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DEPARTMENT OF FISH AND GAME

PACIFIC HERRING, *Clupea harengus pallasi*, STUDIES IN SAN FRANCISCO AND TOMALES BAYS, APRIL 1989 TO MARCH 1990

by

Kenneth T. Oda
and
Frederick Wendell

Marine Resources Division

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ABSTRACT

Herring schools were surveyed hydroacoustically in San Francisco Bay from early November 1989 through mid March 1990. Seven large schools (>1000 tons) and two smaller ones were detected. The total acoustic biomass estimate based on visual integration was 58,100 tons. Merging with the independent spawn escapement estimate yielded a "best" estimate of 64,500 tons.

Sixty-three samples, containing 10,239 herring, were collected. Patterns evident in prior seasons continue. Larger, older fish continue to dominate early season schools. Males continue to be numerically superior during the first half of the season. Mean size and weight at age suggest conditions following the 1988-89 season were not favorable for growth.

Contrary to forecasts, the 1988 year class recruitment strength was high; second only to the 1982 year class. Although still being validated, forecasts suggest the 1989 year class will be strong and the 1990 year class will be extremely weak.

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INTRODUCTION

Pacific herring (Clupea harengus pallasi) have been the target of an intensive and lucrative roe fishery in California since the early 1970's (Spratt 1981). The State of California's Fish and Game Commission was directed by law to regulate this fishery. The implementing regulations they promulgated required the California Department of Fish and Game to manage this fishery by setting quotas based on biomass estimates. Hydroacoustic techniques have played an important role in generating those estimates.

Fisheries acoustics, the application of hydroacoustic techniques to detect fish and estimate their abundance, have been widely utilized since the early 1970's to generate fish biomass estimates (Thorne 1983, and Johannesson and Mitson 1983). The use of this type of remote sampling technique to assess the Pacific herring resource in California began in the late 1970's and became one of the primary assessment tools in the early 1980's (Reilly and Moore 1982). These studies have continued through the period covered by this report (Reilly and Moore 1983, 1984, 1985, 1986, 1987, 1988, and Reilly, Oda, and Wendell 1989).

This report continues the time series by providing the results of hydroacoustic and supporting studies of the Pacific herring population in San Francisco Bay during the 1989-90 spawning period. The primary objective of these studies was to provide a spawning population biomass estimate used in the development of the fishery quota. Since new personnel conducted these studies, an effort was made to identify and describe any significant changes in methodology affecting the interpretation of results, particularly in light of comparisons with results in earlier reports. This report also discusses the status of the Department's efforts to develop a method of forecasting the biomass of future spawning populations.

METHODS

Population Structure Sampling

Field Surveys

Research Vessels All field work during the spawning season was conducted from the R\V Pandalus, a 23-ft Thunderbird Iroquois, equipped with two single drum hydraulic winches.

Sampling Gear A midwater trawl was used as the primary sampling gear. Herring schools were located for trawling by rapidly surveying likely areas with an echosounder, usually with our Apelco XCD-240 fish finder. Information obtained from commercial fishermen and observations of marine mammal and bird activity was also helpful in finding herring.

Once the presence of herring-like schools was confirmed with our echosounders, tow direction and depth were determined. A 12-ft square, 65-ft long, double warp midwater trawl with a 0.5-in. stretched mesh cod end was deployed; the middle of the net was positioned at the bottom of the densest herring marks (Figure 1), enabling capture of fish that may be sounding in response to the trawl (Reilly et al. 1989). Midwater tows were oriented in the direction of the current to maximize tow speed and catch. Tow speeds ranged between 2 to 5 kts. Tow duration, with the trawl at target depth, ranged from 15-sec to 5-min. This included a 30-sec, 300 rpm, increase in engine speed for tows in excess of 30-sec. Tow duration was determined based on observed fish densities, boat

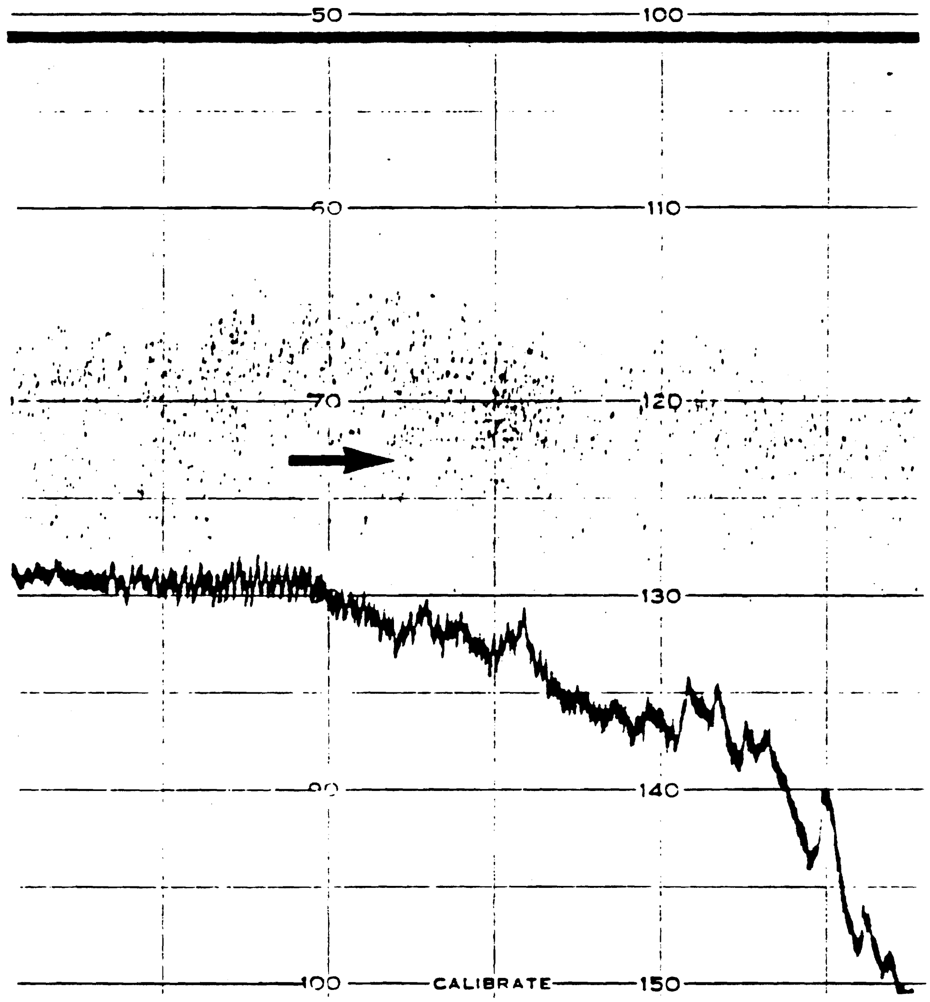

Figure 1. Pacific herring recorded in San Francisco Bay with target depth of midwater trawl indicated (→).

traffic, or obstructions. However, tows were limited to 5-min to limit the probability of harming marine mammals.

Samples were also collected from the roundhaul fishery. The fishery opened for roundhaul permittees, both purse seine and lampara, on January 2, 1990 and closed March 9, 1990. Samples were collected opportunistically throughout the season from fishermen who were preparing to sample their catch for roe content before loading.

Fishing vessels were approached by the R/V Pandalus and a sample was requested from the crew. A 5-gal. bucket was passed to a crewperson, usually the skiff operator, who then filled the bucket from the net using a small long-handled dip net. Samples were labeled and set aside for dockside processing.

Dockside Processing Fish were transferred onto the dock and rinsed with water. Body length (BL), in millimeters measured from the tip of the snout to the end of the pigment underneath the last column of scales on the caudal peduncle, was determined for all fish (Spratt 1981).

Sex and state of maturation were determined by visual examination. The abdominal area was lightly squeezed until sex products were extruded. If sex products were not extruded, a small cut was made above the vent and the gonads were examined. Herring that were very thin, with knife edged concave bellies and greatly reduced bloodshot gonads, were recorded as spent. Spent fish were not included in length weight analysis. Herring that were running ripe were recorded as ripe. Herring not running ripe, with eggs opaque white in appearance, were recorded as immature.

Seventeen fish from 10-mm size classes beginning with 130-mm were haphazardly taken from each school and reserved for aging and length weight analysis. These individuals were tagged by stapling a numbered water-proof paper tag on the operculum, bagged, placed in a cooler, transported to the Menlo Park Laboratory and frozen.

Laboratory Processing

Samples were removed from the freezer and thawed in a water bath, usually the night prior to processing. Thawed fish were arranged on dissecting trays by identification number, then weighed to the 0.1 g on a Mettler 1200N pan balance. Sex and maturity were verified by comparison with the field data sheet. Fish found to have significant egg or milt losses upon examination were not included in length weight analysis.

Otoliths were removed and cleaned with white paper toweling then submerged in 190 proof ethanol. Otoliths were then dried and stored in labeled gelatin capsules prior to aging. In order to age, otoliths were removed from the gelatin capsules and cleared in 190 proof ethanol for surface reading. Ages were assigned based on annuli counts. However, the first and second annuli were located based on measurements (Reilly pers. comm.).

Otoliths were aged independently by two readers. When the ages differed, the otoliths were aged again by one of the readers. If still unresolved, a third reader would assign an age. Ultimately, the age assigned would be an age agreed-upon consensus.

Computer Processing

Length, weight, sex, maturity stage, and age data from all herring samples were entered in a NEC PowerMate 1 microcomputer using dBase III programs. Mean BL by sex and maturity stage and length frequencies for each sample and school were generated.

School assignments were based on a combination of factors: 1) date of sample, 2) percentage of unripe females in the sample, 3) school location, 4) date of spawning as determined by egg deposition surveys, 5) daily landings of the commercial fleet, and 6) miscellaneous information from the commercial fleet.

Most statistical analyses were performed using programs from ABSTAT. Software was developed to facilitate developing age-length keys, assigning ages based on length, and developing an estimate of the age composition of the spawning population.

Age and School Determination Ages were assigned to unaged fish based on the age composition of fish aged using otoliths. Ages were assigned according to the percentage of each age within 2-mm size intervals (age-length key). All fish aged or assigned an age from a school were then combined to determine total age composition.

Total Age Composition for Spawning Season Total age composition, expressed as a percentage, was calculated for the entire spawning season based on two separate biomass estimates for each school: 1) the sum of spawn escapement estimate plus commercial catch (Spratt 1990), 2) the final acoustic biomass estimate. To calculate total age composition as a percent by number of fish, mean length for a school was converted to mean weight, using values from Appendix D. Each school biomass estimate was divided by the appropriate mean weight to produce an estimated total number of fish. The total was multiplied by the percentage composition from combined samples to determine total number of fish by age for each school. Numbers for each age were then summed for all schools and divided by the total number of fish to produce a percentage for that age for the entire season. Data from the nearest school, temporally, were used for schools not sampled. To determine total age composition as a percent by weight, 1989-90 mean weight at age values were used along with the percentage age composition by school.

Hydroacoustic Surveys

Sampling Strategy

San Francisco Bay Pacific herring spawning grounds and holding areas within San Francisco Bay have been identified within an area bounded by the Richmond-San Rafael Bridge on the north and the San Mateo Bridge on the south (Figure 2). The Oakland Bay Bridge provided a convenient landmark to divide the primary survey area into northern and southern components. Although small quantities of herring have been taken beyond the area boundaries, their occurrence and significance were assumed to be low. Consequently, all surveys were conducted within the primary survey area boundaries.

Surveys spanned the typical spawning period (November through March) and were scheduled to occur on 3 to 4 days each week around a daylight slack tide. Because of tide-related time constraints, only a portion of the entire area was covered during any single survey. Fortunately, most schools could be completely surveyed within the available time. Several surveys were typically completed on each school prior to a spawn. Surveys were also frequently conducted within portions of the primary survey area not known to be occupied by a school to provide complete coverage. The surveys conducted in these areas were used to identify the arrival of new fish or the splitting of a school.

