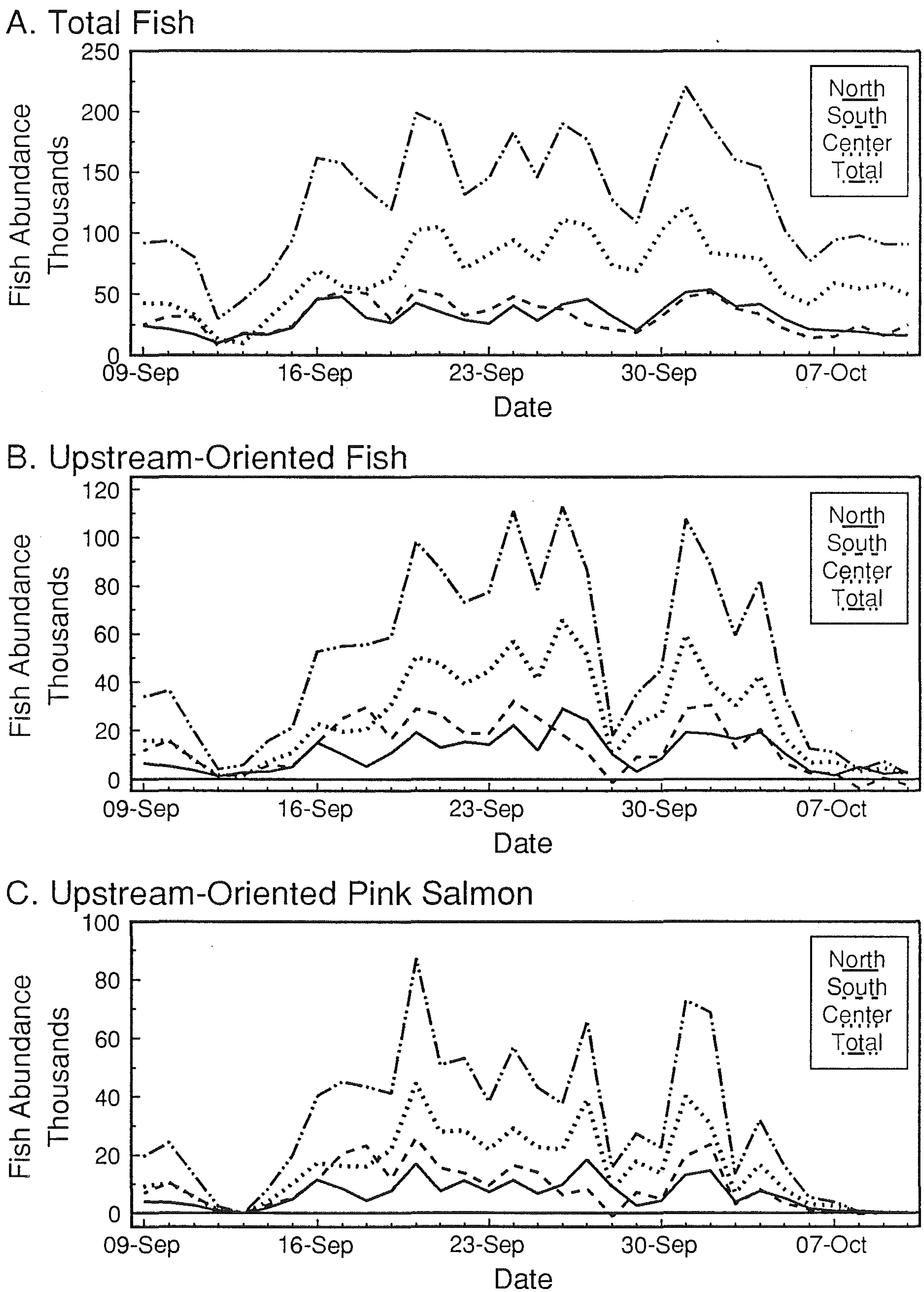


Figure 7. Estimated number of fish enumerated in the north and south transducer arrays and the center mobile section. The combined total is also shown.

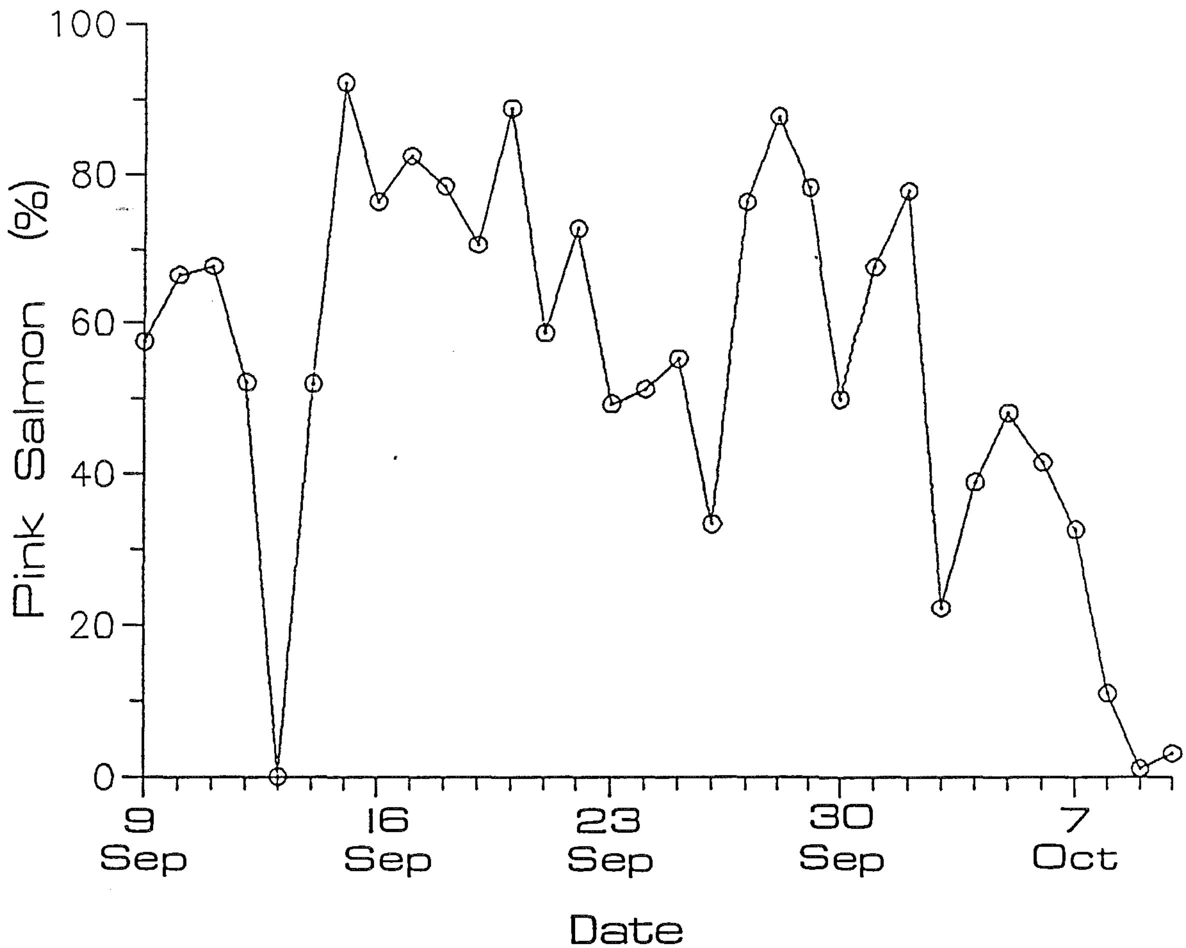


Figure 8. Percentages of pink salmon in gillnet test sets conducted at Cottonwood.

