Pacific Herring, *Clupea pallasi,* Spawning Population Assessment for San Francisco Bay, 1992-93

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Abstract

We conducted hydroacoustic surveys, spawn surveys, and sampled schools and fishery landings from 8 November 1992 through 18 March 1993 to assess the status of San Francisco Bay's Pacific herring spawning population. Our spawning biomass estimate of 21,186 tons is the lowest since 1978 when subtidal spawns were included in estimates; it also represents a third consecutive season of decline. The principal reason for this very low estimate is a lack of two-, three-, and four-year-old herring in the spawning population from the 1991, 1990, and 1989 year-classes. Although four-year-olds were the most abundant cohort, their actual number was very low. Five-year-olds from the highly successful 1988 year-class were the second most abundant cohort.

Warm-water conditions and poor upwelling associated with the 1991-92 El Niño are likely causes of the low spawning biomass, although adverse impacts on the condition and growth of spawners were not apparent. Warm water may have displaced herring to the north of San Francisco Bay.

We also continued to collect data for a herring young-of-the-year abundance index during April, May, and June of 1993. The index was low for the 1990 and 1991 year-classes, but high for the 1989 year-class. The 1989 and 1990 year-classes appear poor; however, the success of the 1991 year-class will not be known until next season when it fully recruits to the spawning population.The index for the 1992 year-class is relatively low as is the index for 1993.

The season's 5,555-ton quota (based on the previous season's biomass estimate) exceeded our harvest goal of no more than 20% of spawning biomass for the first time since the 1970s.The number of three-year-old fish in gill net catches increased substantially this season, possibly indicating the use of smaller mesh.

Because of the extremely low spawning biomass and uncertainty about future recruitment, our recommendation to the Fish and Game Commission was to close the herring roe fishery in San Francisco Bay until the season following a spawning biomass estimate of 26,000 tons.

Introduction

Since the inception of a sac-roe fishery for Pacific herring, *Clupea pallasi*, in 1973, the California Department of Fish and Game (CDFG) has annually assessed the status of the state's two largest herring spawning populations, in Tomales and San Francisco Bays (Spratt 1992, Oda 1994). Each year, the Department estimates spawning biomass, determines the age structure and year-class composition of the spawning population, evaluates growth and general condition, estimates the abundance of young-of-the-year, and monitors biological aspects of the catch. This information, along with trends in oceanic conditions, is considered and then used to set harvest quotas for the fishery for the following season.

San Francisco Bay supports the largest spawning population of Pacific herring, as well as the largest fishery, in the state. Spawning generally occurs from November through March, in intertidal and shallow subtidal regions of the central and southern portions of the Bay. Pacific herring lay adhesive eggs on a variety of substrates, including rock, pier pilings, and vegetation.

The Pacific Herring Research Project assesses the status of the San Francisco Bay herring population. The project estimates spawning biomass with spawn surveys and hydroacoustic surveys of herring schools. These two surveys are conducted independently, then used in combination to estimate biomass. The spawn survey, conducted since 1973 (Spratt 1992), estimates tons of spawning adults based on calculations of the total eggs spawned. Prior to spawning, the hydroacoustic survey estimates tons of spawning adults by measuring school size. Hydroacoustic surveys were conducted experimentally from 1980 to 1988-89, but have since been used in combination with spawn surveys to estimate biomass.

This report presents work conducted during the 1992-93 season in San Francisco Bay, continuing the time series of information on this population of Pacific herring. Unlike previous administrative reports, which presented different parts of the season's work separately (e.g., spawn surveys, hydroacoustic surveys, biological aspects of the catch), we have combined all aspects of the project for the 1992-93 season into this one report.

Study Area

All project activities took place inside San Francisco Bay, primarily within the area bounded by the Richmond-San Rafael Bridge to the north, the Golden Gate Bridge to the west, and the San Mateo Bridge in the south (Figure 1). Spawn surveys were conducted in intertidal and shallow subtidal zones of this area, usually to the north of Candlestick Point; hydroacoustic surveys and sampling of herring schools took place in deeper portions of the

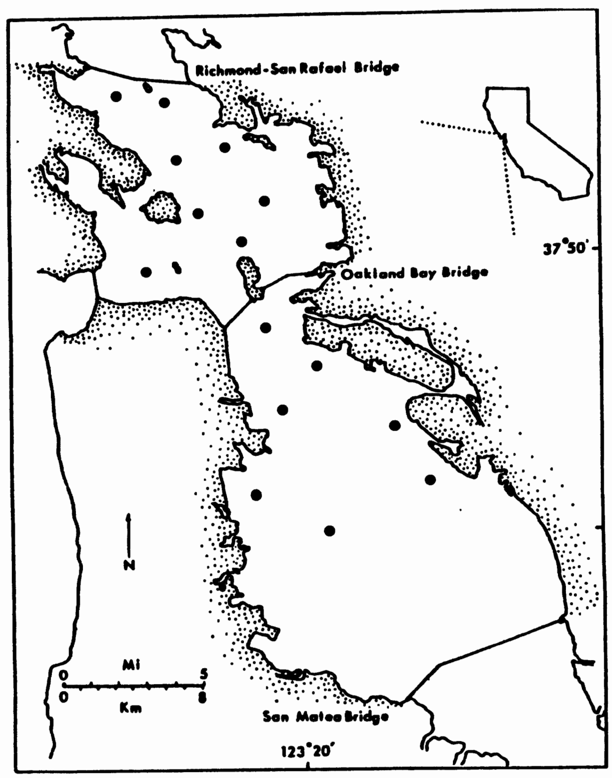

FIGURE 1. Study area for Pacific herring in San Francisco Bay. Dots denote stations where tows for young-of-the-year herring were conducted.

study area (>30 ft.), where schools of herring hold before spawning. Other areas within the Bay were surveyed when herring were present or when timely reports of spawning activity were received.

Methods

Spawning Biomass Estimates

Spawn Survey

We searched for spawning activity from an 18 ft aluminum skiff up to four days per week, from 13 November 1992 through 18 March 1993, during low tide when possible. The study area was divided into three segments, which were surveyed on a rotating basis: north Bay (Richmond - Sausalito), San Francisco (Golden Gate Bridge - Candlestick Point), and east Bay (Berkeley - Bay Farm Island). The intertidal zone was checked by approaching the shoreline and looking for exposed eggs. The subtidal zone was checked by dragging a weighted rake along the bottom, collecting vegetation, and checking it for eggs.

Spawns were often first located by observing the presence of milt in the water and many marine birds and mammals feeding in the area, then confirmed by the presence of eggs. Depending on the type of spawn (intertidal, subtidal, pier pilings), one of three sampling techniques developed by Spratt (1981) were used. Descriptions of each technique follow.

Subtidal Spawns Subtidal spawns require estimates of vegetation density to calculate biomass. We collected subtidal vegetation density data at potential spawning areas in early November 1992. Vegetation samples were collected at known beds composed primarily of the red alga, *Gracilaria spp.*, and eelgrass, *Zostera marina*, at stations throughout the study area. At each station, scuba divers collected three samples from randomly tossed 1-m^2 quadrats. Samples were stored in plastic bags in a cooler, then separated by taxon, rinsed, damp-dried with paper towels, and weighed to the nearest decigram in the laboratory. The average of the three samples was used to estimate vegetation density at each station.

Spawns were located and sampled by dragging a weighted rake along the bottom and collecting vegetation and eggs. The boundaries of the spawn were also located in this manner and recorded on Coast and Geodetic Survey Chart 18649. The area of the spawn was later calculated from its dimensions, measured in one of two ways: 1) measuring buoy-marked boundaries with a Ranging 400 optical rangefinder; or 2) measuring the spawn boundaries from the chart.