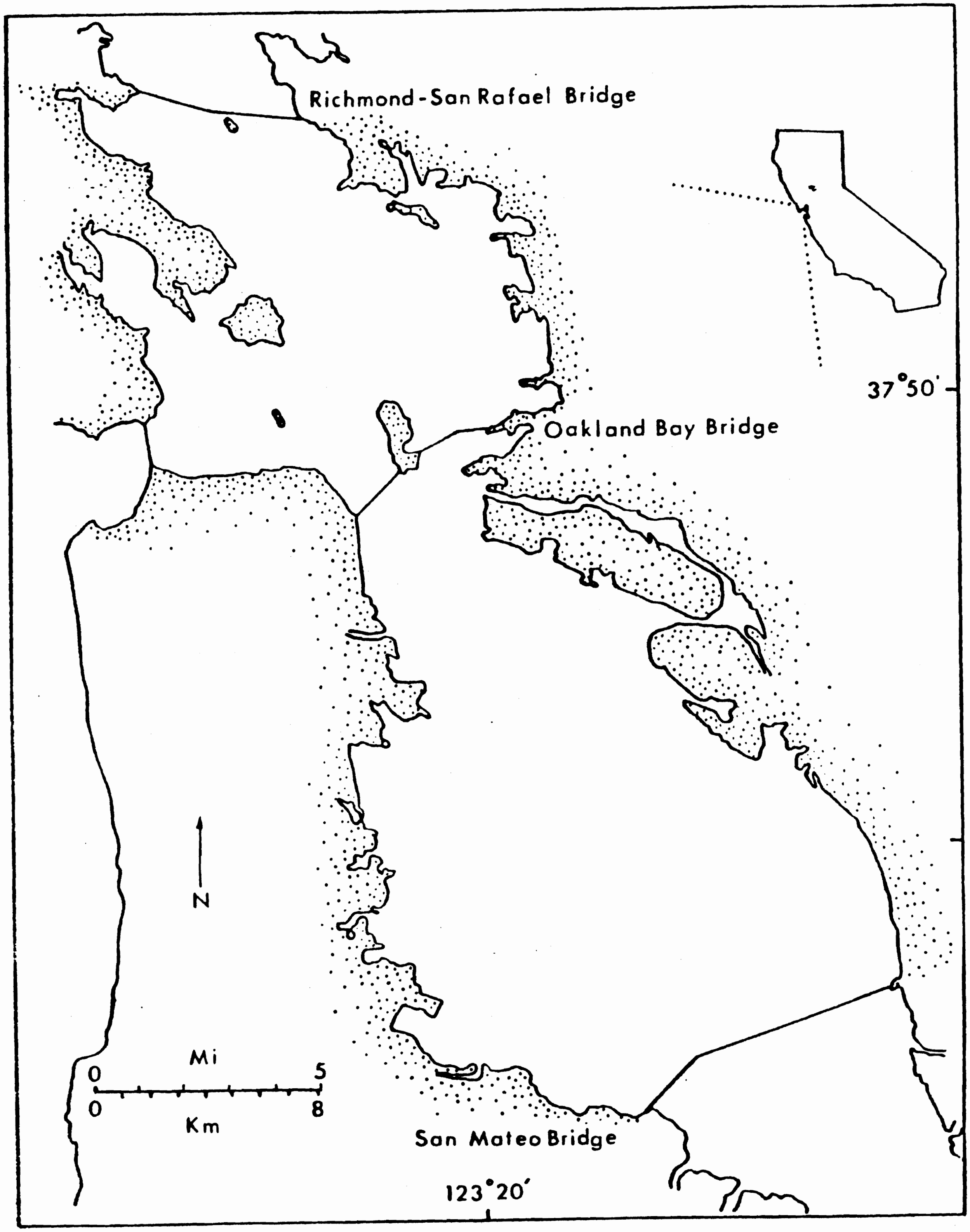

FIGURE 2. Pacific herring acoustic survey and sampling area in San Francisco Bay, 1989-90.

The selection of an area to survey was predicated on the quality of preceding surveys on known schools and the likelihood of a spawn. Highest biomass estimates for a given school were often obtained just prior to a spawn. Information on fish distribution obtained from commercial herring fishermen was also considered in the survey area selection process.

Once an area was selected, a starting point was determined. If a school was known to be within the survey area, the starting point chosen was the edge of the school, that ensured that tide related school movement carried the school under the boat. If no information was available on fish distribution, a convenient point was selected which allowed the boat to work against tidal flow. Both criteria were designed to minimize double counting of fish associated with both the school and boat moving in the same direction.

Surveys were conducted, where possible, in a zig-zag pattern. On occasion, obstructions required a castellate pattern. Turning points were selected to minimize survey time in unoccupied or low likelihood areas. If a school was obviously present, turning points were chosen when a track extended for over a minute beyond the school. If no school was obviously present, turns were made at the 10 fathom contour (60 ft).

Exceptions to these general rules occurred fairly frequently. If the survey extended beyond the slack tide, every effort was made to complete the survey as quickly as possible. In these instances, turns were made in low-density areas rather than extending beyond the school. This made particular sense given the co-occurrence of white croaker (Genyonemus lineatus) in certain areas.

A track angle of approximately 45 degrees was chosen for most zig-zag patterns. This angle was modified when necessary to take advantage of line-of-sight marks used to ensure a straight track. Larger angles left too much area on the open end of the pattern and time constraints prevented use of appreciably smaller angles.

Two hydroacoustic techniques were used to conduct herring biomass surveys. Each technique utilized distinct electronic hardware. A Raytheon model DE-719B recording echo sounder was used to locate and delineate herring schools. The paper recordings from this echo sounder were used to estimate biomass through a technique called "visual integration". A scientific-grade echo sounder, the Biosonics model 105, was also used to estimate biomass by "echo integration".

The Biosonics data collection system consisted of the echo sounder, narrow beam (6 degree), 200 kHz transducer, oscilloscope, chart recorder, video cassette recorder, and digitizer. Reflected echoes from herring were converted to voltages, digitized after being attenuated by a factor of ten, and stored on tape. The echo sounder incorporated a time-varied gain which ensured that a particular fish would reflect the same voltage regardless of distance from the echo sounder.

Bodega Bay Hydroacoustic surveys of herring stocks occupying Bodega Bay were opportunistic in nature. The survey required rapid notification of the presence of quantifiable amounts of herring and deployment of personnel and equipment. The survey area potentially included all portions of Bodega and Tomales Bays (Figure 3).

The Raytheon model DE-719B recording echo sounder was used to

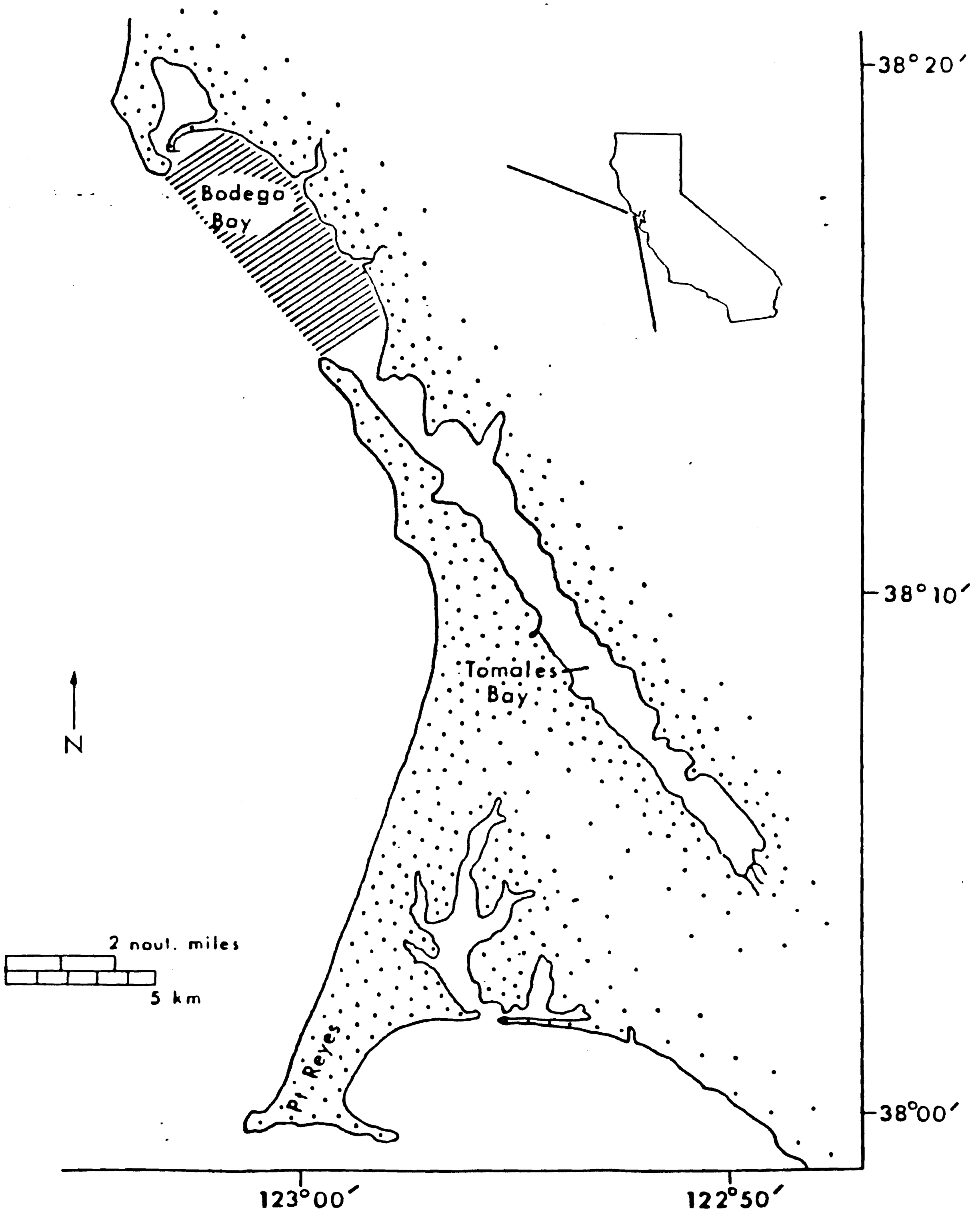

FIGURE 3. Pacific herring acoustic survey area in Bodega Bay, 1990.

locate and delineate herring schools. Biomass was estimated using the visual integration technique.

Biomass Estimation

Visual Integration The zig-zag course followed during a survey utilizing the Raytheon echo sounder was translated to maps of the primary survey area based on Loran C readings taken at each turning point. Each track was then divided into sub-units of equal herring density based on a visual examination of the paper recording. Densities were subjectively assigned based upon a comparison to standardized traces.

Standards were developed from traces obtained during a charter of a purse seine vessel in 1983 (Reilly and Moore 1983). Modifications of the densities assigned to standard traces were subsequently made based on echo integration surveys (Reilly and Moore 1985).

Densities from linear tracks were then converted to areas by joining corresponding linear sub-units with equal density from a zig and a zag in the survey pattern. If densities were unequal along corresponding linear sub-units, the area was divided into half using a bisector of the angle formed by a zig and a zag. Each half was assigned the density from the closest linear sub-units. The entire school was divided into sub-areas with roughly equal density in this manner.

The biomass within each sub-unit was determined by multiplying the assigned density by a measure of the surface area obtained using a Houston Instrument HI-PAD digitizer. School biomass was obtained by summing biomass from these discrete sub-units.

