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SPAWNING BIOMASS OF PACIFIC SARDINE (*Sardinops sagax*) OFF CALIFORNIA IN 2007

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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SUMMARY

The spawning biomass in 2007 of Pacific sardine (*Sardinops sagax*) was estimated to be 392,492 metric tons (mt, CV = 0.45) for an area of 356,159 km^2 off California from San Diego to San Francisco, using the daily egg production estimate of 0.864/0.05m^2 (CV = 0.256) and the daily specific fecundity of 15.68 (number of eggs/population weight (g)/day). The area (356,159 km^2) was similar to some in previous years: 336,774 km^2 (2006; standard DEPM survey area), 253,620 km^2 (2005), 320,620 km^2 (2004) and 365,906 km^2 (2003). In 2007, trawl samples were taken in both high (Region 1) and low (Region 2) sardine egg density areas to ensure accurate estimates of the adult reproductive parameters. Average female sardine weight was 81.62g (CV=0.08) for the 15 trawls taken in 2007. When the trawl samples were later classified as inshore and offshore, larger female sardines were found offshore, similar to the 2005 survey. Sardine females collected by observers from six fishery-dependent, purse-seine sets in April 2007 were combined with the survey females to estimate that 50% of the female sardines were mature (ML_{50}) at 152.8 mm; previous ML_{50}.were 159 mm (1994), 193 mm (2004), and 152 mm (2005). Estimates of spawning biomass of Pacific sardine in 1994 - 2007 are 127,000 mt, 80,000 mt, 83,000 mt, 410,000 mt, 314,000 mt, 282,000 mt, 1.06 million mt, 791,000 mt, 206,000 mt, and 485,000 mt, 282,000 mt, 622,000 mt, 837,000 mt (2006 adjusted) and 392,000 mt respectively. Therefore, the estimates of spawning biomass have been fluctuating and have been higher in most years since 1994. The time series of spawning biomass starting from 1985 is one of the fishery-independent inputs to the annual stock assessment of the Pacific sardine.

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INTRODUCTION

The spawning biomass of Pacific sardine (*Sardinops sagax*) during 1986 (Scannel et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), and 1996 (Barnes et al. 1997) was estimated independently using the daily egg production method (DEPM: Lasker 1985). The DEPM estimates spawning biomass by: 1) calculating the daily egg production (P_0) from ichthyoplankton survey data, 2) estimating the maturity and fecundity of females from adult fish samples, and 3) calculating the biomass of spawning adults. Before 1996, sardine egg production was estimated from CalVET plankton net samples and adult fish were sampled in various ways prior to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average female fish weight (Wolf 1988a, 1988b; Scannell et al. 1996; Macewicz et al. 1996; Lo et al. 1996).

Since 1996, in addition to CalVET and Bongo nets, the Continuous Underway Fish Egg Sampler (CUFES; Checkley, et al. 1997) has been used as a routine sampler for fish eggs, and data of sardine eggs collected with CUFES have been incorporated in various ways depending on the survey design in the estimation procedures of the daily egg production. In the 1997 sardine egg survey (Hill et al. 1998, Lo et al. 2001), CUFES was used to allocate CalVET tows in an adaptive sampling plan. From 1998 to 2000, data of sardine eggs collected with both CalVET and CUFES during each April California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise were used to estimate daily egg production (Hill et al. 1999). Use of the full data sets from both samplers in the DEPM can be time consuming. Furthermore, the CUFES samples are exclusively from 3 m depth and it is not clear whether the distributions of sardine egg stages from CUFES samples are representative. Use of the CUFES data also requires an estimated conversion factor from eggs/min to eggs/0.05m^2. Starting with the 1999 April CalCOFI survey, an adaptive allocation survey design similar to the 1997 survey was implemented. In this design, CalVET tows are added in areas where they were not preassigned if sardine egg densities in CUFES collections are high.

Since 2001, a cost-effective alternative has been adopted to retain the DEPM index, but in a revised form that reduces effort in calculation and egg staging for CUFES collections. This revised DEPM index only uses CalVET samples of eggs and yolk-sac larvae and Bongo samples of yolk-sac larvae in the high density area (Region 1) to provide an estimate of P_0, the variance of which can be large due to small sample size (fewer than 100 plankton tows). Adult samples were collected sporadically in 1997, 2001 and 2002.

Since 2004, full-scale surveys have been conducted for collection of Pacific sardine eggs, larvae, and adults to estimate the spawning biomass in the area off California from San Diego to San Francisco (Lo and Macewicz 2004; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2005 and 2006; Lo et al. 2007). In 2004 the adult samples were taken primarily in the high density area, but beginning in 2005 adult Pacific sardine samples for reproductive output were taken in both high and low density areas. The ichthyoplankton samples taken during regular April CalCOFI cruises were also included in the spawning biomass computation.

MATERIALS AND METHODS

Data

Sardine eggs collected aboard the NOAA vessel *David Starr Jordan* with both CalVET and CUFES, during the March-April 2007 CalCOFI and DEPM surveys, were the data sources for estimating the daily egg production of Pacific sardine. In addition to sardine eggs and yolk-sac larvae collected with the CalVET net, yolk-sac larvae collected with the Bongo net have been included to model the sardine embryonic mortality curve since 2000. Beginning in 2001 (Lo 2001), the CUFES data from the ichthyoplankton surveys are used only to map the spatial distribution of the sardine spawning population with the survey area post-stratified into high density (Region 1) and low density (Region 2) areas according to the egg density from CUFES collections. Staged eggs from CalVET tows and yolk-sac larvae from CalVET and Bongo tows in the high density area have been used to model the embryonic mortality curve in the high density area and later converted to the daily egg production for the whole survey area.

The planned 2007 survey consisted of three legs: Leg 1, the regular CalCOFI survey and Legs 2 and 3, the DEPM survey. Leg 1 (March 27 - April 12) was to occupy 6 CalCOFI lines (93.3 - 76.7). Leg 2 (April 13 - 20) was to occupy 6 lines northward from line 91.7 out to station 70. Leg 3 (April 20 - May 1) was to occupy 4 CalCOFI lines (73.3 - 63.3) off Central California. Due to equipment problems and weather conditions, Leg 1 ended on April 19th with five CalCOFI lines from 93.3 to 80.0 occupied. Leg 2 from April 19 - 23 covered three lines from line 91.7 out to station 70 and ended at Port San Luis. Leg 3 from April 23-May 1 occupied three lines: 76.7, 66.7 and 63.3 due to weather conditions. Thus, the *David Starr Jordan* cruise (March 27 – May 1) occupied 11 lines (93.3- 63.3) out of 17 planned lines; lines were 20 or 40 nm apart (Figure 1). Bongo samples were taken at CalCOFI stations except line 63.3. During leg 1, CalVET tows were taken only at regular CalCOFI survey stations. During legs 2 and 3, CalVET tows were taken at 4 nm intervals on each line after the egg density from each of two consecutive CUFES samples exceeded 1 egg/min and CalVET tows were stopped after the egg density from each of two consecutive CUFES samples was less than 1 egg/min. The threshold value was reduced to 1 egg/min from 2 used in years prior to 2002 to increase the area identified as the high density area and, subsequently, to increase the number of CalVET samples. This adaptive allocation sampling was similar to the 1997 survey (Lo et al. 2001).

The survey area was post-stratified into two regions: Region 1, the high density area, and Region 2, the low density area. Region 1 encompassed the area where the egg density in CUFES collections was at least 1 egg per minute. The sizes of Region 1 and the total survey area were calculated using the formula for trapezoid area. The area of Region 1 was 142,403 km^2, which is 40% of the total survey area of 359,159 km^2. The rest of the survey area was Region 2 (Figure 1). One egg/min is equivalent to two to seven eggs/CalVET tow, depending on the degree of water mixing.

A total of 959 CUFES samples was collected. CUFES sampling intervals ranged from 2 to 50 minutes with a mean of 28 minutes and median of 30 minutes. A total of 84 CalVET samples was collected, of which 43 contained at least one sardine egg (Table 1). Egg densities from each CalVET sample and from the CUFES samples taken within an hour before and after the CalVET tow, were paired and used to derive a conversion factor (*E*) from eggs/min of CUFES sample to CalVET catch. We used a regression estimator to compute the ratio of mean eggs/min from CUFES to mean eggs/tow from CalVET: $E = \mu_y / \mu_x$ where y is the eggs/min and x is eggs/tow.

For adult samples, the survey plan was to use the *David Starr Jordan* to conduct 3-4 trawls a night at the regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections from April 19-30, 2007. Bad weather reduced the amount of survey time and hence, the number of trawls attempted. Although only 18 trawls were conducted at night near the surface (0-6 fathoms), 15 were positive for Pacific sardines (Figure 1).

Up to 50 sardines were randomly sampled from each positive trawl (Table 2). If necessary, additional mature females were collected to obtain 25 mature females per trawl for reproductive parameters or for use in estimating batch fecundity. Each fish was sexed, standard length (mm) and weight (g) were measured, otoliths were removed for aging, tissue was preserved in 95% ethanol for genetics, and for females their ovaries were removed and preserved in 10% neutral buffered formalin. Each preserved ovary was blotted and weighed to the nearest milligram in the laboratory. Ovary wet weight was calculated as preserved ovary weight times 0.78 (unpublished data, CDFG 1986). A piece of each ovary was removed and prepared as hematoxylin and eosin (H&E) histological slides. All slides were analyzed for oocyte development, atresia, and postovulatory follicle age to assign female maturity and reproductive state (Macewicz et al. 1996).

In addition to the trawl survey, 300 sardines were sampled from six sardine-fishery purse-seine sets conducted in the vicinity of Seal Beach, California (Figure 1) on the nights of April 9, 16, 23, and 24. Fifty sardines from each set were randomly sampled by coastal pelagic species (CPS) observers onboard the commercial fishing vessels and kept chilled until docking. Upon arrival the fish were sexed, all ovaries were removed and preserved in 10% neutral buffered formalin, and the bodies were individually bagged and frozen. Later the sardines were thawed, measured, otoliths were removed, and tissue was preserved in 95% ethanol for genetics. Preserved ovaries were processed as above and H&E histological slides were made for evaluation.

