Hydroacoustic Monitoring of Fish Movement in Clifton Court Forebay Outlet Channel June 1–4, 1988

by

Barry Collins, Robert Kano, Marty Gingras, and Robert Fujimura
California Department of Fish and Game

Technical Report 60

May 2002

The Interagency Ecological Program for the Sacramento–San Joaquin Estuary

A cooperative program of the

California Department of Water Resources
State Water Resources Control Board
US Bureau of Reclamation
US Army Corps of Engineers
California Department of Fish and Game
US Fish and Wildlife Service
US Geological Survey
US Environmental Protection Agency

National Marine Fisheries Service

Contents

List of Figures

List of Tables

Hydroacoustic Monitoring of Fish Movement in Clifton Court Forebay Outlet Channel June 1-4, 1988

Barry Collins, Robert Kano, Marty Gingras, and Robert Fujimura
California Department of Fish and Game

Abstract

In June 1988, a fixed-location hydroacoustic system was used to measure the flux of juvenile and small fish in the outlet channel at Clifton Court Forebay and to document their horizontal, vertical, and diel distributions. The effectiveness of the hydroacoustic equipment and their transducer array were also evaluated. The results suggest that hydroacoustic monitoring could be used to estimate prescreeen loss at Clifton Court Forebay. Fish behavior in the outlet channel show that fish exhibit more milling behavior near the trashboom than away from this structure. Diel fish distribution suggests that both surface- and bottom-oriented transducers should be used in future hydroacoustic monitoring programs in the outlet channel. The results also suggest that the State Water Project could modify operations to benefit fisheries using hydroacoustic monitoring to measure the abundance and distribution of fish in the Sacramento-San Joaquin Delta.

Introduction

Water diverted by the State Water Project's Harvey O. Banks Delta Pumping Plant entrains large numbers of fish from the Sacramento-San Joaquin Delta (Delta) into the California Aqueduct system. This entrainment has a substantial impact on fisheries in the Delta. At the discretion of the State Water Project operators, water from Old River is drafted into Clifton Court Forebay, a tidally filled impoundment (1,833 acres), through a series of radial gates (Figure 1). Water from Clifton Court Forebay is pumped into the California Aqueduct. The John E. Skinner Delta Fish Protective Facility (Skinner Fish Facility) salvages some fish from the export flow and returns them by truck to the Delta.

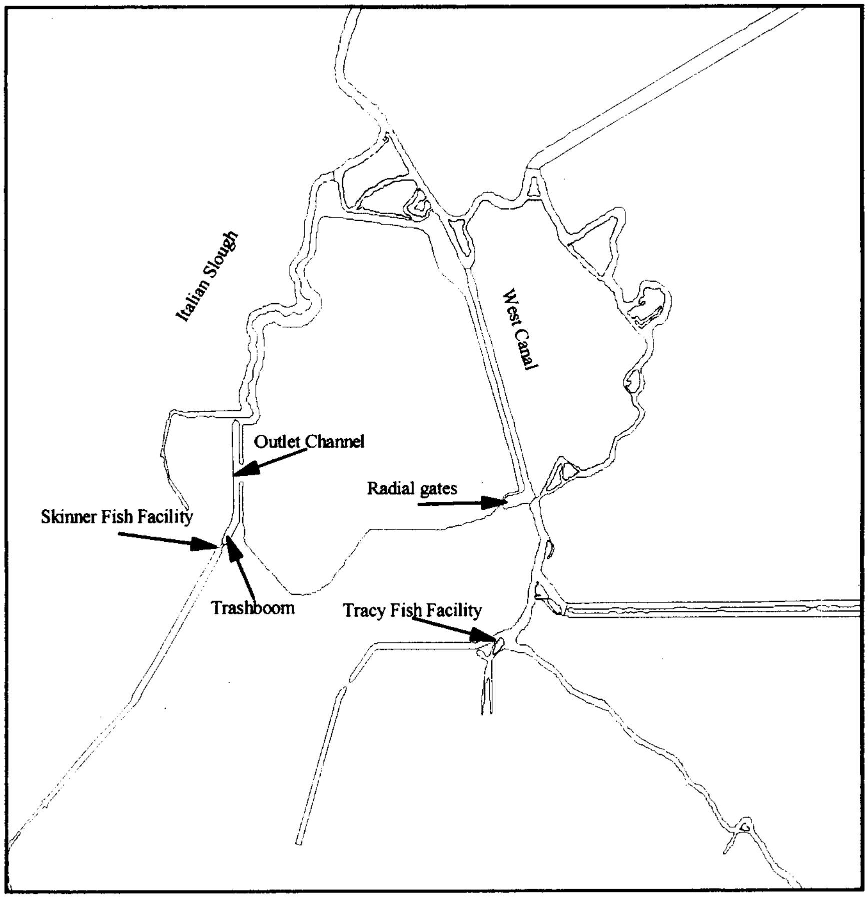


Figure 1 Location of structures around Clifton Court Forebay

The Skinner Fish Facility uses behavioral barriers (louvers) designed to guide fish into the collection facilities. Louver efficiency varies by fish species, fish size, and water velocity (DWR and DFG 1973). Fish passing through the louvers are considered lost from the Delta. Entrained fish are also lost in Clifton Court Forebay during movement from the radial gates to the louvers. This latter loss is called prescreen loss. Prescreen loss is considered the largest source of loss of entrained fish. Predation by subadult and adult striped bass is attributed to much of the prescreen loss (Kano 1990).

Estimates of prescreen loss using mark-recapture methods are subject to a number of potential biases and their accuracy has been questioned (Gingras 1997). DFG and the IEP proposed using hydroacoustic monitoring of fish entrainment and escapement from Clifton Court Forebay as a way to estimate prescreen loss and to measure entrainment directly upstream of the Clifton Court Forebay radial gates (IESP 1991).

A common method of hydroacoustic monitoring is by fixed-aspect sampling. The fixed-aspect technique involves stationary positioning of one or more stationary transducers in specific areas where fish passage is of interest. Information obtained from such systems includes fish distribution, direction and rates of movement, total passage, and (depending on the type of hydroacoustic system used) fish size. Fixed-aspect hydroacoustic techniques have been used to enumerate and monitor fish movement:

1. near turbine intakes and spillways of dams;

   Carlson 1981, 1982
   Johnson and others 1992
   Raemhild and others 1985
   Ranson and Steig 1994
   Skalski and others 1993
   Stansell and others 1991

2. in rivers;

   Banneheka and others 1995
   BioSonics 1981
   Burczynski 1991
   Hendershot and others 1984
   Johnson and others 1985
   Mulligan and Kieser 1986
   San Luis and Delta-Mendota Water Authority and Hansen 1996

3. at diversions;

   Mueller and others 1992
   Ransom and Nealson 1993

4. and at fish-attracting devices

   Thorne and others 1989.

Fixed-aspect hydroacoustic monitoring of fish passage in the outlet channel at Clifton Court Forebay was conducted in June 1988. There were two objectives to the study: (1) to investigate the utility and appropriate configuration for fixed-aspect deployment of hydroacoustic equipment used to estimate the flux of juvenile and small fish in the outlet channel at Clifton Court Forebay, and (2) to document the horizontal, vertical, and diel distribution of fish in the outlet channel at Clifton Court Forebay.

Hydroacoustic monitoring programs are typically conducted in parallel with a low-effort, active monitoring program (for example, trawls, seines). By providing species composition and length distribution information, active fish collection verifies the operational assumptions of hydroacoustic monitoring and allows better interpretation of the results. In place of active monitoring by trawl or seine, salvage data from the Skinner Fish Facility provided general species composition and length distribution information of fish moving through the outlet channel. Direct correlation of fish species and length information cannot be assumed because of salvage inefficiencies, louver or predator selectivity, and target strength variability.

Methods

Skinner Fish Facility Sampling

DFG biologists sampled fish salvaged at the Skinner Fish Facility to compare with targets detected by the hydroacoustic system. Timing of samples taken from the holding tanks corresponded to the periods of hydroacoustic monitoring in the outlet channel. Roughly every two hours, fish were subsampled, identified, counted, and measured. A second count was made for the total number of fish collected during a known sampling period (7 to 15 minutes). For more detailed information about Skinner Fish Facility operation and estimating salvaged fish, see McEwan and Collins (1990).

Equipment Setup

The hydroacoustic data acquisition system (Figure 2) included an echosounder, a multiplexer/equalizer, an oscilloscope, two chart recorders, and a group of five single-beam transducers. All equipment, except the oscilloscope, was designed and manufactured by BioSonics, Inc.

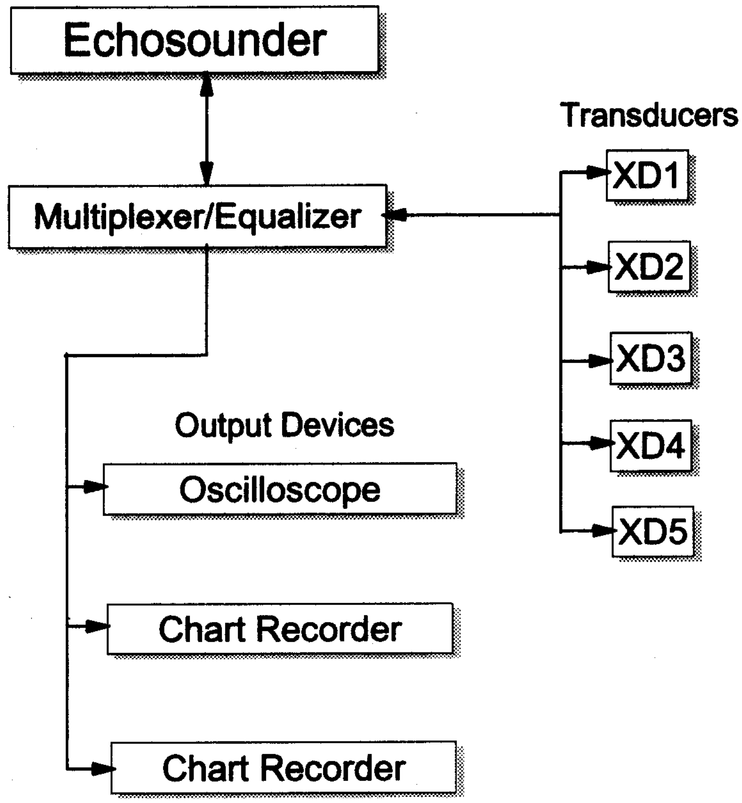


Figure 2 Block diagram of hydroacoustic system used to monitor fish movement in Clifton Court Forebay outlet channel

The 420 kHz echosounder (Model 102) generated 0.4 millisecond (ms) electrical pulses at 1000 watts, which were converted by the transducer into sound energy and transmitted through the water. Sound energy encountering a target was reflected back to the transducer and was converted into electrical energy (signal). The returned signal was amplified by the echosounder using a time-varied gain to compensate for energy losses from spreading and attenuation from the target to the transducer (Appendix A, Table 1).