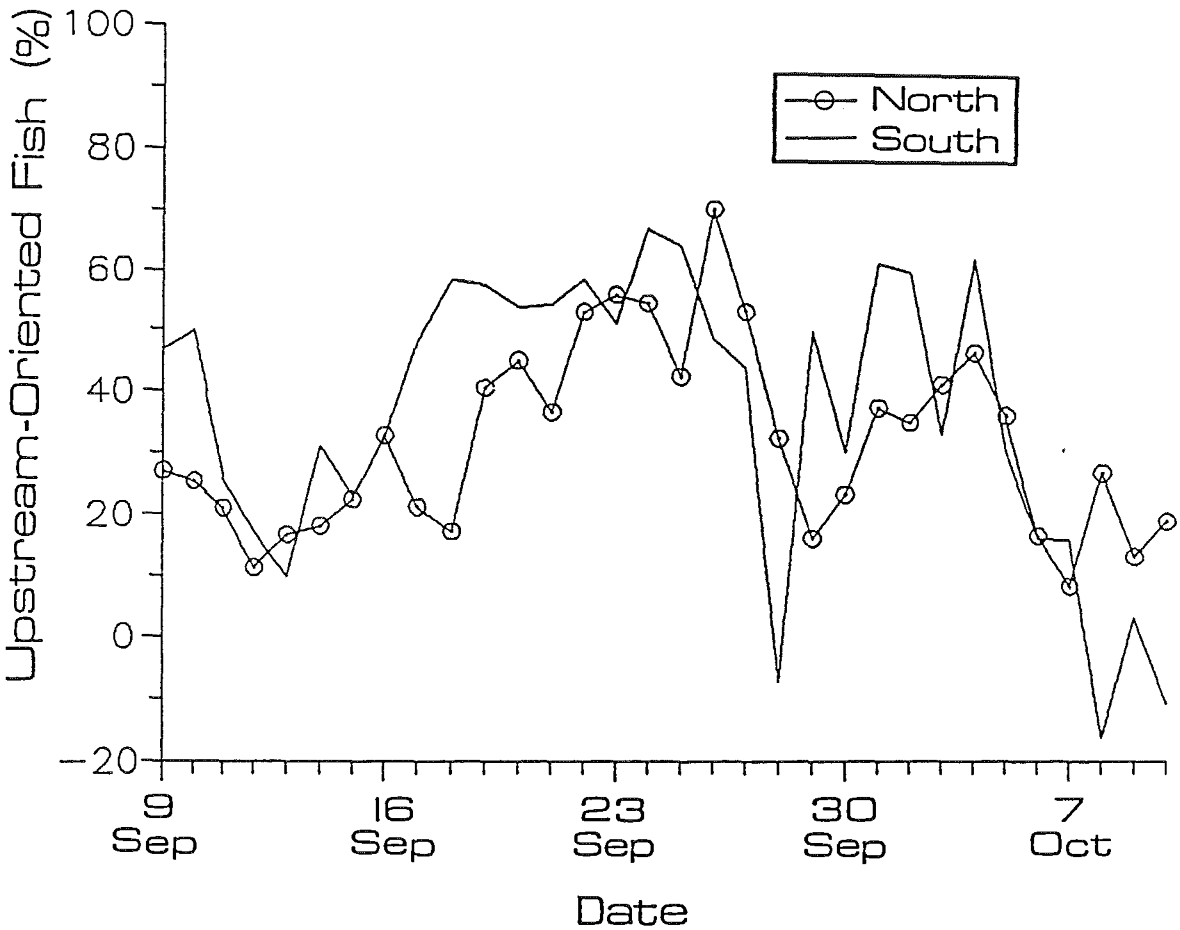
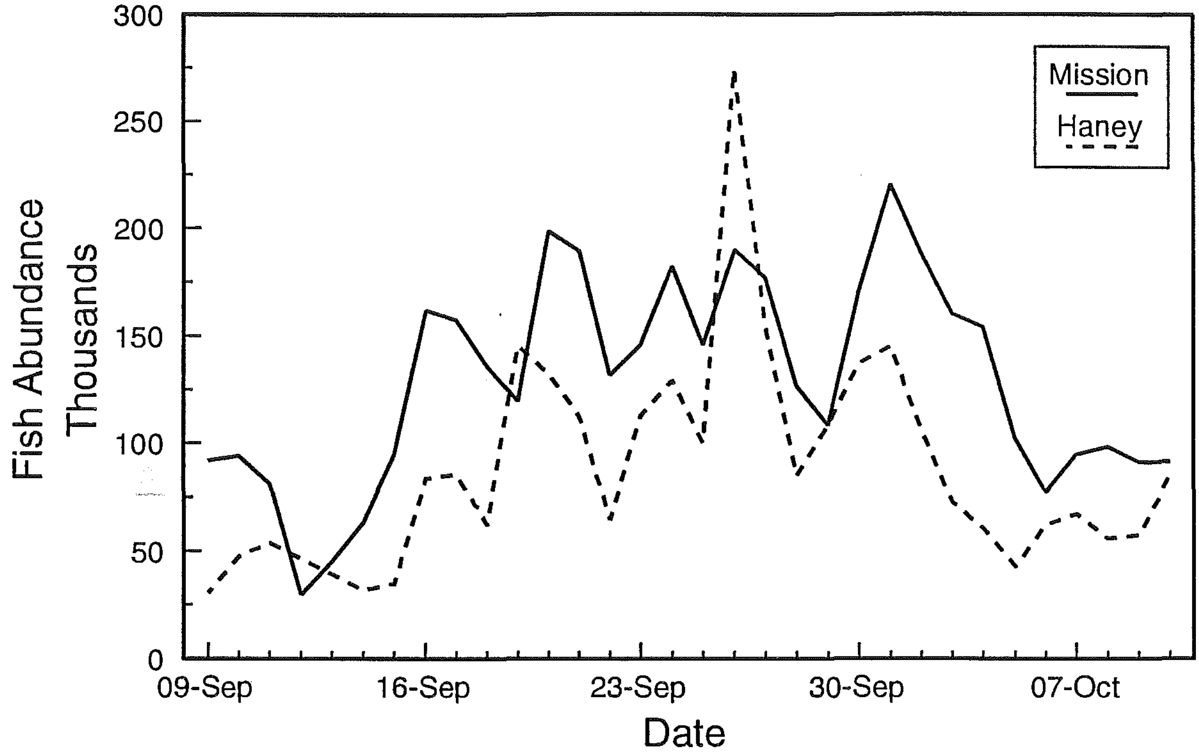


Figure 9. Percentages of upstream-oriented fish targets on echograms from the north and south transducer arrays.