Daily egg production (P_0)

Similar to the 2001-2006 procedure (Lo 2001), we used the net tow as the sampling unit. Eggs from CalVET tows and yolk-sac larvae from both CalVET and Bongo tows in Region 1 were used to compute egg production based on data from 10 transects (lines 93-66) (Figure 1). A total of 36 of the 55 CalVET samples in this region contained at least 1 sardine egg; these eggs were examined for their developmental stages (Figure 2).

Based on aboard-ship counts of eggs in CUFES samples, 590 of the 959 collections were positive for sardine eggs. In Region 1, there were 342 positive CUFES collections out of 400 total collections. In Region 2, 248 of the total 559 collections were positive (Table 1).

For modeling the embryonic mortality curve, yolk-sac larvae (larvae ≤ 5 mm in preserved length) were included assuming the mortality rate of yolk-sac larvae was the same as that of eggs (Lo 1986). Yolk-sac larval production was computed as the number of yolk-sac larvae/0.05m^2 divided by the duration of the yolk-sac stage (number of larvae/0.05m^2/day), and the duration was computed based on the temperature-dependent growth curve (Table 3 of Zweifel and Lasker 1976) for each tow. For yolk-sac larvae caught by the Bongo net, the larval abundance was further adjusted for size-specific extrusion from 0.505 mm mesh (Table 7 of Lo 1983) and for the percent of each sample that was sorted. The adjusted yolk-sac larvae/0.05 m^2 was then computed for each tow and was termed daily larval production/0.05 m^2. In the entire survey area, 38 of 84 CalVET and 26 of 68 Bongo samples had at least one yolk-sac larva (Figure 3). In Region 1, 34 of 55 CalVET and17 of 23 Bongo samples were positive for yolk-sac larvae. In Region 2, 4 of 29 CalVET and 9 of 45 Bongo samples were positive for yolk-sac larvae (Table 1).

Daily egg production in Region 1 ($P_{0,1}$)

Sardine eggs and yolk-sac larvae and their ages were used to construct an embryonic mortality curve (Lo et al. 1996). Sardine egg density for each developmental stage was computed based on CalVET samples (Figure 2). The density of eggs in 2007 was lower than some of the previous years (Lo 2003; Lo and Macewicz 2002, 2004, 2006; Lo et al. 2005 and 2007). Unlike most of the past data where the density of eggs in stage 6 was highest, the density of eggs in stage 9 was highest in 2007. A temperature-dependent stage-to-age model (Lo et. al. 1996) was used to assign age to each stage. Sardine egg abundances and estimated ages were used directly in nonlinear regression. Eggs ≤ 3-h old and eggs older than 2.5 days were excluded because of possible bias. The average sea surface temperature for CalVET tows with ≥ 1 egg was 13.7˚C, lower than 14.95˚C in 2006 and 14.2˚C in 2005, and similar to 13.4˚C in 2004 and 13.8˚C in 2003.

The sardine embryonic mortality curve was modeled by an exponential decay curve (Lo et al. 1996):

$$P_t = P_{\mathbf{0}} e^{-zt} \qquad [1]$$

where P_t is either eggs/0.05m^2/day from CalVET tows or yolk-sac-larvae/0.05m^2/day from CalVET and Bongo tows, and t is the age (days) of eggs or yolk-sac larvae from each tow. A weighted nonlinear regression was used to estimate two parameters in equation (1) where the weights were 1/SD. The standard deviation (SD) of eggs was 2.06, 1.73, and 3.26, for day one, day two and day three age groups respectively. The SD of yolk-sac larval production from CalVETs was 0.71 and the SD of yolk-sac larval production from Bongo samples was 1.77.

A simulation study (Lo 2001) indicated that $P_{0,1}$ computed from a weighted nonlinear regression based on the original data points has a relative bias (RB) of -0.04 of the estimate where the RB = (mean of 1,000 estimates - true value)/mean of 1,000 estimates. Therefore the bias-corrected estimate of egg production in Region 1: $P_{0,1,c} = P_{0,1}$ * (1- RB) = $P_{0,1}$ *(1.04), and SE ($P_{0,1,c}$) = SE($P_{0,1}$) * 1.04.

Daily egg production in Region 2 ($P_{0,2}$)

Although 29 CalVET samples were taken in Region 2, only 7 tows had ≥ 1 sardine egg, ranging from 1 to 5 eggs per tow (Table 1). Therefore, we estimated daily egg production in Region 2 ($P_{0,2}$) as the product of the bias-corrected egg production in Region 1 ($P_{0,1,c}$) and the ratio of egg density in Region 2 to Region 1 (***q***) from CUFES samples, assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET is the same for the whole survey area:

$$P_{0,2} = P_{0,1,c} q \qquad [2]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}} m_i}{\sum_i m_i} \qquad [3]$$

$$\mathrm{var}(q) = \frac{[n/(n-1)] \sum_i m_i^2 (q_i - q)^2}{\left(\sum_i m_i \right)^2}$$

where ***q*** is the ratio of eggs/min between the low density and high density areas, m_i was the total CUFES time (minutes) in the i[th] transect, $\bar{x}_{j,i}$ is eggs/min of the i[th] transect in the j[th] Region, and $q_i = \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}}$ is the catch ratio in the i[th] transect.

Daily egg production for the whole survey area (P_0)

P_0 was computed as the weighted average of $P_{0,1}$ and $P_{0,2}$:

$$\begin{aligned} P_0 &= \frac{P_{0,1,c} A_1 + P_{0,2} A_2}{A_1 + A_2} \\ &= P_{0,1,c} w_1 + P_{0,2} w_2 \\ &= P_{0,1,c} [w_1 + q w_2] \end{aligned} \qquad [4]$$

and

$$mse(P_0) = mse(P_{0,1,c})(w_1 + w_2 q)^2 + P_{0,1,c}^2 w_2^2 V(q) - mse(P_{0,1,c}) w_2^2 V(q)$$

(Goodman 1960) where $mse\ (P_{0,1,c}) = \mathrm{v}(P_{0,1}) + \mathrm{bias}^2 = \mathrm{v}(P_{0,1}) + (P_{0,1}\ \mathrm{RB})^2$

and $w_i = \dfrac{A_i}{A_1 + A_2}$, and A_i is the area size for i = 1 or 2.

Adult parameters

Four adult parameters are needed for estimation of spawning biomass: 1) daily spawning fraction or the number of spawning females per mature female per day (S); 2) the average batch fecundity (F); 3) the proportion of mature female fish by weight (sex ratio, R); and 4) the average weight of mature females (g, W_f). Population values for S, R, F and W_f were estimated by methods in Picquelle and Stauffer (1985). Daily specific fecundity (number of eggs per population weight (g) per day) is $(RSF)/W_f$. Correlations among all pairs of adult parameters were calculated for computing the variance of the estimate of spawning biomass (Parker 1985). An MS ACCESS[1] Visual Basic program (Chen et al. 2003) was used to summarize the trawl adult parameters, calculate adult parameter correlations and covariance, and to estimate spawning biomass and its coefficient of variation.

Spawning fraction (S). A total of 203 mature female sardines was analyzed and considered to be a random sample of the population in the area trawled. Histological criteria can be used to identify four different spawning nights: postovulatory follicles aged 44-54 hours old indicated spawning two nights before capture (A); postovulatory follicles aged about 20-30 hours old indicated spawning the night before capture (B); hydrated oocytes or new (without deterioration) postovulatory follicles indicated spawning the night of capture (C); and early stages of migratory-nucleus oocytes indicated that spawning would have occurred the night after capture (D). The daily spawning fraction can be estimated by using the number of females spawning on one night, an average of several nights, or all nights. We used the number of females identified as having spawned the night before capture (B) and the adjusted number of mature females caught in each trawl (Table 2) to estimate the population spawning fraction and variance which is the default spawning night in the EPM program (Chen et al. 2003) and the traditional method of Picquelle and Stauffer (1985).

Batch fecundity (F). Batch fecundity (number of oocytes per spawn) was considered to be the number of migratory-nucleus-stage oocytes or the number of hydrated oocytes in the ovary (Hunter et al., 1985). We used the gravimetric method (Macewicz et al. 1996; Hunter et al. 1985, 1992) to estimate mean batch fecundity for 27 females caught during the April 2007 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = -3922 + 319.9W_{of}$ where $r^2 = 0.877$ but the intercept did not differ from zero (P = 0.081). Therefore, we forced the regression through 0 yielding the relationship $F_b = 279.23W_{of}$ where W_{of} ranged from 35 to 197g (Figure 4). We used this equation to predict batch fecundity for each of the 203 mature Pacific sardine females analyzed to estimate spawning frequency.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Female weight (W_f). The observed female weight was adjusted downward for females with hydrated ovaries because their ovary weights were temporarily inflated. We obtained the adjusted female weight by the linear equation $W_f = 1.05W_{of}$ where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated mature females taken during the April 2007 survey.

Sex ratio (R). The female proportion by weight was determined for each trawl (or each collection). The average weight of males and females (calculated from the first 10 males and 25 females) was multiplied by the number of males or females in the collection of 50 randomly selected fish to calculate total weight by sex in each collection. Thus, the female proportion by weight in each collection (Table 2) was calculated as estimated total female weight divided by estimated total weight in the sample. The estimate of the population's sex ratio by weight was calculated (Picquelle and Stauffer, 1985).

Length measurements of frozen and thawed sardines are less than fresh measurements because fish shrink in length after freezing. Based on 167 sardines (collected in 2007 and measured fresh and again after freezing and thawing; Figure 5), the relationship of fresh SL to thawed SL, as determined by simple linear regression, was *fresh SL* = 2.89 + 1.0286•(*thawed SL*) where $r^2 = 0.995$. We used this equation to calculate fresh SL for each thawed SL of the 300 sardines sampled from the six fishery sets.