A 16-channel multiplexer/equalizer (Model 151) controlled the rate of pulse transmission and the duration and sequence in which the echosounder transmitted pulses to and received signals from (interrogated) the transducers. Pulses were triggered at 0.1-s intervals (ten pings per second) during the fast multiplexing sequence used for the bottom-mounted transducers and at 0.05-s intervals (20 pings per second) during the normal multiplexing sequence used for the surface-mounted transducer. Transducers were interrogated individually or in pairs (fast multiplexing).

Single-beam transducers were attached to the multiplexer/equalizer ports (X1, X2, X3, X4, and X5) as shown in Figure 3. The multiplexer/equalizer *sequence programming* establishes the order that the ports are interrogated and the length of each interrogation. This program works with the multiplexer/equalizer's *equalization programming* (Appendix A, Table 2) and sets the amount of gain added to a signal received by a given port. These programs allow signals from all ports to produce the same voltage output from the same size target. Source levels and receiving sensitivities of the elliptical transducers were higher than those for the conical transducer. Less gain was added to the signal received from the elliptical transducer than to the signal received from the conical transducers. Equalization was calculated and programmed so that the voltage output from each transducer equaled 0.1 volts (-20 dB) for signals returned by a one-inch fish (dorsal aspect) on the acoustical axis (Appendix A, Table 3).

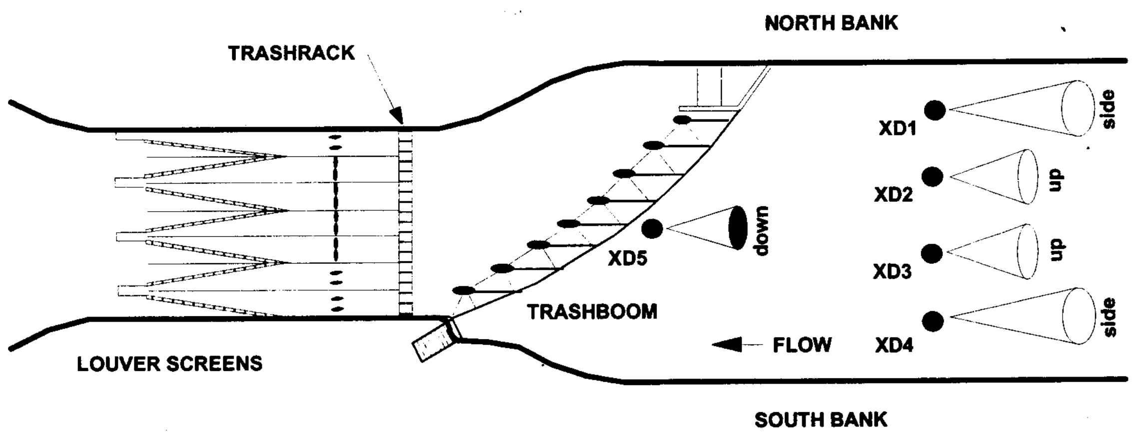


Figure 3 Diagram of transducer sites used to monitor fish movement in Clifton Court Forebay

The oscilloscope (Hitachi, Model V423) and thermal chart recorders (Model 111) displayed returned signals output by the hydroacoustic system. While the oscilloscope permitted visual inspection of the signals, the chart recorders produced permanent records on paper (echograms) to be used for data reduction and analysis. Chart recorder printing thresholds were set to record signals that exceeded 0.1 volts (Appendix A, Table 4). Other data included on the echograms were time of sample, multiplexer sequencing, and the range that the signals were received.

Transducer Deployment

A group of circular-beam and elliptical-beam transducers were deployed across the 250-foot width of the outlet channel between 500 and 600 feet upstream of the Skinner Fish Facility louver array (Figure 3). The transducers were placed to monitor three cross-sectional areas (REGIONS) of the channel. Three circular transducers with 15-degree nominal beam widths sampled the midchannel area (REGION = 3). Two circular transducers (XD2 and XD3) were placed at the bottom of the channel and upstream of the trashboom. One surface-mounted transducer (XD5) was mounted on the trashboom. Water depth was about 24 ft at the site of the upstream transducers and about 30 ft at the trashboom.

Two elliptical transducers (XD1 and XD4), each having minor and major-axis beam widths of 6° and 12°, respectively, were used in the nearshore areas. These transducers were positioned at the bottom on either side of the channel. Water depth was about 16 ft at these locations. REGION = 1 was monitored using transducer XD1 that was about 60 ft from the north bank of the channel. REGION = 1 was monitored using transducer XD1 positioned about 60 ft from the north bank of the channel. REGION = 1 extended about 65 ft from shore. Conversely, REGION = 2 was covered by transducer XD4 positioned about 60 ft from the south bank of the channel. REGION = 2 extended about 65 ft from the shore.

The bottom-mounted transducers were individually mounted on concrete pads and arranged across the channel about 60 ft apart. The transducers' beams were directed upstream and toward the water surface. Circular transducers (XD2 and XD3) were oriented so that their beam axes were angled 20° from vertical (0° = straight up, Figure 4).

The remaining circular transducer (XD5) was attached to the Skinner Fish Facility trashboom. It was mounted about 2.0 ft below the surface, with its beam directed toward the bottom and upstream. Orientation of its beam axis was 170° from vertical (Figure 4). The elliptical transducers (XD1 and XD4) were oriented approximately 80° from vertical, with their minor axes oriented perpendicular to the bottom (Figure 5). The intent was to aim the beams directly into the path of fish moving downstream (toward the louvers).

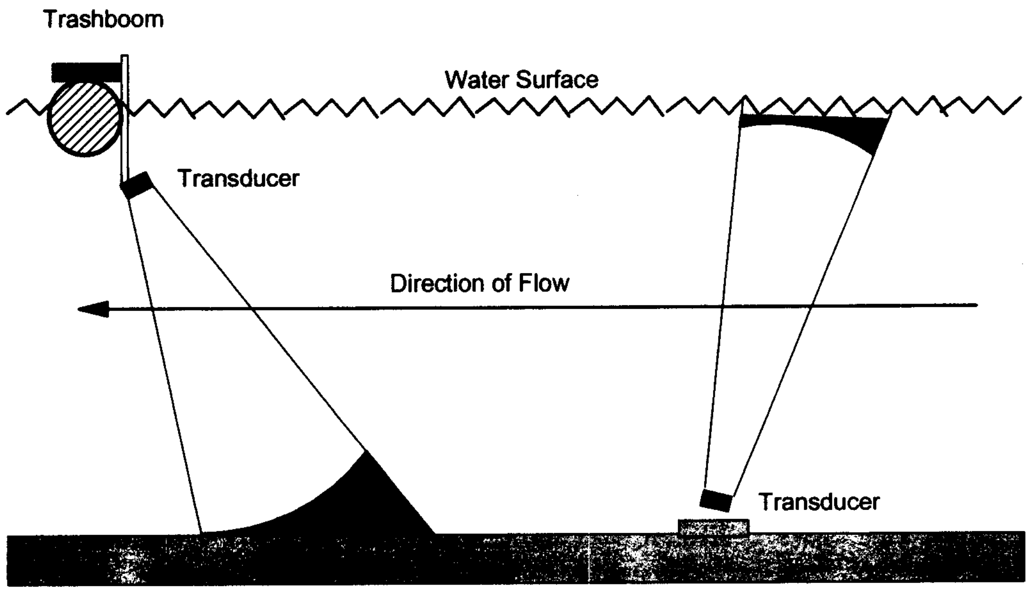


Figure 4 Orientation of bottom-mounted transducers (XD2 and XD3) and surface-mounted transducer (XD5) used to monitor fish movement in the Clifton Court Forebay outlet channel. Shaded regions show potentially undersampled volumes.

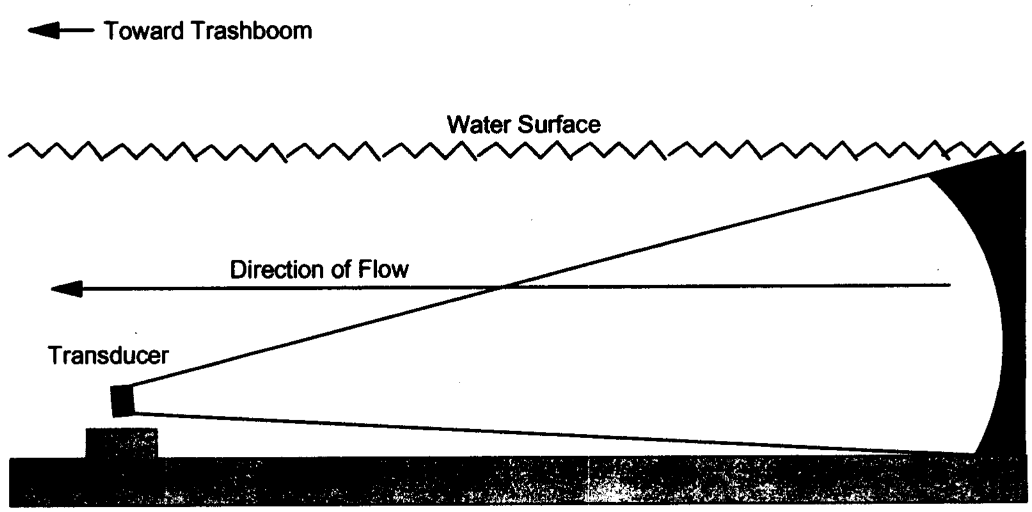


Figure 5 Orientation of bottom-mounted transducers (XD1 and XD4) used to monitor fish movement in the Clifton Court Forebay outlet channel. Shaded regions indicate potentially undersampled volumes.

Hydroacoustic Monitoring

Monitoring occurred from 0500 to 1000 hrs (PERIOD = 1) and from 2000 to 0100 hrs (PERIOD = 2) from June 1 through 4, 1988 (DAY = 1, 2 and 3, respectively). Transducers operated for three, one-hour intervals and ten, one-minute intervals during each period. During the morning, transducers began sampling at 0500, 0700, and 0900 hrs (SAMPLE = 1, 2, and 3, respectively). During the evening, transducers started monitoring at 2000, 2200, and 2400 hrs (SAMPLE = 1, 2, and 3, respectively). Each bottom-mounted transducer was operated for a total of 30 minutes and the surface-mounted transducer was operated for ten minutes. Pairs of bottom-mounted transducers (a circular and an elliptical-beam transducer) were operated twice hourly using fast multiplexing (Appendix A, Table 5); each monitoring interval lasted 15 minutes. The surface transducer was operated individually during a single ten-minute interval.

Digitizing Echograms

Data processing involved identifying fish target traces on echograms and transcribing them into an ASCII data file using a digitizing tablet (Summagraphics Bitpad Two) and a digitizing program (DIGISTOR, BioSonics, Inc.). The ASCII data file with digitized echogram data was imported into a statistical analysis program for further data reduction and analysis.