A. Total Fish



B. Upstream-Oriented Pink Salmon

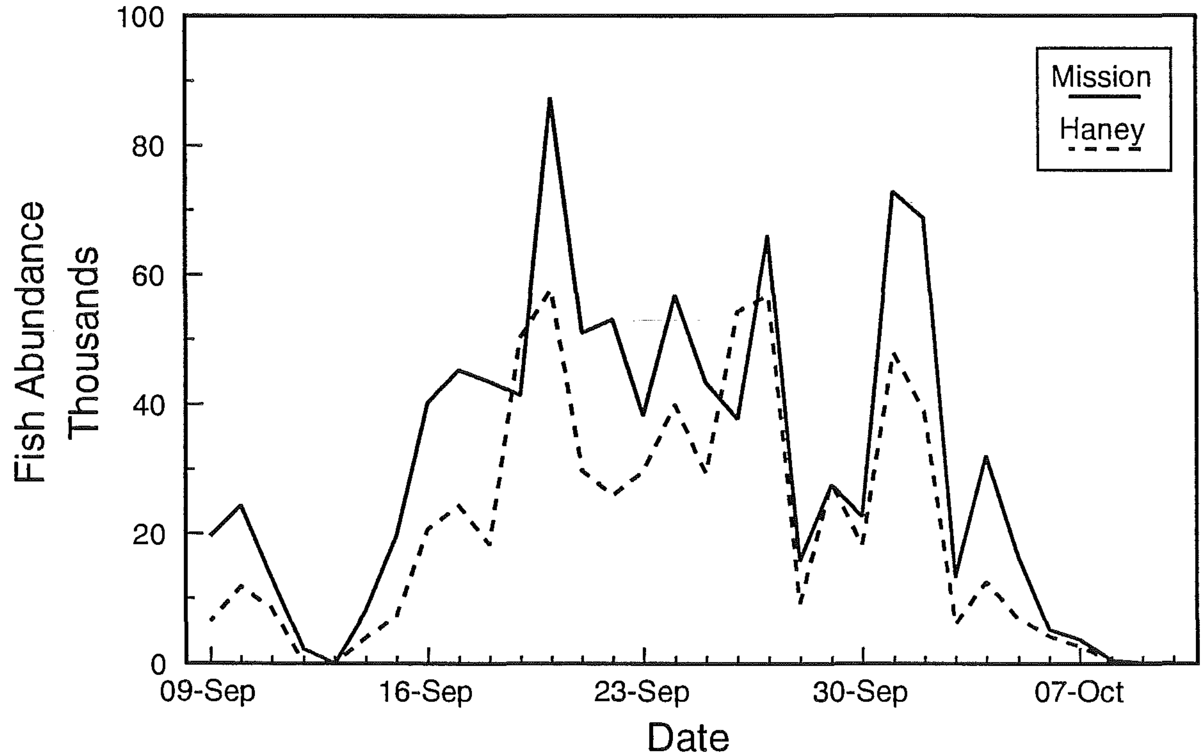


Figure 10. Estimated number of fish enumerated at Mission and Haney. Results are shown for total fish targets (A) and upstream-oriented pink salmon (B).

Table 3. The number of upstream migrating pink salmon at Haney, determined from the number of fish targets at Haney, the percentage of upstream-oriented targets and the percentage of pink salmon in Cottonwood gillnet sets.

Date	Total Fish	Percentage Upstream-Oriented	Net Upstream Fish	Percentage Pink Salmon	Net Upstream Pink Salmon
09-Sep	30,542	36.9	11,300	57.5	6,500
10-Sep	47,523	37.6	17,900	66.5	11,900
11-Sep	53,538	23.6	12,600	67.7	8,500
12-Sep		14.3	0	52.2	0
13-Sep		13.3	0	0.0	0
14-Sep	31,755	24.6	7,800	52.0	4,100
15-Sep	34,800	22.7	7,900	92.2	7,300
16-Sep	83,402	32.5	27,100	76.4	20,700
17-Sep	85,500	34.6	29,600	82.5	24,400
18-Sep	62,001	37.8	23,400	78.4	18,300
19-Sep	145,300	49.0	71,200	70.6	50,300
20-Sep	132,000	49.3	65,100	88.9	57,800
21-Sep	112,300	45.3	50,900	58.6	29,800
22-Sep	64,300	55.6	35,700	72.8	26,000
23-Sep	112,400	53.4	60,000	49.4	29,700
24-Sep	128,900	60.5	78,000	51.3	40,000
25-Sep	100,000	53.1	53,100	55.3	29,300
26-Sep	274,400	59.2	162,400	33.4	54,300
27-Sep	154,000	48.4	74,500	76.4	56,900
28-Sep	84,500	12.5	10,600	87.8	9,300
29-Sep	108,200	32.9	35,600	78.3	27,900
30-Sep	136,800	26.6	36,400	50.1	18,200
01-Oct	145,000	49.1	71,200	67.6	48,100
02-Oct	106,000	47.1	49,900	77.8	38,800
03-Oct	72,500	37.0	26,800	22.4	6,000
04-Oct	60,200	53.8	32,400	39.0	12,600
05-Oct	42,600	33.2	14,200	48.2	6,900
06-Oct	61,800	16.3	10,000	41.7	4,200
07-Oct	67,000	12.0	8,000	32.7	2,600
08-Oct	55,700	5.3	3,000	11.1	300
09-Oct	57,100	8.2	4,700	1.1	100
10-Oct	85,070	4.0	3,400	3.1	100
TOTAL	2,735,131		1,094,700		650,900

pattern of pink salmon in the Fraser River. The latter peaks were coherent at both the Haney and Mission sampling sites (Figure 10A).

HORIZONTAL DISTRIBUTION

Consideration of the relative numbers of fish targets enumerated in the fixed-aspect arrays at Mission, compared to the center mobile portion of the river (Table 1), indicates that pink salmon tend to migrate close to shore in this reach of the Fraser River. Each of the transducer arrays covered 17% (84 m) of the horizontal distance across the river, compared to 66% (319 m) covered by the center mobile section (Figure 2). Total fish enumerated in the north, south and center sections of the river (Table 2) amounted to 21%, 27% and 52%, respectively, of the total fish population enumerated at Mission. The high representation of fish in the fixed-aspect arrays, relative to the percentage of the river covered, suggests a non-uniform horizontal distribution of fish across the Fraser River. The distribution was skewed towards the north and south shore areas at Mission.

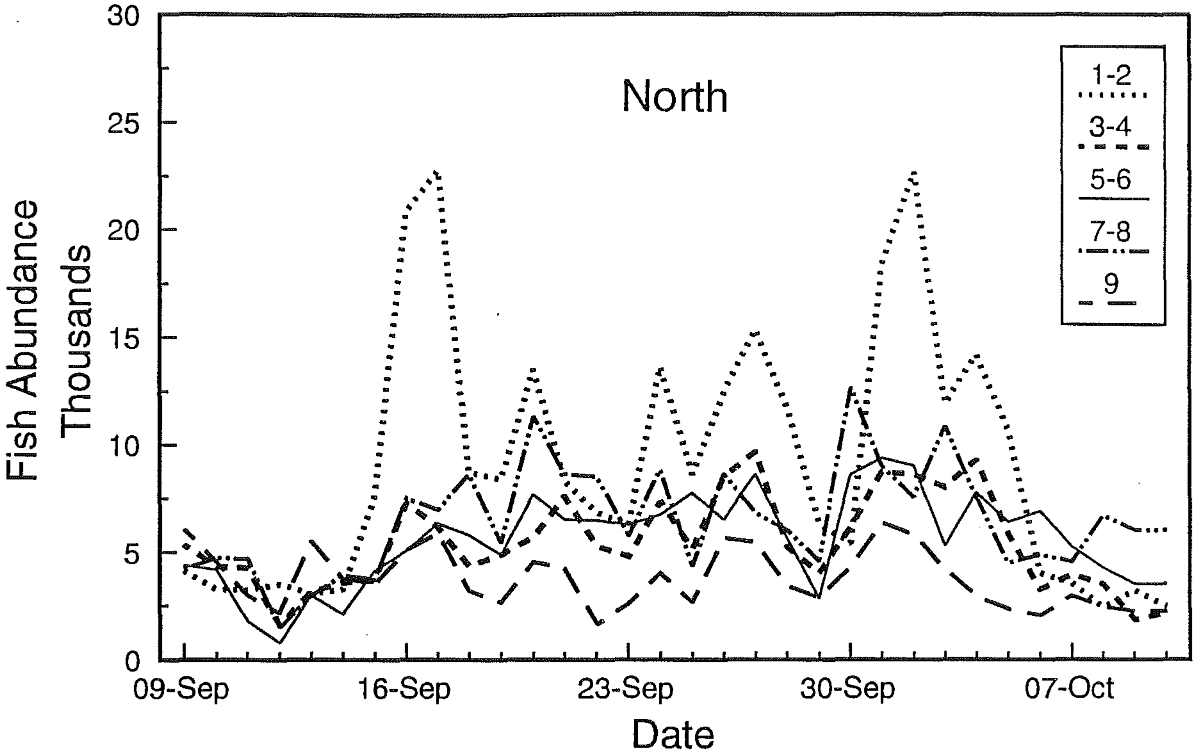
The near-shore horizontal distribution of fish was further analyzed by segregating the fixed array data sets by transducer pairs (Figure 11). The sidelooking transducer (transducer 9) was situated closest to the shoreline, with opposing transducer pairs (one uplooking, one downlooking) 1-2, 3-4, 5-6 and 7-8 sampling adjacent areas further from shore (Figure 4). Results of this comparison (Figure 11) showed that the transducer pair 1-2 consistently sampled higher total fish numbers over the migration period, both in the north and south fixed-aspect arrays. The observed non-random distribution of fish targets was likely due to adult pink salmon concentrating in specific areas of the near-shore zone (horizontally) during the upstream migration period.