Echo Integration The survey pattern used in echo integration surveys was the same as that used in visual integration surveys. However, the nature of the data and subsequent analysis were appreciably different. Once the echoing signal was received back at the transducer, it was converted to voltage and attenuated by a factor of ten for recording on high-quality beta video tape. Calibration data was obtained during each survey to ensure that playback voltages were boosted accurately for analysis.

Analysis was completed using the CDFG Bay-Delta Fishery Project's echo signal processor (ESP) and interface. The ESP system calculated average densities for each track within predetermined depth strata. The depth strata chosen were 5 m increments starting at 5 m below the surface. Each track was treated as the diagonal in a trapezoid. The average density was then multiplied by the trapezoidal area within each strata. Biomass from each strata was summed for a given trapezoid and all trapezoidal areas summed to yield the school biomass.

Final Biomass Estimate A final biomass estimate was selected for each school. In all cases the estimate selected was the largest obtained regardless of technique. However, if estimates were essentially the same for both techniques, the echo integration estimate was used.

A seasonal total biomass estimate was generated by meshing the final hydroacoustic estimate with the spawn escapement estimate for each school. Each estimate was adjusted for any commercial take prior to the survey and rounded off to the nearest 100 tons. If the estimates from both techniques were judged adequate for a school, the meshing simply averaged the two values. If either estimate was unavailable or inadequate, the remaining value was used.

Young-of-the-Year Surveys

Sampling Strategy

Post-spawning season surveys were designed and conducted to assess young-of-the-year (YOY) growth characteristics and relative year class strength. These surveys continued this year; however, the emphasis was placed on assessing growth characteristics. Tows conducted by the Department's Bay-Delta Fisheries project provided information used in assessing relative year class strength.

Year class strength was assessed by creating an index of abundance based on catch-per-unit-effort (CPUE) samples collected from midwater trawl tows. Tows were conducted within the primary survey area (Figure 2) at stations selected and sampled by the Department's Bay-Delta Fishery Project (Figure 4). These stations were of interest because the Bay-Delta Project's CPUE data on herring YOY correlated highly with measures of herring abundance when they subsequently recruited into the fishery as 2-year olds.

Herring collected for growth assessments were measured to the nearest millimeter. All non-target species were identified and quantified. If a large quantity of non-target fish were collected, a volume measure was substituted for counts.

Abundance Estimation

The catch of YOY herring from Bay-Delta Fisheries Project tows was adjusted by dividing by the volume of water filtered and multiplied by 10,000. Adjusted catch was summed from all tows to provide the index of year-class strength. This index was used with

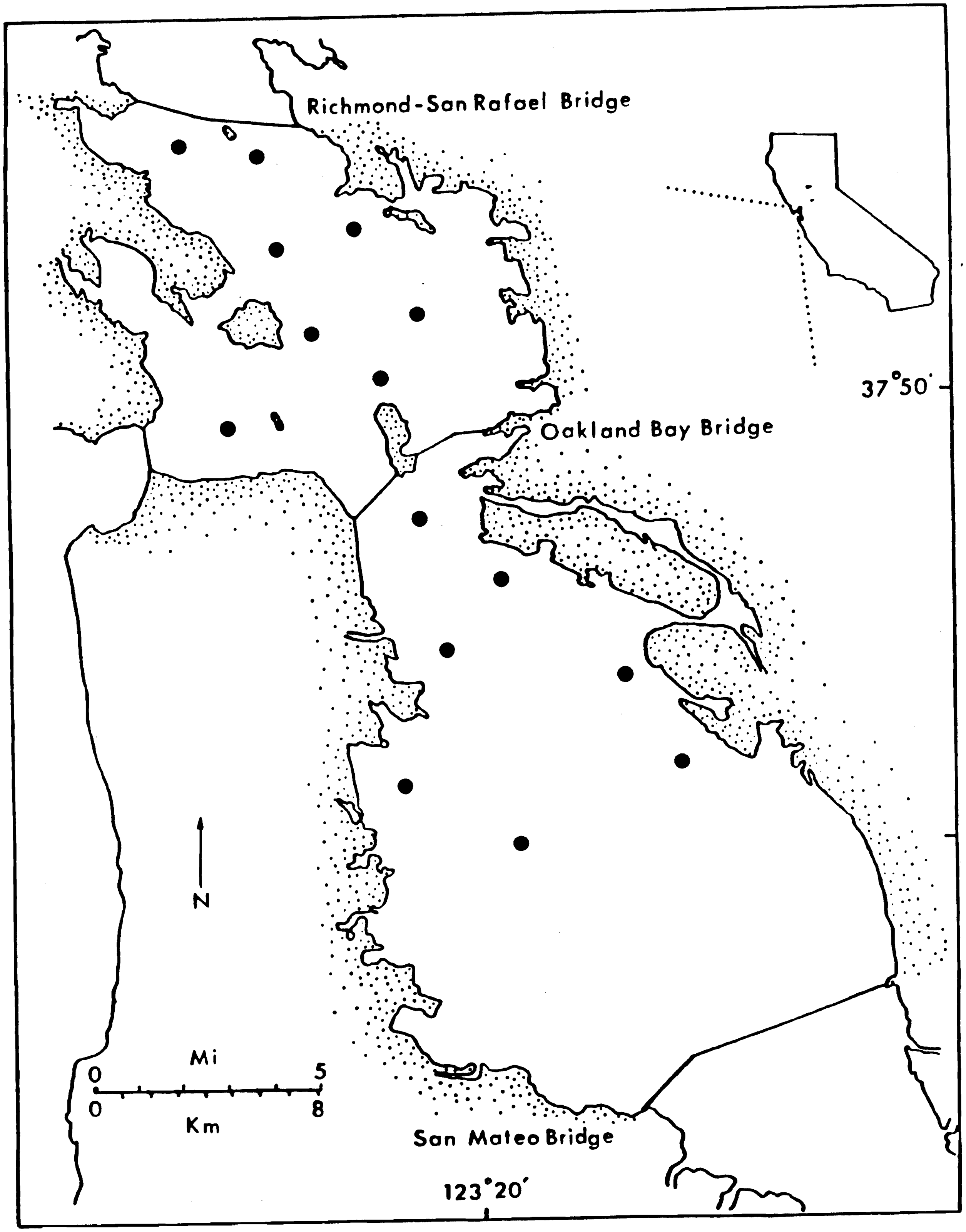

FIGURE 4. Location of selected stations in San Francisco Bay used to sample young-of-the-year herring for recruitment forecasting.

indices generated from earlier surveys (1980- on) to assess their utility as forecasters of future fishery recruitment strength.

RESULTS

Population Structure

Sixty-three midwater trawl or roundhaul net samples of Pacific herring were collected in San Francisco Bay from November 27, 1989 to March 15, 1990 (Appendix A). These samples contained 10,239 individuals collected from nine schools, of which 10,193 were greater than 129 mm BL (Figure 5).

Length Composition

Midwater Trawl Samples A total of 8,880 herring from nine schools were sampled by midwater trawl (Appendix B). All known schools were sampled using the midwater trawl. Changes in mean length (Table 1) of herring within schools suggested a gradual decrease in the size composition of schools through January (school 5). Mean length for schools decreased from 182 to 165 mm during this period. Last season's mean length for schools sampled by midwater trawl ranged between 171 and 185 mm.

Roundhaul Samples A total of 1,359 herring were sampled from the roundhaul fleet (Appendix C). Only schools 5 through 8 were sampled by obtaining herring from the roundhaul fleet. Mean length for these schools (Table 2) ranged from 164 to 173 mm. The mean length of all roundhaul samples combined was 168.2 mm, lower than last season's mean of 170.5 mm (Table 3).

Comparison by Gear Type Midwater trawl samples were similar in length composition to roundhaul samples last season. The midwater trawl caught smaller fish than roundhaul gear this season (Table 4).

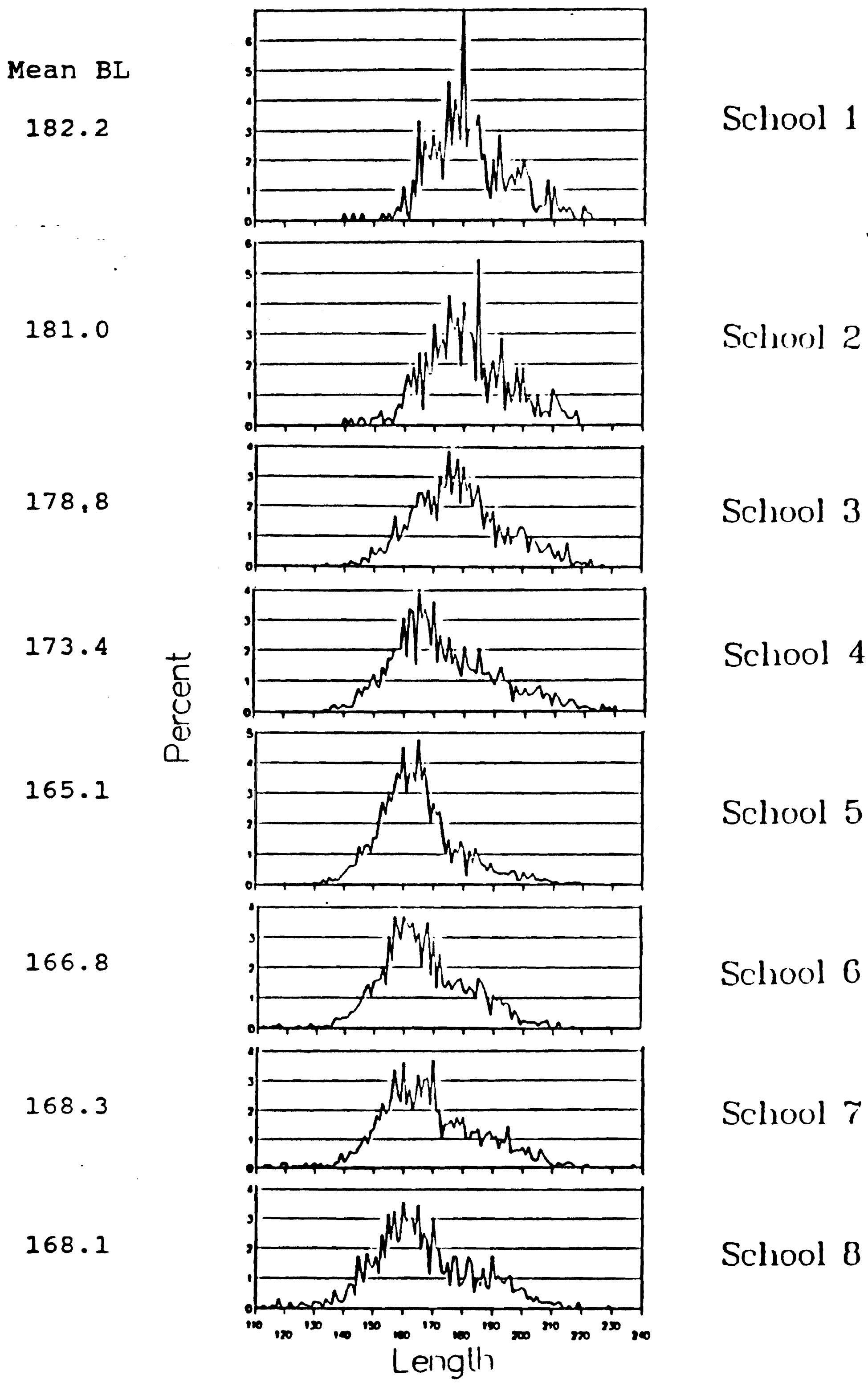

FIGURE 5. **Length frequency distributions of Pacific herring from samples combined by schools in San Francisco Bay from November 1989 to March 1990.**

Table 1. Number of Pacific Herring by Body Length (2 mm Interval) Combined by School from Midwater Trawl Net Samples Collected in San Francisco Bay, November 1989 to March 1990.