Spawning biomass (B_s)

The spawning biomass was computed according to:

$$B_s = \frac{P_0 AC}{RSF / W_f} \quad [5]$$

where A is the survey area in unit of 0.05 m^2, S is the number of females spawning per mature females per day, F is the batch fecundity (number of eggs per mature female), R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (g), and C is the conversion factor from grams (g) to metric tons (mt). P_0A is the total daily egg production in the survey area, and the denominator (RSF/W_f) is the daily specific fecundity (number of eggs/population weight (g)/day).

The variance of the spawning biomass estimate $\left(\hat{B}_s\right)$ was computed from the Taylor expansion and in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

$$VAR\left(\hat{B}_s\right) = \hat{B}_s^{\,2}\left[CV\left(\hat{P}_0\right)^2 + CV\left(\hat{W}_f\right)^2 + CV\left(\hat{S}\right)^2 + CV\left(\hat{R}\right)^2 + CV\left(\hat{F}\right)^2 + 2COVS\right] \quad [6]$$

The last term involving covariance term on the right-hand side is

$$COVS = \sum_i \sum_{i<j} sign \frac{COV(x_i, x_j)}{x_i x_j}$$

where x's are the adult parameter estimates, and subscripts i and j represent different adult parameters; e.g., $x_i = F$ and $x_j = W_f$. The sign of any two terms is positive if they are both in the numerator of B_S or denominator of B_S (equation 5); otherwise, the sign is negative. The covariance term is

$$\text{cov}(x_{i,} x_j) = \frac{[n/(n-1)]\sum_k m_k (x_{i,k} - x_i) g_k (x_{j,k} - x_j)}{\left(\sum_k m_k\right)\left(\sum_k g_k\right)}$$

where k refers to k^{th} tow, and k=1,…,n. The terms of m_k and g_k are sample sizes and $x_{i,k}$ and $x_{j,k}$ are sample means from the k^{th} tow for x_i and x_j respectively.

RESULTS

Daily egg production (P_0)

In Region 1, the daily egg production ($P_{0,1}$) was 1.27/0.05 m^2/day (CV = 0.20; equation 1 and Figure 6) compared to 5.32/0.05 m^2/day (CV = 0.25) in 2006 for the standard DEPM survey area, egg mortality was Z = 0.133 (CV = 0.36) compared to 0.31 (CV = 0.25) in 2006, and the area was 142,403km^2 (41,608nm^2) compared to 98,034 km^2 (28,644 nm^2) in 2006 (Table 4). The bias-corrected egg production, ($P_{0,1,c}$) is 1.32 (CV = 0.2; Table 3). The ratio (***q***) of egg density between Region 2 and Region 1 from CUFES samples was 0.427 (CV = 0.42) (equation 3). In Region 2, the egg production ($P_{0,2}$) was 0.56 /0.05 m^2/day (CV = 0.45) for an area of 216,756 km^2 (63,333 nm^2). The estimate of the daily egg production for the entire survey area was 0.864/0.05 m^2 (CV = 0.256) (equation 4) for a total area of 356,159 km^2 (104,940 nm^2) (Table 3). The point estimate of egg mortality was lower than those in the past years (Table 4).

Catch ratio between CUFES and CalVET (E)

Although this ratio is no longer needed in the current estimation procedure, we computed it for comparison purposes. The catch ratio of eggs/min to eggs/tow (eggs/min = E * eggs/0.05 m^2) was computed from 43 pairs of CalVET tows and CUFES collections (Figure 7). The eggs/min corresponding to each positive CalVET tow was the mean of all CUFES collections taken from one hour before to one hour after each positive CalVET tow. The catch ratio was 0.15 (CV = 0.09) compared to the 2006 estimate of 0.32 (CV = 0.12) and the 2005 estimate of 0.18 (CV = 0.28). A ratio of 0.15 means that one egg/tow from a CalVET tow was equivalent to approximately 0.15 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 6.66 eggs/tow from the CalVET sample.

Adult parameters

Standard length (SL) of the first 50 randomly selected sardine in each trawl ranged from 118 to 262 mm for 217 males and from 111 to 258 mm for 216 females. The gonad from a 115 mm fish was lost during processing and fish was classed as indeterminate. 5.5% of the females ranging from 111 to 170 mm SL were immature. There were 151 females (119-190mm SL) and 149 males/indeterminates (113-179mm SL) in the six commercial-fishery samples (Figure 8). Preliminary examination of the histological slides of ovary sections indicated that chilling or delay in preservation may affect postovulatory follicles but may not affect ooctye development and atresia. Therefore, we used the 151 females (45.6% were immature) to increase the number of females for maturity estimation but did not use them for estimation of adult reproductive output (daily specific fecundity) or spawning biomass estimation. Using logistic regression (Macewicz et. al 1996, Lo et al. 2005), the length at which 50% of females are mature (ML_{50}) was calculated as 152.8 mm SL (Figure 9).

Reproductive parameters of the 203 mature female sardines for the individual trawls (25 maximum per trawl) are given in Table 2. The April 2007 population sex ratio (R), was 0.515 (CV = 0.09) (Table 5). Estimates of the other female sardine parameters were: F, mean batch fecundity, was 21,761 eggs/batch (CV = 0.095); S, spawning fraction, was 0.114 per day (CV = 0.33); and W_f, mean female fish weight, was 81.62 grams (CV = 0.085). The average interval between spawning (spawning frequency) was about 9 days (inverse of spawning fraction or 1/0.114), and the daily specific fecundity was 15.68 eggs/gm/day (Table 5). The correlation matrix for the adult parameter estimates is shown in Table 5.

Spawning biomass (B_s)

The final estimate of spawning biomass of sardine in 2007 (equation 5, Table 5) was 392,492mt (CV=0.45) or 431,741 short tons (st) (=392,492 x 1.1) for an area of 356,159 km^2 (104,940 nm^2) from San Diego to San Francisco. The point estimates of spawning biomass of Pacific sardine in 1994-2007 are, respectively: 127,102; 79,997; 83,176; 409,579; 313,986; 282,248; 1,063,837; 790,925; 206,333; 485,121; 281,639; 621,657; 837,501; and 392,492 mt (Table 4).

DISCUSSION

Pacific sardine eggs

Sardine eggs were evenly distributed in the middle of the survey area with slightly high density in the southern area between CalCOFI lines 83.3 and 93.3 (Figure 1). The egg density (0.87 egg/min, Table 3) from CUFES samples in 2007 was lower than 2006 (1.07 egg/min, Lo et al. 2007) and 2003 (1.57 egg/min, Lo 2003). The egg densities by stage are much lower than those in previous years. Unlike in 2002-2005, there seemed to be less spawning activity in the northern part of the survey area during 2007, similar to 2006.

The adaptive allocation sampling procedure was used only for legs 2 and 3 during the DEPM survey, which covered the area between CalCOFI lines 91.7 and 63.3, and out to station 70 for most lines, but not for leg 1, the regular CalCOFI survey, even though a high percentage of the positive CalVET tows taken during the CalCOFI cruise was in the high density area (9 out of 15). Additional CalVET tows that the adaptive sampling procedure would have allocated were not taken. As a result, the 84 total CalVET tows was lower than that taken in 2004 (n = 124). Again, we highly recommend that the adaptive allocation sampling be applied aboard the research vessel that conducts the routine spring (March-April) CalCOFI survey in the future to ensure the quality of the estimate of the spawning biomass of Pacific sardine.

Embryonic mortality curve

The estimates of the daily egg production at age 0 (P_0/0.05 m^2) and the daily embryonic mortality were lower than many other years. These low values were due to the low density of eggs and also partially caused by the distribution of egg developmental stages (Figure 2). In 2007, the density among egg developmental stages seemed to increase with stage for stage 3, 6, and 9. The combined data of staged eggs and yolk-sac larvae in the embryonic mortality curve enabled us to obtain a robust estimate of the mortality rate, even though the coefficient of variation (CV) of Z was high (0.36) (Table 4). This high CV is likely due to the smaller sample size of CalVET tows (84) in 2007 than in previous years: 217 in 2002, 192 in 2003 and 124 in 2004.

Catch ratio between CUFES and CalVET (E)

The 2007 catch ratio between CUFES and CalVET (0.15) was lower than most of those obtained in recent years: 1998 (0.32), 1999 (0.34), 2000 (0.277), 2001 (0.145 (CV = 0.026)), 2002 (0.24 (CV = 0.06)), 2003 (0.39 (CV = 0.11)), 2004 (0.22 (CV = 0.09), 2005 (0.18 (CV = 0.28)). and 2006 (0.32 (CV = 0.12)). This 2007 value was quite different from the 1996 estimate of 0.73. This could be because the 1996 CalVET samples were taken only in the southern area near San Diego while after 1997 CalVET samples were taken in a larger area extending far north of San Diego.

Adult parameters

During the 2007 Pacific sardine survey, we were able to conduct some trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) egg density to yield a better estimate of spawning biomass for the whole population in the large oceanic area from San Diego to San Francisco. The point estimates of the average mature female weight (W) were different between these two regions (86 grams (SE = 8) in Region 1 and 69 grams (SE = 12.3) in Region 2, Table 3), and so were the point estimates of the spawning fraction, S, (based on females that spawned the night before capture, night B or "Day 1") between two regions: 0.093 (SE = 0.03) in Region 1 and 0.151 (SE = 0.09) in Region 2. However, both differences were not statistically significant between regions ($t < 1.16$). In 2005 and 2006, point estimates of the average weight were similar and S was higher in Region 1 (Lo and Macewicz 2006, Lo et. al 2007). In 2007, the high value of the spawning fraction estimate in Region 2 was primarily due to data from one trawl (# 1) with an unusually high fraction of females spawning (10 of 22, Table 2). If the data from trawl number 1 were excluded, *S* would be 0.044 (2/45) in Region 2. We recommend that number of trawls be increased in both high and low egg density areas for future biomass surveys.