Data Analysis

Skinner Fish Facility salvage collection data were used to determine fish salvage rates (fish per minute). Salvage rates are calculated by dividing the number of fish collected in holding tanks by the duration of the sampling period. The salvage rate is then multiplied by the duration of pumping (export by the Banks Pumping Plant) since the last sample was taken to calculate the number of fish salvaged during that period.

To compare salvage rates at the Skinner Fish Facility with passage rates estimated from hydroacoustic monitoring in the outlet channel, salvage rates for fish >1 inch were calculated. Since striped bass were the most abundant fish encountered, the number of striped bass >1 inch in each sample was calculated separately from all other species combined. The number of striped bass >1 inch and the number of all other fish >1 inch in each sample were then added and divided by the duration of the sample to estimate salvage rates for fish >1 inch.

Target weighting factors were an important facet of data analysis for this hydroacoustic survey (Appendix B). These factors were used to measure vertical and horizontal fish distributions and to estimate flux (fish/ft^2/min). Since the acoustic beam has a conical dispersion pattern, the area or volume of water sampled increases with distance from the transducer. The weighting factors adjust the observed target counts to account for this increasing sampling power. Vertical and horizontal distributions of fish in the outlet channel were calculated by summing the weighted fish detections from XD3 and XD5. Transducer XD3 was bottom-mounted and used primarily to sample fish in the upper half of the water column, while transducer XD5 was surface-mounted and used primarily to sample fish in the lower half of the water column.

Flux may be calculated by assuming that all the fish detected are entrained to the fish screens. However, since the transducers were deployed upstream of the Skinner Fish Facility louvers in an open water habitat, it could not be assumed that all fish detected were passing toward the louvers. To determine the general direction of fish movement, bottom- and surface-mounted transducers were aimed at an angle to the surface and at an angle relative to entrained fish movement. Flux was based on targets with trace types showing movement toward the screens (Appendix C).

A *flux factor* was calculated for each fish trace that indicated movement toward the louvers. The flux factor is the target weighing factor divided by the sampling interval. Flux at each depth interval is the sum of the flux factors for all the targets in that depth interval divided by the depth interval. Estimated numbers of fish passing through cross-sectional areas of the channel during the sampling period are the product of flux multiplied by the sample area and the time interval.

Outlet channel passage rates (fish per minute) were calculated for each hydroacoustic sampling sequence from flux estimates of fish moving toward the louvers and from approximate cross-sectional areas for three regions along the channel transect upstream of the trashboom (Figure 6; Appendix A, Tables 6 and 7). Flux in REGION = 1 was estimated from data gathered from transducer XD1 and based on a cross-sectional area of 57 yd^2. Flux in REGION = 2 was measured using transducer XD4 with a monitoring area about 53 yd^2. REGION = 3 encompassed the mid-channel with an area of about 322 yd^2. Flux in the upper half of the water column of REGION = 3 was estimated from transducer XD3, while flux in the lower half of the water column was estimated from transducer XD5. The overall flux in REGION = 3 was calculated as the mean of these two rates. Overall outlet channel passage rates were determined by summing the passage rates from the three regions.

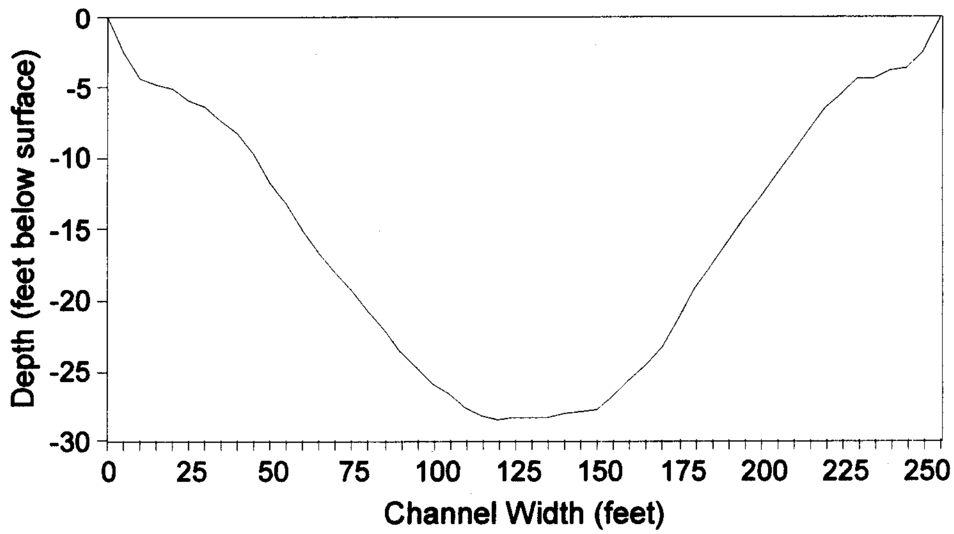


Figure 6 Cross-section of the Clifton Court Forebay outlet channel. X-axis origin is at north shore. Cross-section is vertically exaggerated.

Results

Relative Abundance

Striped bass were the most common fish salvaged at the Skinner Fish Facility during the study period. The mean relative abundance of striped bass was 78.0% (Tables 1, 2, and 3). The next most common species were prickly sculpin (6.7%), longfin smelt (4.5%), delta smelt (4.5%), chinook salmon (3.2%), and white catfish (2.1%). Although the overall composition of yellowfin goby and splittail were less than or equal to 1%, some holding tank samples exceeded this percentage. The relative abundances of other species observed were always less than 1%.

Length-Frequency Distributions

Of the 12,359 fish salvaged and measured at the Skinner Fish Facility, 10,555 were striped bass (Table 4). Most striped bass (93.5%) were young-of-the-year (YOY), and 85.9% were ≤ 1 inch. For all species combined, 9,138 fish or 73.9% were ≤ 1 inch. About 14% of YOY striped bass were fish >1 inch.

Salvage Rates

Comparison of the overall salvage rates and salvage rates for fish >1 inch covary very well (Figure 7). The correlation coefficient (*r*) for the estimated salvage rates for all fish with the rate of fish >1 inch is 0.92.

Table 1 Relative abundance and total catch from samples taken at Skinner Fish Facility, June 1 and 2, 1988[a]

	Sampling Time (hours)					
Species	*0500*	*0710*	*0900*	*2000*	*2200*	*0000*
Striped Bass	77.74	56.78	89.80	83.41	82.20	91.16
Prickly Sculpin	8.80	19.05	0.45	3.69	10.24	4.96
Longfin Smelt	4.85	6.96	4.08	3.23	1.22	0.56
Chinook Salmon	2.87	5.13	1.59	3.69	1.10	0.77
Delta Smelt	0.54	5.13	1.36	1.84	2.07	0.20
White Catfish	0.54	3.66	1.13	3.23	1.22	0.66
Yellowfin Goby	2.15	1.10	0	0.46	1.22	1.28
Splittail	0.72	1.10	0.45	0.46	0.37	0.15
Bigscale Logperch	0.36	0.37	0.91	0	0	0
Shimofuri Goby	0.18	0	0	0	0	0.05
Tule Perch	0.18	0	0.23	0	0.12	0.05
Threadfin Shad	0.18	0.37	0	0	0	0.05
American Shad	0.18	0	0	0	0	0
Steelhead	0	0.37	0	0	0	0
Mosquitofish	0	0	0	0	0	0.05
Bluegill	0.18	0	0	0	0	0
Starry Flounder	0.18	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0
Pacific Lamprey	0	0	0	0	0	0
Staghorn Sculpin	0.18	0	0	0	0	0
Black Crappie	0.18	0	0	0	0	0
Threespine Stickleback	0	0	0	0	0.12	0.05
Sacramento Sucker	0	0	0	0	0.12	0
Number of Species	17	11	9	8	11	13
Total Sample Catch	557	273	441	217	820	1956
Salvage Rate (fish/min)	55.7	27.3	29.4	43.4	82.0	195.6
Total Expanded Catch	6684	3549	3234	7812	9840	23472
Total Minutes Pumping	120	130	110	180	120	120
Length of Sample (min)	10	10	15	5	10	10

a. Species catch is reported as percent of total catch.

Table 2 Relative abundance and total catch from samples taken at Skinner Fish Facility, June 2 and 3, 1988[a]

	Sampling Time (hours)					
Species	*0525*	*0725*	*0925*	*2000*	*2200*	*0000*
Striped Bass	71.74	68.33	84.42	95.36	78.73	63.49
Prickly Sculpin	4.35	1.67	0.28	0.36	10.71	19.05
Longfin Smelt	9.29	10.00	5.95	1.39	4.35	3.17
Chinook Salmon	6.72	5.83	2.27	0.44	0.78	6.35
Delta Smelt	0.59	1.67	2.27	1.67	2.64	1.90
White Catfish	3.16	9.17	2.27	0.59	1.71	1.27
Yellowfin Goby	2.77	0	0	0.08	0.93	3.49
Splittail	0.79	3.33	0.57	0.03	0.16	0.95
Bigscale Logperch	0	0	0.57	0.03	0	0
Shimofuri Goby	0.20	0	0.85	0	0	0
Tule Perch	0	0	0	0.03	0	0
Threadfin Shad	0	0	0	0	0	0
American Shad	0.20	0	0	0	0	0
Steelhead	0	0	0.28	0	0	0
Mosquitofish	0	0	0	0	0	0
Bluegill	0	0	0.28	0	0	0
Starry Flounder	0	0	0	0	0	0
Channel Catfish	0.20	0	0	0	0	0
Pacific Lamprey	0	0	0	0	0	0.32
Staghorn Sculpin	0	0	0	0.03	0	0
Black Crappie	0	0	0	0	0	0
Threespine Stickleback	0	0	0	0	0	0
Sacramento Sucker	0	0	0	0	0	0
Number of Species	11	7	11	11	8	9
Total Sample Catch	506	120	353	3881	644	315
Salvage Rate (fish/min)	50.6	12.0	17.7	129.4	92.0	63.0
Total Expanded Catch	7337	1440	2118	23286	11040	7560
Total Minutes Pumping	145	120	120	180	120	120
Length of Sample (min)	10	10	20	30	7	5

a. Species catch is reported as percent of total catch.