Samples were collected randomly within the spawn boundaries, often during the process of finding boundaries. A sample was collected approximately every 9,000 m^2, with at least three samples collected for small spawns, and at least ten samples collected for spawns >93,000 m^2. Samples were stored in labeled plastic bags and kept cool before laboratory processing.

In the laboratory, a sub-sample weighing at least 10 g was removed from each sample, rinsed with water to remove sediment and debris, damp-dried with paper towels, and weighed to the nearest decigram. The number of eggs/kg vegetation was determined by removing eggs, counting or weighing them (1 g = 750 eggs), and re-weighing the vegetation. Eggs/kg vegetation was averaged for all samples. The total number of eggs in the spawn was then estimated:

total eggs=(mean eggs/Kg veg)x(Kg veg/area) x area

Intertidal Spawns Intertidal spawns were sampled in a random two-stepped process, which consisted of selecting a segment of shoreline within the spawn area, then randomly collecting three samples within the chosen segment of shoreline. Samples were collected from 100-cm^2 quadrats.

The area of the spawn was determined by measuring its length and width with a Ranging 400 optical rangefinder or from a chart. Area was adjusted for the effects of topography using conversions developed by Spratt (1981).

In the laboratory, the eggs in each sample were counted or their numbers estimated (by weight) to determine the eggs/m^2, which was then averaged for all of the samples. The total number of eggs in the spawn was calculated as follows:

total eggs = (mean eggs/m^2) x spawn area x correction factor for topography

Pier Piling Spawns Spawns on pier pilings cannot be sampled randomly, since all pilings are not accessible. Instead, 100-cm^2 samples were collected or visual estimates of coverage were made at regular intervals, usually 300-500 yds. apart. The area of the spawn was determined by measuring the depth of the spawn on pilings and multiplying it by either: 1) a predetermined linear surface of the pier; or 2) the number of pilings spawned upon x piling circumference. Spawn depth on pilings was determined subjectively based on bottom depth, density of eggs, and the deepest depth from which eggs could be scraped from the piling, or from weighted lines hung before the start of the season. Total eggs were estimated by multiplying spawn area by the average eggs/m^2 as determined from samples or estimates.

Spawn Survey Biomass Estimates For each spawn, the tons of spawning fish were derived from a conversion of the total number of eggs estimated for each spawn. The conversion factor was based upon the sex ratio of the school and average fecundity for San Francisco herring (Reilly and Moore 1986):

$$\frac{1}{F \times (f/P) \times (g/lb) \times (lbs/ton)}$$

where:

F = fecundity (113 eggs/g body wt., males and females combined)
f = percent females in a given spawning run
P = percent females in population (assumed to be 50%)

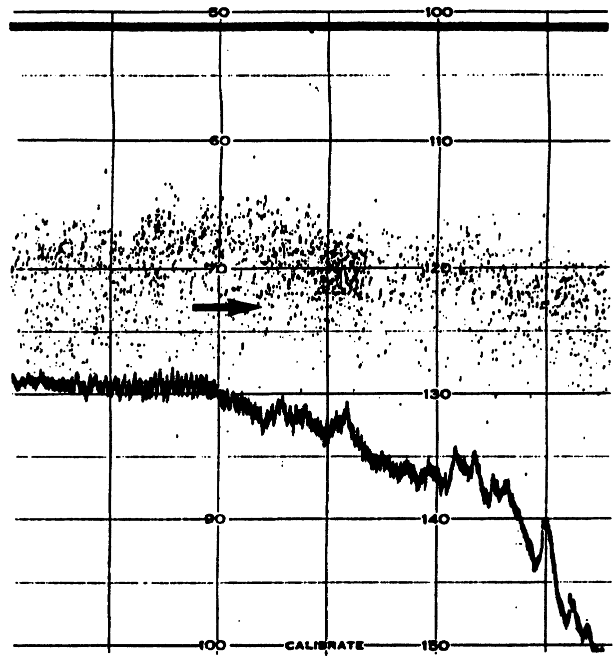

FIGURE 2. Pacific herring recorded in San Francisco Bay by a Raytheon model DE-719B paper recording fathometer. Arrow indicates target depth of midwater trawl.

Hydroacoustic Survey

We conducted hydroacoustic surveys during daylight hours up to four days per week from 8 November 1992 through 8 March 1993, from the R/V *Huachinango*, a 28-ft Radon boat. Schools were initially found and qualitatively surveyed with a Lowrance X-60 fish finder. Surveys were conducted during slack tides (usually high) to reduce error due to tide-related school movement. Herring-like marks were confirmed by sampling the school with the midwater trawl. Once we verified schools as herring, formal surveys were conducted with a Raytheon model DE-719B paper recording fathometer and the 'visual integration' method (Oda 1994)(Figure 2).

Due to tide-related constraints, we could not quantitatively survey the entire study area each day. Therefore, we usually conducted quantitative surveys of herring schools in the north Bay (north of the Bay Bridge) or south Bay (south of the Bay Bridge) on a given day (Figure 1). Qualitative surveys of likely holding areas within the study area could be completed in one field day. We frequently metered beyond portions of the primary survey area to provide complete coverage and monitor the arrival of new herring schools or the splitting of an existing school in the Bay.

A general search (metering) pattern for herring schools in the north Bay began near the R6 buoy marking the east side of the channel separating the Berkeley flats and Angel Island (Figure 1). Metering continued to the north, crisscrossing the channel between Richmond and Tiburon. In general, ripening herring tend to hold in channels >50 ft in depth during the daylight hours prior to spawning. Therefore turns were generally initiated at the 50-ft contour unless fish were present, in which case, we continued the transect until herring-like marks dissipated.

If fish were not found on the east side of Tiburon to the San Rafael Bridge, searching resumed between Bluff Pt. and Pt. Campbell and continued through Raccoon Strait. We searched the area between Sausalito and Harding Rock and the channel between Lime Pt. and Fort Pt.

During low-tide surveys, our transects sometimes extended beyond the Golden Gate Bridge to account for herring that may have moved out of the Bay with the ebb tide. Surveys west of the Golden Gate Bridge did not extend beyond Point

Bonita. If time allowed, transects continued down the Bay across the channels between Alcatraz, Angel Island, Treasure Island, and San Francisco to the Bay Bridge.

Typically, south Bay qualitative surveys commenced on the 50-ft contour near the south tip of Yerba Buena Island, the northwest end of Treasure Island, or at the end of Pier 29. We routinely searched the south Bay channel as far south as Hunter's Pt. and at times, to Oyster Pt. Several qualitative surveys were conducted to monitor each school before spawning.

Quantitative surveys of herring schools were conducted as spawning became imminent, when herring schools often coalesced. Spawn probability was determined based on the ripeness of fish sampled from the school, distribution of herring "marks", moon phase, and associated tides. Spawning events in San Francisco Bay often occur during neap tides (Oda 1994).

Starting points for surveys were slightly up current of the school's edge based on preliminary surveying. We traversed the school at approximately 45 degree angles at 8 kn to record school density. Turns were made using the criteria as described above in qualitative surveys; however, during quantitative surveys we marked turning points on the paper tracings and recorded their range in nautical miles and bearing to a way point using Loran C. We plotted the course of the survey on a chart to provide an aerial view of the school's dimensions. We modified forty-five degree transects when necessary to use line-of-sight marks for navigation or to avoid obstacles.

We could survey most schools during a slack-tide period; however, if the survey extended beyond this period into the ebb tide, the survey was completed as quickly as possible to reduce double counting of fish ensonified earlier. In such cases, when surveys were completed quickly, transect turns were made in low-density areas rather than extending beyond the edge of the school.

Hydroacoustic Biomass Estimation We estimated biomass for each school from paper traces using the 'visual integration' method (Reilly and Moore 1983). We compared herring marks on the paper traces (Figure 2) with standards of density estimates, and assigned densities (short tons/10^6 ft^2) to them. The standards were developed by chartering a purse seiner, calculating the surface area of water within each net set, and weighing the catch, after recording fish density on the Raytheon fathometer (Reilly and Moore 1983). Standards were further refined using echo-integration equipment (Reilly and Moore 1985).