We estimated that 50% of the female sardines were mature (ML_{50}) at 153 mm during April 2007 (Figure 9). The April 2007 estimate of ML_{50} is much lower than the 2004 value (193 mm) and about the same as the estimate from 2005 (152 mm) and 1994 (159 mm) (Lo et al. 2005, Lo and Macewicz 2006). The variation in ML_{50} could be real due to change in maturity or it may be the result of sample bias from one or more of the following: a) sardines were from the high egg density area only, b) all or a majority of the sardines were from offshore, c) all or a majority of the sardines were from inshore or near islands, d) migration of sardine subpopulations, and e) age and length relationship. We recommend continued evaluation of maturity to eliminate any biases.

Trawling during the 2007 survey covered a broad area and we obtained six additional inshore samples from CPS observers on commercial fishing vessels. We examined female parameters in offshore and inshore (or near island) areas. We found that female sardines were larger offshore, which is similar to 2005 (Figure 8, Table 7). When we examined maturity we included the CPS observer samples and found that a higher proportion of the randomly selected females were immature in the inshore area, which is consistent with 2005 (Table 7). In 2007, a smaller fraction of the mature females offshore were spawning than inshore, which is opposite of the pattern in 2005 (Table 7) that suggested larger female may spawn more frequently (Lo and Macewicz 2006). The higher *S* inshore, like the high *S* in Region 2, may have been the contagion of trawl number 1 with an unusually high fraction of females spawning (10 of 22). Higher temperature may increase spawning rate because in 2007 (Table 2) the fraction of mature females spawning in trawls at higher temperatures (14.1-14.9°C) was higher (0.237 (14/59) with trawl 1 or 0.108 (4/37) without trawl 1) than the fraction (0.076 = 11/144) in trawls at lower temperatures (11.9-13.4°C). We recommend that future biomass surveys sample sardines both offshore and inshore.

Stock assessments and many biological comparisons use length as one of the variables: first maturity, 50% maturity, age and growth rates, spawning rates, fecundity, and more. It is important to have consistent measurement of length. Pacific sardine DEPM trawl surveys measure standard length while the fish are fresh. In 2007 for the first time, we used data from sardines obtained by CPS observers on commercial fishing vessels that were frozen prior to measurement. To ensure that fresh and thawed standard lengths were comparable, sardines were opportunistically obtained during 2007 and the relationship determined (*fresh SL* = 2.89 + 1.0286•*thawed SL*). We feel our estimation of maturity is more accurate because of these length adjustments. We recommend future surveys conduct additional measurements to investigate if the fresh - thawed standard length relationship has any inter-annual variation. It may have important ramifications for stock assessments.

In 2007 the collection of adult sardines occurred (before May) during typical peak spawning (Lo et al. 2007) and was within 15 days or less of sardine egg sampling. The 2007 estimation of the spawning fraction, *S*, (0.114, based on females that spawned the night before capture, night *B* or “Day 1”) was similar to recent point estimates in 1997, 2004, and 2005 (Table

6) when night B was also used to estimate *S*. Therefore, we feel that it would be acceptable to adjust the low 2006 estimate of *S* (0.0698) that may have been biased as a result of: end of season sampling, 15-30 day delay from peak egg collection, and low number of trawls. We estimated that the average *S* using 1997, 2004, 2005, and 2007 data (Table 6) was 0.126. We calculated that adult reproductive output (daily specific fecundity, RFS/W) for 2006 would be increased from 8.62 to 15.57 eggs/g/day ((0.451)(18474)(0.126)/67.41) and the spawning biomass would be estimated downward from 1,512,882mt to 837,501mt.

Spawning biomass

The 2007 estimate of spawning biomass is considerably lower than that in 2006 and close to that in 2003. These differences are primarily due to the difference of both egg production and adult daily reproductive output. The 2007 egg production (0.86 eggs/0.05m^2) was lower than in the 2006 standard DEPM survey area (1.94 eggs/0.05m^2) and many other years, while the area of Region 1 of 142,403 km^2 was bigger than during many recent years after 2000 (Table 4). The adult daily reproductive output (daily specific fecundity) was similar to that in 2005 (15.67 eggs/g/day) and the adjusted 2006 estimate (15.57 eggs/g/day), and lower than during 1997-2004 (Table 6). The higher values in early years were due to the fact that trawl samples were taken in the high density area only while since 2005 trawl samples were taken in both Region 1 (the high egg density area) and Region 2 (the low egg density area).

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Table 1. Number of positive tows and total number of tows of Pacific sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, and eggs from CUFES in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min <1) for *David Starr Jordan* cruise 0704.

		Region		
		1	**2**	**Total**
CalVET eggs	Positive	36	7	43
	Total	55	29	84
CalVET-yolk-sac	Positive	34	4	38
	Total	55	29	84
BONGO-yolk-sac	Positive	17	9	26
	Total	23	45	68
CUFES eggs	Positive	342	248	590
	Total	400	559	959

Table 2. Individual trawl information, sex ratio[a], and parameters for mature female *Sardinops sagax*, used in estimation of March-April 2007 spawning biomass; trawls are listed from north to south.

COLLECTION INFORMATION									MATURE FEMALES							
				Location									Number spawning time periods[b]			
Sardine egg density regions 1=high 2=low	Trawl No.	Month-Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	Number of fish sampled	Proportion of females	Number analyzed	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	C	B	A	Number Females Adjusted[c]
2	13	4-28	2:50	36.3952	122.858	12.1	19	0.698	13	110.31	106.78	29817	0	0	0	13
1	14	4-28	20:50	35.7960	124.187	12.5	44	0.576	25	110.19	104.21	29099	4	5	1	26
2	18	4-30	3:48	35.7482	125.244	12.6	9	0.512	5	111.80	105.41	29432	0	1	1	6
1	15	4-29	2:20	35.6028	124.508	12.3	50	0.676	25	107.84	102.44	28604	0	4	8	29
2	11	4-22	22:18	33.7303	121.537	13.4	24	0.483	12	77.04	73.88	20630	0	0	0	12
1	10	4-22	19:09	33.5153	121.761	13.4	1	0.000	0	--	--	--	--	--	--	--
1	8	4-21	22:05	33.3708	120.155	12.5	50	0.379	16	59.59	56.62	15809	0	0	0	16
1	7	4-21	19:31	33.2805	120.084	11.9	50	0.522	23	69.26	65.95	18416	0	0	0	23
1	9	4-22	2:36	33.2723	120.540	12.9	50	0.543	25	77.78	74.66	20848	0	1	5	26
2	1	4-19	19:30	33.0452	117.807	14.9	30	0.787	22	52.48	50.43	14081	0	10	6	32
2	2	4-19	23:56	32.9030	118.117	14.2	23	0.467	10	51.45	49.41	13798	0	1	3	11
2	3	4-20	5:08	32.7432	118.461	14.3	9	0.576	5	51.80	49.35	13779	0	0	1	5
1	4	4-20	19:24	31.9372	120.109	14.3	6	0.183	1	81.50	79.17	22106	0	0	0	1
1	5	4-20	22:08	31.8590	120.275	14.1	50	0.232	16	79.63	76.49	21357	3	3	2	16
1	6	4-21	1:01	31.7922	120.416	14.1	19	0.270	5	85.20	81.87	22860	2	0	1	3

[a] Sex ratio, proportion of females by weight, based on average weights (Picquelle and Stauffer 1985).

[b] Night of capture (C); Night before capture (B); 2 Nights before capture (A)

[c] Required to estimate the fraction of mature females that spawned the night before capture if the number of females spawning on the night of capture is an overestimate (equation 9 of Picquelle and Stauffer 1985).

Table 3. Pacific sardine egg production (P_0), adult parameters, and spawning biomass estimates in Region 1 (eggs/min ≥ 1), in Region 2 (eggs/min < 1) and for the whole area of the 2007 DEPM survey. For comparison, spawning biomass estimate is given using 2005 adult parameter data.

Parameter	Region 1	Region 2	Whole area	
CUFES samples	400	559	**959**	959
Calvet samples	55	29	**84**	84
P_0 / 0.05m^2	1.32	0.56	**0.86**	0.86
CV	0.20	0.46	**0.26**	0.26
Area (km^2)	142403	213756	**356159**	356159
%	39.98	60.02	**100**	100
Year for adult samples	2007	2007	**2007**	2005
Female fish wt (W_f)	86.2	69.1	**81.62**	65.34
Batch fecundity(F)	22929	18578	**21761**	17662
Spawning fraction (S)	0.093	0.151	**0.114**	0.1236
Sex ratio (R)	0.488	0.615	**0.515**	0.468
Eggs/g biomass/day (RSF/W_f)	12.06	24.9	**15.68**	15.67
Spawning biomass(mt) [b]	311774	96819	**392492**	390934
CV	0.45	0.82	**0.45**	
Daily mortality(Z)	0.13			
CV	0.36			
eggs/min	1.54	0.43	**0.87**	
CV	0.2	0.32	**0.17**	
q = eggs/min in Region 2 / eggs/min in Region 1			**0.427**	
CV			**0.42**	
E = eggs.min/eggs/tow			**0.15**	
CV			**0.09**	
Bongo samples	23	45	**68**	
Area in nm^2	41608	63333	**104940.5**	
S. biomass(short ton)	342951	106501	**431731**	430027

[a] 1.32 was corrected for bias of P_0.
[b] biomass was computed from estimates of parameters in each column, i.e. 2007 whole area is an average of adult parameters and 392492 ≠ 311774 + 96819