Analyses were undertaken on the fixed-aspect data set to determine whether there was an influence of horizontal position on the directionality of fish targets. Net upstream migration percentages were computed separately for sidelooking transducer 9 and the opposing transducer pairs. The results (Figure 12) suggest a largely uniform distribution in upstream migration tendency across the transducer array, with the exception of the fish closest to shore (sidelooking transducer 9). In the latter, there was a lower percentage of fish (10% or less) oriented in an upstream direction. Taken together, the horizontal comparisons of abundance (Figure 11) and upstream orientation (Figure 12) suggest the existence of specific near-shore riverine migration zones where pink salmon concentrate during the upstream migration period.

VERTICAL DISTRIBUTION

The mean depth of fish targets in the transducer beam was calculated by weighting the numbers of fish targets in successive range bins by the mean depth of the strata, and dividing by the total numbers of fish targets in the water column. Due to tidal effects on the riverine water column depth, calculations were undertaken for transducers positioned at the surface only (transducers 1, 3, 5 and 7), as well as for the mobile transect data obtained in the center section of the river. Mean depths were expressed relative to the depth level at the river surface (0 m).

Results indicated a mean depth position of 5 m and 3.75 m in the north and south fixed-aspect arrays (Figure 13). Fish were deeper (8.5 m in mean depth) in the center section of the river (Figure 13). These variable results suggest that pink salmon riverine depth distribution is probably affected by local bottom topography during upstream migration.



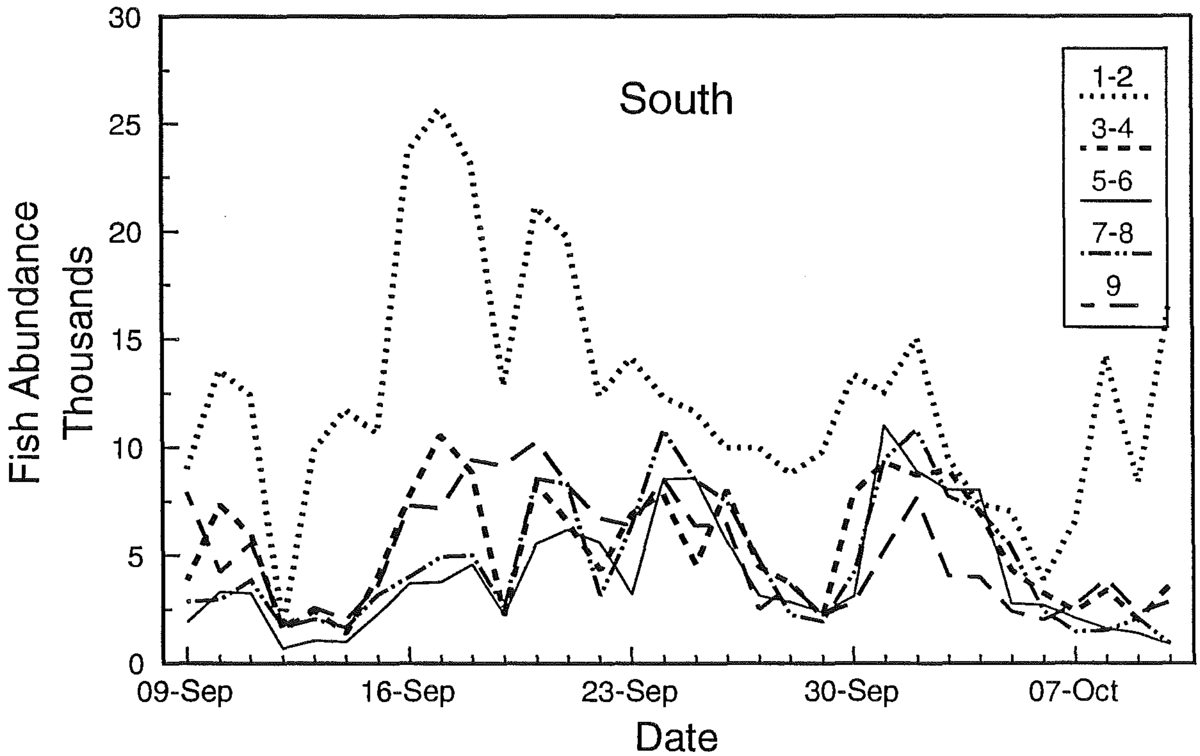


Figure 11. Number of fish enumerated in corresponding transducer pairs 1-2, 3-4, 5-6, 7-8 and sidelooking transducer 9 in north and south transducer arrays.

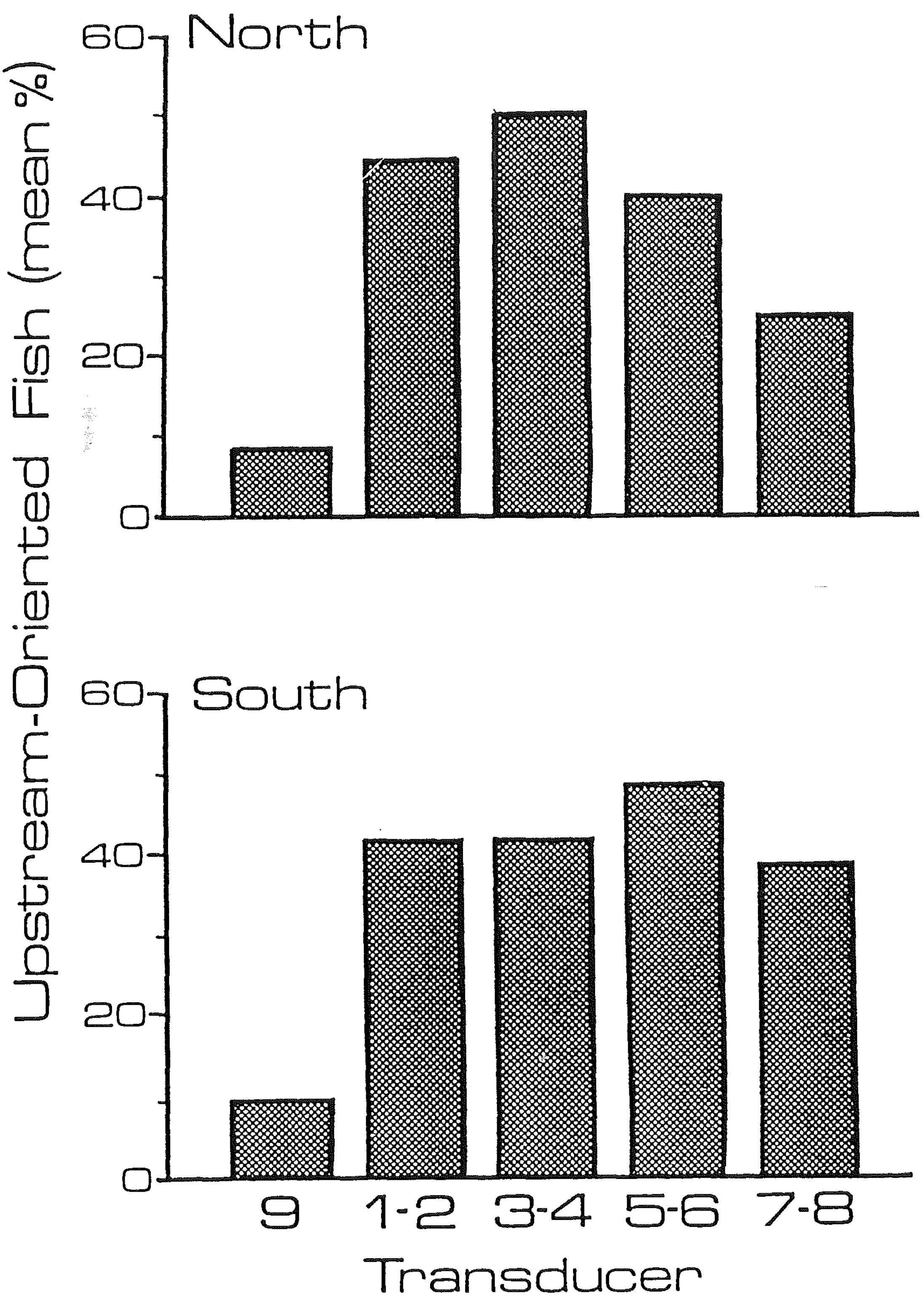


Figure 12. Mean percentage of upstream-oriented fish targets estimated by corresponding transducer pairs 1-2, 3-4, 5-6, 7-8 and sidelooking transducer 9 in north and south transducer arrays.