The plot of the survey transect was divided into a series of trapezoids by bisecting the angle of each turn and connecting the turning points. Each trapezoid's area was calculated with a Houston Instrument HI-PAD digitizing pad.

A weighted-average density of herring marks was calculated for each transect. We divided transects into segments based on density assignments. The length of each segment was multiplied by the assigned density. Multiplying the density (short tons per 10^6 ft^2) estimated for the transect by the trapezoid area then determined biomass for each trapezoid. We derived school biomass from the sum of all trapezoid estimates.

Best Estimate of Spawning Biomass

At the end of the spawning season, we derived a final biomass estimate for each school from the spawn and hydroacoustic surveys. If both surveys yielded similar estimates and were judged equally strong, an average of the two was used. If a problem was found with one survey (ie, equipment failure, missed school or spawn), then the biomass estimate from the other survey was used. The total of these 'best estimates' was used as the spawning biomass for the season.

Biological Aspects of the Spawning Population

Herring were sampled from each school with a midwater trawl to collect length, weight, sex, ripeness, and age data. The midwater trawl measures 12 ft x 12 ft at the mouth and is 58 ft long; mesh size (stretched) ranges from 8 in. at the mouth to 0.5 in. at the cod end. Midwater trawl tows were conducted as described by Oda (1994).

The body length (BL) of each fish was measured from the tip of the snout to the end of the pigment on the caudal peduncle (Spratt 1981). Sex and state of gonadal maturation was determined by lightly squeezing the abdominal area until we extruded sex products. We coded herring as ripe when we easily extruded eggs or milt; eggs are typically yellow and translucent and milt is thin in viscosity at this stage. We coded females with opaque eggs or males with toothpaste-consistency milt as immature (not yet ripe). When we did not extrude eggs or milt, a fish's sex and condition were determined by dissecting the gonads. Fish that were very thin, with knife-edged, concave bellies, and greatly reduced, bloodshot gonads, we recorded as spent, and were not used for length-weight analysis.

For each spawning wave, seventeen specimens were collected from each 10-mm size-class (>130 mm), labeled, and frozen for later weighing and otolith removal (Reilly and Moore 1982). We thawed samples in the laboratory and weighed them to the nearest 0.1 g with a Mettler 1200N balance. Fish with significant milt or egg losses were not used for length-weight analysis.

We removed and cleaned otoliths with 190-proof ethanol, dried with paper toweling, and stored in labeled gelatin capsules. To determine age, we immersed otoliths in 190-proof ethanol on a black background and examined whole at 12x-25x with reflected light. We interpreted and counted opaque and translucent zones of growth on the distal side in the dorsal region. When the first two zones of growth were difficult to see (usually in older fish), predetermined measurements of these zones were used to aid in ageing. Each otolith was independently aged twice by the senior author. If the two readings did not agree, the second one was assigned.

Unaged fish were assigned ages, based on the age-length relationship of aged fish, with a computer program. Aged fish and those assigned ages were then combined by spawning wave and the age composition in percent was determined. The total number of fish of each age for each spawning wave was calculated using the biomass estimate for the wave, percent age composition, and average weight-at-age.

Young-of-the-Year Abundance and Recruitment Forecasting

Herring young-of-the-year (YOY) were sampled with a midwater trawl at fifteen stations in the central Bay during April, May and June 1993 (Figure 1). Each station was sampled once each month. Tows were conducted from the R/V *Huachinango* with the same net used to sample herring during the spawning season. A General Oceanics, Inc. Model A2030 flowmeter was used to calculate how much water was filtered by the trawl. Captured YOY were counted and measured (mm BL).

Biological Aspects of the Catch

Herring were sampled from gill net and round haul catches at buying stations in Sausalito, San Francisco, and Oakland. Twenty to 25 fish were randomly collected from each vessel's landing and as many vessels as possible were sampled. Herring were also sampled from round haul vessels on the fishing grounds; they were brailed from the drawn net by a deckhand into a 5-gallon bucket that was then passed to a crew member on the R/V *Huachinango*. Samples were processed in a fresh condition. Fish were measured in body length, sexed, and weighed to the nearest 0.1 g. When a fish fell into a size category for which ages were needed, otoliths were removed and processed as described previously.

Results

Spawning Biomass Estimates

Spawn Survey

Vegetation Density Subtidal vegetation density data were collected 12-13 November 1992, at 29 stations in the north Bay (Richardson Bay, Belvedere, Kiel Cove) (Figure 3), and south Bay (Alameda, Bay Farm Island) (Figure 4). For the first time since the Fall of 1987, stations in Richardson Bay were sampled. Samples here were dominated by *Gracilaria* spp., with densities ranging from 0.00 to 0.39 kg/m^2; densities were slightly higher than in 1987 but considerably lower than in 1981 (Spratt 1988, 1982). Only one station was sampled in Belvedere Cove, where density was quite high. Kiel Cove, dominated by *Zostera marina* and *Gracilaria* spp., had vegetation densities slightly less than in 1991. Vegetation densities at Alameda and Bay Farm Island were lower than in 1991; samples were composed of *Zostera marina* and *Gracilaria* spp..

Biomass Estimate Sixteen herring spawning events were documented in San Francisco Bay during the 1992-93 season (Table 1), with the first occurring in early November and the last mid-March. Most spawning occurred in December and January, with the greatest activity occurring in the first week in January. Spawning activity dropped off after the first week in February, and only one small spawn was found in the first week in March.

Spawns documented during the 1992-93 season were all relatively small (ie. < 2,500 tons). Many spawns were light and patchy, making them difficult to sample.

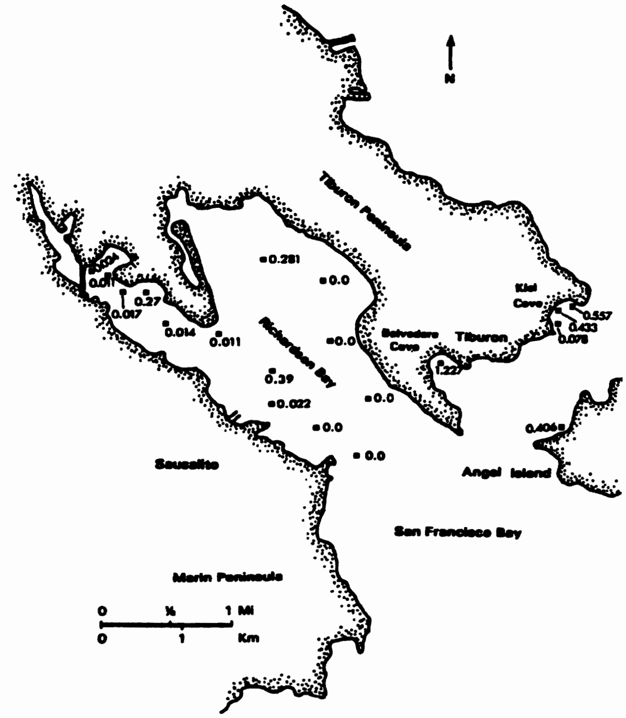

FIGURE 3. Subtidal vegetation densities (Kg/m²) at sampled stations in north San Francisco Bay, 12-13 November 1992.