Table 3 Relative abundance and total catch from samples taken at Skinner Fish Facility, June 3 and 4, 1988[a]

	Sampling time (hours)					
Species	*0500*	*0700*	*0900*	*2020*	*2150*	*0010*
Striped Bass	77.63	58.30	85.54	93.70	63.43	82.45
Prickly Sculpin	3.23	0.43	0	0.97	26.12	6.42
Longfin Smelt	6.74	7.66	5.54	2.18	1.49	2.26
Chinook Salmon	1.89	11.49	1.23	0.48	1.99	2.83
Delta Smelt	8.09	16.17	5.54	1.69	2.49	1.32
White Catfish	0.81	3.40	1.23	0.73	1.49	1.70
Yellowfin Goby	0.81	0	0	0	2.24	1.51
Splittail	0.27	0.43	0.62	0.24	0.50	0.38
Bigscale Logperch	0.27	0.85	0.31	0	0.25	0.38
Shimofuri Goby	0	0	0	0	0	0
Tule Perch	0	0.43	0	0	0	0.19
Threadfin Shad	0	0.43	0	0	0	0
American Shad	0	0	0	0	0	0.38
Steelhead	0	0	0	0	0	0
Mosquitofish	0	0.43	0	0	0	0
Bluegill	0	0	0	0	0	0
Starry Flounder	0.27	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0.19
Pacific Lamprey	0	0	0	0	0	0
Staghorn Sculpin	0	0	0	0	0	0
Black Crappie	0	0	0	0	0	0
Threespine Stickleback	0	0	0	0	0	0
Sacramento Sucker	0	0	0	0	0	0
Number of Species	10	11	7	7	9	12
Total Sample Catch	371	235	325	413	402	530
Salvage Rate (fish/min)	37.1	15.7	16.3	41.3	40.2	53.0
Total Expanded Catch	2226	1880	1950	8260	3618	7420
Total Minutes Pumping	60	120	120	200	90	140
Length of Sample (min)	10	15	20	10	10	10

a. Species catch is reported as percent of total catch.

Table 4 Length-frequency distribution by species and total catch and relative abundance from Skinner Fish Facility holding tank samples, June 1–4, 1988

	Number of Fish in Length Interval Endpoint of Interval (inches)																			
Species	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*8.0*	*9.0*	*10.0*	*11.0*	*12.0*	*13.0*	*14.0*	*15.0*	*16.0*	*>16.0*	*Cum. total*	*% total*	*Total*
Striped Bass	9065	806	0	24	318	147	49	122	0	24	0	0	0	0	0	0	0	10555	85.40	85.4
Prickly Sculpin	31	578	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	616	4.98	90.4
Longfin Smelt	6	272	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	352	2.85	93.2
Delta Smelt	25	232	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	260	2.10	95.3
Chinook Salmon	0	0	7	195	20	0	0	0	0	0	0	0	0	0	0	0	0	222	1.80	97.1
White Catfish	0	0	4	6	17	45	45	17	10	4	3	1	1	0	0	1	0	154	1.25	98.4
Yellowfin Goby	2	71	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105	0.85	99.2
Splittail	0	13	5	1	0	0	0	0	7	0	2	2	4	5	1	0	0	40	0.32	99.6
Bigscale Logperch	6	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0.14	99.7
Tule Perch	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0.06	99.7
Threadfin Shad	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0.03	99.8
Black Crappie	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.03	99.8
American Shad	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	4	0.03	99.8
Shimofuri Goby	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.02	99.9
Starry Flounder	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.02	99.9
Bluegill	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0.02	99.9
Mosquitofish	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.02	99.9
Threespine Stickleback	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.02	99.9
Channel Catfish	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.02	100
Staghorn Sculpin	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0.02	100
Steelhead	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2	0.02	100
Pacific Lamprey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.01	100
Sacramento Sucker	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.01	100
Total	9138	1996	129	237	358	194	97	141	19	28	6	3	5	5	1	1	1	12359		
Percent Total	73.9	16.1	1.0	1.9	2.9	1.6	0.8	1.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0			

Table 5 Comparison of salvage rates for all fish and fish >1 inch at the Skinner Fish Facility and passage rates in the Clifton Court Forebay outlet channel with the pumping rate at the Banks Pumping Plant, June 1–4, 1988

		Salvage Rate (fish/min)				
Date	*Time (hours)*	*Pumping Rate (cfs)*	*All Fish*	*Fish >1 inch*	*Outlet Channel Passage Rate (fish/min)*	*Sample Number*
June 1	0100	4895	137.0	54.5	---	---
June 1	0300	4895	124.0	33.1	---	---
June 1	0500	4895	57.0	19.3	35.5	11.1
June 1	0800	4895	27.4	13.6	16.1	11.2
June 1	0900	2635	29.4	6.6	16.0	11.3
June 1	1300	2635	59.6	12.2	---	---
June 1	1700	2635	47.2	12.6	---	---
June 1	2000	2635	43.4	12.0	20.5	12.1
June 1	2200	2635	82.0	23.5	22.7	12.2
June 1	2400	4895	195.6	41.8	46.3	12.3
June 2	0100	6025	186.0	70.5	---	---
June 2	0300	6025	237.0	56.9	---	---
June 2	0500	6025	50.6	18.8	68.2	21.1
June 2	0800	6025	12.0	4.8	22.3	21.2
June 2	0900	2635	17.7	4.7	31.0	21.3
June 2	1100	2635	14.1	3.4	---	---
June 2	1300	2635	31.0	7.8	---	---
June 2	1500	2635	28.3	6.8	---	---
June 2	1700	2635	27.0	6.5	---	---
June 2	2000	2635	129.3	23.1	21.2	22.1
June 2	2200	2635	92.0	29.0	27.8	22.2
June 2	2400	6025	63.0	27.7	27.7	22.3
June 3	0200	6025	69.0	33.5	---	---
June 3	0400	6025	35.0	11.0	---	---
June 3	0500	6025	37.1	12.0	43.6	31.1
June 3	0800	6025	15.7	7.6	32.1	31.2
June 3	0900	2635	16.3	4.2	13.2	31.3
June 3	1100	2635	13.0	4.1	---	---
June 3	1300	2635	53.0	11.9	---	---
June 3	1500	2635	29.4	9.2	---	---
June 3	1700	2635	38.4	12.0	---	---
June 3	2000	2635	41.3	8.0	40.3	32.1
June 3	2200	2635	38.8	17.3	76.3	32.2
June 3	2400	6025	52.9	15.0	143.6	32.3
June 4	0200	6025	41.2	15.8	---	---
June 4	0400	6025	35.6	13.7	---	---
June 4	0600	6025	31.4	12.0	---	---
June 4	0800	6025	15.2	5.8	---	---
June 4	0900	0	0.0	0.0	---	---
June 4	2400	0	0.0	0.0	---	---

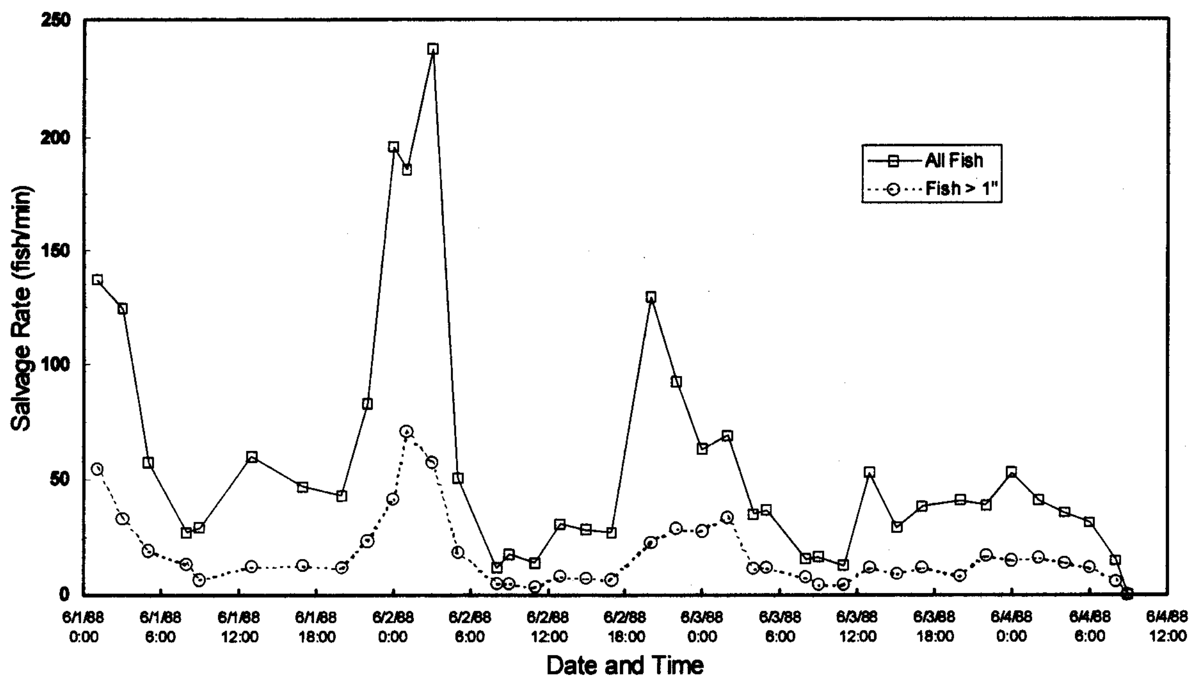


Figure 7 Skinner Fish Facility salvage rates for all fish and for fish >1 inch during program to monitor fish movement in the Clifton Court Forebay outlet channel

Fish Behavior, Distribution, and Outlet Channel Passage Rate

The percentage of fish detected moving toward the screens upstream of the trashboom (XD3) during PERIOD = 1 decreased from 90% at 0500 hours to 76% at 0900 hours (Figures 8 and 9), and was accompanied by an increase in the percentage of fish detected moving away from the screens, 8% at 0500 hours to 17% at 0900 hours. Wallowing or milling behavior also increased over this period: 1% at 0500 hours to 7% at 0900 hours.

The opposite behavior was observed at this location during PERIOD = 2. The percentage of fish detected moving toward the screens increased from 82% at 2000 hours to 98% at 2400 hours, while the percentage moving away from the screen decreased from 14% at 2000 hours to 1% at 2400 hours. The proportion of fish wallowing or milling also decreased: 4% at 2000 hours to 1% at 2400 hours.

The trashboom transducer (XD5) detected a similar pattern of movement as observed at XD3. During PERIOD = 1 the percentage of fish moving toward the screens did not appear to change: 62% at 0500 hours and 64% at 0900 hours (Figures 8 and 9). There was a slight increase in fish moving away from the screens between 0500 hours (13%) and 0700 hours (16%), but the percentage at 0900 hours (4%) was lower than at 0500 hours. Wallowing or milling behavior increased: 10% at 0500 hours to 25% at 0900 hours.