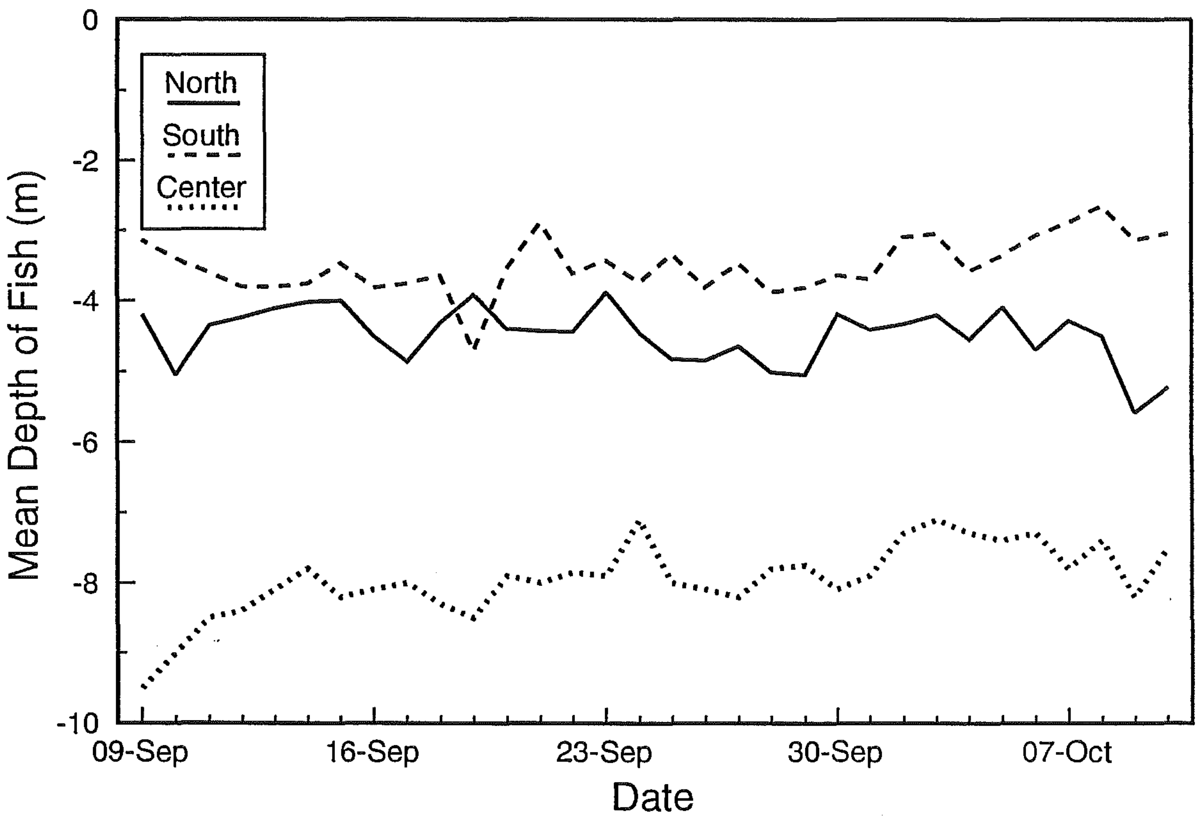


Figure 13. Mean depth of fish measured in downlooking transducers from the north and south arrays and the center mobile surveys in the Fraser River.

COMPARISON OF UPLOOKING, DOWNLOOKING AND SIDELOOKING ESTIMATES

Acoustic data for the uplooking (transducers 2, 4, 6 and 8), downlooking (transducers 1, 3, 5 and 7) and sidelooking (transducer 9) transducers were compiled separately and compared to evaluate the effectiveness of different deployments for monitoring Fraser River pink salmon populations. In both the north and south arrays, lowest numbers of fish were enumerated by the sidelooking transducer (transducer 9) situated closest to shore (Figure 14). In the north array, bottom-mounted, uplooking transducers consistently enumerated higher numbers of fish than the surface-oriented, downlooking transducers (Figure 14). By contrast, downlooking transducers produced higher numbers of fish than uplooking transducers in the south array on most dates during the first half of the pink salmon migration (Figure 14). The effectiveness of the different transducer deployments (uplooking versus downlooking) was, therefore, site-specific in this region of the Fraser River.

Analyses were also undertaken to determine the influence of transducer orientation on the measured migration direction of the fish. In the north array, lowest upstream migration percentages were observed in the sidelooking transducer on most dates (Figure 15). Highest values were observed by the downlooking transducers on most dates in the north array and on all dates for the south array (Figure 15). In the south array, similar upstream migration percentages were observed by sidelooking and uplooking transducers (Figure 15).

DIEL PERIODICITY

Fish population estimates for the entire monitoring period were segregated according to hour of observation to examine diel influences on fish passage. Diel periodicity was most evident in the center mobile data set (Figure 16A) with distinct crepuscular (dawn and dusk) peaks in fish population estimates. The dusk peak in population number (T=2000) was slightly more pronounced than the dawn peak (T=0500). Crepuscular peaks were also observed in the upstream migration tendency of the fish (Figure 16B). Upstream migration peaks, however, were somewhat out of phase with the numerical values, occurring later at dawn (T=0800) and earlier at dusk (T=1800) than the numerical peaks.

Similar analyses were undertaken for a smaller sub-set of the Haney mobile data, spanning four days during the middle of the pink salmon migration between September 24 and 27, 1987. Mission data for the same period were similarly analyzed for comparative purposes (Figure 17). The results confirm a pulsed migration pattern at Haney, as well as at Mission, with a minor peak in fish numbers at dawn and a major peak in the late afternoon.

Hourly population estimates from Haney were compared to those from Mission, since similar groups of fish would be sampled at both locations, albeit with a time lag of about eleven hours (assuming a swimming velocity of 1.8 km/ hour; Harder et al. 1987). The results (Figure 17B) suggest a diel pattern in population numbers from both locations. However, there was no evidence for lagged synchrony in the relative size of the numerical peaks at Haney and Mission (Figure 17A). This suggests that pink salmon do not maintain strong spatial associations with co-migrants over time; rather, there appears to be staggered time-lags and mixing occurring as the migration proceeds, such that minor numerical peaks may be transitory events.