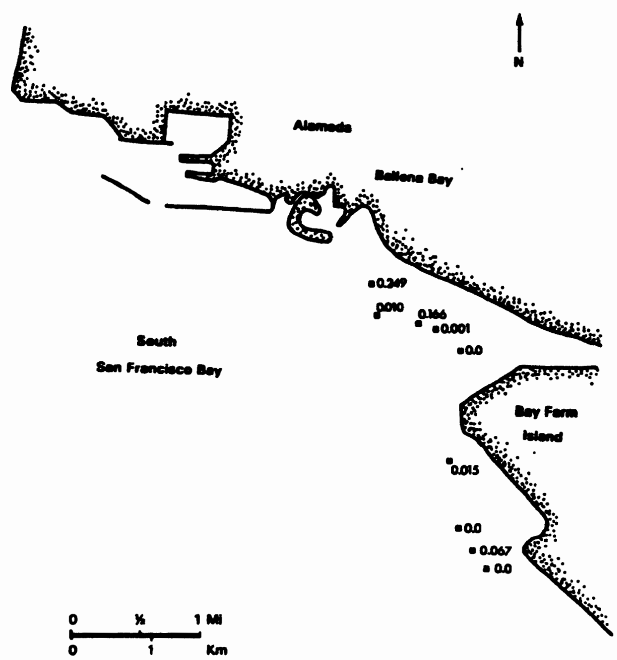

FIGURE 4. Vegetation densities (Kg/m²) at south San Francisco Bay stations, 12-13 November, 1992.

Hydroacoustic Survey

Herring schools were particularly difficult to survey during the 1992-93 season; groups of ripe fish often split away from primary schools to spawn, and unripe fish often joined ripened schools. These behavioral changes created difficulties in interpreting results of several surveys. Thirteen acoustic surveys were completed for five spawning waves during the season. The first acoustic survey of a spawning wave occurred 19 November 1992 and the last wave was surveyed 22 February 1993. Biomass estimates ranged from a high of 10,394 tons for wave four to a low of 2,384 tons for wave five.

Best Estimate of Spawning Biomass

Nine spawning waves were detected and surveyed with spawn and/or acoustic surveys during 1992-93 (Table 2). These estimates ranged from one to 10,394 tons. The 1992-93 season total biomass estimate was 21,186 tons.

Biological Aspects of the Spawning Population

Thirty-two midwater trawl and eleven round haul samples totaling 2,671 herring were collected from 23 November 1992 to 4 March 1993 (Appendix A). Spawning waves four through eight were represented by these samples.

No apparent pattern existed in the sex composition of spawning waves (Table 3). Males outnumbered females in waves four, seven and eight; females dominated waves five and six.

As with previous seasons, the length composition of spawning waves decreased throughout the season. Mean lengths of herring ranged from 185 mm for wave four to 156 mm for wave eight.

Length-weight relationships were generated from 417 herring collected during the season. The relationships, described by regression, were:

Unripe females: $\ln(W) = 12.94 + 3.35 \ln(L)$ ($r^2=0.97$, $n=124$)
Ripe females: $\ln(W) = 13.85 + 3.53 \ln(L)$ ($r^2=0.98$, $n=115$)
Unripe males: $\ln(W) = 14.42 + 3.64 \ln(L)$ ($r^2=0.98$, $n=16$)
Ripe males: $\ln(W) = 13.48 + 3.45 \ln(L)$ ($r^2=0.98$, $n=154$)
Ripe males and females: $\ln(W) = 13.59 + 3.48 \ln(L)$ ($r^2=0.98$, $n=269$)

None of the regression coefficients differed significantly from 1990-91coefficients. Weights predicted by regression ranged from 20.6-230.0 g for ripe females 120-238 mm BL, and from 21.3-227.0 g for ripe males 120-238 mm BL (Appendix B).

Ages were determined from otoliths of 446 herring; these ages were then used to create the age-length key used to assign ages to the remaining fish sampled (Table 4).

For most age groups, mean lengths and weights at age were similar to recent years, remaining lower since the 1989-90 season (Table 5). For two- through five-year-olds (1991 through 1988 year-classes), average lengths were similar to recent seasons, while average weights were higher. Mean lengths of six-, seven-, and eight-yr-olds (1987 through 1985 year-classes) were the lowest of the last 10 seasons, while mean weights of these same age groups were the lowest since the 1983-84 season.

Spawning waves four through seven were dominated by four-year-old fish from the 1989 year-class, and to a lesser extent, three and five-year-olds (Table 6). The percent by number of two-year-old herring was low, but increased with each successive spawning wave. Wave eight was dominated by two-year-old herring.

For all waves combined, the strong 1988 year-class was present again in high percentages as five-year-olds (Table 7). Percent by number and weight of two- and three-year-old herring was low compared with prior seasons, indicating two consecutive years of poor recruitment.

Although the 1992-93 spawning population was dominated by four-year-old herring from the 1989 year-class, the estimated number of fish at this age was much lower than in previous seasons (Table 8). This was also the case for the estimated numbers of two- and three-year-old herring, which were dramatically lower than in previous years.

Young-of-the-Year Abundance

The estimated numbers of two-year-olds from the 1991 year-class was the second lowest recorded (Table 9). The index of abundance for YOYs of this year-class was also quite low.

To assess the abundance of herring young-of-the-year for the 1992 year-class, 45 tows were conducted at the 15 central Bay stations from 10 April 1992 through 1 July 1992. Twenty-seven of these tows caught a total of 1,394 YOY, yielding an index almost double that for 1991, but low compared with prior years (Table 9). Mean length of 1992 YOY herring caught in May was higher than recent years, showing good conditions for growth (Table 10).

For 1993, 44 tows were conducted at the same stations from 19 April 1993 through 24 June 1993. Twenty-eight of these tows caught 925 YOY herring. The index for the 1993 year-class was low, suggesting the fourth in a series of poor year-classes (Table 9). Mean length of 1993 YOY herring caught in May was lower than for 1992, but higher than recent years (Table 10).

Biological Characteristics of the Catch

San Francisco Bay's sac-roe fishery landed 5,382 tons during the 1992-93 season, less than the 5,555 ton quota (Table 11). However, the catch was 25% of the biomass estimate of 21,500 tons for 1992-93, exceeding the Department's harvest goal of no more than 20% of spawning biomass.

Length Composition

Twenty-five gill net samples, consisting of 519 fish, and eleven round haul samples, consisting of 761 fish, were collected from the fishery (Table 12, Table 13). The mean length and range of lengths of gill net-caught fish was similar to prior years in which 2-1/8 in. mesh was used (Table 14). The mean length and range of the round haul catch was also similar to prior years (Table 14).

Age Composition

There was considerable overlap in lengths between all ages of herring in gill net catches (Table 15). In numbers and weight, gill net catches were dominated by four and five-year-old fish, from the 1989 and 1988 year-classes, respectively (Table 16). There were higher than usual percentages of three-year-old herring present in gill net catches during 1992-93. All ages were represented in round haul samples (Table 17). Round haul samples were dominated by three, four, and five-year-old fish from the 1990, 1989, and 1988 year classes, respectively. When compared with round haul samples combined from the past 16 years, 1992-93 samples were noticeably different (Table 18). The number of two-year-old fish in the catch was very low in 1992-93, while numbers of four and five-year-olds were much higher.

Discussion

Subtidal spawning substrate has increased slightly since 1987 but continues to be sparse in Richardson Bay, an historically important spawning area. Densities of *Gracilaria* spp. in November 1992 remained well below the densities measured prior to the 1982 El Niño (Spratt 1988, 1982), when storm activity removed virtually all of this algae from Richardson Bay.

The 1992-93 spawning season was characterized by a higher than usual number of very small spawns. The season was also shorter than usual, with spawning activity dropping off after the first week in February, instead of continuing well into March. Many spawns were light and patchy, making them difficult to sample and increasing sample variability. Hydroacoustic surveys were also difficult to interpret because of the unusually dynamic nature of schools (ie. ripe fish breaking away from the school to spawn, unripe fish joining ripened schools). The typical pattern of increasing numbers of smaller and younger fish entering the bay with each successive spawning wave was observed again this season.

The spawning biomass estimate of 21,186 tons is less than half of last season's estimate of 46,600 tons. It is the lowest recorded since the 1978-79 season (prior to this, the project did not survey for subtidal spawns and biomass estimates are considered less reliable). The principal reason for this very low estimate is a lack of two-, three-, and four-year-old herring in the spawning population. Estimated numbers of fish at these ages are extremely low for 1992-93.