Size interval	School number 1	2	3	4	5	6	7	8	9
110-139			1	9	29	23	22	40	11
140-141	1	1	1	5	20	8	5	7	1
142	1	1	3	4	28	13	9	17	6
144		1	1	16	42	18	10	25	2
146	1	1	6	17	42	27	20	20	6
148		1	8	22	50	28	17	34	10
150		2	9	27	57	36	34	31	2
152	1	2	12	29	99	38	35	38	7
154	1	2	14	38	110	52	42	51	12
156	1	2	30	49	114	68	61	60	14
158	3	5	20	54	143	66	54	44	8
160	6	12	29	64	133	80	62	65	15
162	6	13	42	89	132	84	49	56	11
164	18	14	50	72	148	68	57	59	10
166	17	12	51	85	128	55	61	43	6
168	19	14	48	67	96	61	52	30	10
170	22	23	44	69	88	48	55	51	7
172	18	23	64	58	84	39	31	30	9
174	33	27	74	53	50	35	25	27	9
176	29	27	61	45	35	34	32	24	6
178	28	23	65	34	48	33	27	27	7
180	43	30	66	48	27	27	28	21	5
182	28	25	55	36	29	32	22	31	10
184	30	29	57	43	32	29	18	22	6
186	19	14	36	32	22	26	17	23	7
188	8	10	37	31	24	13	14	22	6
190	13	14	28	26	13	24	24	26	3
192	19	20	28	33	12	16	9	24	4
194	10	8	23	25	13	16	18	23	1
196	12	7	19	15	18	10	10	16	3
198	14	11	27	14	4	1	10	12	1
200	16	11	27	17	10	6	9	13	
202	8	7	17	15	12	5	8	8	2
204	3	5	18	21	8	1	4	5	3
206	4	3	11	13	7	6	9	5	5
208	6	3	16	9	5	2	4	4	
210	7	9	8	14	4			4	1
212	3	5	8	5	1	2	2	4	1
214	3	3	12	8	3		1	2	1
216	1	2	3	8	1	1	1	3	
218		2	4	3	4			2	
220	3		3	4				1	1
222	1		3	2	1			1	
226			1	3					
228				2				1	
230				2					
236							1		
n	456	424	1140	1335	1926	1131	969	1052	229
Mean	182.2	181.0	178.8	173.4	164.6	166.3	167.7	167.8	167.6

Table 2. Number of Pacific Herring by Body Length (2 mm Interval) Combined by School from Roundhaul Net Samples Collected in San Francisco Bay, January to March 1990.

Size interval	School number 5	6	7	8
110-139	4	5	1	1
140-141	3	2		
142	4	3	2	1
144	8	4	1	
146	16	7	2	3
148	13	10	6	1
150	23	11	3	2
152	30	16	7	3
154	28	15		2
156	42	21	4	2
158	46	27	2	4
160	65	29	4	4
162	66	19	4	10
164	68	22	4	7
166	65	21	3	5
168	36	18	7	10
170	43	16	7	6
172	24	20	3	5
174	15	9	8	3
176	15	7	2	4
178	17	16	6	4
180	10	9	3	1
182	18	8	2	5
184	24	10	6	1
186	12	16	2	0
188	6	7	7	1
190	9	6		2
192	7	11	2	5
194	5	9	2	3
196	6	3	2	1
198	3	6	2	3
200	6	1	3	1
202	4	1	3	1
204	1	3	2	1
206	1		2	1
208	2	2		1
210				
212		1	1	
214				
216	2			
218				
220	1			
n	748	391	115	104
Mean	166.3	168.4	172.8	171.6

Table 3. Number of Pacific Herring by Body Length (2 mm Interval) from Roundhaul Samples, 1981-82 to 1989-90.

Body length	Season 1981-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90
130-139	2	9	247	27	16	24	31	21	12
140-141	4	4	84	6	3	8	23	12	5
142	6	6	130	10	2	23	25	13	10
144	7	3	146	8	6	16	39	29	13
146	12	6	223	20	8	26	90	28	28
148	3	9	187	26	7	33	83	53	30
150	6	7	274	38	15	31	104	81	39
152	21	17	399	82	40	67	201	91	56
154	27	29	334	103	28	72	171	132	45
156	26	55	522	154	57	147	320	183	69
158	33	42	428	178	88	135	243	162	79
160	27	76	441	180	113	152	214	225	102
162	56	136	498	344	218	265	368	227	99
164	56	120	345	312	213	231	201	231	101
166	68	178	302	309	276	359	274	211	94
168	79	157	235	238	256	255	202	144	71
170	89	196	121	210	260	263	154	206	72
172	115	267	145	234	353	386	205	192	52
174	103	173	82	159	281	207	111	166	35
176	105	261	94	139	309	253	134	147	28
178	88	252	92	109	268	145	75	113	43
180	74	241	79	78	228	111	84	114	23
182	91	340	147	107	313	140	116	136	33
184	51	238	128	83	243	96	73	116	41
186	53	310	129	83	253	89	106	90	30
188	60	186	81	64	181	72	75	77	21
190	50	205	93	47	166	57	75	77	17
192	41	236	90	54	207	92	90	54	25
194	22	124	68	28	120	57	52	56	19
196	22	166	51	34	136	69	53	44	12
198	20	106	34	24	100	54	43	27	14
200	12	64	20	16	84	48	25	34	11
202	9	77	14	19	70	50	25	22	9
204	5	52	7	15	57	27	21	17	7
206	3	42	5	8	43	24	16	13	4
208	4	13	2	7	26	14	15	11	5
210	2	17	3	3	16	18	6	5	
212	3	11	3	5	18	7	12	5	2
214		7		3	7	5	10	7	
216	1	4		2	6	4	3	8	2
218	1	3			3	1	5	2	
220		3			2	3	2	1	1
222	1		1	1	2		3	2	
224	1	2			1		1		
226						1		1	
230								1	
n	1459	4452	6294	3566	5099	4137	4179	3587	1359
Mean	175.2	180.8	162.4	169.3	178.5	172.6	168.2	170.5	167.8
% < 150 mm	2.3	0.8	16.2	2.7	0.8	3.1	7.0	4.3	7.2

TABLE 4. Mean Size (in Body Length) of Pacific Herring by School and Gear Type in San Francisco Bay, November 1989 to March 1990.

School #	Midwater Trawl Mean BL	n	Roundhaul Mean BL	n
1	182.2	456		
2	181.0	424		
3	178.8	1140		
4	173.4	1335		
5	164.6	1926	166.3	748
6	166.3	1131	168.4	391
7	167.7	969	172.8	115
8	167.8	1052	171.6	104
9	167.6	229		

The midwater trawl codend was 0.5 in stretched mesh. A 1.0 in. stretched mesh codend was used to sample in the 1988-89 season. Mean lengths from midwater trawl and roundhaul samples combined for a given school ranged between 182.2 and 165.1 mm.

Weight and Length Weights and lengths of 1,215 herring collected throughout the spawning season were used to generate length-weight relationships. Using natural logarithms the relationships by sex and ripeness were:

unripe females	$\ln W = -13.28 + 3.42 \ln L$	$r = .99$, $n = 188$
ripe females	$\ln W = -13.51 + 3.46 \ln L$	$r = .98$, $n = 347$
unripe males	$\ln W = -13.29 + 3.42 \ln L$	$r = .99$, $n = 21$
ripe males	$\ln W = -13.01 + 3.36 \ln L$	$r = .98$, $n = 451$
all ripe herring	$\ln W = -13.27 + 3.42 \ln L$	$r = .98$, $n = 798$

Estimated weights for ripe male herring for 130 and 230 mm BL (Appendix D) were 28.4 and 192.9 g. The estimated weights for ripe female herring of the same size were 28.0 and 201.5 g. These values were lower than those obtained from samples collected during the 1989-90 season.

Sex Ratios

The percentage of females in each school changed through the 1989-90 spawning season (Table 5) in a pattern similar to previous seasons (range 45 to 53 %). In general, females were numerically dominant in schools occupying the bay later in the season, with the exception of school 8. Herring schools from the beginning of the season through early January were composed of a higher percentage of males. Males were not as dominant in early January as in the 1988-89 season (Reilly, Oda, and Wendell 1989). Schools appearing in late January through the end of the season were dominated by females.

TABLE 5. Composition of Pacific Herring Samples by School and Sex for Gears Combined from San Francisco Bay, November 1989 to March 1990.

School #	Month	n	Percent by number male	female
1	Nov	456	52	48
2	Dec	424	52	48
3	Dec	1140	55	45
4	Dec-Jan	1335	53	47
5	Jan	2674	51	49
6	Jan-Feb	1523	48	52
7	Feb	1084	48	52
8	Feb	1160	51	49
9	Mar	229	47	53

Length at Age

The 1988 year class entering San Francisco Bay this season as 2-yr-old herring, had the smallest mean length in eight seasons. The 1987 year class exhibited the second lowest annual growth increment and the smallest mean length of returning 3-yr olds. Annual growth increments of most older year classes were within the previously-noted range for their respective ages. The mean length for the 1983 year class, at age 7, was an exception; it was the highest recorded mean length for that age (Table 6).

Weight at Age

Mean weight at age reflected the same growth patterns as mean length at age for 2- and 3-yr-old herring. The 1987 and 1988 year classes had the lowest corresponding mean weights in eight seasons of data collection. Annual growth increments for ages older than 5 were lower than previous seasons (Table 6), possibly reflecting poor growth conditions following the 1988-89 season.

Age Composition

Otoliths were aged from 1,237 herring collected from midwater trawls and roundhaul nets. All schools were sampled by midwater trawl. Roundhaul samples were collected from schools 5 through 8.

Surface ageing and age assignments based on an age-length key (Table 7) from all samples combined indicated that early season schools (schools 1 to 3) were composed largely of 3- and 4-yr-old herring. Unlike the 1988-89 season, 2-yr-old herring numerically dominated schools 5 through 9. School 4 had equal proportions of 2 and 3-yr olds (Table 8).

TABLE 6. Mean Body Length (mm) and Weight (g) of Pacific Herring in San Francisco Bay by Age and Season, 1983-84 to 1989-90.

Season	2	3	4	Length at Age 5	6	7	8
83-84	153	172	182	194	201	210	214
84-85	161	182	190	198	204	210	213
85-86	162	178	194	199	206	211	217
86-87	160	179	190	204	209	215	218
87-88	159	176	191	202	211	215	217
88-89	156	171	190	205	214	218	224
89-90	149	170	184	198	209	220	221

Season	2	3	4	Weight at Age 5	6	7	8
83-84	47.3	68.3	81.6	99.7	111.4	127.8	135.6
84-85	64.1	96.5	111.2	126.0	138.1	148.8	156.1
85-86	63.5	88.6	118.5	127.4	141.5	155.4	166.3
86-87	61.5	89.7	112.8	140.2	152.3	160.5	166.7
87-88	58.0	81.0	106.8	130.8	151.7	155.4	167.7
88-89	56.7	78.0	108.9	141.4	167.8	180.0	202.3
89-90	46.4	70.5	95.7	122.3	144.0	162.4	173.0

Table 7. Pacific Herring Age-Length Key for 1989-90 Season from Fish Collected in San Francisco Bay.