Table 4. Estimates of daily egg production (P_0)[a] for the survey area, daily instantaneous mortality rates (Z) from high density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardine and average sea surface temperature for the years 1994 to 2007.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	RSF/W	Spawning biomass (mt) (CV)[b]	Mean Temp. for positive egg or yolk-sac samples	Mean temperature all CalVETs
1994	0.193 (0.210)	0.120 (0.91)	380,175 (174,880)	11.38	127,102 (0.32)	14.3	14.7
1995	0.830 (05)	0.400 (0.4)	113,188.9 (113188.9)	23.55[c]	79,997 (0.6)	15.5	14.7
1996	0.415 (0.42)	0.105 (4.15)	235,960 (112,322)	23.55	83,176 (0.48)	14.5	15.0
1997	2.770 (0.21)	0.350 (0.14)	174,096 (66,841)	23.55[d]	409,579 (0.31)	13.7	13.9
1998	2.279 (0.34)	0.255 (0.37)	162,253 (162,253)	23.55	313,986 (0.41)	14.38	14.6
1999	1.092 (0.35)	0.100 (0.6)	304,191 (130,890)	23.55	282,248 (0.42)	12.5	12.6
2000	4.235 (0.4)	0.420 (0.73)	295,759 (57,525)	23.55	1,063,837 (0.67)	14.1	14.4
2001	2.898 (0.39)	0.370 (0.21)	321,386 (70,148)	23.55	790,925 (0.45)	13.3	13.2
2002	0.728 (0.17)	0.400 (0.15)	325,082 (88,403)	22.94	206,333 (0.35)	13.6	13.6
2003	1.520 (0.18)	0.480 (0.08)	365,906 (82,578)	22.94	485,121 (0.36)	13.7	13.8
2004	0.960 (0.24)	0.250 (0.04)	320,620 (68,234)	21.86[e]	281,639 (0.3)	13.4	13.7
2005	1.916 (0.417)	0.579 (0.20)	253,620 (46,203)	15.67	621,657 (0.54)	14.21	14.1
2006	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	15.57[f]	837,501[f] (0.46)	14.95	14.5
2007	0.864 (0.256)	0.133(0.36)	356,159 (142,403)	15.68	392,492 (0.45)	13.7	13.6

[a] weighted non-linear regression on original data and bias correction of 1.04, except in 1994 and 1997 when grouped data and a correction factor of 1.14 was used (appendix Lo 2001).

[b] $CV(B_s) = (CV^2(P_0) + allotherCOV^2)^{1/2} = (CV^2(P_0)+0.054)^{1/2}$. For years 1995-2001 $allotherCOV^2$ was from 1994 data (Lo et al. 1996). For year 2003, allotherCOV was from 2002 data (Lo and Macewicz 2002)

[c] 23.55 was from computation for 1994 based on S = 0.149 (the average spawning fraction (day 0 + day 1) of active females from 1986-1994; Macewicz et al. 1996).

[d] is 25.94 when calculated from parameters in table 6 and estimated spawning biomass is 371,725 mt with CV = 0.36.

[c] uses R = 0.5 (Lo and Macewicz 2004); if use survey R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt

[f] value for standard DEPM sampling area off California when calculated using S = 0.126, the average of females spawning the night before capture ("day 1") from 1997, 2004, 2005, and 2007. When survey S of 0.0698 was previously used (Lo et al. 2007), the 2006 DEPM spawning biomass was estimated as 1,512,882 mt (CV 0.46) and the 2006 coast-wide spawning biomass was estimated as 1,682,260 mt.

Table 5. The 2007 output from "frmBIOMASS" form in the EPM program after input of 2007 parameters and estimation of adult parameters (top box), and 'Estimate Correlation and Biomass also' (bottom box) (Appendix II Chen et al. 2003).

EPM PROGRAM

Calculate Correlation, Biomass and CV

Input Parameters:

Enter first collection number	4262
Enter last collection number	4279
Enter first collection number of 2nd set	
Enter last collection of 2nd set	
Mean gonad-free weight used in regression	83.5
Number of fish used in regression	27
Variance about regression	18298053
Variance of regression slope	84.162
Po (eggs/day - 0.05m2)	0.864
Variance of Po	0.049
Area (square kilometers)	356159

Statistic Results:

	Average	Variance
Whole Body Weight	81.619829089	48.201437719
Gonad Fee Weight	77.930879310	42.772181322
Batch fecundity	21760.63943	4278735.0391
Spawners, Day 0	0.0443349754	0.0005915074
Spawners Day 1	0.1141552511	0.0014610609
Sex Ratio	0.5152110284	0.0024047847
Daily specific fecundity	15.680395642	
Number of Sets	14	

Enter the name of DBSET table	DBSET07b
Estimate Average and Variance only	Estimate
Estimate Correlation and Biomass also	Estimate

EGG PRODUCTION VALUES

Po (eggs/day - .05 m2):	0.864
CV of Po:	0.25620305117
Area (square kilometers):	356159

BIOMASS ESTIMATE

Biomass (m - tons) =	392491.851637
CV (biomass) =	0.44869866691

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.88253605	-0.0820636	0.36283493
Batch Fecundity (F)			-0.0771749	0.31825118
Fraction Spawning (S)				0.20187282
Sex Ratio (R)				

Table 6. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007
Midpoint date of trawl survey		April 22	March 25	May 1	April 21	April 25	April 13	May 2	April 24
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/6	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30
N collections with mature females		37	4	2	6	16	14	7	14
N collection within Region 1		11	4	2	6	16	6	2	8
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515
Average mature female weight (grams): with ovary	**W_f**	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62
without ovary	**W_{of}**	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93
Average batch fecundity[a] (all mature females, oocytes estimated)	**F**	24283	42002	22456	54403	55711	17662	18474	21760
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267
N mature females analyzed		583	77	9	23	290	175	86	203
N active mature females		327	77	9	23	290	148	72	187
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114
Spawning fraction of active females[c]	**S_a**	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68

[a] 1994-2001 estimates were calculated using $F_b = -10858 + 439.53\ W_{of.}$ (Macewicz et al. 1996), 2004 used $F_b = -356.46W_{of.}$.(Lo and Macewicz 2004), 2005 used $F_b = -6085 + 376.28\ W_{of.}$ (Lo and Macewicz 2006), and 2006 used $F_b = -396 + 293.39\ W_{of.}$ (Lo et al. 2007)

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season).

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

Table 7. Pacific sardine female parameters by location and year for fishery independent surveys.

Parameters	Location			
	Inshore		Offshore	
	2005	2007	2005	2007
Trawl number	1, 2, 6, 7, 9, 10, 11, 14	1, 2, 3	3, 8, 12, 16, 18, 19	4, 5, 6, 7, 8, 9, 11, 13, 14, 15, 18
Number of females	172	38[a]	57	178
Standard length (mm)				
Mean	158	165[b]	197	195
Range	121 - 195	149 - 186	161 – 265	111 – 258
Whole body weight (g)				
Mean	44.6	51.9	97.4	87.4
Range	18.5 - 95.5	37.5 - 67.5	50.0 - 210.0	15.5 - 217.5
Proportion Immature (%)	40.7	2.6[c]	7.0	6.2
Average fraction of mature [d] spawning	0.064	0.149	0.189	0.072
spawning the night of capture	0.010	0.0	0.208	0.054
spawned the night before capture	0.118	0.297	0.170	0.090
Average fraction of active [e] spawning	0.080	0.153	0.209	0.079
spawning the night of capture	0.012	0.0	0.229	0.059
spawned the night before capture	0.148	0.306	0.188	0.098
Proportion of postbreeding [f] mature (%)	20.6	2.7	9.4	8.4

[a] also collected 151 females in CPS observer sampled fishery-dependent purse-seine sets
[b] mean SL = 154 mm and range is 119-190 mm for females in CPS sampled sets.
[c] 45.6% immature females identified in CPS sampled sets.
[d] number of mature females includes all active and post-breeding females.
[e] active females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles < 60 hours old.
[f] postbreeding females are mature females that are no longer active and considered incapable of further spawning in the season (Macewicz et el. 1996).