Four-year-old fish from the 1989 year-class were the predominant cohort in this season's spawning population but this year-class appears to be a poor one. It represents the second smallest cohort of four-year-olds since data have been collected, and also appeared in low numbers as three-year-olds during the 1991-92 season. Five-year-old fish from the very successful 1988 year-class were the second most abundant cohort during 1992-93, which was accentuated by the weakness of younger cohorts. The 1990 year-class, fully recruited to the spawning population this season, was the weakest cohort of three-year-olds on record. This year-class also appeared in record low numbers as two-year-olds during the 1991-92 season. The 1991 year-class as two-year-olds was the second poorest cohort at this age on record, but will not fully recruit to the spawning population until next season.

Unfavorable ocean conditions continued to persist during 1992-93, and are the most likely cause of the poor showing of the 1989, 1990, and 1991 year-classes in 1992-93. The 1991-92 El Niño ended in October 1992, but above-average sea surface temperatures persisted throughout 1993(National Oceanographic and Atmospheric Administration, Coast Watch data). In addition, upwelling indices continued to be low. Warm-water conditions also may have affected spawning biomass by displacing fish to the north of San Francisco Bay.

Within the spawning population in San Francisco Bay, the potential effects of poor ocean conditions on condition and growth were less obvious. Length-weight relationships were good for the season. Mean lengths and weights at age, however, have continued to be smaller since the 1989-90 season.

The herring young-of-the-year abundance index was low for the 1990 and 1991 year-classes, but high for the 1989 year-class; the 1989 and 1990 year-classes appear to be poor but the success or failure of the 1991 year-class will not be known until next season when it fully recruits into the spawning population. The index for the 1992 year-class is better but remains low compared with earlier years. These indices alone do not predict a dramatic increase in San Francisco Bay's spawning population in the near future.

The Department's harvest goal of no more than 20% of spawning biomass was exceeded during the 1992-93 season. Landings of 5,382 tons (5,555 ton quota) represented 25% of the season's 21,500 ton spawning biomass estimate. Because biomass estimates are not complete until the spawning season is over, quotas for the San Francisco Bay fishery are based on the previous season's biomass estimate. This leaves a greater potential for exceeding a 20% harvest rate; however, it has only occurred two other times (in the 1970s) during the history of the fishery.

The lack of two-year-old fish and relative abundance of five-year-olds in the population was reflected in round haul catches in 1992-93, as would be expected. Worth noting is the substantial jump in the percentage of three-year-old fish in gill net catches. The size of three-year-olds did not increase this year which would make them more vulnerable to the gear. This suggests that an alteration in gear occurred this season, such as a decrease in mesh size.

If warm-water conditions displaced herring to the north of San Francisco Bay, the return of these fish could mean an increase in biomass during 1993-94. Otherwise, a strong year-class is needed to increase San Francisco Bay's spawning population of herring, but the strength of the 1992 year-class is uncertain. While it is not unusual for herring populations to fluctuate widely in size, this season's biomass reaches an extremely low level that has never been observed before. We do not know what biomass level acts as a critical threshold beyond which population recovery is hampered for San Francisco Bay herring. Because of the extremely low biomass estimate, and uncertainty about the strength of the 1992 year-class, we have recommended for the first time in the history of the fishery that the Fish and Game Commission close San Francisco Bay's herring roe fishery until the season following a spawning biomass exceeding 26,000 tons. This is 50% of the long-term average biomass of 52,000 tons for San Francisco Bay.

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Literature Cited

National Oceanic and Atmospheric Administration. 1993. El Niño watch advisory series. Nat. Mar. Fish. Svc., La Jolla, CA.

Oda, K.T. 1994. Pacific herring, *Clupea pallasi*, studies in San Francisco Bay, April 1990 to March 1992. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 92-2. 38 p.

Reilly, P.N. and T.O. Moore. 1982. Pacific herring, *Clupea harengus pallasi*, studies in San Francisco Bay, December 1981 to March 1982. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 82-8. 43 p.

Reilly, P.N. and T.O. Moore. 1983. Pacific herring, *Clupea harengus pallasi*, studies in San Francisco Bay, Monterey Bay, and the Gulf of the Farallones, July 1982 to March 1983. Calif. Dept. Fish and Game, Mar. Res. Admin. Rep. 83-5. 49 p.

Reilly, P.N. and T.O. Moore. 1985. Pacific herring, *Clupea harengus pallasi*, studies in San Francisco Bay and the Gulf of the Farallones, June 1984 to March 1985. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 85-4. 73 p.

Reilly, P.N. and T.O. Moore. 1986. Pacific herring, *Clupea harengus pallasi*, studies in San Francisco Bay, central and northern California, and Washington, March 1985 to May 1986. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 86-6. 88 p.

Spratt, J.D. 1981. Status of the Pacific herring, *Clupea harengus pallasi*, resource in California 1972 to 1980. Calif. Dept. Fish and Game, Fish. Bull. 171. 107p.

Spratt, J.D. 1982. Biomass estimates of Pacific herring, *Clupea harengus pallasi*, in California from the 1980-81 spawning-ground surveys. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 82-2. 19 p.

Spratt, J.D. 1988. Biomass estimates of Pacific herring, *Clupea harengus pallasi*, in California from the 1987-88 spawning-ground surveys. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 88-7. 28 p.

Spratt, J.D., T.O. Moore, P. Collier. 1992. Biomass estimates of Pacific herring, *Clupea pallasi*, in California from the 1991-92 spawning-ground surveys. Calif. Dept. Fish and Game, Mar. Res. Admin. Rpt. 92-2. 43 p.

TABLE 1. San Francisco Bay herring spawn data, 1992-93 season.

Date	Location	Area (m^2)	Average eggs/m^2	Millions of eggs	Conversion factor (x 10^{-8})	Tons
10 Nov	Richardson Bay	10,701	3,720	40	1.600	0.64
21 Nov	Richardson Bay	228,893	117,504	26,900	1.600	430
25 Nov	Richardson Bay	57,117	18,981	1,185	1.600	2
29 Nov	Belvedere Cove	22,775	5,484,134	124,059	1.600	1,985
13 Dec	Oakland/Alameda	7,476,597	204,699	154,489	1.015	1,569
15 Dec	San Francisco	13,410	297,143	6,729	1.070	72
22 Dec	Oakland/Alameda	357,831	7,593	2,720	0.881	24
28 Dec	Richardson Bay	322,466	242,732	156,029	0.966	1,507
4 Jan	San Francisco	190,158	1,165,093	203,490	1.070	2,178
5 Jan	Oakland Estuary	4,509	501,393	2,415	1.377	34
7 Jan	Sausalito	13,623	204,909	557	1.070	6.4
12 Jan	Oakland Estuary	6,000	750,000	4,500	1.070	48
13 Jan	Richardson Bay	1,300	792,200	1,078	1.070	11
31 Jan	Oakland/Alameda	175,305	1,424	107	1.070	3
9 Feb	Oyster Point	65,832	422,900	27,800	1.070	297
4 Mar	San Francisco	274	783,500	215	0.966	2
Totals:		8,946,791		712,313		8,169

TABLE 2. Pacific herring spawning waves surveyed by spawn and hydroacoustic methods in San Francisco Bay, 1992-93 season.

Wave Number	Spawn Date(s)	Acoustic estimate (tons)	Spawn estimate (tons)	Best estimate (tons)	Method
1	10 Nov	NA	1	1	2
2	21-25 Nov	NA	432	432	2
3	29 Nov	NA	1,985	1,985	2
4	13-22 Dec	2,384	2,829	2,829	2
5	28 Dec - 7 Jan	10,394	3,725	10,394	1
6	12-13 Jan	NA	59	59	2
7	21 Jan	2,954	NA	2,954	1
8	28 Jan - 9 Feb	2,530	300	2,530	1
9	4 Mar	NA	2	2	2
	Total			21,186	

TABLE 3. Sex composition of Pacific herring by wave in San Francisco Bay, from midwater trawl and round haul samples, November 1992 to February 1993. Waves 1-3 and 9 were not sampled.