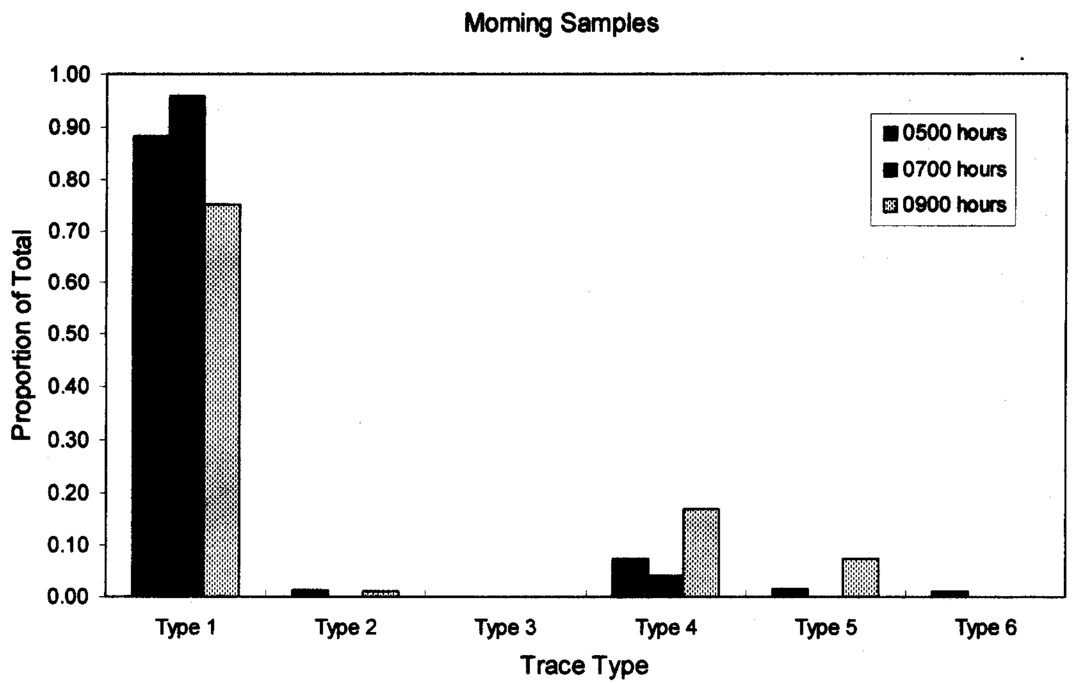
The percentage of fish observed at the trashboom site exhibiting a milling-type behavior was much higher than observed at the upstream location. Behavior during PERIOD = 2 at the trashboom location was also the same as that observed upstream. The percentage of fish detected moving toward the screens increased from 77% at 2000 hours to 96% at 2400 hours, while the percentage moving away from the screen decreased from 10% at 2000 hours to 0% at 2400 hours. Fish wallowing or milling decreased from 9% at 2000 hours to 1% at 2400 hours.

Due to the near-field effect (Appendix D), fish detected within the first five feet of XD5 and from 20 ft for XD3 were excluded from analysis. During the day, fish were more concentrated near the surface and bottom of the channel than throughout the mid-depths. At night fish adopted a more uniform distribution (Figure 10).

The outlet channel passage rate averaged 39.1 fish per minute for all samples. Passage rates during PERIOD = 1 ($\bar{x}$ = 30.9 fish/min) and PERIOD = 2 ($\bar{x}$ = 47.4 fish/min) were not significantly different (P = 0.25; Student's t-test). Passage rates generally decreased during PERIOD = 1 and increased in PERIOD = 2.

Relationship Between Passage Rates and Salvage Rate

Very little of the variance in the salvage rate of fish >1 inch was explained by outlet channel passage rate (r = 0.12). Changes in outlet channel passage rates had a weak positive correlation to changes in salvage rates. However, in 11 of 12 observations, the direction of change in a passage rate was the same as the direction of change in a salvage rate (Figure 12).



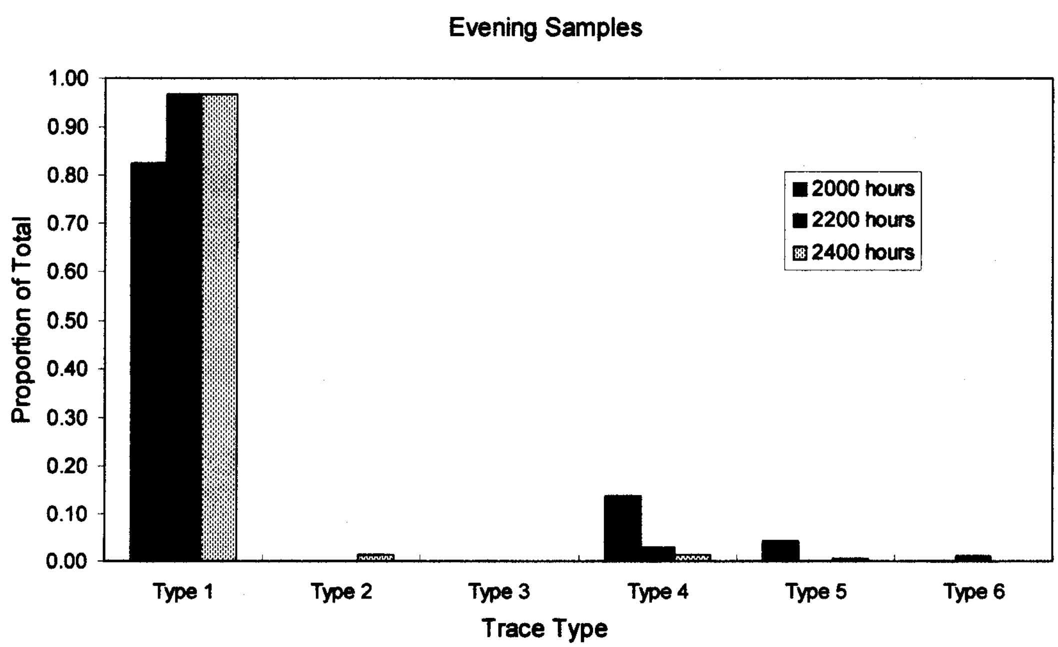
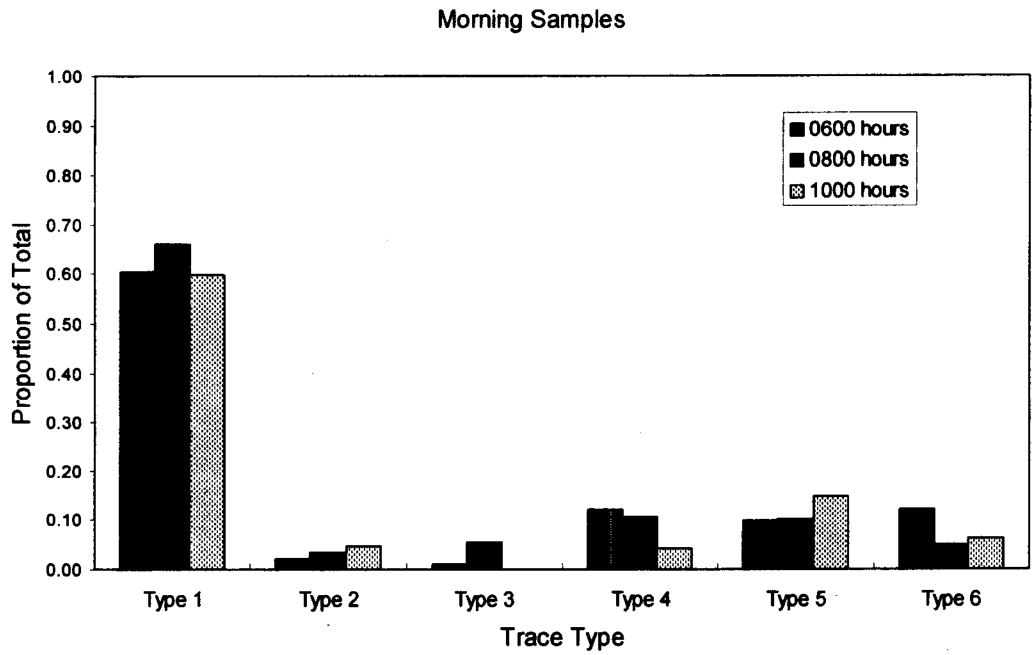


Figure 8 Proportion of fish trace types observed upstream of the trashboom (XD3), corrected by target weighing factor, during a fish monitoring program in the Clifton Court Forebay outlet channel for two daily periods. Types 1 and 2 = downstream movement; Types 3 and 4 = upstream movement; Type 5 = behavior unknown; and Type 6 = "wallowing" movement.



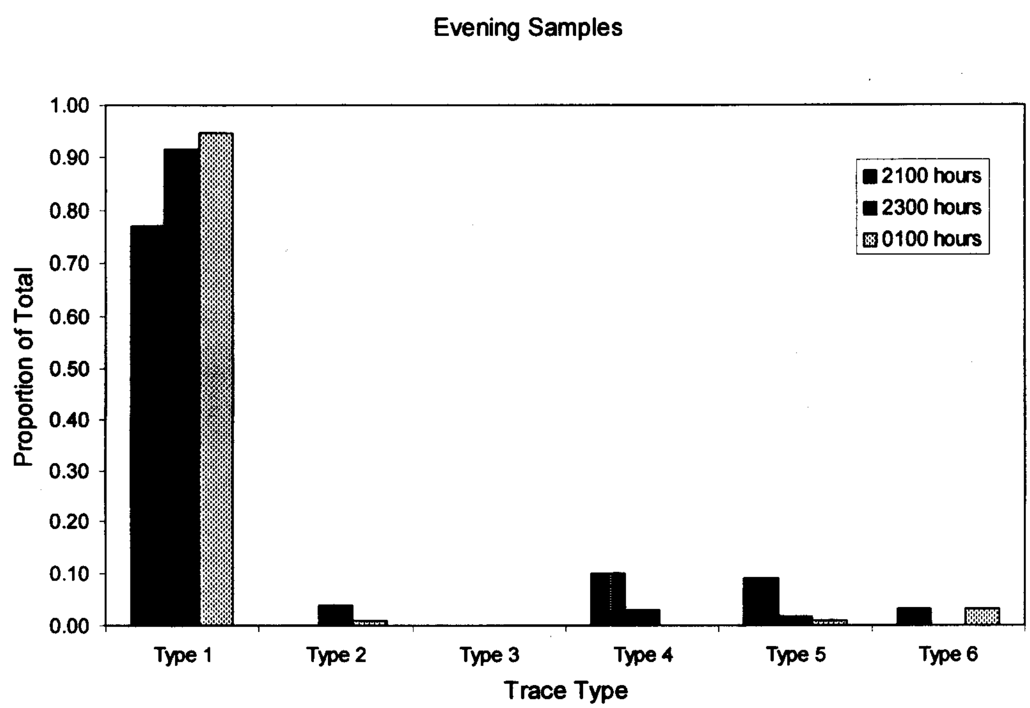


Figure 9 Proportion of fish trace types observed at the trashboom (XD5), corrected by target weighing factor, during a fish monitoring program in the Clifton Court Forebay outlet channel for two daily periods. Types 1 and 2 = downstream movement; Types 3 and 4 = upstream movement; Type 5 = behavior unknown; and Type 6 = "wallowing" movement.