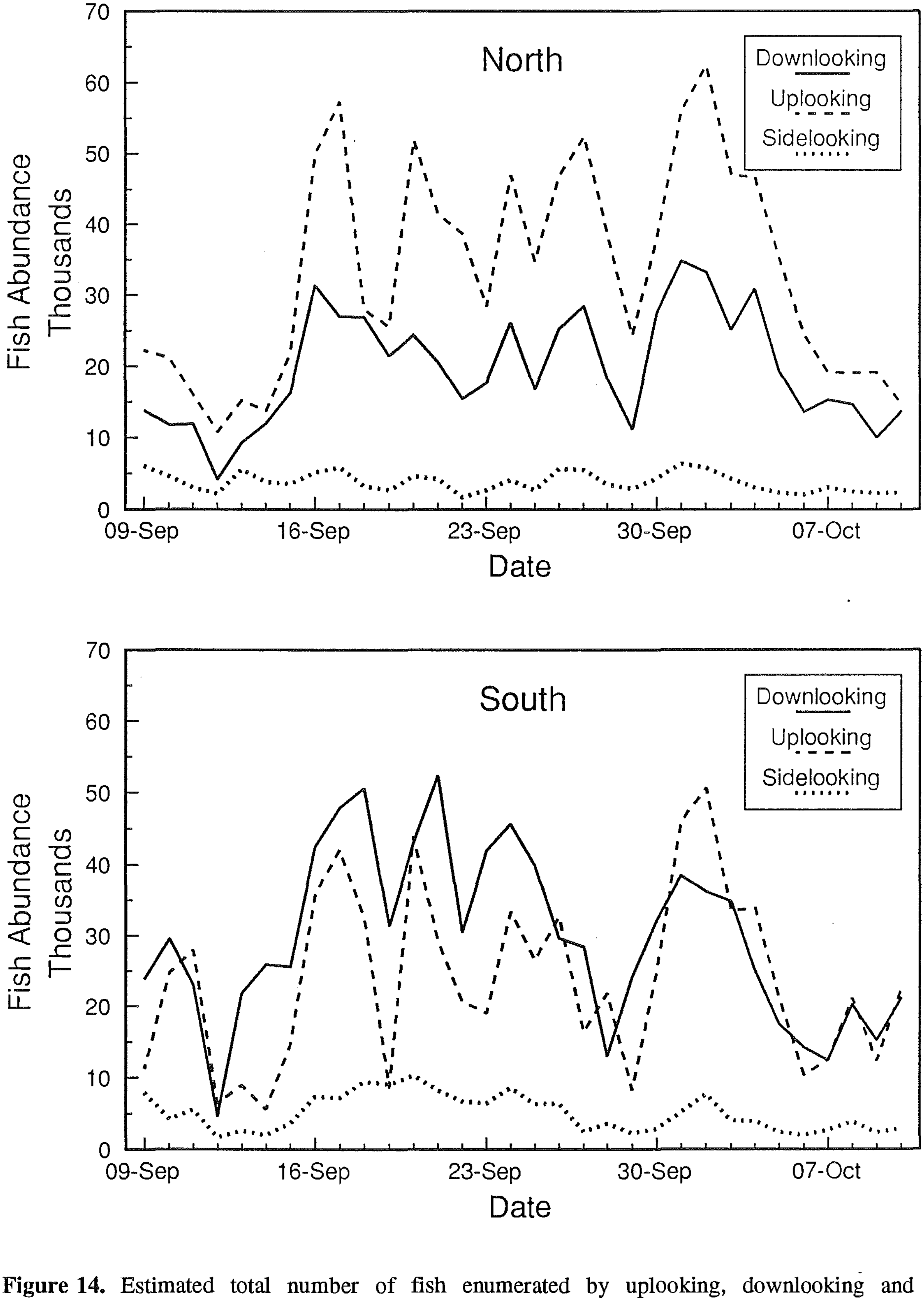


Figure 14. Estimated total number of fish enumerated by uplooking, downlooking and sidelooking transducers in the north and south transducer arrays.

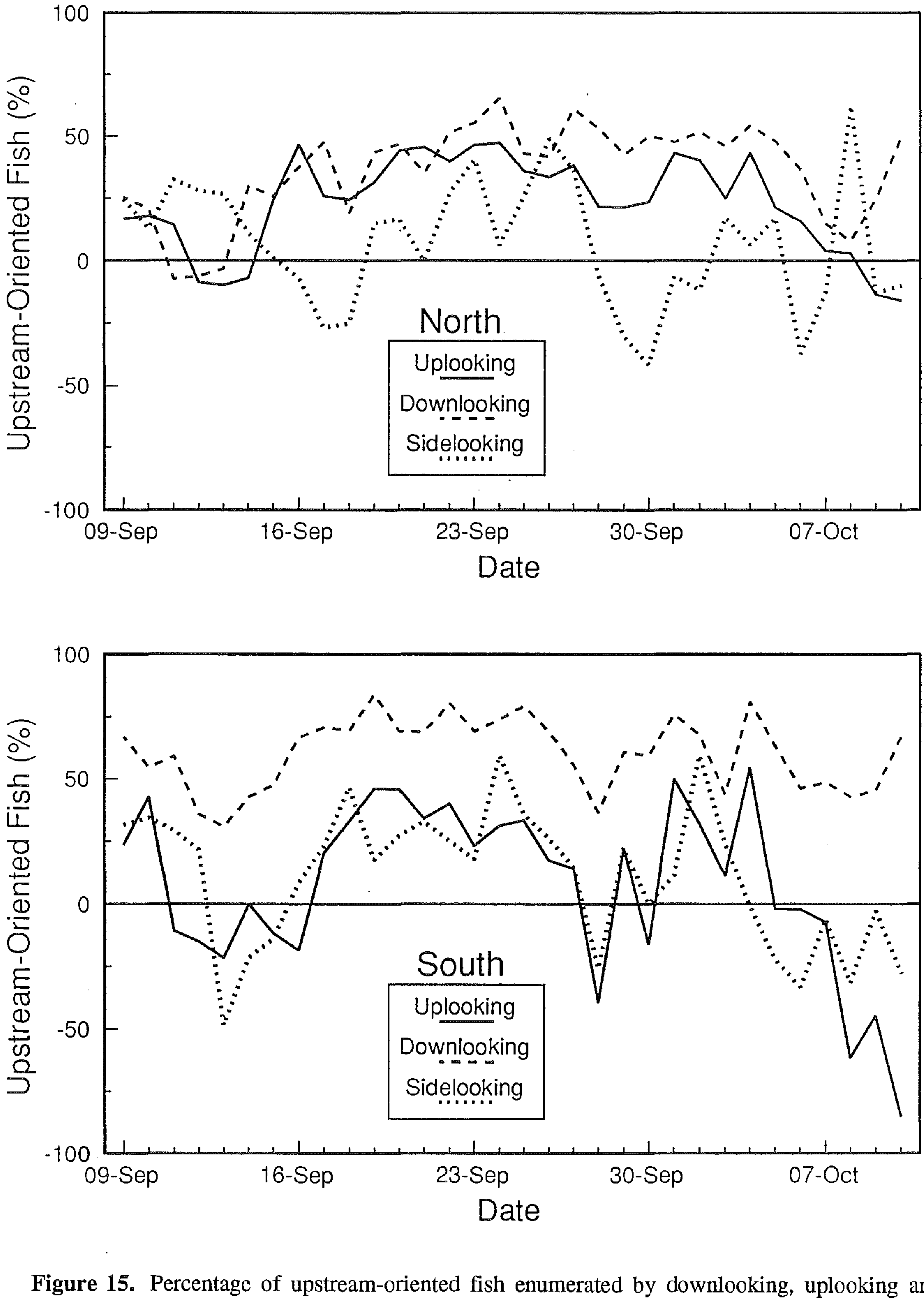


Figure 15. Percentage of upstream-oriented fish enumerated by downlooking, uplooking and sidelooking transducers in the north and south transducer arrays.