			Percent by number	
Wave Number	Month(s)	*n*	Male	Female
4	Nov-Dec	565	55	45
5	Dec-Jan	793	47	53
6	Jan	874	48	52
7	Feb	369	54	46
8	Feb	54	76	24

TABLE 4. Age-length relationship for Pacific herring from San Francisco Bay, 1992-93 season.

Size Interval	Age (years) 1	2	3	4	5	6	7	8
< 130								
130-139	7				1			
140								
142								
144								
146								
148								
150								
152		4	3					
154		2	1	1				
156			2					
158		7	9	1		1		
160		3	10					
162		1	5	1				
164		3	7	4	1			
166		3	7	5	1			
168		2	10	2	1			
170		2	4	1		1		
172		2	6	2	1			
174			8	2	4			
176		3	4	5	2			
178			7	4	4			
180				5	3			
182			2	7	5	1		
184			4	8	1			
186			3	7	4	1		
188				6	7			
190			1	10	5	1		
192				5	3	1		
194				6	4	1		
196			2	6	6	1		
198			2	3	2			
200			1	7	6	2		
202				3	11	3	3	1
204					5			
206					3	2	1	
208				1	2	1		
210				1	4	1		
212					3	6	2	1
214					4		1	2
216				1	2	1		1
218					1	2	1	
220							1	
222								
224						1		
226								
228								
230								
232								
234					1			
n	7	74	98	106	97	27	9	5
μ	133	147	171	185	194	199	207	211
s.e.	0.6	2.1	1.1	1.2	1.5	3.6	3.8	2.5

TABLE 5. Mean body length (mm) and weight (g) at age of Pacific herring in San Francisco Bay, 1983-84 to 1992-93.

Season	Length at Age						
	2	3	4	5	6	7	8
1983-84	153	172	182	194	201	210	214
1984-85	161	182	190	198	204	210	213
1985-86	162	178	194	199	206	211	217
1986-87	160	179	190	204	209	215	218
1987-88	159	176	191	202	211	215	217
1988-89	156	171	190	205	214	218	224
1989-90	149	170	184	198	209	220	221
1990-91	147	172	184	198	210	215	219
1991-92	147	167	184	196	205	215	228
1992-93	147	171	185	194	199	207	211
Season	**Weight at Age**						
	2	3	4	5	6	7	8
1983-84	47.3	68.3	81.6	99.7	111.4	127.8	135.6
1984-85	64.1	96.5	111.2	126.0	138.1	148.8	156.1
1985-86	63.5	88.6	118.5	127.4	141.5	155.4	166.3
1986-87	61.5	89.7	112.8	140.2	152.3	160.5	166.7
1987-88	58.0	81.0	106.8	130.8	151.7	155.4	167.7
1988-89	56.7	78.0	108.9	141.4	167.8	180.0	202.3
1989-90	46.4	70.5	95.7	122.3	144.0	162.4	173.0
1990-91	46.3	73.8	90.6	104.2	134.2	141.5	161.2
1991-92	44.6	65.9	92.2	116.0	133.9	151.5	198.6
1992-93	45.2	74.0	96.0	114.1	125.5	136.6	146.1

TABLE 6. Age composition (percent by number) by spawning wave for Pacific herring in San Francisco Bay, 1992-93 season. Spawning waves 1-3 were not sampled.

Wave Number	1	2	3	Age (yr) 4	5	6	7	8	*n*
4	0.0	6.2	24.4	37.2	28.2	4.0	0.0	0.0	563
5	0.0	5.7	22.3	36.5	27.1	6.9	0.7	0.7	790
6	0.7	11.1	25.3	35.8	22.9	3.7	0.4	0.0	874
7	3.6	23.9	21.2	30.5	17.4	2.8	0.3	0.3	363
8	9.3	55.5	5.5	16.6	11.1	1.8	0.0	0.0	54

TABLE 7. Age composition (percent by number and weight) of Pacific herring in San Francisco Bay, 1983-84 season to present. Data are based on biomass estimates from: 1) spawn surveys for seasons prior to 1989-90; and 2) a combination of spawn and hydroacoustic surveys for 1989-90 to present.

	Age (years)						
	2	3	4	5	6	7	8&9
Season	Percent by number						
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	37.6	30.3	17.4	10.8	3.1	0.8	0.0
1990-91	NA	NA	NA	NA	NA	NA	NA
1991-92	3.1	27.5	45.3	18.1	5.2	0.8	0.0
1992-93	20.5	21.1	33.1	21.7	3.6	0.0	0.0
	Percent by weight						
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	23.5	28.7	22.4	17.7	5.9	1.8	0.0
1990-91	NA	NA	NA	NA	NA	NA	NA
1991-92	1.5	20.1	46.2	23.3	7.7	1.3	0.0
1992-93	10.8	18.2	37.0	28.8	5.3	0.0	0.0

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

TABLE 8. Estimated numbers of 2-, 3-, and 4-year-old Pacific herring (x 1,000) by year-class in the San Francisco Bay spawning population. Numbers based on biomass estimates from: 1) spawn escapement surveys for 1981 to 1987 year-classes; and 2) a combination of spawn escapement and hydroacoustic surveys for 1988 to 1991 year-classes.

Year-class	Age 2	Age 3	Age 4
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	136,248
1987	146,525	237,377	*NA
1988	294,631	*NA	208,265
1989	*NA	126,616	79,045
1990	14,073	50,398	
1991	48,925		

*not available due to incomplete 1990-91 field season.

TABLE 9. Forecasting index value (adjusted catch of young-of-the-year herring from selected stations) by year-class and subsequent recruitment strength (x 1,000) as 2-year-olds.

Year-class	Index	Recruitment Season	Recruitment Strength
1980	3783	--	--
1981	495	82-83	87,908
1982	13580	83-84	332,699
1983	641	84-85	185,742
1984	3517	85-86	162,422
1985	4107	86-87	168,962
1986	9296	87-88	233,193
1987	4241	88-89	146,525
1988	1640	89-90	262,728
1989	6250	90-91	*NA
1990	506	91-92	11,374
1991	1054	92-93	50,398
1992	1985	93-94	--

*Data collected during the shortened 1990-91 field season.

TABLE 10. Mean length of young-of-the-year, collected in May, for the 1983 through 1993 year-classes.

Year-class	*n*	Mean BL (mm)	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
1990	164	42.0	Jan 3 - 6
1991	189	41.9	Dec 27 - 30
1992	43	51.0	Jan 1 - 5
1993	91	46.8	Dec 28 - Jan 7

TABLE 11. San Francisco Bay herring fishery landings, 1972-73 through 1992-93 seasons.