Size interval	2	3	4	5	6	7	8
< 130	24						
130-139	63						
140-149	140	2					
150-151	23	3					
152	23						
154	24						
156	42	2					
158	36	1					
160	14	7					
162	24	12					
164	10	25					
166	7	25					
168	5	20	3				
170	1	33	1				
172	1	23	2				
174		23	7				
176		17	11				
178		18	15				
180		5	26	2			
182		2	34				
184			26	4			
186			23	7			
188			15	7			
190			17	20			
192			6	29	1		
194		1	4	19	1		
196			1	21	2		
198			3	19	1		
200			4	30	8		
202			1	15	7		
204				16	5	1	
206				16	9		
208				13	11	1	
210				8	12	1	
212				2	11	3	1
214				3	12	3	1
216				2	4	5	1
218					2	1	
220					6	9	1
222					1	7	1
224						1	
226						4	2
228						2	1
230						3	
232							
234							
236						1	
n	437	216	199	233	93	42	8
Mean	149	170	184	198	209	220	221

TABLE 8. Age Composition (%) by School for All Gears Combined. Data Comprised of Ages From Otolith Reading and Assigned Ages Based on Length Using an Age-Length Key for the 1989-90 Season.

School #	1	2	3	4	5	6	7	8	# fish
1		6.4	31.8	36.4	20.0	4.8	0.6		456
2		9.4	34.2	30.4	20.8	4.5	0.7		424
3		17.1	32.6	28.3	16.1	4.2	1.7		1140
4		31.9	31.3	19.1	12.9	3.5	1.1	0.2	1135
5		50.5	32.4	10.9	4.9	1.0	0.2	0.1	2674
6	0.1	45.6	29.6	16.0	8.0	0.6	0.1		1523
7	0.2	42.2	32.0	14.7	9.0	1.5	0.2	0.2	1085
8	0.3	43.8	27.3	14.2	11.6	2.3	0.5		1160
9		43.7	26.6	15.7	10.1	2.6	1.3		229

Total Age Composition

Age structure of the spawning herring population this season was similar to previous seasons with a few exceptions. The percentage of 2-yr olds was high, second only to the 1983-84 season. The percentage of 3-yr-old fish was the second lowest in eight seasons, and the percentage of 5-yr olds was the second highest (Table 9). However, when adjusted for variable school biomass, 3-yr-old herring were relatively abundant (Table 10).

Maturation

The state of maturity, assessed for all sampled herring provided insight into maturation patterns on a population level. The proportion of ripe females, compiled by sampling day, fluctuated to a great extent early in the spawning season (Figure 6). Early in the season, the difference in percent ripe females between adjacent sampling days was a great as 65 percent. The largest differences were typically associated with spawning events. As the season progressed, differences in percent ripeness decreased. By the end of the spawning season, the largest difference between adjacent sampling days was only 14 percent.

This pattern suggested that herring schools occupied spawning grounds in a less mature state during the early portion of the spawning season. By the latter part of January, schools were considerably more mature upon arrival on the spawning grounds.

Tides and Spawning

Six of eight documented spawning runs this season took place during tidal cycles when the highest high tide occurred between sunset and sunrise. One spawn occurred when the highest high tide was midday. Six of eight spawning runs occurred when the highest

TABLE 9. Age Composition (percent by # and Wt.) of Pacific Herring in San Francisco Bay for 1983-84 through 1989-90 Spawning Seasons Using Spawn Escapement (A) and Hydro-acoustic (B) Biomass Estimates.

Method	Season	Age (yr) 2	3	4	5	6	7	8&9
% by # - A	1983-84	56.6	11.9	15.8	12.6	2.9	0.2	0.0
	1984-85	38.7	40.0	9.8	4.6	5.4	1.4	0.1
	1985-86	32.5	32.1	25.3	5.3	3.2	1.5	0.1
	*1986-87	29.2	33.6	23.1	11.2	1.6	1.1	0.2
	1987-88	30.6	38.3	17.9	8.7	3.3	0.7	0.5
	1988-89	25.8	39.0	24.6	7.8	2.2	0.5	0.1
	1989-90	34.4	31.2	18.8	11.8	2.8	0.8	0.1
% by # - B	1983-84	51.1	11.7	16.5	15.8	4.3	0.5	0.1
	1984-85	36.9	40.7	9.9	4.9	5.8	1.6	0.2
	1985-86	31.6	31.7	25.9	5.5	3.4	1.7	0.2
	1986-87	33.4	33.7	20.6	9.7	1.5	0.9	0.1
	1987-88	27.7	37.6	19.3	9.8	4.2	0.8	0.7
	1988-89	23.9	37.8	25.9	9.2	2.5	0.6	0.1
	1989-90	39.0	30.7	16.7	10.5	2.3	0.6	0.1
% by Wt. - A	1983-84	42.1	12.7	20.1	19.6	5.1	0.4	0.0
	1984-85	27.6	42.9	12.1	6.5	8.3	2.3	0.3
	1985-86	22.1	30.6	32.2	7.3	4.9	2.6	0.3
	1986-87	19.0	31.9	27.8	16.6	2.6	1.8	0.3
	1987-88	20.6	36.0	22.2	13.2	5.8	1.2	1.0
	1988-89	16.8	35.0	30.6	12.3	4.1	1.1	0.2
	1989-90	21.1	28.9	23.4	19.0	5.5	1.9	0.2
% by Wt. - B	1983-84	36.2	12.0	20.1	23.5	7.1	1.0	0.1
	1984-85	26.1	43.4	12.1	6.7	8.8	2.6	0.3
	1985-86	21.6	30.0	32.8	7.4	5.2	2.7	0.3
	1986-87	22.4	33.0	25.4	14.9	2.5	1.5	0.4
	1987-88	18.1	34.4	23.2	14.4	7.1	1.4	1.3
	1988-89	15.2	33.0	31.4	14.2	4.7	1.2	0.2
	1989-90	24.8	29.6	21.7	17.6	4.6	1.5	0.3

* Data from 1986-87 have been revised subsequent to publication of previous administrative report (Reilly and Moore 1987).

Table 10. **Estimated Number of 2, 3, and 4-year Old Herring (x 1000) by Year Class in the San Francisco Bay Spawning Population.**

Estimation method	Year class	Age 2	Age 3	Age 4
Hydroacoustic	1981	88,921	39,248	30,143
	1982	170,899	124,036	110,941
	1983	113,543	135,796	122,204
	1984	135,352	200,093	144,960
	1985	198,316	283,013	142,909
	1986	208,308	208,274	125,687
	1987	131,679	230,678	-
	1988	292,626	-	-
Spawn-plus-catch	1981	87,908	69,654	46,613
	1982	332,699	190,998	126,535
	1983	185,742	160,613	134,528
	1984	162,422	194,365	136,604
	1985	168,962	292,508	139,906
	1986	233,193	222,058	143,039
	1987	146,525	238,158	-
	1988	262,728	-	-

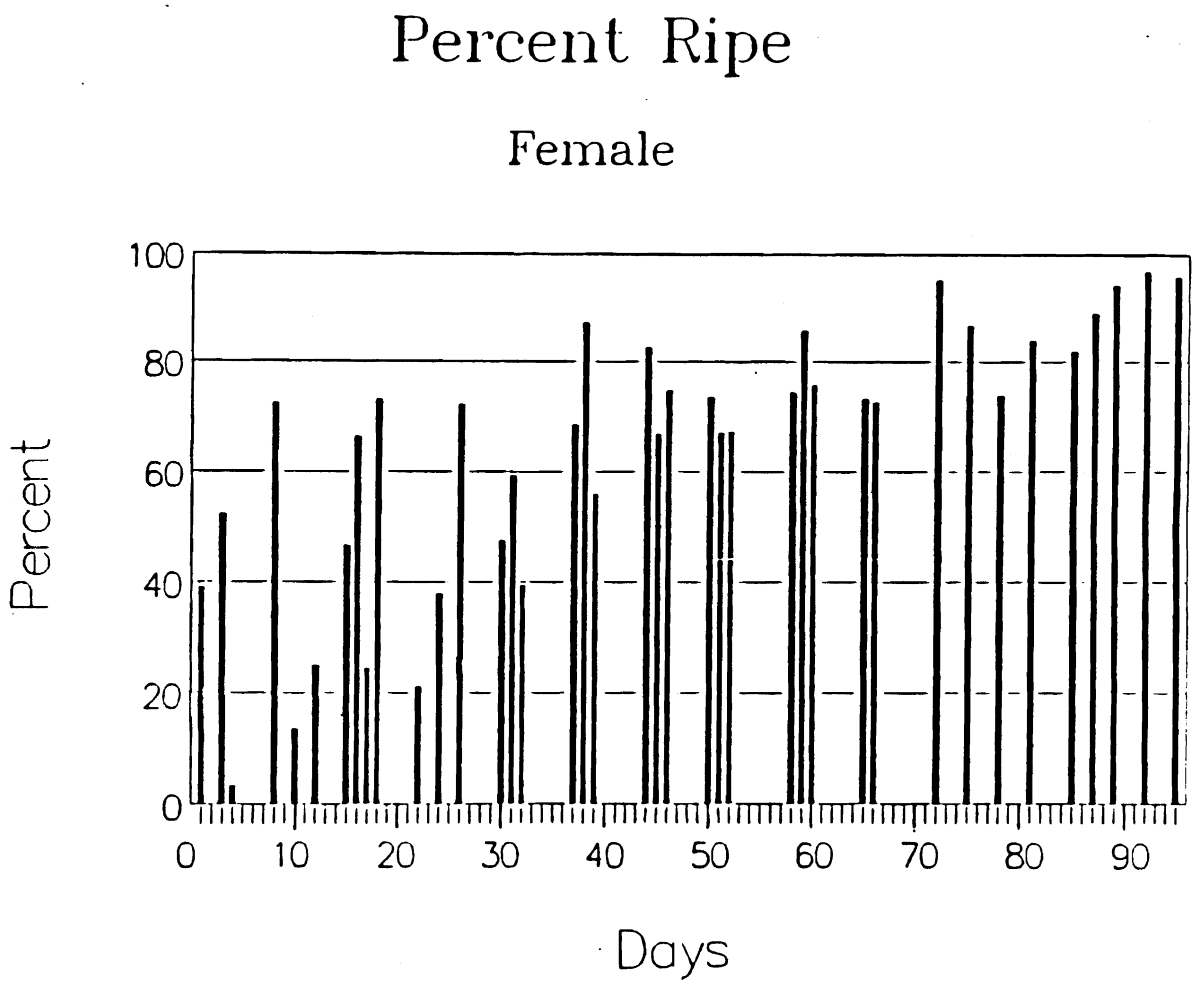

FIGURE 6. Changes in the percentage of ripe females from all samples combined by day through the 1989-90 spawning season in San Francisco Bay.

high tide was 5.4 ft or greater at the Golden Gate Bridge. Average highest high tide associated with spawning events this season was 5.4 ft (range 4.6 to 6.7 ft).

Biomass Estimation

Visual Integration

The visual integration method of assessing biomass was used throughout the 1989-90 spawning season. Twenty-five surveys provided several biomass estimates for all but the last of nine schools to occupy San Francisco Bay spawning grounds (Figure 7). The last school identified in the Bay was surveyed only once. In two instances, biomass estimates were combined when information indicated the surveys were conducted on discrete subcomponents of a school.

The highest biomass estimate for each school was selected when generating seasonal biomass totals (Table 11). When adjusted for any commercial take and rounded off, the seasonal biomass total using this technique was 58,100 tons.

Echo Integration

The biomass of schools 3 through 8 was estimated using the echo integration method. School 6 was surveyed twice; all others were surveyed once. The data, recorded on tape, was subsequently (post-spawning season) processed using an echo signal processor. The resulting biomass estimates were considerably different from those obtained from spawn escapement and visual integration hydroacoustic surveys. Since the results were suspect and considered spurious, a subset of data was submitted to consultants (BioSonics, Inc.) for review of input parameters and comparative analysis.