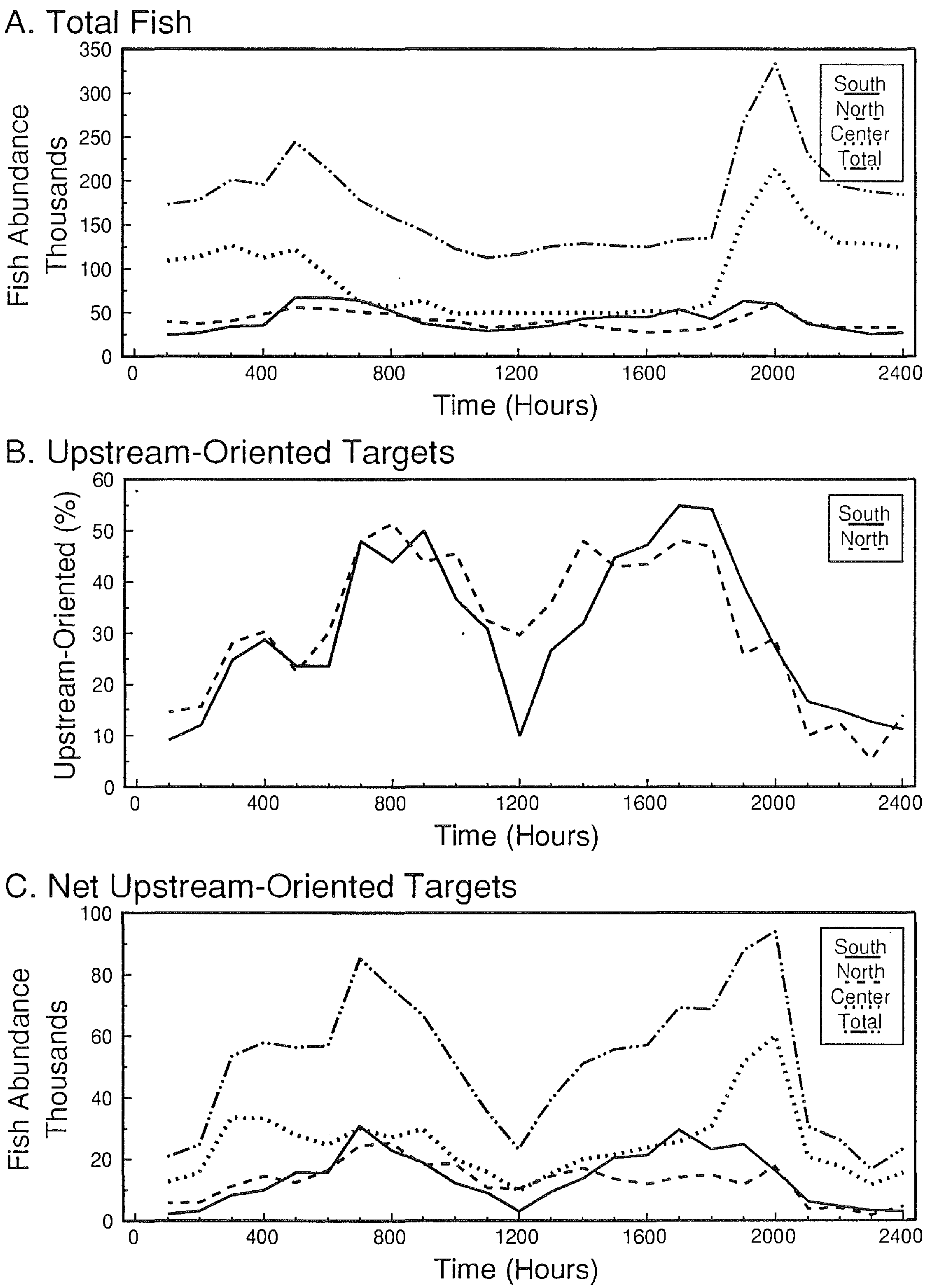


Figure 16. Estimated number of fish enumerated in the north and south transducer arrays and the center mobile section, as a function of time of day. The combined total is also shown.

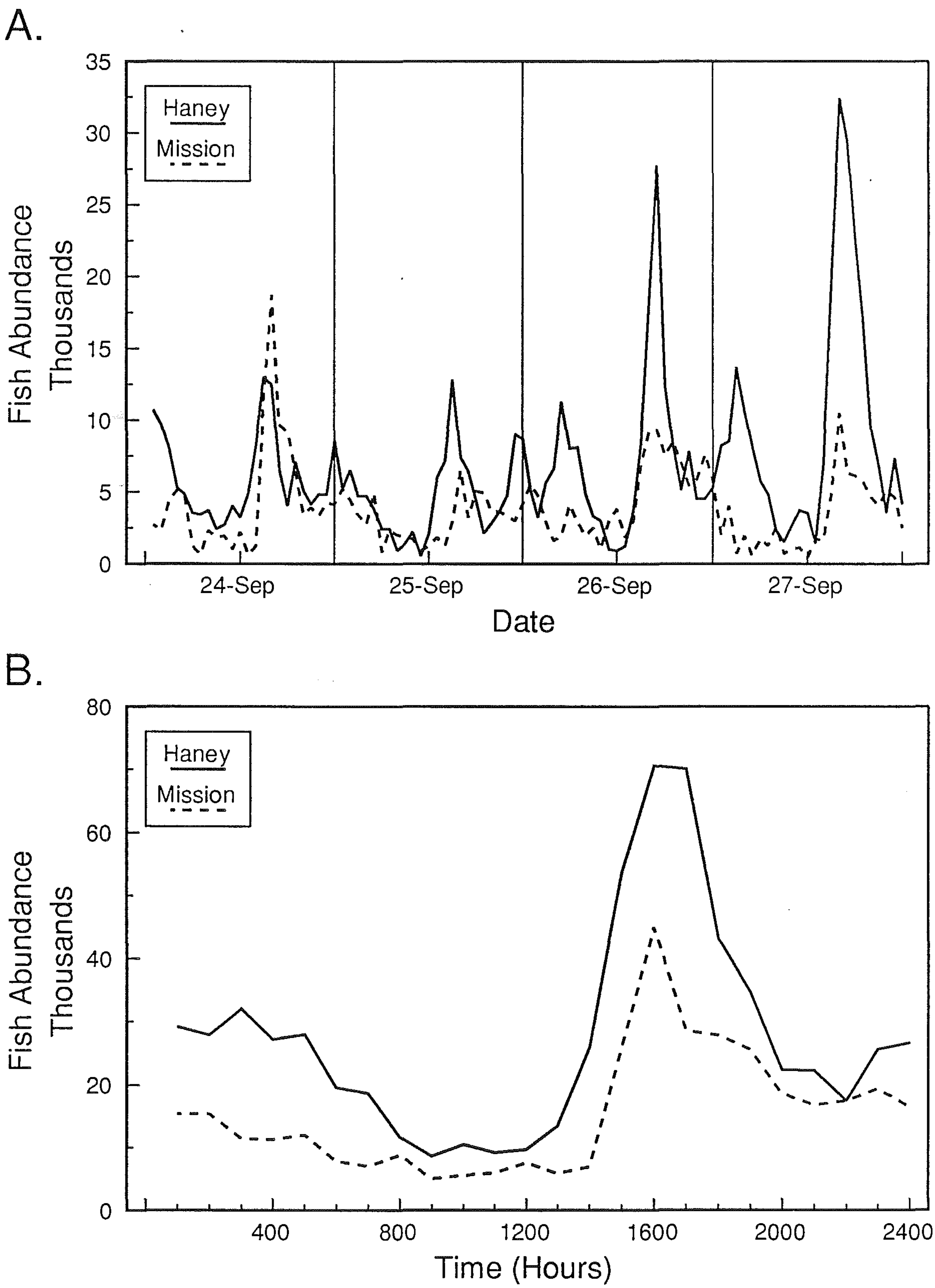


Figure 17. A) Hourly numerical estimates of total fish targets at Haney and Mission (center mobile data set) between September 24 and September 27 and B) total fish target estimates for the four days as a function of time of day.

DISCUSSION

The primary purpose of this study was to develop and field test an acoustic enumeration system for adult pink salmon populations of the Fraser River. To be useful for ongoing in-season pink salmon management, the system should be cost-effective, accurate and reasonably precise. The combined estimate from the fixed-aspect and mobile transect surveys was 970,000 adult pink salmon at Mission, far less than the 3,224,000 pink salmon estimated by the Canada Department of Fisheries and Oceans mark-recapture program (Pacific Salmon Commission 1988). A number of factors may have contributed to the discrepancy in pink salmon numbers estimated by the two different assessment programs.

It is likely that the acoustic program underestimated the pink salmon population. Acoustic underestimation may have resulted from inaccurately estimating upstream fish orientation in both the fixed-aspect arrays, as well as in the center mobile portion of the Fraser River at Mission. Net upstream movement in the north and south arrays averaged 31.6% and 36.4% , respectively, over the 32 days of measurement (Figure 9). As shown in Table 2, there is a direct influence of net upstream migration rate errors on the numerical population estimates: a 50% error in upstream migration rate produces a 50% error in the pink salmon estimate. The daily mean of the north and south upstream migration rate values was applied to the center mobile transect data (Table 2), potentially compounding the numerical effect of upstream migration rate errors. In the event that the acoustic enumeration program for pink salmon is undertaken in future, it would be desirable to obtain additional estimates for the upstream passage rate of pink salmon past the enumeration site, perhaps using telemetric methods (Stasko and Pincock 1977; Hawkins and Urquhart 1983) or recently developed (BioSonics) methods of acoustic target tracking. Harder et al. (MS 1987) followed the upstream passage of radio-tagged pink salmon within the lower Fraser River adjacent to Annacis Island during 1985. Out of twenty-five tagged pink salmon, migration delays and, in some cases, downstream movement were observed for 61% of the radio-tagged fish. These radiotelemetry results tend to confirm the estimates of upstream fish orientation from the present study and also suggest that adult pink salmon migrate through the lower reaches of the Fraser River in an erratic fashion.