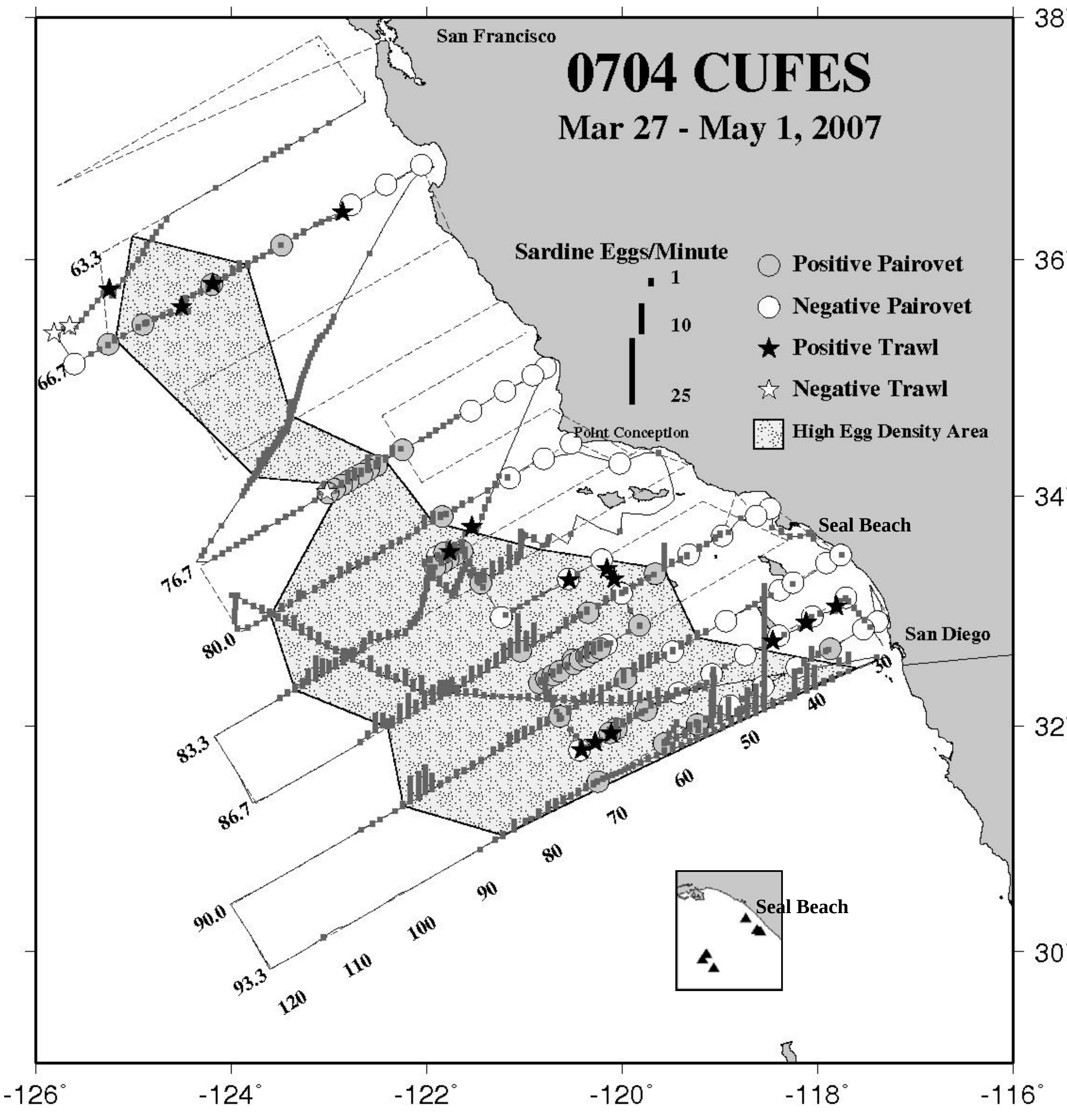

Figure 1. Location of Pacific sardine eggs from CalVET, a.k.a. Pairovet; (solid circle denotes positive catch and open circle denotes zero catch) and from CUFES (stick denotes positive collection) in 2007. Trawl locations (solid star is catch with sardine adults and open star is catch without sardines). The numbers on line 93.3 are CalCOFI station numbers. Region 1 is stippled area. Dashed lines without net tows were station lines planned but not occupied. Insert shows area of CPS observer sampled sets.

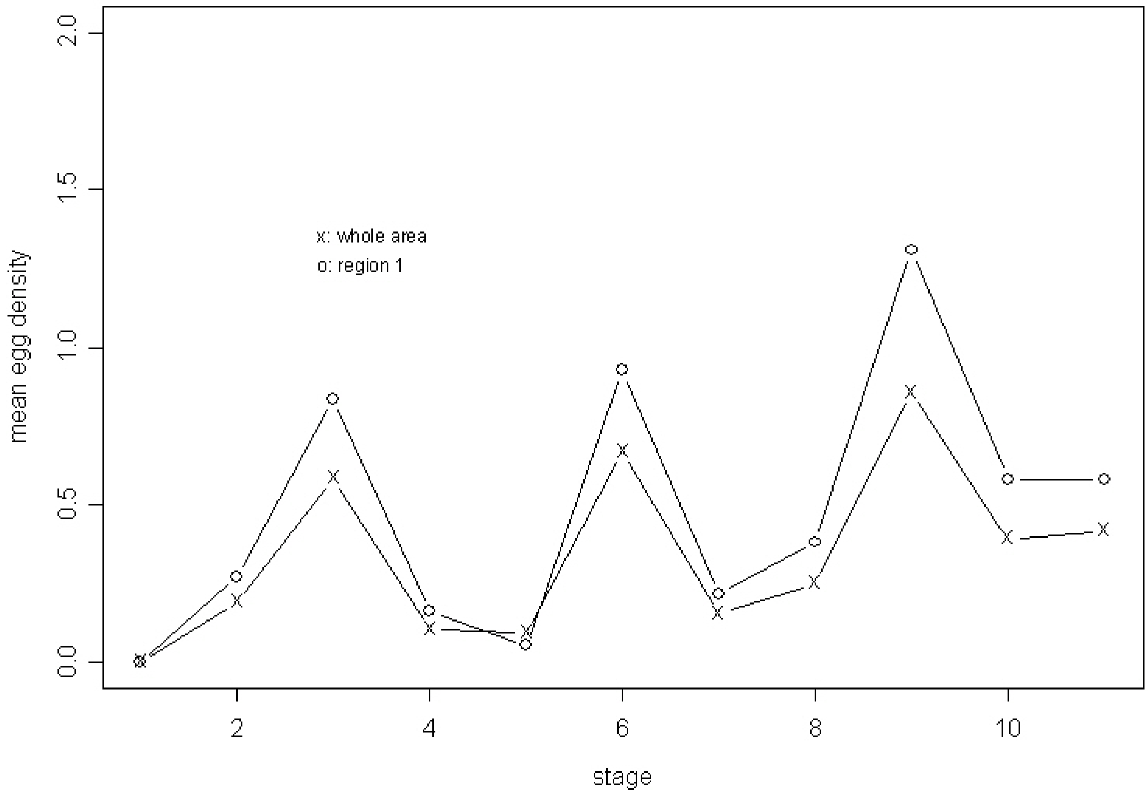

Figure 2. Pacific sardine eggs per 0.05 m^2 for each developmental stage for March 27 - May 1, 2007 . Symbols: o = Region 1 and x = entire survey area.

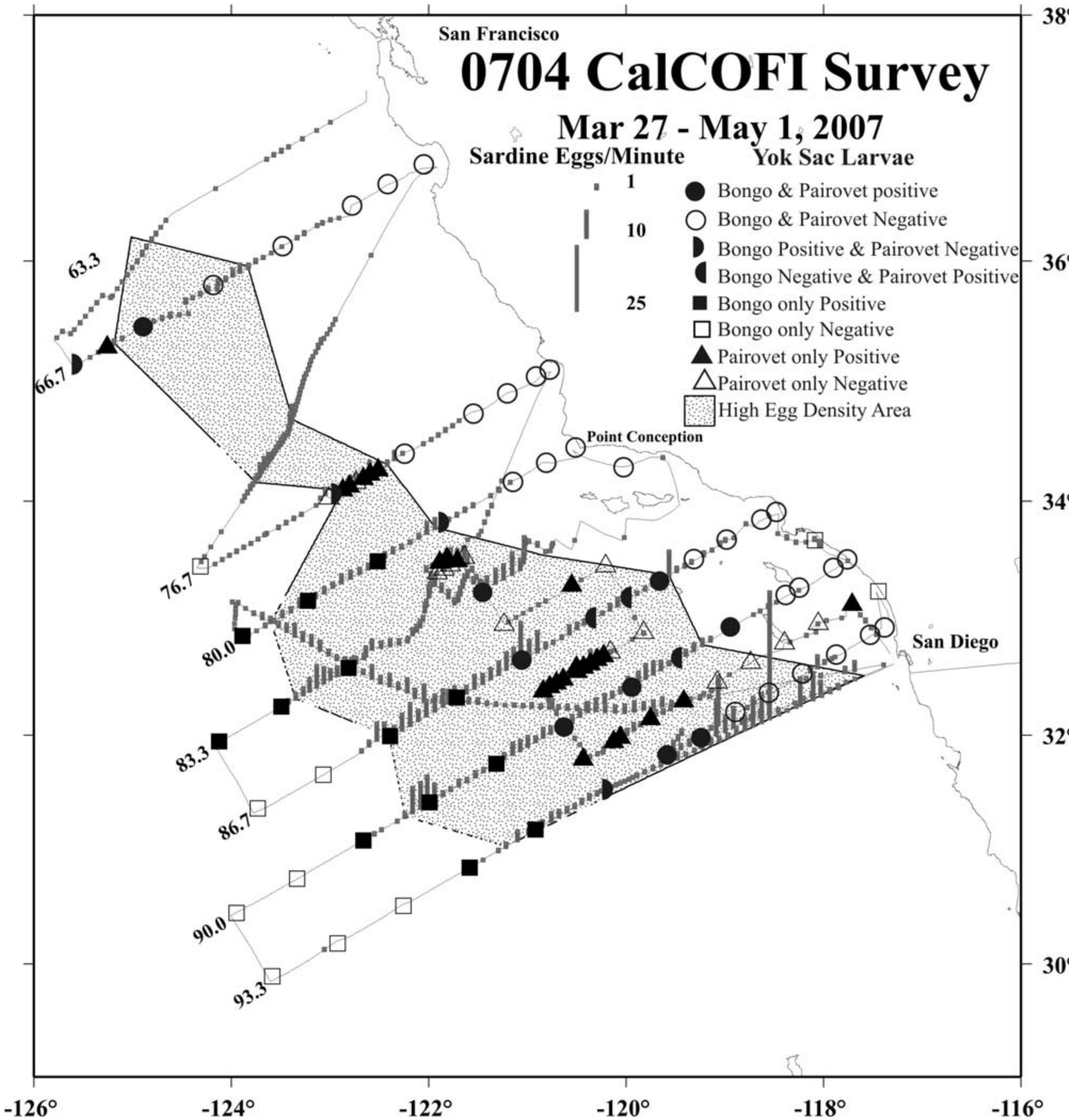

Figure 3. Locations of Pacific sardine yolk-sac larvae from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) in 2007. Solid symbols are positive and open symbols are zero catch.