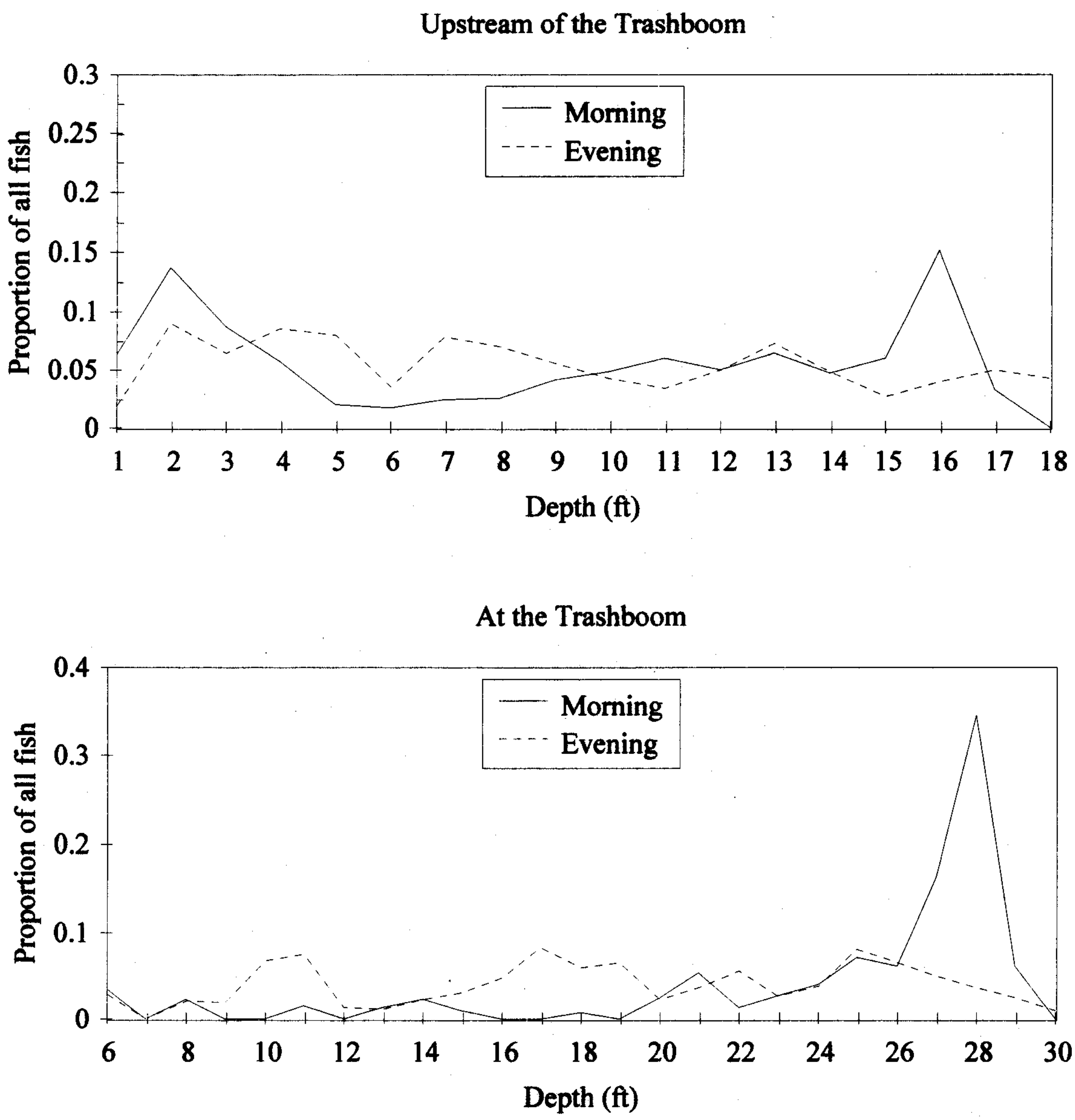


Figure 10 Vertical distribution of fish observed during a fish monitoring program for two locations of the Clifton Court Forebay outlet channel

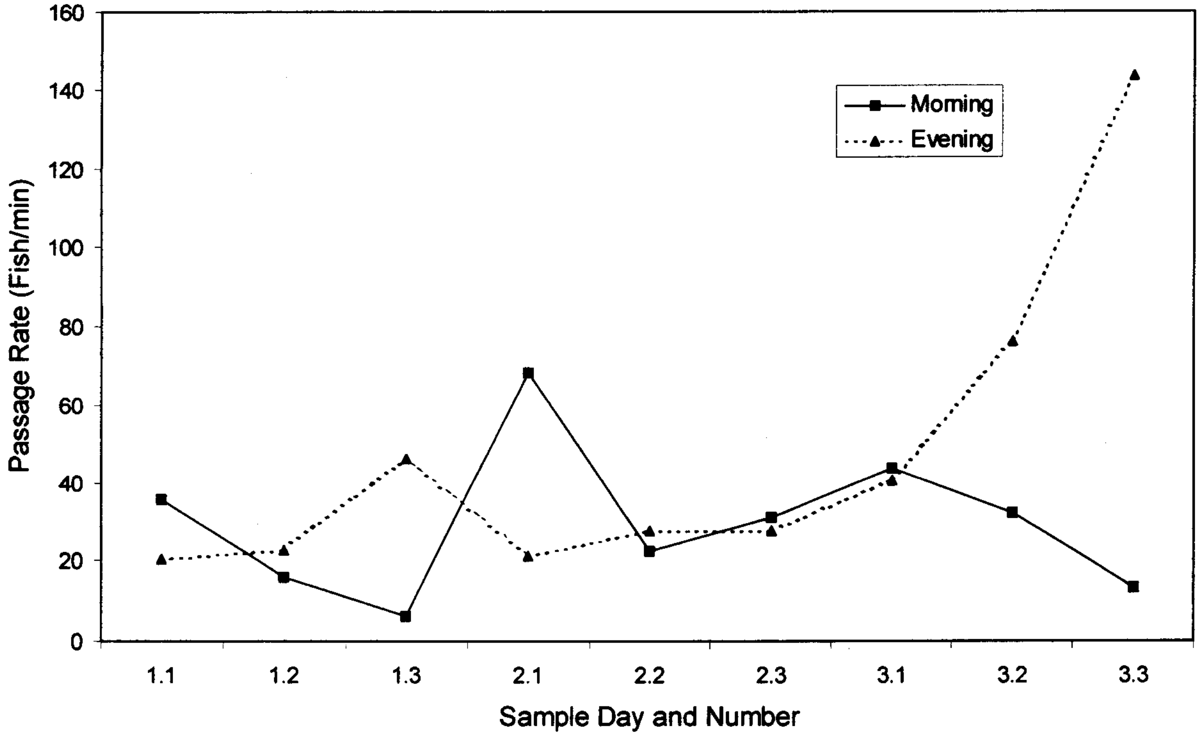


Figure 11 Trends in morning and evening passage rates as observed by XD1, XD3, and XD5 during a fish movement study in the Clifton Court Forebay outlet channel

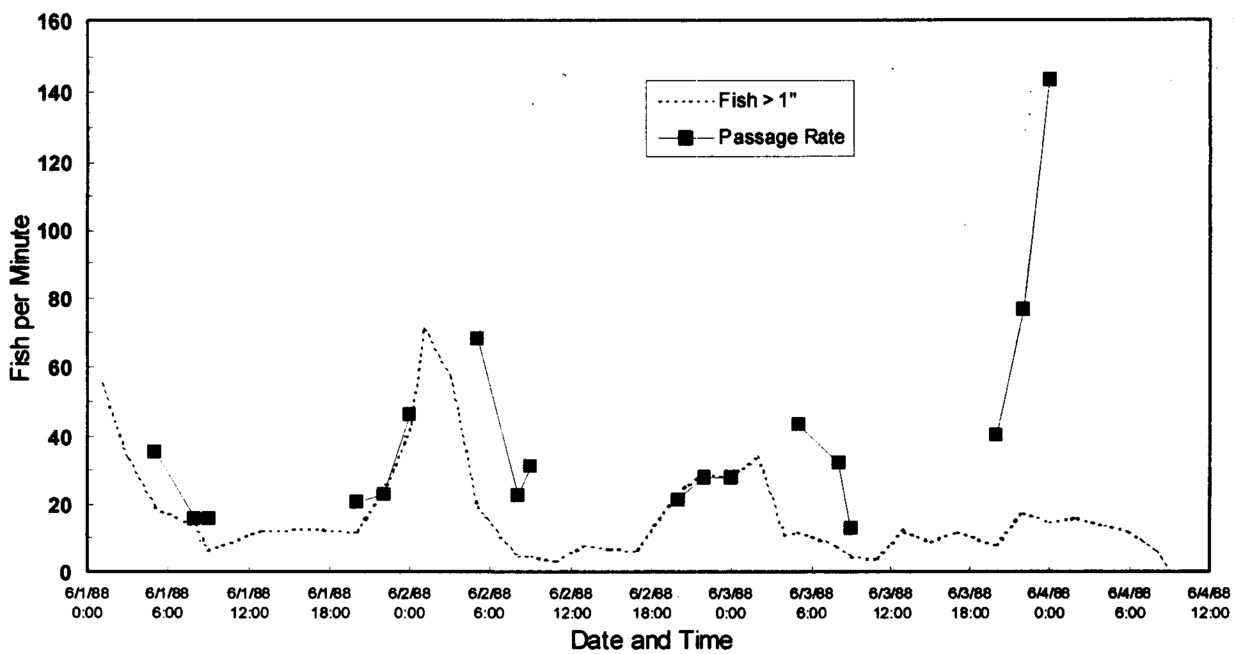


Figure 12 Trends in salvage rates of fish >1 inch and passage rate during a fish movement study in the Clifton Court Forebay outlet channel

Discussion

Implications of the Hydroacoustic Results

This study provides new information on fish behavior and distribution in the outlet channel. Results show that there was a moderate shift in vertical distribution related to the time of day. Fish appear to be more concentrated near the surface and bottom of the channel during daylight and are distributed more uniformly at night. This shows that both surface-mounted (down-looking) and bottom-mounted (up-looking) transducers should be used to measure fish passage rates in future hydroacoustic studies.

The corresponding changes in fish movement patterns are likely products of fish behavior and water export. Hydroacoustic analysis suggests that the proportion of fish moving toward the fish screens increases during the evening and decreases during the day. These results seem consistent with salvage data. The increase in pumping rate at 2000 hours generally results in an increase in salvage rate. Typically, an increase in salvage occurs within the first hour after increased pumping rate is initiated. Salvage rate usually peaks three to five hours later (at 0100 to 0300 hours) followed by a steady decrease until 0800 hours when the pumping rate drops and light conditions change. From direct observations, it appears that fish resist entering the fish screening bypasses during daylight. Salvage rate often increases at night, presumably because fish lose their visual cues. Increases in salvage rate also occur when the pumping rate is increased, overcoming a fish's ability to swim against the current for long periods.

The number of milling fish observed upstream of the trashboom was much less than at the trashboom. If net movement of fish toward the fish facility is a major objective, an upstream location is more suitable to count fish entrained into the fish screens because there is less chance of including milling fish in the sample.