Season	Round haul	Gillnet DH	Gillnet Even	Gillnet Odd	ROK[1]	Quota	Biomass
1972-73	436	[2]	[2]	[2]	2.2	1,500	49,100
1973-74	1,931	[2]	[2]	[2]	3.8	500	6,200
1974-75	517	[2]	[2]	[2]	3.9	600	27,200
1975-76	1,414	305[3]	[3]	[3]	3.8	3,050	27,100
1976-77	3,197	1,004	[3]	[3]	2.4	4,000	26,900
1977-78	2,981	2,006	[3]	[3]	3.9	5,000	8,700
1978-79	2,019	2,097	[3]	[3]	2.7	5,000	36,700
1979-80	3,410	[4]	1,522	1,498	1.5	6,000	53,000
1980-81	2,855	1,442[5]	324	1,190	0.8	7,250	65,400
1981-82	3,982	1,714	2,146	2,573	0.9	10,000	99,600
1982-83	3,444	1,833	2,061	2,357	0.6	10,399	59,200
1983-84	1,270	47	965	516	0.0	10,399	40,800
1984-85	2,235	1,418	2,256	1,822	0.0	6,500	46,900
1985-86	1,179	1,589	1,788	2,226	2.8[6]	7,530	49,100
1986-87	2,375	1,697	1,892	2,134	110.9	7,530	56,800
1987-88	2,840	1,919	2,023	1,991	19.7	8,500	68,900
1988-89	2,705	2,019	2,808	2,219	47.1	9,500	66,000
1989-90	2,239	2,152	2,308	2,263	107.1	9,500	64,500
1990-91	1,909	1,928	1,661	2,243	47.0	9,500	51,000
1991-92	1,946	1,937	1,728	1,806	84.2	7,650	46,600
1992-93	1,302	1,164	1,471	1,214	47.4	5,555	21,500

[1] Represents roe-on-kelp product. Conversion of roe-on-kelp product to whole fish presented in Moore and Reilly 1989.
[2] Round haul fishery only.
[3] Gill net fishery established, no platoon system.
[4] "Odd" and "even" gill net platoon system instituted.
[5] December gill net platoon established.
[6] Roe-on-kelp experimental fishery using open ponds initiated. In prior seasons, harvests were restricted to spawn on native algae allotments A and B - 2.5 tons each.

TABLE 12. Number of Pacific herring by body length (2-mm interval) from gill net samples collected in San Francisco Bay, December 1992 to January 1993.

Body length (mm)	Number
160-61	
162	1
164	1
166	
168	
170	1
172	5
174	5
176	5
178	13
180	21
182	25
184	43
186	40
188	46
190	40
192	45
194	49
196	39
198	44
200	27
202	22
204	15
206	11
208	4
210	8
212	1
214	3
216	1
218	3
220	1
n	519
μ	192.2
s.d.	8.8

TABLE 13. Length frequencies of Pacific herring (2-mm intervals) from round haul samples, 1983-84 to 1992-93 seasons. Herring <130 mm body length were not included in this table.

Body Length	Season 83-84	84-85	85-86	86-87	87-88	88-89	89-90	91-92	92-93
130-139	247	27	16	24	31	21	12	9	26
140-141	84	6	3	8	23	12	5	4	2
142	130	10	2	23	25	13	10	1	7
144	146	8	6	16	39	29	13	1	3
146	223	20	8	26	90	28	28		1
148	187	26	7	33	83	53	30	2	
150	274	38	15	31	104	81	39	1	3
152	399	82	40	67	201	91	56	2	2
154	334	103	28	72	171	132	45	2	3
156	522	154	57	147	320	183	69	3	6
158	428	178	88	135	243	162	79	6	6
160	441	180	113	152	214	225	102	10	9
162	498	344	218	265	368	227	99	16	25
164	345	312	213	231	201	231	101	21	28
166	302	309	276	359	274	211	94	35	28
168	235	238	256	255	202	144	71	23	38
170	121	210	260	263	154	206	72	32	47
172	145	234	353	386	205	192	52	45	40
174	82	159	281	207	111	166	35	42	32
176	94	139	309	253	134	147	28	57	34
178	92	109	268	145	75	113	43	58	32
180	79	78	228	111	84	114	23	62	40
182	147	107	313	140	116	136	33	58	35
184	128	83	243	96	73	116	41	55	46
186	129	83	253	89	106	90	30	37	41
188	81	64	181	72	75	77	21	28	41
190	93	47	166	57	75	77	17	23	40
192	90	54	207	92	90	54	25	28	28
194	68	28	120	57	52	56	19	31	38
196	51	34	136	69	53	44	12	14	31
198	34	24	100	54	43	27	14	11	12
200	20	16	84	48	25	34	11	10	18
202	14	19	70	50	25	22	9	7	8
204	7	15	57	27	21	17	7	4	3
206	5	8	43	24	16	13	4	3	4
208	2	7	26	14	15	11	5	2	2
210	3	3	16	18	6	5		2	
212	3	5	18	7	12	5	2	1	
214		3	7	5	10	7			1
216		2	6	4	3	8	2		1
218			3	1	5	2			
220			2	3	2	1	1		
222	1	1	2		3	2			
224			1		1				
226				1		1			
228									
230						1			
n	6,294	3,566	5,099	4,137	4,179	3,587	1,359	746	761
$\bar{x}$	162.4	169.3	178.5	172.6	168.2	170.5	167.8	179.1	178.3
%<150	16.2	2.7	0.8	3.1	7.0	4.3	7.2	2.3	5.5

TABLE 14. Mean length of herring from San Francisco Bay sac-roe fisheries, 1973-74 through 1992-93.

Season	Gill net		Round haul	
	Mean body length (mm)	Range	Mean body length (mm)	Range
1973-74	-	-	177	134-222
1974-75	-	-	178	132-226
1975-76	-	-	178	128-230
1976-77	212	192-236	181	142-228
1977-78	211	178-236	178	144-232
1978-79	203	164-234	183	146-222
1979-80	208	184-230	180	148-220
1980-81	205	170-236	178	150-226
1981-82	201	160-228	177	148-226
1982-83	203	170-230	183	152-226
1983-84	205	182-232	165	132-208
1984-85	196	158-238	176	150-206
1985-86	196	166-226	178	142-214
1986-87	194	168-222	174	110-214
1987-88	195	160-230	168	130-225
1988-89	195	164-226	171	130-231
1989-90	196	172-226	168	110-220
1990-91	192	162-226	172	126-224
1991-92	189	168-220	179	140-218
1992-93	192	162-220	178	120-216

Note: Prior to the 1984-85 season, the minimum mesh size for the San Francisco gill net fishery was 2-1/4 in. The 1984-85 season was the first full season in which 2-1/8 in mesh was allowed.

TABLE 15. Length frequency of Pacific herring (2-mm interval) from the San Francisco Bay gill net catch, 1992-93 season.

Body Length	Age 1	2	3	4	5	6	7	8
139-140								
142								
144								
146								
148								
150								
152								
154								
156								
158								
160								
162				1				
164								
166			1					
168								
170					1			
172		1	3					
174		1	1	1	1			
176			1	3	1		1	
178			3	2	2		1	
180		3	2	7	6			
182			6	11	5			
184			9	14	7			
186			6	15	17	3		
188			10	23	20	1		
190			2	14	19	1		
192			4	14	20	4		
194			3	21	19	3		
196			11	20	14	2		
198			8	10	18	6		
200			3	12	12	5	1	
202			4	5	10	1	1	
204			1	4	12	1	1	
206			1	1	11	6		
208				1	1	1		
210					5			
212					3		2	
214					2			
216					3			
218				1				
220					2			
222						1		
n	-	5	79	181	211	35	8	-
$\bar{x}$	-	177.0	188.8	190.4	194.2	197.5	197.4	-
s.d.	-	3.7	8.5	7.5	8.9	7.5	13.4	-

TABLE 16. Age and weight composition of the San Francisco Bay gill net catch, 1982-83 through 1992-93 seasons.