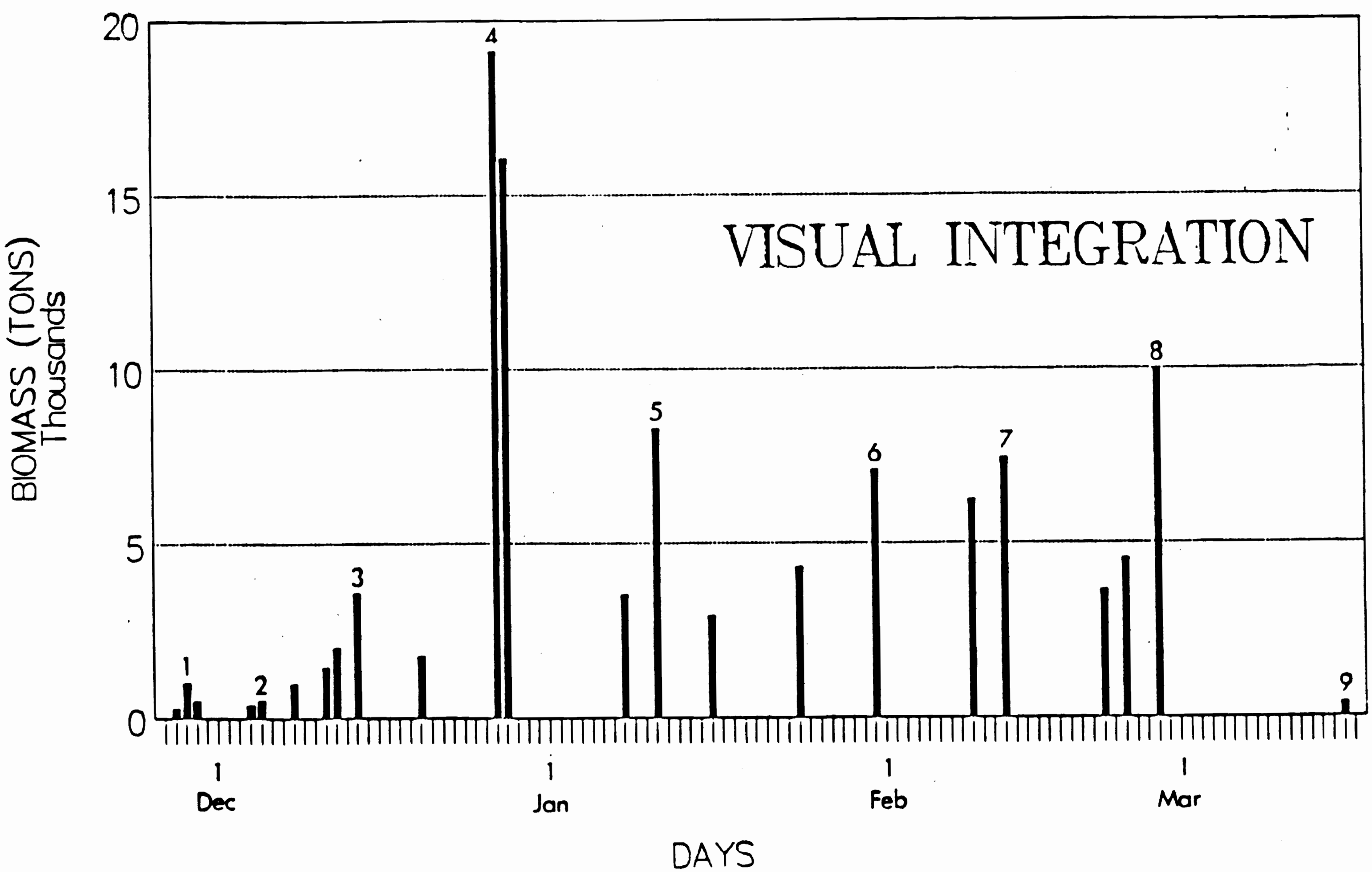

FIGURE 7. Biomass estimates of Pacific herring in San Francisco Bay during the 1989-90 spawning season. Peak biomass for each school is identified by school number.

Table 11. Biomass Estimates for the 1989-90 Season by School and Survey Technique and Coordinated "Best" Estimate.

School	Hydroacoustic* estimate	Spawn* estimate	"Best" estimate	Method** used
1	1000	700	850	3
2	500	3500	2000	3
3	3700	10100	6900	3
4	19100	25500	23300	3
5	8300	9700	9000	3
6	7500	4100	5800	3
7	7500	400	7500	1
8	10100	7400	8750	3
9	400	-	400	1
Total			64500	

* adjusted for catch - estimates rounded to nearest 100 tons

** 1 = hydroacoustic, 2 = spawn escapement, 3 = average

Selection of the value used in the bottom tracking parameter was identified by the consultants as the primary reason for the spurious results. Although not apparent during analysis, the selected bottom tracking value (1 v) was low enough that the echo signal processor identified the upper layer of dense fish concentrations as the bottom. The inability to discriminate was exacerbated by fish concentrations near the bottom.

Reanalysis of the data subset, using a new value for the bottom tracking parameter (6 v), yielded values high enough to account for differences observed between estimation methods. Reanalysis of the entire data base will be conducted and reported upon in the next administrative report.

Total Biomass Estimate

The meshing of biomass estimates from the hydroacoustic and spawn escapement surveys provided a seasonal total biomass estimate of 64,500 tons (Table 11). This estimate was higher than the total from either of the surveys individually.

Bodega Bay

A hydroacoustic survey of the Bodega Bay area was conducted on February 22, 1990. A number of dense concentrations of fish, assumed to be herring, were observed hydroacoustically in the immediate area being fished by herring gill net permittees. The biomass estimate was 354 tons. An additional 95 tons of herring were landed and assumed to be additional to those assessed hydroacoustically. The total, then, for the Bodega Bay area within the survey time frame was approximately 445 tons.

Young-of-the-Year

Field Surveys

Forty YOY survey tows were conducted from April to July, 1989. Six of the tows did not yield YOY herring. The remaining 34 tows yielded 1883 YOY herring, 1441 of which were measured. The mean length for the 1989 year class increased from 39 mm in April to 57 mm in July. Mean length of YOY in May 1989, when compared to May values obtained in prior years, suggested that the 1989 year class had appreciably slower than normal growth through May (Table 12). However, the mean length for July samples (57 mm) was slightly greater than the value obtained in July 1988 (53 mm).

Relative year class strength was assessed by creating an index of abundance based on CPUE data from the Department's Bay-Delta Fishery project surveys. The catch of YOY herring was adjusted by considering the volume of water filtered and summed to create an index of abundance. The 1989-90 index value for selected Bay-Delta Fishery project tows was 6249, a relatively high value in comparison to similar values obtained in most prior years (Table 13). This suggests that the 1989 year class may be strong.

Recruitment Forecasting

Evaluation continued on the value of the index as a forecaster of recruitment strength. Validation is based on comparisons between predicted and assessed recruitment levels through time (Figure 8). This season (1989-90) provided the first opportunity to compare predicted and assessed values.

The index value for the 1988 year class (1640) was the seventh lowest in rank out of nine years of available data. The estimated abundance of that year class as 2-year olds during the 1989-90

Table 12. Comparison of Growth of Young-of-the-Year, Measured by May Mean Body Length, for the 1983 through 1989 Year Classes.

Year class	n	Mean BL	Dates of peak spawn
1983	2327	52.4	Jan 5 - 12
1984	1818	54.0	Jan 25 - Feb 2
1985	4452	44.7	Jan 6 - 9
1986	1813	54.2	Jan 5 - 8
1987	205	53.5	Jan 18 - 23
1988	874	45.9	Jan 25 - 28
1989	310	39.6	Jan 12 - 18

Table 13. Forecasting Index Value (Adjusted Catch of Young-of-the-Year Herring from Selected Stations) by Year Class and Subsequent Recruitment Strength as 2-yr olds.

Year class	Index value	Recruitment season	Recruitment strength
1980	3783	-	-
1981	495	82-83	87908
1982	13580	83-84	332699
1983	641	84-85	185742
1984	3517	85-86	162422
1985	4107	86-87	168962
1986	9296	87-88	233193
1987	4241	88-89	146525
1988	1640	89-90	262729
1989	6250		

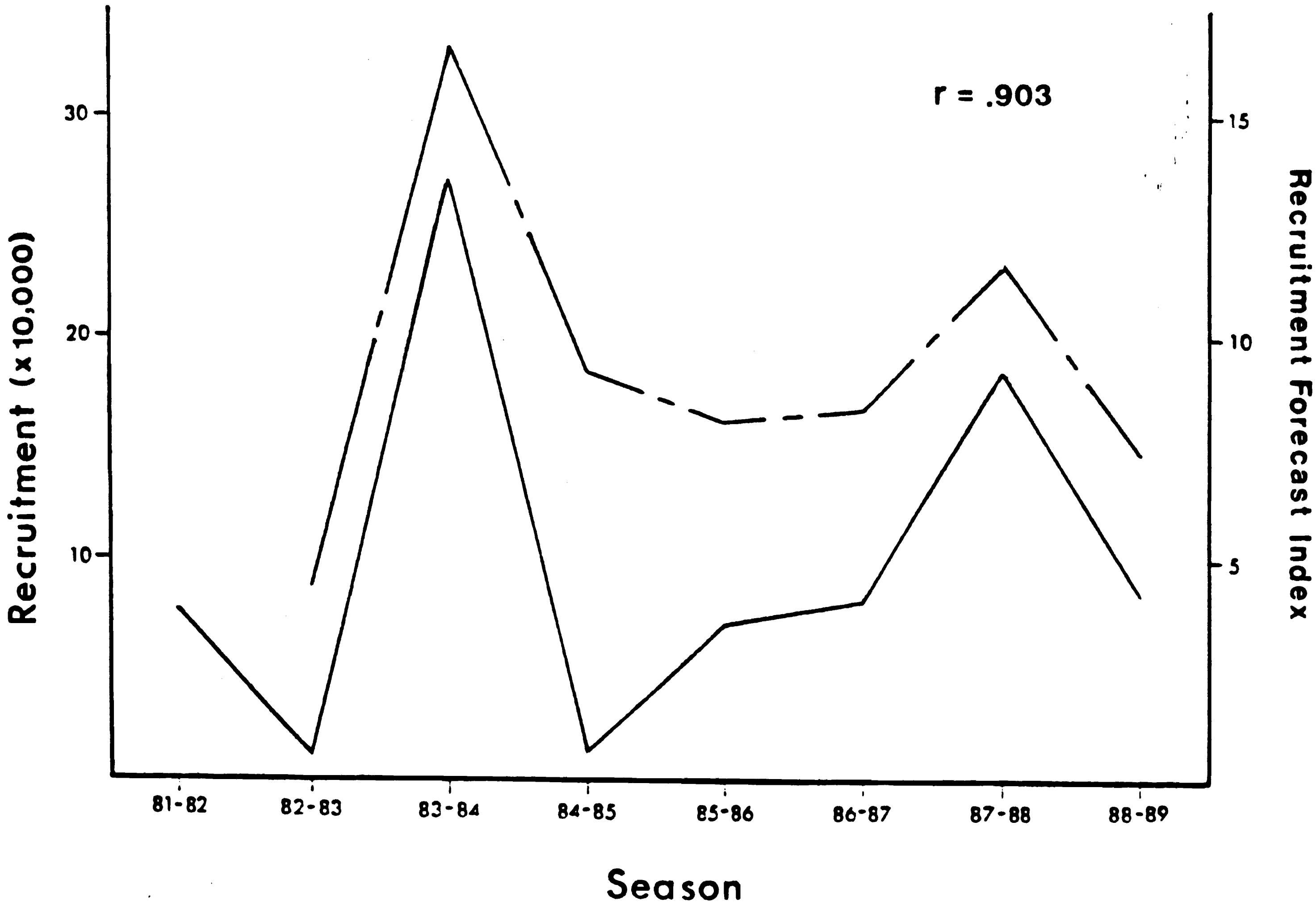

FIGURE 8. Relationship between a forecast of recruitment (solid line) and the subsequent estimate of recruitment strength as 2-year olds by spawning season.

season was the second highest in rank in a series of eight. The resulting correlation between the index of recruitment (predicted value) and the subsequent estimation of abundance dropped considerably (r = 0.903 to r = 0.722).