Inaccurate estimation of salmon species composition within the Fraser River (by the Cottonwood gillnet test drifts) was a potential source of numerical error due perhaps to gillnet selectivity effects or non-uniform salmon species distribution across the river. An alternative method of assigning species composition, based on catch-per-unit-effort statistics from Cottonwood and subtraction of post-season estimates of coho, chinook, chum and sockeye escapements, was also applied to the hydroacoustic data set. This method produced an estimate of 1,004,700 pink salmon over the entire migration period, very close to the 970,200 pink salmon estimated by direct scaling with the Cottonwood test fishing results (Table 2). Therefore, inaccuracy of the hydroacoustic estimate during the present study was probably unrelated to errors in species composition estimates.

The 1987 mark-recapture program may have overestimated the pink salmon population in the Fraser River. The accuracy of the Petersen method of mark-recapture depends on numerous assumptions (reviewed by Krebs 1989) which are rarely satisfied. In a comparison of pink salmon population estimates obtained by mark-recapture methods with estimates from counting fences, Simpson (1984) found an average of 45% (range of 17.1% to 167.6%) overestimation of pink salmon population numbers by mark-recapture methods. In all of the cases considered, mark-recapture methods overestimated the true population size (counting fence value) of adult pink salmon spawning migrants (Simpson 1984). The 1987 mark-recapture estimate of 3,224,000 pink salmon in the Fraser River may also be an overestimate, but the magnitude of error is presently difficult to determine. To improve the future monitoring and management of this stock, it is important to resolve the discrepancies in estimates of pink salmon escapement obtained by mark-recapture versus acoustic methods.

The mobile sampling program at Haney estimated a lower pink salmon population size (total number = 650,000) than the combined fixed arrays and mobile transect values (total number = 970,000) for Mission (Figure 10). This difference probably resulted from the different acoustic sampling methodologies applied at the two sites. An estimate of the pink salmon population at Mission was generated from the center mobile data set alone, by extrapolating the center mobile values over the 168 m shore zone covered by the fixed-aspect arrays (Figure 2) and assuming a uniform horizontal distribution of pink salmon across the river. These assumptions permit direct comparison of the Mission results with those obtained at Haney: the estimate of 750,000 pink salmon at Mission is in reasonable agreement with the 650,000 figure obtained at Haney. The fixed-aspect arrays were apparently more effective in sampling near-shore areas where pink salmon densities were highest.

Pink salmon during the present study showed evidence of crepuscular (dawn and dusk) timing in their upstream migration, measured in terms of both the fish numbers and the upstream migration percentage over the diel cycle. Although migrating salmonids frequently undertake directed migrations during crepuscular periods (Johnson and Groot 1963; Groot 1965), the significance of a pulsed migration of pink salmon (particularly during late-afternoon/dusk periods) for both navigation purposes and migration energetics is unclear. In addition to diel effects, there was probably an effect of tidal stage on pink salmon passage within the Fraser River. In the lower reaches of the Fraser River, which are strongly affected by tidal fluctuations, radio-tagged pink salmon migrated more rapidly on flood tides than on ebb tides (2.1 km/h versus 1.7 km/h) due to lower opposing water velocities (Harder et al. MS 1987). Tidal effects were not considered by the present study.

In spite of the observed concentration of pink salmon in the near-shore zone at Mission (49% of the pink salmon population was enumerated by the two fixed-aspect arrays which covered 34% of the river width), a large fraction (51%) of the population migrated in the center (66% of the river width) portion of the river. Any enumeration or monitoring system for pink salmon must therefore cover the entire width of the river. In future enumerations of pink salmon in the Fraser River, it would be desirable to allocate sampling effort in proportion to the observed (1987) distribution patterns, namely, 50% of effort allocated to the two shore zones and 50% to the center section. Sampling (acoustic or otherwise) should also be undertaken according to a stratified random design (Jolly and Hampton 1990) so as to permit unbiased estimates of variance in the numerical estimates. For a fixed-aspect system, random assignment of transducer sampling times would generate statistically independent observations. Because of known diel effects, temporal sampling strata should be defined (i.e., day period, night period, dawn period, dusk period). Measurement of the variability in the pink salmon population estimates (standard deviation, 95% confidence interval) could then be incorporated into future enumeration programs.

The present study indicates that pink salmon in the Fraser River can be enumerated acoustically with either bottom- or surface-deployed transducers. Pink salmon concentrate in middle depths of the riverine water column, minimizing boundary interference problems. During 1987, differences were observed in the mean depth position of the fish (Figure 13), depending upon the location across the river. The observed variation in depth distribution across the river suggests that pink salmon might orient towards the river bottom during upstream migration (i.e., maintain a fixed distance above the bottom substrate).

If a complete fixed-aspect array was established across the river (e.g., Levy et al. 1991; Nealson and Murphy MS 1987), the concentration of pink salmon in shallow near-shore areas could be sampled more effectively by a shift in multiplexing strategy. Rather than programming the multiplexer to sample every transducer across the river on a fixed schedule, sampling could be intensified in shallow areas by more frequent interrogation of the near-shore transducers. Moreover, if sampling was scheduled at random (within pre-determined temporal and spatial strata), this would improve the statistical properties of the observations.

Optimal transducer orientation for enumerating migrant pink adults should be ascertained during any future fixed-aspect work from Mission Bridge support structures. In 1986, transducers were oriented across the river current, facing slightly (60° or 330° to the river current) upstream (Levy et al. 1991; Nealson and Murphy MS 1987). To improve the signal-to-noise ratio, it may be preferable to orient transducers slightly downstream (150° or 210° to the river current) during future deployments. Transducers should be aimed in a direction which minimizes the complication of pink salmon holding adjacent to or moving erratically in the vicinity of the bridge structures. If necessary, transducer extension mounts could be fashioned to physically move the transducers away from areas where pink salmon congregate and hold in the river.

The requirement for real-time monitoring of Fraser River pink and sockeye runs (millions of fish) necessitates the use of remote sampling technology to provide the desired numerical information. Acoustic methods provide the most cost-effective technology at the present time and are evolving rapidly. Additional field trials would be desirable to refine acoustic estimation procedures for Fraser River pink salmon and to determine their accuracy compared to mark-recapture estimation procedures.

RECOMMENDATIONS

1. Until the discrepancy is resolved between pink salmon numerical estimates from the acoustic enumeration program at Mission and the mark-recapture estimates from the spawning grounds, acoustic enumeration results for pink salmon in the Fraser River should be interpreted with caution and viewed as a relative index of pink salmon escapement.

2. Future acoustic enumerations of pink salmon would be operationally-simplified by using a single fixed-aspect (downlooking) array across the entire Fraser River.

3. The Mission Railway Bridge provides a convenient structure from which to deploy surface, downlooking transducers to enumerate pink salmon in the Fraser River. Transducer deployment should be critically evaluated in future in order to minimize complications imposed by adults holding in the vicinity of the bridge support structures. If necessary, transducer extension mounts should be fashioned to move transducers away from locations where pink salmon migrate upstream erratically.

4. Results in 1987 confirmed a partial shore orientation of adult pink salmon in the Fraser River. In future acoustic enumeration work, near-shore transducers should be sampled more frequently than mid-channel transducers, to optimize the allocation of sampling effort.

5. Additional effort is warranted to gain a better understanding of pink salmon migration behavior in the mainstem Fraser River, particularly adjacent to the acoustic enumeration site. Telemetric methods may provide a useful complement to future acoustic enumeration programs.

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