Diel changes in behavioral patterns suggest that fish are able to swim against export flows and are abundant in the outlet channel. These fish probably include predator-sized (subadult) striped bass. A decrease in milling fish near the trashboom at night may suggest that these fish are large striped bass preying on smaller fish. Therefore, effective predator removal or exclusion may reduce prescreen loss in front of the primary louvers and the trashboom.

Limitations of the Hydroacoustic Equipment

Although the comparison of the hydroacoustic passage rates and the salvage rates does not provide a close linear relationship, our study results suggest that modern hydroacoustic sampling could provide more information on fish size and densities near fish facilities. Technological features of hydroacoustic monitoring systems have changed substantially since this study was conducted. Multibeam transducers have mostly replaced the single-beam transducers used in this study. Using multibeam transducers and the associated echo analysis software allows for accurate target size determinations (Traynor and Ehrenberg 1979). The size of detected fish can be estimated using established relationships between target size and fish size (Love 1977).

Target size is also used to establish sample volume. The poor relationship between actual salvage rate and outlet channel passage rate in this study is partly due to the exclusive use of single-beam transducers and inadequacies in establishing sample volumes. Errors in the transducer's sampling volume will affect the accuracy of the expansion factors and, therefore, the total abundance estimates obtained using these methods. If hydroacoustic methods are used to estimate fish passage rates, it will be essential to use the best available technology and operate it to minimize the errors associated with expansion factors. Interference from debris or entrained air bubbles, errors in expanding actual salvage counts to total salvage estimates, vagaries in entrained fish behavior, predation, and salvage efficiency at the Skinner Fish Facility may also confound the relationship.

Automated signal processing has eliminated the manual echogram digitization process and allows the use of many behavior and size criteria to discern fish from other targets. These modern systems reduce several potential biases and the time required for data reduction and analysis.

Future Use of Hydroacoustic Technology

This study and an earlier entrainment study where transducers were operated in Old River directly upstream of the Clifton Court Forebay radial gates (IESP 1991) show that hydroacoustic technology may be able to estimate prescreen loss. Standardizing the unit of sampling effort between stations and establishing appropriate expansion factors are the biggest problems in accurately estimating prescreen loss using hydroacoustics (or conventional fish-capture methods) to measure entrainment and escapement. The methods used in this study to calculate actual detections to total abundance (in other words, expansion factors) were probably inadequate for accurately estimating prescreen loss. Therefore, if hydroacoustic methods are used to estimate prescreen loss, it will be essential to use the best available technology to operate it to reduce the error associated with expansion factors.

The results of this study also suggest the State Water Project (SWP) may modify operations to benefit fisheries using information from hydroacoustic monitoring of fish abundance and distribution in the Sacramento-San Joaquin Delta.

An effective monitoring program must track a wide range of fish behaviors and provide abundance or passage rate estimates that correlate with salvage rates or patterns. This study showed changes that were expected in the vertical distribution of fish during day and night, since most fish species exhibit distinct diurnal movement (Gunderson 1993). This study also documented fish behavior in the outlet channel (for example, milling and fish movement relative to the screens) that was consistent with field observations at the Skinner Fish Facility. These findings are necessary for any real-time or near real-time effort to estimate fish passage to modify SWP operations to benefit fisheries.

At present, real-time monitoring of fish species composition and catch per unit effort are being conducted with active sampling throughout the Delta (Armor and others 1996) to provide similar information for SWP operators. The real-time monitoring program is costly and has shown limited results. Fish trawls sample less than one-third of the day and a small proportion of the water column, and is often constrained by take limits on endangered fish. Fixed-aspect hydroacoustic monitoring would be a feasible addition or an alternative to the real-time monitoring program. Hydroacoustic monitoring can be conducted continuously, samples a large portion of the water column, and would present no take liability. Active sampling required to obtain species composition information could be done at a reduced level of effort.

Automated signal processing would improve the timeliness of data presentation and allow real-time reporting. These attributes of modern hydroacoustic monitoring should allow us to track changes in the relative abundance and size distribution of fishes in Delta channels upstream of Clifton Court Forebay. Accurate abundance and size distribution data are very important to a real-time program so SWP operators can modify operations for fish protection.

Modern hydroacoustic systems using varying degrees of real-time analysis and reporting are already in use at several facilities, including some that are undergoing FERC relicensing. At the New York State Dam, a system using remote operation (via modems), robotics, and real-time analysis and reporting is used to protect blue-backed herring by automatically controlling spill based on patterns of fish density changes upstream of spillways (Thorne and Hedgepeth 1996). At the Dalles Dam, and previously at several dams on the Columbia River, a remotely operated hydroacoustic system with automated signal processing is being used to assess various experimental fish passage devices (Hedgepeth, personal communication, see "Notes"). In many applications, hydroacoustic monitoring is more cost effective, accomplishes fish management objectives that were not met by conventional sampling methods and has no impact on special status species (Thomas 1992).

References

Armor C, Winternitz L, Sweetnam D, Brandes P. 1996. 1995 Pilot Real-Time Monitoring Program: evaluation and recommendations. Interagency Ecological Program for the San Francisco/Delta Estuary. Technical Report 47. Sacramento (CA): California Department of Water Resources.

Banneheka SG, Routledge RD, Guthrie IC, Woodey JC. 1995. Estimation of in-river fish passage using a combination of transect and stationary hydroacoustic sampling. Can J Fish Aquat Sci 52(2):335–43.

BioSonics Inc. 1981. Feasibility study of the utility of hydroacoustic techniques to study fish in the Sacramento River. Unpublished manuscript.

Burczynski J. 1991. Hydroacoustic survey of fish distribution and reaction to dredge disposal activities in San Francisco Bay. Final Report. Seattle (WA): BioSonics, Inc.

Carlson TJ, Acker WC, Gaudet DM. 1981. Hydroacoustic assessment of downstream migrant salmon and steelhead at Priest Rapids Dam in 1980. Report nr. APL-UW 8016. Seattle (WA): University of Washington Applied Physics Laboratory.

Carlson TJ. 1982. Fixed aspect hydroacoustic techniques for estimating the abundance and distribution of downstream migrating juvenile salmon and steelhead at Columbia River hydropower dams. Seattle (WA): BioSonics, Inc.

[DWR and DFG] Department of Water Resources and Department of Fish and Game. 1973. Evaluation testing program for Delta Fish Protective Facility, State Water Project, California Aqueduct, North San Joaquin Division. Memorandum report. Available from DFG Fish Facilities Unit Project Files, 4001 N. Wilson Way, Stockton, CA 94205.

Gingras M. 1997. Mark-recapture experiments at Clifton Court Forebay to estimate pre-screening loss to entrained juvenile fishes: 1976-1993. Interagency Ecological Program for the San Francisco/Delta Estuary. Technical Report 55. Sacramento (CA): California Department of Water Resources.

Gunderson DR.1993. Surveys of fisheries resources. New York (NY): J Wiley.

Hendershot RG, Acker WC, Sullivan RD. 1984. Doppler techniques applied to fisheries hydroacoustics. Seattle (WA): BioSonics, Inc.

[IESP] Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. 1991. 1990 annual report. Sacramento (CA): California Department of Water Resources.

Johnson GE, Sullivan CM, Erho MW. 1992. Hydroacoustic studies for developing a smolt bypass system at Wells Dam. Fisheries Research 14:221-37.

Johnson GE, Skalski JR, Degan DJ. 1994. Statistical precision of hydroacoustic sampling of fish entrainment at hydroelectric facilities. North Am J Fish Manage 14:323-33.

Johnson L, Noyes C, Johnson G. 1982a. Hydroacoustic evaluation of the efficiency of the Ice Harbor Dam ice and trash sluiceway for passing downstream migrating juvenile salmon and steelhead. Final report. Seattle (WA): BioSonics, Inc.

Johnson L, Noyes C, Johnson G. 1982b. Hydroacoustic evaluation of the efficiency of the Ice Harbor Dam ice and trash sluiceway for passing downstream migrating juvenile salmon and steelhead, 1982. Report to U.S. Army Corps of Engineers, Walla Walla District. Vol. I. Seattle (WA): BioSonics, Inc.

Johnston SV, Gaudet DM, Skvorc P. 1985. The application of a dual-beam hydroacoustic system as a fish size classifier on the Kenai River, Alaska. Seattle (WA): BioSonics, Inc. and Alaska Department of Fish and Game.

Johnston SV, Ransom BH, Bohr JR. 1993. Comparison of hydroacoustic and net catch estimates of fish entrainment at Tower and Kleber dams, Black River, Michigan. Hydroacoustic Technology, Inc. Reprint from Waterpower '93.

Kano R. 1990. Occurrence and abundance of predator fish in Clifton Court Forebay, California. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 24. Sacramento (CA): California Department of Water Resources.

Love RH. 1977. Target strength of an individual fish at any aspect. J Acoustic Soc Am 62(6):1397-1403.

McEwan D, Collins B. 1990. Fish sampling at the J. E. Skinner Fish Facility. Final report prepared for the Department of Water Resources. Stockton (CA): California Department of the Fish and Game Bay-Delta Project.

Mueller G, Hiebert S, Walline P. 1992. Preliminary evaluation in the use of single-beam hydroacoustics at Tracy Fish Salvage Facility, California. U.S. Bureau of Reclamation and Israel Oceanographic and Limnological Research.

Mulligan TJ, Kieser R. 1986. Comparison of acoustic population estimates of salmon in a lake with a weir count. J Fish Res Board Can 43:1373-85.

Raemhild GA, Nason R, Hays S. 1985. Hydroacoustic studies of downstream migrating salmonids at hydropower dams: two case studies. Seattle (WA): BioSonics, Inc.

Ransom BH, Nealson PA. 1993. Feasibility of using hydroacoustics to monitor fish passage at hydroelectric facilities. Pacific Gas & Electric Research and Development.

Ransom BH, Steig TW. 1994. Using hydroacoustics to monitor fish at hydropower dams. Lake Res Manage 9(1):163-9.

[SLDMWA and Hanson] San Luis & Delta-Mendota Water Authority, Hanson CH. 1996. Georgiana Slough Acoustic Barrier Applied Research Project: results of 1994 Phase II field tests. Interagency Ecological Program for the San Francisco/Delta Estuary. Technical Report 44. Sacramento (CA): California Department of Water Resources.

Skalski JR, Hoffmann A, Ransom BH, Steig T. 1993. Fixed-location hydroacoustic monitoring designs for estimating fish passage using stratified random and systematic sampling. J Fish Res Board Can 50:1208–21.

Stansell RJ, Beck LM, Nagy WT, Magne RA. 1991. Hydroacoustic evaluation of juvenile salmonid fish passage at the Dalles Dam Fish Attraction Water Units in 1990. U.S. Army Corps of Engineers.