DISCUSSION

The 1989-90 season showed the same general pattern of changes in sex and age composition observed in prior seasons. Three- and four-year-old herring dominated early season schools and males outnumbered females. Younger fish became more abundant as the season progressed, and by January 90% of the herring by number were 2- and 3-yr olds.

The 1987 year class rebounded during the 1989-90 season from a poor showing as 2-yr olds. As 2-yr olds, the 1987 year class was the second lowest in percent composition for any season studies (Table 9). As 3-yr olds, they comprised over 30% of the spawning biomass, just below the seven-year average of 32%.

The 1988 year class made a very strong showing with the second highest percent composition in eight years of study. The relative abundance of 2- and 3-yr olds during the last two years suggested that any ageing bias from the new personnel was minor. At least no consistent pattern existed which might suggest a directional bias.

Conditions following the 1988-89 spawning season were not favorable to the growth of herring. The mean size of 2-yr-old herring was the lowest in eight seasons. Mean weights of older herring also suggested poor growing conditions; however, not to the degree suggested by 2-yr-old herring mean size. Young-of-the-year and 1-yr olds may be more sensitive to fluctuations in conditions affecting growth. There are indications from a wide range of sources suggesting that poor growing conditions may continue.

Water temperatures along the California coast appeared to be elevated during the summer of 1990. Surf fishermen, fishing south of the Golden Gate Bridge, reported frequent sightings of bottle nose dolphins throughout the summer. Jack salmon returning to the American River were significantly smaller than average. The National Marine Fisheries Service juvenile-rockfish surveys indicated a very weak year class for most species. The California Department of Fish and Game's Bay-Delta Fisheries Project also reported low numbers of young-of-the-year for most species within the Bay Delta area, including herring.

Although not validated, the forecasting index value obtained for the 1990 year class was extremely low. These data were not presented in results, and typically would not be presented until the next report is published. However, the possibility of an extremely weak year class should be considered in the management process.

The hydroacoustic biomass estimate for the 1989-90 spawning season was within 5 % of the spawn escapement biomass estimate. However, the final spawn escapement estimate was augmented with hydroacoustic data, leading to an estimate which was higher than it would have been without meshing the two techniques and not totally independent. This was the fourth season in a row where both estimation techniques yielded similar results when treated separately. Spawn escapement estimates of school biomass have also been used in the past when hydroacoustic estimates were not available.

A seasonal total biomass estimate was generated for the first time to formalize the process of meshing estimates from the two techniques. Averaging estimates for a school when both techniques were deemed to have provided reasonable results would tend to minimize biases inherent in both techniques. Using one when the other is deemed inadequate, should enhance precision of the final season total. However, the seasonal combined or pooled biomass estimate was higher than the total from either technique taken separately.

The development of quotas based on this estimate should consider the probability that meshing produces optimistic yield estimates by limiting a conservative bias. Quotas have typically been set at values representing 15 to 20 percent of the spawning biomass. While meshing is evaluated, it seems prudent to set the quota at the lower end of the yield range.

A problem was encountered in the analysis of the echo integration data. Although resolved, the existence of the problem highlighted the need to consider future direction in hydroacoustic survey efforts. Visual integration provides an intuitively meaningful data base which lacks precision. Echo integration, on the other hand, is theoretically more precise. However, it is very sensitive to subtle changes in input parameters that can result in significant differences in final biomass estimates. The appropriateness of selected input values is not intuitively obvious and those selected cannot be readily validated.

Given the extended learning period necessary to properly operate the echo integration system and analyze the data, it may make more sense to use echo integration to refine the precision of the visual integration technique. This course of action also makes sense when one considers the likelihood of recurrent personnel changes.

If this direction is taken, echo integration would be used to refine density standards currently used in the visual integration analysis process. It would free the echo integration equipment for other uses, particularly open ocean applications where visual integration would not work.

The visual integration survey of the Bodega Bay outer waters yielded enough information to generate a biomass estimate. However, the results may not be as accurate as those obtained from surveys within San Francisco Bay. The distribution of fish was markedly different. In the Bodega Bay area, fish were clustered in very tight, dense, and small balls. Very subtle differences in course could yield widely different pictures of herring abundance. It was difficult to plot distribution on maps and to apply density standards.

If this distribution was typical for the Bodega Bay area, the utility of visual integrations methods are limited. A very wide spread open ocean distribution would also limit the utility of visual integration. In both cases, the echo integration system would provide better data.

The maturation pattern for the female herring population has some significance when management of the fishery is considered. Wrapping and releasing of herring by roundhaul nets has been considered to cause mortality from chafing. Fish release is most likely to occur when the ripeness of females is most variable. The maturation pattern suggests that releasing of captured fish is most likely early in the season (Nov - Dec). The use of test boats to sample fish would be most critical during this period.

Forecasting recruitment strength is a necessary first step in the process of setting quotas based on anticipated biomass levels. Quotas, based on current biomass levels, do not consider the possibility that the incoming year class strength can be significantly different in the next year. The relative abundance of year classes, particularly for a pelagic shoaling species like herring, can vary widely.

A method of forecasting recruitment strength has been developed and is being validated. However, the initial appraisal in the validation process suggested that the technique may be more useful as a measure of relative abundance, rather than as an estimate of absolute abundance. Several more years will be necessary to fully evaluate the technique's predictive capabilities and integrate it into a new system for estimating biomass levels.

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Appendix A. Summary of Herring Samples from San Francisco Bay, November 1989 to March 1990.

Sample number	Date	Location*	Gear**	Number measured	Number aged	Assigned school #
804	Nov 27	SB	MT	196	93	1
805	29	SB	MT	43	2	1
806	29	SB	MT	217	16	1
807	30	SB	MT	51	3	2
808	Dec 4	RS	MT	360	16	2
809	4	SB	MT	5		2
810	6	BB	MT	8		2
811	6	TI	MT	164	116	3
812	8	SB	MT	285	14	3
813	11	SB	MT	84	1	3
814	12	SB	MT	282	9	3
815	13	SB	MT	129		3
817	14	SB	MT	120	2	3
818	14	SB	MT	76	3	3
819	18	AL	MT	122	6	4
820	20	HR	MT	79	69	4
821	22	AL	MT	151	71	4
822	26	SB	MT	309	8	4
823	27	SB	MT	203	3	4
824	28	SB	MT	64	1	4
825	Jan 2	AL	MT	95		4
826	3	SB	MT	324	4	4
827	3	AL	MT	214		?
828	4	RS	MT	208	2	5
829	9	SA	MT	238	76	5
830	9	SA	RH	147	19	5
831	9	SA	RH	147	11	5
832	10	RS	MT	169	9	5
833	10	SB	MT	184		5
834	10	SA	RH	163	5	5
835	10	SA	RH	126	6	5
836	11	SB	MT	219		5
837	11	RS	RH	165	3	5
838	15	RS	MT	223	7	5
839	15	SB	MT	292	109	5
840	16	SB	MT	167	17	5
841	17	RS	MT	226	3	5
842	23	SB	MT	150		6
843	24	TB	MT	314		6
844	25	SB	MT	135		6
845	30	SB	MT	72	68	6
846	31	HR	MT	225	43	6
847	Feb 6	HP	MT	235	14	6
848	6	HP	RH	161	5	6
849	6	HP	RH	123	3	6
850	6	HP	RH	108	3	6
851	9	SB	MT	335		7
852	9	AL	MT	180		7

Appendix A. Summary of Herring Samples - Cont'd

Sample number	Date	Location*	Gear**	Number measured	Number aged	Assigned school #
853	Feb 12	SB	MT	136	95	7
854	15	HR	MT	179	19	7
855	19	TI	MT	43	4	7
856	19	SB	MT	96	3	7
857	19	TI	RH	115	12	7
858	21	HP	MT	171	10	8
859	23	HP	MT	3		?
860	23	TI	MT	17		8
861	23	HP	MT	154		8
862	26	AL	MT	381		8
863	26	AL	RH	104		8
864	27	TI	MT	136	107	8
865	Mar 1	TI	MT	194	21	8
866	15	HR	MT	231	120	9

* AL=Alcatraz BB=Oakland-Bay Bridge HP=Hunter Point
HR=Harding Rock RS=Raccoon Strait SA=Sausalito
SB= South Bay TB=Tiburon TI=Treasure Island

** MT=midwater trawl RH=roundhaul net

Appendix B. Number of Pacific Herring by Body Length (2 mm Interval from Midwater Trawl Samples Collected in San Francisco Bay, November 1989 to March 1990.

Size interval	Sample # 804	805	806	807	808	809	810	811	812	813
110-139										
140-141			1		1					
142			1	1						
144					1			1		
146			1		1			1	1	
148					1			1	3	
150					2			2	2	1
152	1						2	1	1	2
154			1		1				1	4
156			1		3			3	4	2
158			3		4		1	1	1	2
160	5		1	1	11			2	6	1
162	2	1	3	1	11	1		6	9	
164	8	4	6	2	11	1		4	13	3
166	11		6	1	11			5	8	4
168	6		13	1	10	2	1	7	5	3
170	9	1	12	6	17			6	11	4
172	8	1	9	3	20			9	20	3
174	12	2	19	1	24		2	5	16	7
176	9	5	15	4	23			5	16	4
178	14	2	12	4	19			13	20	3
180	15	2	26	3	27			6	21	6
182	12	1	15	1	24			4	22	4
184	7	8	15	4	25			12	23	5
186	10	1	8	2	11		1	6	11	1
188	3	1	4		10			13	5	
190	6	2	5	2	11	1		4	9	3
192	13	2	4	3	16		1	6	8	2
194	4	2	4	2	6			3	4	5
196	6		6	1	6			3	3	
198	8	1	5	3	8			8	4	3
200	9	2	5	1	10			6	8	2
202	3	2	3	1	6			1	9	1
204	2		1		5			3	2	3
206	2	1	1	1	2			4	4	
208	3		3		3			5	4	2
210	2	1	4		9			2	1	1
212	2		1		5			3	1	
214	2		1	1	2			3	5	2
216			1		2					
218				1	1				2	
220	2	1								1
222			1						2	
224										
n	196	43	217	51	360	5	8	164	285	84
Mean	183.2	184.7	180.7	182.0	181.2	171.2	170.0	183.0	180.9	180.2

Appendix B. Midwater Trawl Samples - Cont'd

Size interval	Sample # 814	815	817	818	819	820	821	822	823	824
110-139	1						1	5	2	
140-141	1								1	
142	1	1		1			1	1		
144						1	1	5		1
146	1		2	1	1			6	1	1
148	2	1	1		2	2	2	3	5	1
150	2		2		1		4	9	3	
152	5	2		1		1		8	5	2
154	2	2	4	1	3	1	2	16	3	
156	9	4	3	5	4	1	3	13	7	1
158	4	5	3	4	2	1	5	21	8	
160	7	7	5	1	7	2	4	24	10	1
162	14	8	2	3	10	7	2	30	11	4
164	10	9	8	3	7	6	4	15	9	3
166	14	9	6	5	6	4	7	16	10	8
168	10	8	9	6	2	2	7	18	7	5
170	8	6	6	3	9	1	4	13	13	4
172	17	7	5	3	5	2	4	9	10	7
174	26	4	10	6	4	1	3	11	9	2
176	13	10	9	4	9	5	7	7	4	4
178	16	4	6	3	4	3	3	6	5	1
180	8	6	8	11	8	7	2	11	9	4
182	11	9	3	2	1	5	9	8	5	1
184	6	5	4	2	5	3	6	10	10	1
186	12	3	3		1	1	4	5	9	2
188	10	3	6		2	2	5	10	6	
190	6	1	4	1	3	3	4	2	6	
192	9	1	1	1	2	4	7	6	6	3
194	8	1	1	1	3	1	3	2	3	1
196	6	2	4	1	2	2	1	3	3	
198	8	1	2	1	3		5	3	1	
200	6	2		3	2	1	4	3	2	1
202	4	1	1		2	1	2		4	1
204	7	1		2	4	2	3	3	3	1
206	2	1			2	2	2	2	1	
208	2	3				2	2		3	
210	3		1		1	2	5		2	2
212	3	1				1	2		1	
214	2				1		3	1	2	1
216	1	1	1		1		3	2	1	
218	2								2	
220	2				1		1	1		1
222	1				2					
224										
226				1			1	1	1	
228							1			
n	282	129	120	76	122	79	139	309	203	64
Mean	179.0	174.3	174.4	174.4	177.3	178.8	182.0	168.6	175.5	174.9