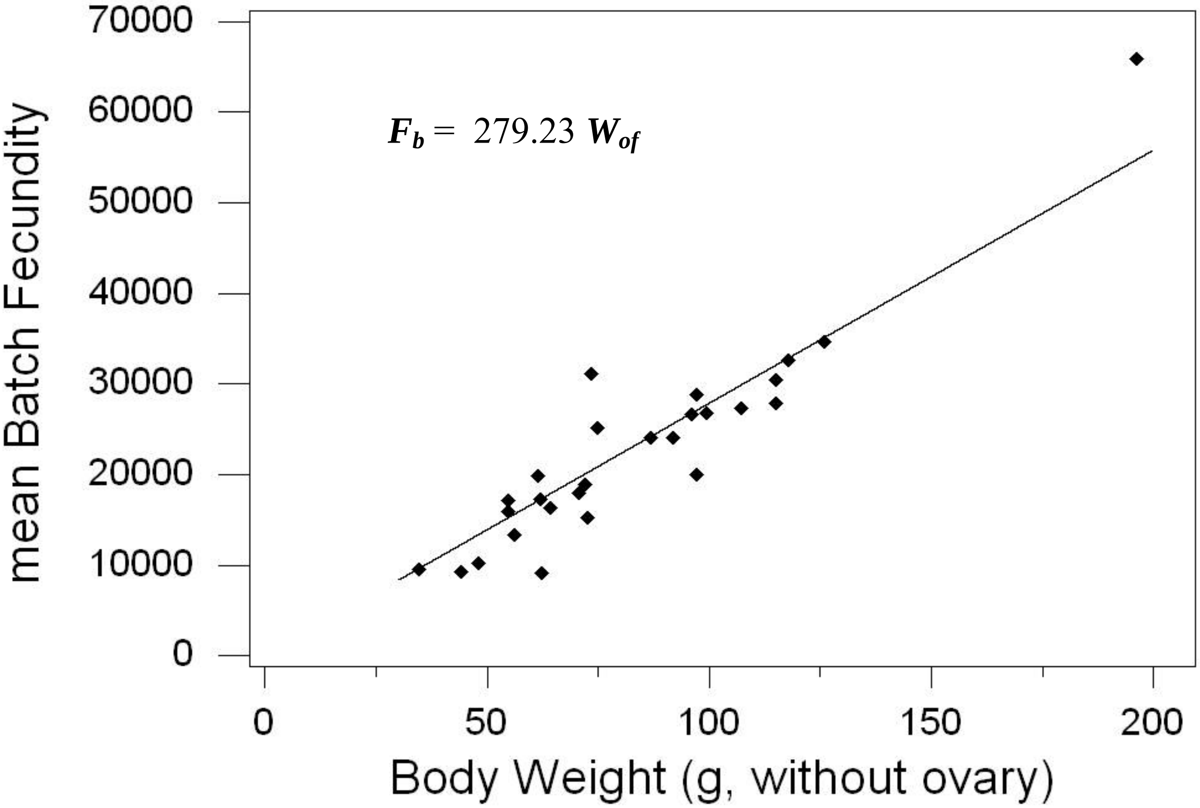

Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 27 females taken during April 2007. The batch was estimated from numbers of hydrated or migratory-nucleus-stage oocytes.

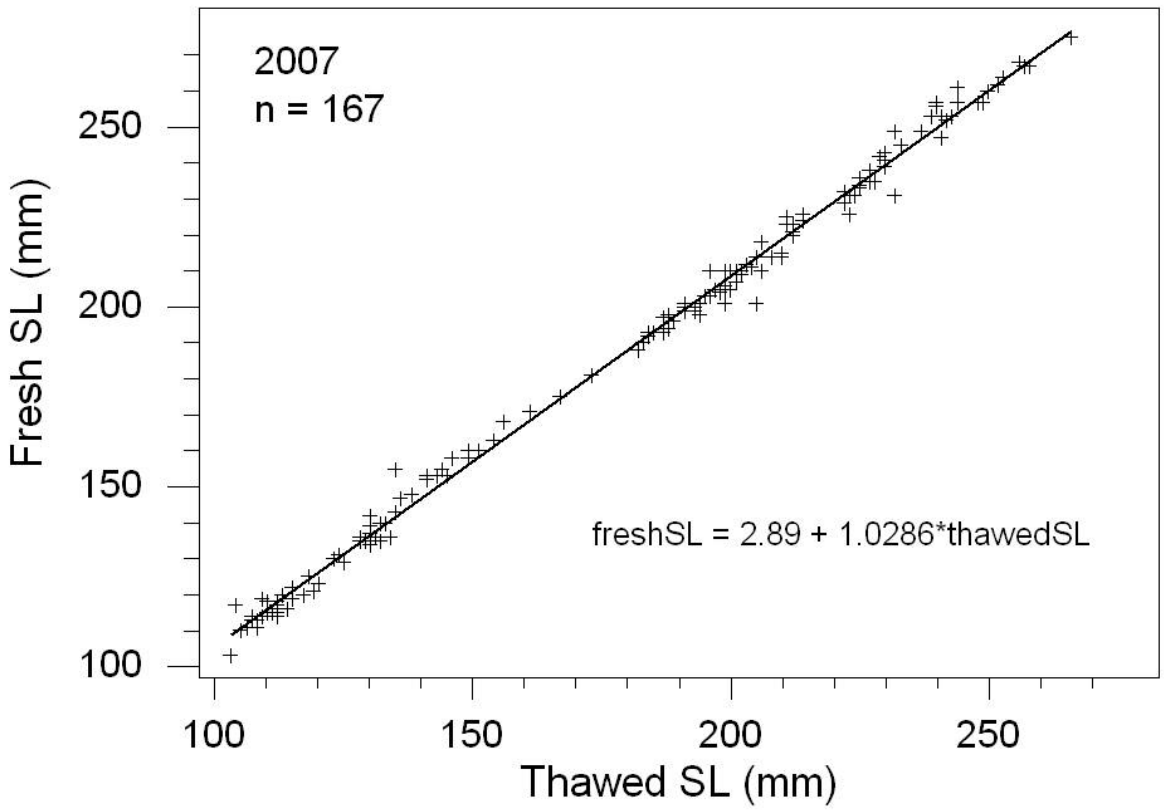

Figure 5. Relationship of standard length (SL) for Pacific sardines measured fresh and again after having been frozen and thawed.

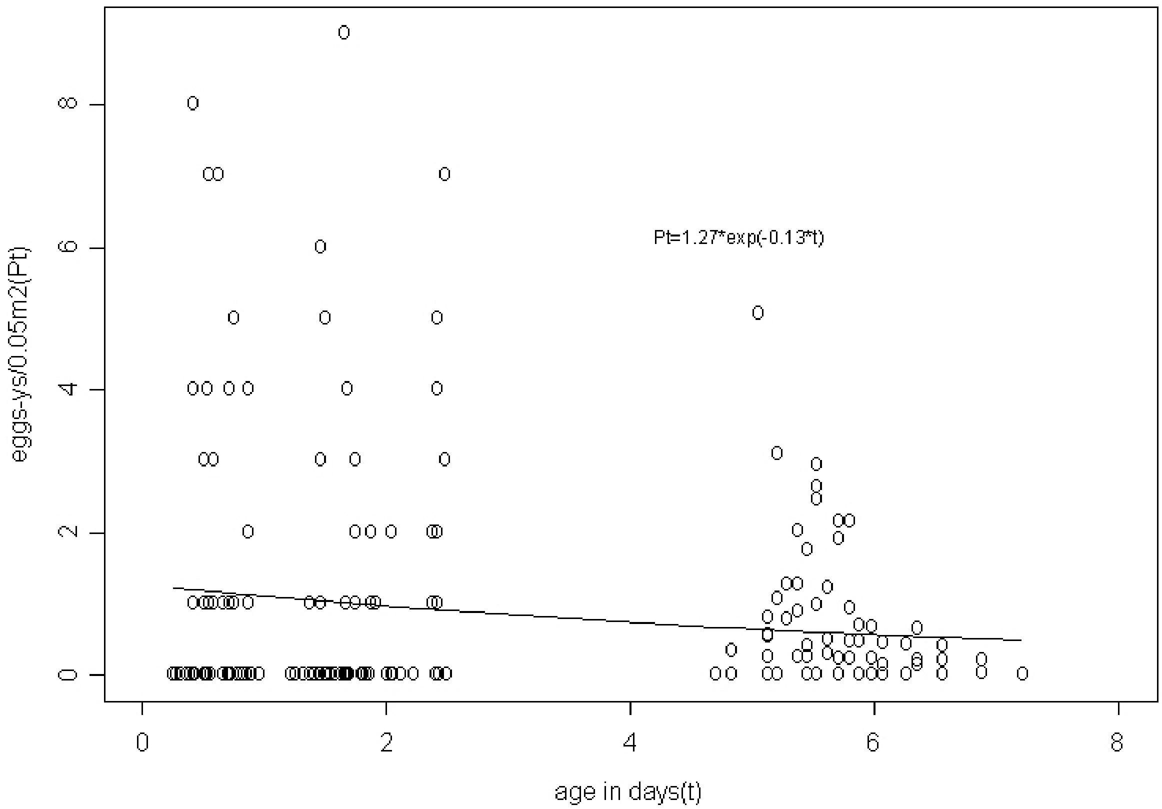

Figure 6. Embryonic mortality curve of Pacific sardine. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo in 2007. The number, 1.27, is the estimate of daily egg production before correction for bias.