Season	Age 2	3	4	5	6	7	8	9
1982-83								
% by number	-	<1	8	32	32	18	8	<2
% by weight	-	<1	6	29	33	20	9	2
1983-84								
% by number	-	-	<1	12	48	25	11	4
% by weight	-	-	<1	10	46	26	13	5
1984-85								
% by number	-	6	21	29	24	15	4	1
% by weight	-	5	18	28	25	18	5	1
1985-86								
% by number	<1	13	38	26	13	7	3	-
% by weight	<1	12	36	27	14	7	4	-
1986-87								
% by number	<1	7	33	37	16	4	2	<1
% by weight	<1	6	29	38	18	5	3	<1
1987-88								
% by number	<1	4	20	36	26	9	3	<1
% by weight	<1	3	18	34	29	11	4	<1
1988-89								
% by number	<1	3	23	32	29	9	3	<1
% by weight	<1	2	19	31	31	12	3	<1
1989-90								
% by number	-	3	13	32	31	16	4	1
% by weight	-	2	11	29	32	19	5	2
1990-91								
% by number	<1	9	27	29	23	10	1	<1
% by weight	<1	7	24	28	26	12	2	1
1991-92								
% by number	-	8	34	38	15	4	1	<1
% by weight	-	6	31	38	17	5	2	1
1992-93								
% by number	1	15	35	41	7	2	-	-
% by weight	<1	11	33	45	8	2	-	-

TABLE 17. Length frequency of herring from the San Francisco Bay round haul catch, 1992-93 season.

Body Length	Age 1	2	3	4	5	6	7	8
<130	2	6						
130-132	2	1						
134		3						
136	1	7						
138		5						
140		7						
142	1	2						
144		6						
146		1						
148		1						
150		2	1					
152		1		1				
154		1						
156		2	3					
158		1	6	1				
160		1	4					
162		3	15	4				
164		4	9	7	1			
166		6	17	3				
168		1	23	6	4	2		
170		12	30	6	3	3		
172		7	18	8	2			
174		4	12	8	5			
176		4	19	10	6		1	
178			14	8	10		1	
180			9	20	9			
182		1	6	13	7	2		
184			9	23	12	1		
186			8	16	14	3		
188			5	27	10	4		
190			6	20	16	1		
192				16	13	2		
194			4	15	12	4		
196			2	13	9	3		
198			1	8	13	3	1	
200			1	4	6	3		
202			1	1	8		3	
204				1	4	1		
206				1	2		1	
208					1		1	
210								
212								
214								
216					1	1		
218								
220				1				
n	8	88	223	241	168	33	8	-
$\bar{x}$	132.3	153.6	172.7	183.7	187.9	189.2	196.0	-
s.d.	4.5	16.7	9.3	9.8	9.6	10.9	12.0	-

TABLE 18. Comparison of the percentage age compositon of the 1992-93 San Francisco Bay round haul catch with 16-year composite age compostion.

	Round haul age composition			
	16-yr. composite		1992-93 season	
Age	*n*	%	*n*	%
1	8	<1	8	1
2	1,185	29	88	11
3	1,140	28	223	29
4	816	20	241	31
5	537	13	168	22
6	232	6	33	4
7	86	2	8	1
8	31	1	-	-
9	9	<1	-	-
Total	4,044		769	

APPENDIX A. Herring samples collected in San Francisco Bay, November 1992 through February 1993.

Sample number	Date	Location[1]	Gear[2]	Number measured	Number aged	Wave number
975	Nov 23	PP	MT	31	30	4
976	23	IB	MT	4	2	4
977	24	PP	MT	73	42	4
978	25		MT	30	4	4
979	28	PP	MT	11	2	4
980	28	PP	MT	57	11	4
981	30	IC	MT	2	1	4
982	30		MT	120	10	4
983	Dec 4	YBI	MT	63	1	4
984	7	IC	MT	21	0	4
985	7	IC	MT	52	1	4
986	11	PP	MT	36	0	4
987	14	YBI	MT	17	1	4
988	14	IB	MT	59	3	4
989	14		GN	22	2	4
990	14		GN	20	5	4
991	14		GN	21	1	4
992	14		GN	22	0	4
993	14		GN	22	0	4
994	14		GN	23	0	4
995	18	BB	MT	152	0	5
996	21	PP	MT	405	103	5
997	23	CHB	MT	49	1	5
998	24	PP	MT	37	2	5
999	24	IB	MT	78	0	5
001	28	OE	MT	22	1	5
002	Jan 5	AL	MT	29	0	5
003	Jan 4		GN	21	0	5
004	4		GN	20	0	5
005	4		GN	21	0	5
006	4		GN	20	0	5
007	4		GN	22	0	5
008	5		RH	20	0	5
009	4		GN	22	0	5
010	4		GN	21	0	5
011	4		GN	20	0	5
012	4		GN	19	0	5
013	4		GN	20	0	5
014	4		GN	21	0	5
015	11	PP	MT	144	88	6
016	11	IB	MT	92	12	6
017	18	YB	RH	121	13	6
018	18	YB	RH	113	2	6
019	19	YB	RH	59	7	6
020	19	YB	RH	96	10	6
021	18		RH	20	0	6
022	18		GN	20	0	6
023	18		GN	20	0	6
024	18		GN	18	0	6

APPENDIX A. (continued)

025	18		GN	19	0	6
026	18		RH	20	0	6
027	18		RH	20	0	6
028	18		RH	20	0	6
029	18		GN	20	0	6
030	Dec 4		GN	21	0	6
031	4		GN	19	0	6
032	4		GN	23	0	6
033	Jan 26	IB	MT	15	0	7
034	26	SB	RH	156	0	6
035	Feb 3	CB	RH	126	0	7
036	3	PP	MT	47	0	7
037	Feb 8		MT	17	6	7
038	8	IB	MT	110	78	7
039	10	PP	MT	70	7	7
040	22	PP	MT	3	0	8
041	22	CNB	MT	51	0	8
042	Mar 4	OE	MT	1	0	9
043	4	FM	MT	2	0	9

1
AL - Alameda
BB - Bay Bridge
CB - Carrier Basin
CHB - China Basin
CNB - Central Basin
FM - Fort Mason
IB - "1" buoy
IC - Islais Creek
OE - Oakland Estuary
PP - Portrero Point
SB - South Bay
YB - Yellow Bluff
YBI - Yerba Buena Island

2
MT - midwater trawl
RH - round haul
GN - gillnet

APPENDIX B. Estimated weight (g) at length (mm), based on regression, for ripe Pacific herring from San Francisco Bay, 1992-93 season.

Body Length	Weight			Body Length	Weight		
	male	female	both		male	female	both
130	28.1	27.3	27.9	186	96.9	96.6	96.8
132	29.6	28.8	29.4	188	100.5	100.3	100.5
134	31.2	30.4	31.0	190	104.2	104.1	104.2
136	32.8	32.0	32.6	192	108.1	108.0	108.1
138	34.5	33.7	34.3	194	112.0	112.0	112.0
140	36.3	35.5	36.0	196	116.1	116.2	116.1
142	38.1	37.3	37.9	198	120.2	120.4	120.3
144	40.0	39.2	39.8	200	124.5	124.7	124.5
146	42.0	41.1	41.7	202	128.8	129.2	128.9
148	44.0	43.1	43.7	204	133.3	133.8	133.4
150	46.1	45.2	45.8	206	137.8	138.4	138.0
152	48.2	47.4	48.0	208	142.5	143.2	142.7
154	50.4	49.6	50.2	210	147.3	148.2	147.6
156	52.7	52.0	52.5	212	152.2	153.2	152.5
158	55.1	54.3	55.0	214	157.2	158.4	157.7
160	57.6	56.8	57.3	216	162.4	163.6	162.7
162	60.1	59.3	59.9	218	167.6	169.1	168.0
164	62.7	62.0	62.5	220	173.0	174.6	173.5
166	65.4	64.7	65.2	222	178.5	180.2	179.0
168	68.1	67.5	68.0	224	184.1	186.0	184.7
170	70.1	70.3	70.8	226	189.9	191.9	190.5
172	73.9	73.3	73.7	228	195.7	198.0	196.4
174	76.9	76.3	76.8	230	201.7	204.2	202.4
176	80.0	79.5	79.9	232	207.8	210.5	208.6
178	83.2	82.7	83.1	234	214.1	217.0	217.0
180	86.5	86.0	86.4	236	220.5	223.6	221.4
182	89.8	89.5	89.7	238	227.0	230.3	228.0
184	93.3	93.0	93.2				