Appendix B. Midwater Trawl Samples - Cont'd

Size interval	Sample # 825	826	828	829	832	833	836	838	839	840
110-139		1	1	4	1		3	5	3	5
140-141	2	2	2	1	1			5	3	5
142	1	1	1	4	1	1	3	6	6	2
144		8	6	8	1	4	1	2	7	3
146	4	4	4	7	5	3	4	4	7	3
148	4	3	4	9	2	3	3	4	7	6
150	5	5	4	10	7	2	2	5	11	6
152	3	10	14	14	7	3	13	8	17	8
154	7	6	13	15	9	5	5	9	18	17
156	6	14	5	21	11	6	11	14	17	8
158	7	10	12	26	11	8	12	23	21	12
160	5	11	11	20	8	13	15	21	17	12
162	4	21	14	19	6	6	19	20	16	15
164	9	19	17	20	8	15	19	12	28	9
166	8	26	14	24	15	14	14	15	15	11
168	4	22	17	7	13	14	13	9	14	3
170	5	20	10	6	11	11	16	11	11	6
172	5	16	10	5	8	15	12	10	10	5
174	2	21	1	4	11	9	10	4	7	2
176	3	6	6	2	4	3	5	7	2	1
178	2	10	4	6	5	10	5	7	6	3
180		7	8	1	3	4	2	2	4	2
182		7	5	1	1	4	5	3	5	2
184		8	4	1	3	5	5	4	6	3
186		10	3		5	5	3		5	
188		6	3		3	3	2	1	4	5
190	1	7	4		1		2	1	3	1
192	1	4	1			2	1	3	1	3
194	3	9	1		1	3	2	1	3	1
196		4	2	1	3	1	3	1	5	2
198		2			1	2			1	
200	2	2	1	1	1	1	1	1	2	2
202	2	3	3		1	2	3	1	1	1
204		5	1			2	1	1	1	2
206		4	1			2	1	1	1	
208		2					1	1	3	
210		2		1		1	1		1	
212		1			1					
214							1		2	
216		1								1
218		1				2		1	1	
220										
222			1							
224										
226										
228		1								
230		2								
n	95	324	208	238	169	184	219	223	292	167
Mean	164.2	172.4	166.6	160.0	166.7	170.7	167.5	163.8	165.3	163.3

Appendix B. Midwater Trawl Samples - Cont'd

Size interval	841	842	843	844	845	846	847	851	852	853
					Sample #					
110-139	7	6	2		4	4	7	6	4	1
140-141	3	2		1	2		3	1	1	2
142	4	2	6	1		3	1	4	1	1
144	10	5	3	1	2	4	3	6	1	1
146	5	3	4	4	1	11	4	9	5	1
148	12	3	8	1	1	8	7	4	4	4
150	10	6	6	4	3	9	8	15	6	5
152	15	9	8	6	1	7	7	12	8	5
154	19	11	12	7	3	12	7	13	10	4
156	21	11	19	6	3	16	13	30	10	8
158	18	9	21	6	4	14	12	24	11	4
160	16	6	27	7	5	22	13	26	12	7
162	17	14	24	14	4	16	12	21	8	6
164	20	10	19	12	1	14	12	19	17	8
166	6	6	16	5	1	12	15	19	10	4
168	6	7	17	10	6	8	13	17	11	5
170	6	6	14	5	5	11	7	18	16	6
172	9	4	11	7	2	7	8	7	9	4
174	2	5	10	7	2	5	6	11	4	2
176	5	2	7	4	2	6	13	11	6	6
178	2	2	12	4	1	4	10	5	8	4
180	1	2	11	5	2	2	5	4	5	8
182	3	1	12	1	2	6	10	10		6
184	1	5	8	4	3	5	4	2	2	4
186	1	1	8	2	3	4	8	7	1	5
188	3	2	4	2	2	2	1	2	2	3
190	1	3	4	2	1	4	10	10		5
192	1	2	3	1	2	3	5		1	4
194	1	1	4	4		3	4	5	2	5
196		1	6	1		1	1	2	2	1
198		1						3		2
200		1	3		2			2	1	2
202		1			1	1	2	4		
204					1			1		
206	1	1	1	1			3	2	1	1
208			1			1		2		2
210										
212			1				1	1		
214										
216			1						1	
218										
220										
222										
224										
226										
228										
n	226	151	313	135	72	225	235	335	180	136
Mean	159.2	163.1	167.9	167.2	167.4	163.8	167.9	165.7	164.9	171.4

Appendix B. Midwater Trawl Samples - Cont'd

Size interval	Sample # 854	855	856	858	860	861	862	864	865	866
110-139	5	3	3	6		5	15	10	5	11
140-141			1	1		2	2	1	1	1
142	2		1	2	3	1	6	3	2	6
144	1		1	4	1	3	10	1	6	2
146	3		2	3		4	8	3	2	6
148	2	1	2	3		2	11	6	12	10
150	6	2		3		5	13	1	9	2
152	5	1	4	6		8	11	9	4	7
154	8	1	6	6		7	21	4	13	12
156	7		6	8		10	26	3	13	14
158	9	1	5	4	1	1	21	2	15	8
160	8	1	8	6	2	13	28	7	9	15
162	9	2	3	6	1	8	26	7	8	11
164	8	2	3	8	3	8	17	8	15	10
166	15	3	10	4		10	19	5	5	6
168	14	2	3	7		1	15	3	4	10
170	11	1	3	8	1	10	15	6	11	7
172	5	2	4	4		4	11	4	7	9
174	6	2		5	1	3	7	6	5	9
176	3	2	4	4		3	7	3	7	6
178	4	4	2	7		3	6	3	8	7
180	7	1	3	4	1	2	9	3	2	5
182	4		2	4		6	9	4	8	10
184	6	1	3	8	1	2	6	2	3	6
186	4			3	1	6	9	2	2	7
188	5	1	1	10		5	4	1	2	6
190	5	2	2	2		2	12	7	3	3
192		1	3	9		2	9	3	1	4
194	4		2	8		5	7		3	1
196	4		1	1		4	6	1	4	3
198	2		3	3		2	3	2	2	1
200	3	1		2		1	3	7		
202	2	1	1	2	1	1	3		1	2
204		1	2				3	2		3
206	1	2	2	2			1	2		5
208				1				3		
210				1		2			1	1
212		1				1	1	1	1	1
214	1			2						1
216				2			1			
218						2				
220				1						1
222				1						
-										
228								1		
236		1								
n	179	43	96	171	17	154	381	136	194	229
Mean	169.6	176.9	168.6	173.0	165.1	168.7	166.0	169.0	165.0	167.6

Appendix C. Number of Pacific Herring by Body Length (2 mm Interval) from Roundhaul Net Samples Collected in San Francisco Bay, January to March 1990.

Size interval	Sample # 830	831	834	835	837	848	849	850	857	863
110-139	1	1	2			3	1	2	1	1
140-141		1	1		1	1	1			
142	1	2		1			3		2	1
144	2	2	2		2	2	1	1	1	
146	3	3	3	4	3	2	5		2	3
148	4		2	1	6	4	4	2	6	1
150	9	1	7	1	5	4	3	4	3	2
152	6	3	8	8	5	11	4	1	7	3
154	6	7	8	4	3	6	4	5		2
156	9	5	11	7	10	8	9	4	4	2
158	11	8	11	7	9	9	12	6	2	4
160	19	15	9	7	15	12	10	7	4	4
162	10	15	12	14	15	7	8	4	4	10
164	10	14	14	17	13	11	7	4	4	7
166	12	11	16	11	15	8	10	3	3	5
168	6	5	10	6	9	9	5	4	7	10
170	8	11	6	8	10	4	6	6	7	6
172	4	5	1	9	5	9	5	6	3	5
174	1	3	4	2	5	4	2	3	8	3
176	2	4	2	1	6		2	5	2	4
178	5	2	8		2	7	4	5	6	4
180	6	1	1		2	3	3	3	3	1
182	4	3	1	4	6	3	2	3	2	5
184	4	8	5	2	5	5	2	3	6	1
186		4	3	4	1	7	2	7	2	
188		1	3		2	4	1	2	7	1
190	2	3	1	1	2		2	4		2
192		1	3		3	6	1	4	2	5
194				4	1	6	1	2	2	3
196	1	1	4			1		2	2	1
198			1	2		3		3	2	3
200		3	2		1	1			3	1
202	1	1	1		1			1	3	1
204		1				1	2		2	1
206					1				2	1
208			1		1		1	1		1
210										
212								1	1	
214										
216		2								
218										
220				1						
n	147	147	163	126	165	161	123	108	115	104
Mean	163.8	168.2	166.3	166.5	166.6	168.3	164.7	172.5	172.8	171.6

Appendix D. Estimated Weight (g) at Length (mm) for Ripe Pacific Herring in San Francisco Bay Collected During the 1989-90 Season.

Body length	Weight male	Weight female	Weight both	Body length	Weight male	Weight female	Weight both
130	28.4	28.0	29.3	180	84.6	86.3	89.1
132	29.9	29.5	30.9	182	87.8	89.6	92.5
134	31.4	31.1	32.5	184	91.1	93.1	96.1
136	33.0	32.7	34.2	186	94.5	96.6	99.7
138	34.7	34.4	35.9	188	97.9	100.3	103.4
140	36.4	36.2	37.7	190	101.5	104.0	107.2
142	38.2	38.0	39.6	192	105.1	107.9	111.1
144	40.0	39.9	41.5	194	108.9	111.8	115.1
146	41.9	41.8	43.6	196	112.7	115.8	119.2
148	43.8	43.8	45.6	198	116.6	120.0	123.5
150	45.9	45.9	47.8	200	120.6	124.2	127.8
152	48.0	48.1	50.0	202	124.7	128.6	132.2
154	50.1	50.3	52.3	204	128.9	133.0	136.7
156	52.3	52.6	54.6	206	133.2	137.6	141.4
158	54.6	55.0	57.1	208	137.6	142.3	146.1
160	57.0	57.4	59.6	210	142.1	147.1	151.0
162	59.4	59.9	62.2	212	146.7	152.0	155.9
164	61.9	62.5	64.8	214	151.4	157.0	161.0
166	64.5	65.2	67.6	216	156.2	162.1	166.2
168	67.1	68.0	70.4	218	161.1	167.4	171.6
170	69.8	70.8	73.3	220	166.1	172.8	177.0
172	72.6	73.7	76.3	222	171.2	178.3	182.6
174	75.5	76.7	79.4	224	176.5	183.9	188.3
176	78.5	79.8	82.5	226	181.8	189.6	194.1
178	81.5	83.0	85.8	228	187.3	195.5	200.0
				230	192.9	201.5	206.1