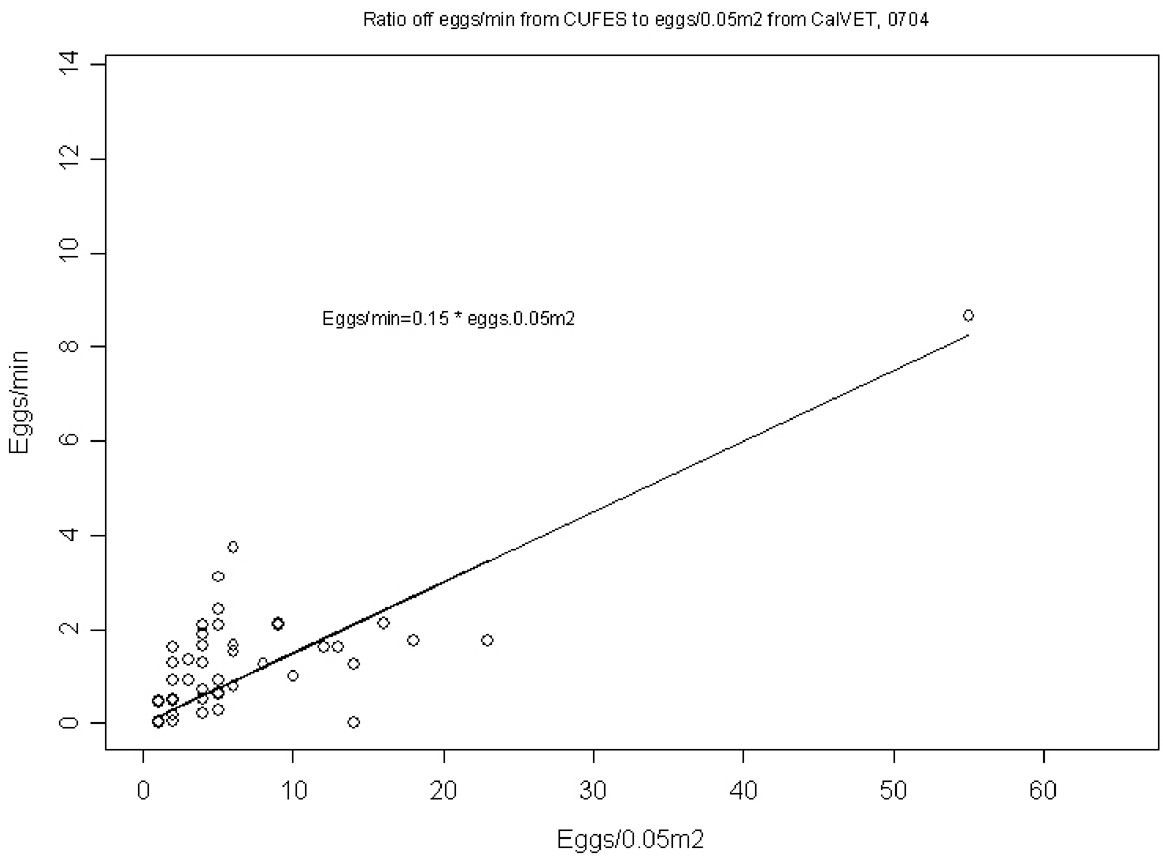

Figure 7. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April 2007.

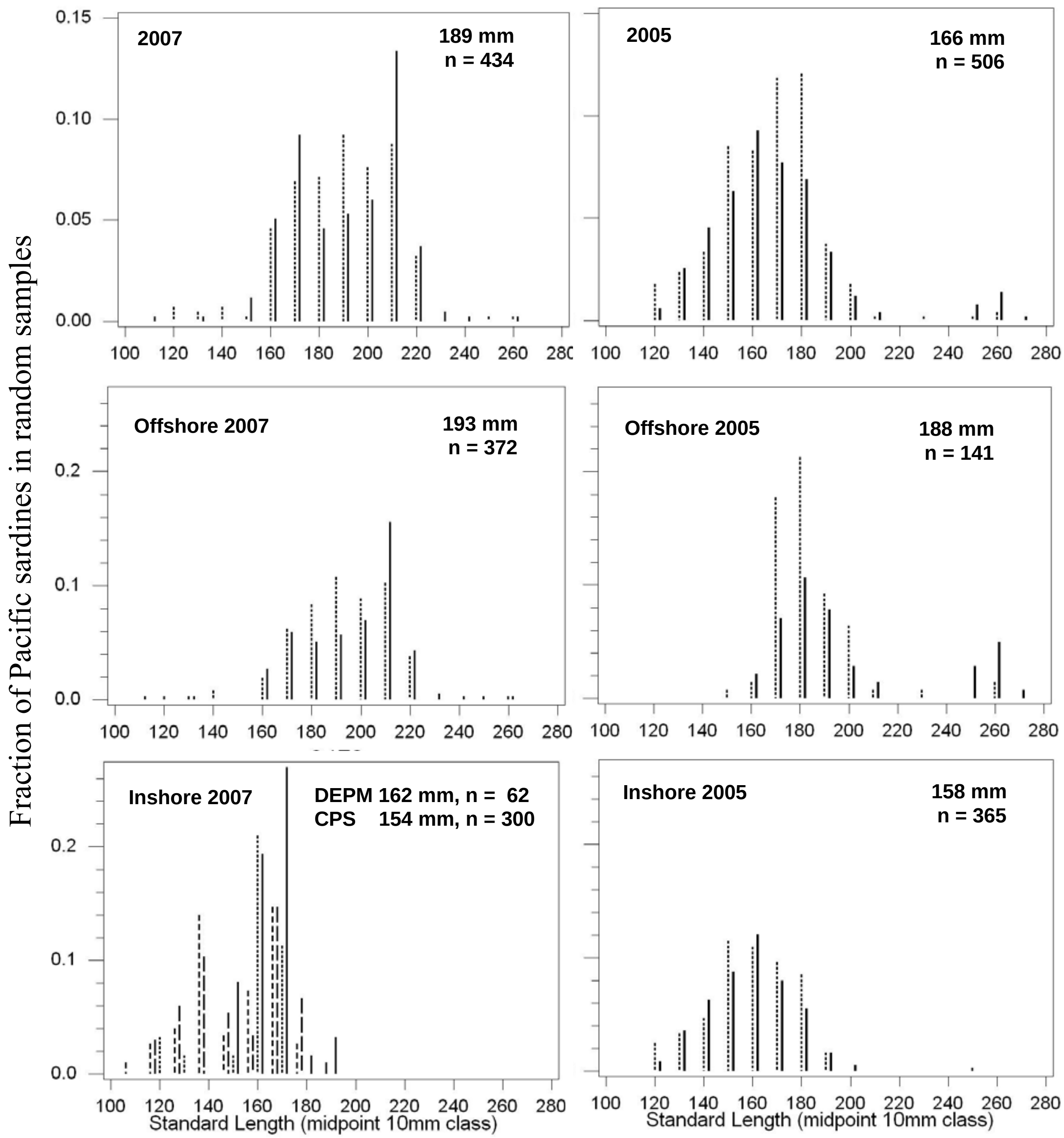

Figure 8. Length distribution and mean length of Pacific sardines caught in the 2007 and 2005 surveys and for each subarea. DEPM survey males are indicated by dotted bar and females by solid bar; CPS observer sample males indicated by dash bar and females by long dash bar.

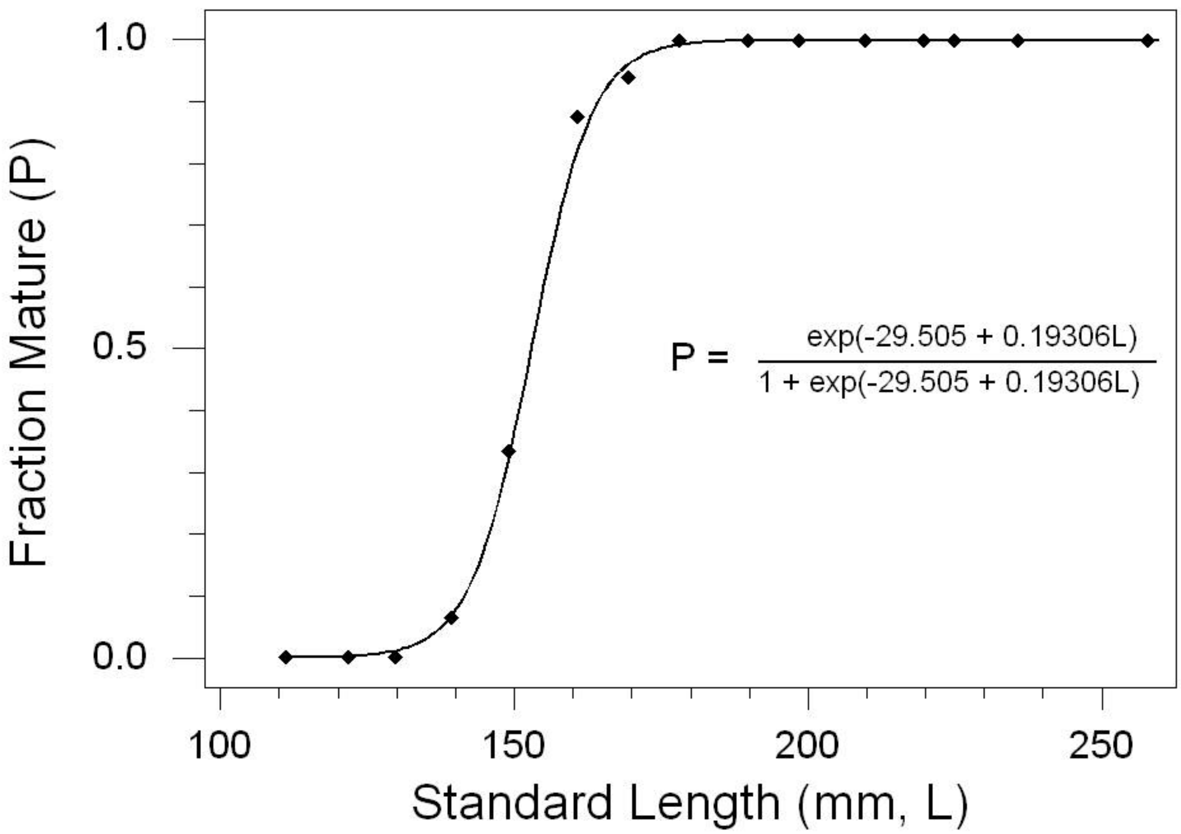

Figure 9. Fraction of Pacific sardine females randomly sampled during April 2007 that were sexually mature as a function of standard length. Sardine females included 216 from *David Starr Jordan* trawls and 151 from CPS observer-sampled fishery sets. Symbols represent actual fraction mature within 10 mm length classes. Length at 50% mature was calculated as 152.8 mm.