Steig TW, Ransom BH. 1991. Hydroacoustic evaluation of deep and shallow spill as a bypass mechanism for downstream migration salmon at Rock Island Dam on the Columbia River. Hydroacoustic Technology, Inc. Reprint from Waterpower '91.

Thomas GL. 1992. Successes and failures of fisheries acoustics—an international, federal, and regional point of view. Fish Res 14:95-104.

Thorne RE, Hedgepeth JB, Campos J. 1989. Hydroacoustic observations of fish abundance and behavior around an artificial reef in Costa Rica. Bull Mar Sci 44(2):1058–64.

Thorne R, Hedgepeth JB. 1996. New York State Dam Hydropower Project. FERC Project No. 7481: juvenile blueback herring monitoring, final report. 1995 monitoring report and summary of the 1990-1995 fish monitoring data. Final contract report. Seattle (WA): BioSonics Inc.

Traynor JJ, Ehrenberg JE. 1979. Evaluation of the dual beam acoustic fish target strength measurement method. J Fish Res Board Can 36:1065–71.

Notes

Hedgepeth JB (BioSonics, Inc.). Presentation during BioSonics Hydroacoustic Short Course, January 24, 1997, Seattle, WA.

Appendix A: Tables

Appendix A, Table 1 Echosounder settings used during the Clifton Court Forebay Outlet Channel Survey, June 1–4, 1988

Model 102 Frequency 1 = 420 kHz	
Receiver	
Receiver X1 Gain (dB)	0
Bandwidth (kHz)	5
TVG (20 or 40 Log R)	40
Attenuation (FW or SW)	FW
Calibration	
Level (dB)	OFF
Pulse or CW (PL or CW)	CW
Separation (ft)	0
Trigger	
Bottom Detect Sensitivity	0
Int. Trigger Interval (s)	
Ext. (CR, MPX, Mann)	MPX
Control	
Blank At Range, Normal (R or N)	R
Blanking Distance (ft)	0.3
Range (ft)	98 and 49
Transmitter	
Power (dB)	0
Pulse Width (ms)	0.4
Mode	
Setting (F1/X1, EXT, etc.)	F1/X1

Multiplexer Equalization Calculation Worksheet

The examples in the worksheet below calculate the multiplexer equalization values necessary for one of the circular-beam and one of the elliptical-beam transducers used during this survey, to increase voltage output from the echosounder so that it will equal the chart recorder threshold value for a one inch fish on the acoustical axis. The on-axis multiplexer equalization for this target strength is adjusted to produce an effective beam width equal to the nominal beam width.

Appendix A, Table 2 Multiplexer equalization calculation worksheet

Data Needed		*Circular*	*Elliptical*
BioSonics System Calibrations			
Calibration Date		2/24/86	2/24/86
f = frequency (kHz)		420	420
Range (ft)		40	40
Transducer S/N		192	61249
Cable Length (ft)		500	500
Cable S/N		285	284
Beam Width		15	6 × 12
Receiver # 1	40 log R		
Gx = Receiving Sensitivity		–145.9	–136.9
Xmit = Transmitter Setting (dB)		0	0
SL = Source Level (dB)		208.4	214.3
FL = Minimum fish length (inch) to detect		1.0	1.0
CR_T = Chart Recorder Threshold (volts)		0.1	0.1
RG = Echosounder Receiver Gain Setting (dB)		0	0
G1 = Receiving Sensitivity at 3.3 ft =		–189.8	–180.8
G1 =	Gx – 40 logR – RG		
Note: RG at 3.3 ft =		0	0
Target strength = target strength (dB) =		–56.6	–56.6
Target strength = 19.1 × log (FL) – 0.9 × log (f)		–62.0	
CR_T = Chart Recorder Threshold (dB) =		–20	–20
CR_T =	20 × log (CR_T v)		
V_0 = Voltage output (dB) =		–38.0	–23.1
V_0 = SL + G1 + Target strength + RG			
MPX_EQ = On-Axis Multiplexer Equalization =		18.0	3.1
MPX_EQ =	CR_T – V_0		
MPX Equalization to achieve Nominal Beam Width =	CR_T – V_0 + 6 =	24.0	9.1

Appendix A, Table 3 Equalization program used during the Clifton Court Forebay Outlet Channel Survey, June 1–4, 1988

XD#	*XD Status*	*EQUAL Gain (dB)*	*XD S/N*	*Cable#*	*Area*	*Subarea*	*V(deg.)*	*AIM*
1	on	3.1	61250	283	1	15	85	1
2	on	3.1	192	285	2	16	20	1
3	on	18.0	193	278	2	18	20	1
4	on	18.0	61249	284	1	19	80	1
5	on	18.2	211	370	2	37	170	1

Appendix A, Table 4 Chart recorder (CR) settings used during the Clifton Court Forebay Outlet Channel Survey, June 1–4, 1988

Model 111	*CR#2*	*CR#3*
Miscellaneous Switches		
W.L. (On, Off)	Off	Off
Grid (On, Off)	On	On
Paper Speed (mm/ping)	1/16	1/16
Gray Level (1, 2, or 3)	3	3
Thumbwheel Switches		
Start (ft)	0.00	0.00
Range (ft)	40	30
Trigger (PPS)	0.0	0.0
Threshold (V)	0.1	0.1
Signal Switches		
Coupling (AC, DC)	DC	DC
Polarity (–, +/–, +)	+	+
Sync Controls		
Level (0, Clock)	0	0
Polarity (–,+)	+	+

Appendix A, Table 5 Sequence programs used during the Clifton Court Forebay Outlet Channel Survey, June 1–4, 1988

Interval #	*Ends (min:sec)*	*Pings per second (PPS)*	*Ping 1*		*Ping 2*	
Sequence No. 1 Fast Multiplexing for the Bottom-mounted transducers						
			x[a]	c	x	c
1	15:00	10.0	1	2	3	3
2	30:00	10.0	2	2	4	3
3	45:00	10.0	1	2	3	3
4	0:00	10.0	2	2	4	3
Sequence No. 2 Normal Multiplexing for the Surface-mounted Transducer						
			x	c	x	c
1	05:00	20.0	5		2	
2	15:00	20.0	5		2	
3	00:00	20.00	5		2	

a. x = mutilplexer/equalizer port number.

Appendix A, Table 6 Cross-sectional area of Clifton Court Forebay Outlet Channel at the location of the transducers for the north half of channel

Distance Across Channel from North Bank (ft)	*Depth (ft)*	*Total Area of Interval (ft^2)*	*Adjusted Area of Interval (ft^2)*	*Cumulative Area from North Bank (ft^2)*
0	0.00	0	0	0
5	2.47	12.375	6.188	6.188
10	4.46	22.275	17.325	23.513
15	4.79	23.925	23.100	46.613
20	5.11	25.575	24.750	71.363
25	5.94	29.700	27.638	99.000
30	6.44	32.175	30.938	129.938
35	7.43	37.125	34.650	164.588
40	8.25	41.250	39.188	203.775
45	9.73	48.675	44.963	248.738
50	11.72	58.575	53.625	302.363
55	13.20	66.000	62.288	364.650
60	15.02	75.075	70.538	435.188
65	16.67	83.325	79.200	514.388
70	17.99	89.925	86.625	601.013
75	19.31	96.525	93.225	694.238
80	20.63	103.125	99.825	794.063
85	21.95	109.725	106.425	900.488
90	23.60	117.975	113.850	1014.338
95	24.75	123.750	120.863	1135.200
100	25.91	129.525	126.638	1261.838
105	26.57	132.825	131.175	1393.013
110	27.56	137.775	135.300	1528.313
115	28.22	141.075	139.425	1667.738
120	28.55	142.725	141.900	1809.638
125	28.38	141.900	142.313	1951.950

Appendix A, Table 7 Cross-sectional area of Clifton Court Forebay Outlet Channel at the location of the transducers for the south half of channel

Distance across Channel from South Bank (ft)	*Depth (ft)*	*Total Area of Interval (ft^2)*	*Adjusted Area of Interval (ft^2)*	*Cumulative Area from South Bank (ft^2)*
0	0.00	0	0	0
5	2.47	12.375	6.188	6.188
10	3.63	18.150	15.263	21.450
15	3.80	18.975	18.563	40.013
20	4.46	22.275	20.625	60.638
25	4.46	22.275	22.275	82.913
30	5.61	28.050	25.163	108.075
35	6.60	33.000	30.525	138.600
40	8.09	40.425	36.713	175.313
45	9.73	48.675	44.550	219.863
50	11.39	56.925	52.800	272.663
55	12.87	64.350	60.638	333.300
60	14.36	71.775	68.063	401.363
65	16.00	80.025	75.900	477.263
70	17.49	87.450	83.738	561.000
75	19.14	95.700	91.575	652.575
80	21.29	106.425	101.063	753.638
85	23.27	116.325	111.375	865.013
90	24.59	122.925	119.625	984.638
95	25.58	127.875	125.400	1110.038
100	26.73	133.650	130.763	1240.800
105	27.72	138.600	136.125	1376.925
110	27.89	139.425	139.013	1515.938
115	28.05	140.250	139.838	1655.775
120	28.38	141.900	141.075	1796.850
125	28.38	141.900	141.900	1938.750

Appendix B: Target Weighting Factor

The target weighting factor is directly proportional to the reciprocal of the target range from the transducer. The factor adjusts for the cone-shaped acoustic sample volume produced by the transducer. The target weighting factor is calculated as the reciprocal of either the beam diameter (circular beam) or the beam area at the range where the fish is detected (elliptical beam), depending on transducer orienting. The weighing factor for each fish detection can then be multiplied by a normalization width to extrapolate individual detections to the number of fish that detection represents in the normalized area.

Appendix C: Trace Type

A target's trace type is determined from its echogram as it travels through the ensonified volume. The trace type is a description of the target's trace in relation to a change in range between its entry (INDEPTH) and exit (OUTDEPTH) points from the ensonified volume and is recorded during the digitizing process as one of the following:

1 = LS (Long to Short); the target enters the ensonified volume at a longer range from the transducer than it exits (downstream movement, toward the louvers).

2 = BD (Bend Decreasing); the overall trace is LS with a bend.

3 = SL (Short to Long); the target enters the beam at a shorter range from the transducer than it exits (upstream movement, away from the louvers).

4 = BI (Bent Increasing); the overall trace is SL with a bend.

5 = NC (No Change); no difference in rage between entry and exit points (direction unknown), sometimes caused by the target moving relatively quickly into and out of the beam.

6 = WW (Wallowing); a NC trace type that stays in the beam for a while.

Appendix D: Near-Field Effect

At ranges close to the transducer, the sample volume is quite small and the probability of detecting a fish is quite low. Chance detections at these close ranges produce disproportionately large sample errors. In this analysis, only targets detected at ranges with weighting factors <20 percent larger than the factor from the next larger range interval are included. For the bottom-mounted and surface-mounted transducers, this includes targets detected at ranges greater than five feet from the transducer. For the horizontally-aimed transducer this includes targets detected at ranges greater than ten feet from the transducer.