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Nancy C.H. Lo
Beverly J. Macewicz
David A. Griffith
Richard L. Charter

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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National Oceanic & Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
La Jolla Laboratory
8604 La Jolla Shores Drive
La Jolla, California, USA 92037
Nancy.Lo@NOAA.GOV

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U.S. DEPARTMENT OF COMMERCE
Carlos M. Gutierrez, Secretary
National Oceanic and Atmospheric Administration
William J. Brennan, Acting Undersecretary for Oceans and Atmosphere
National Marine Fisheries Service
James W. Balsiger, Acting Assistant Administrator for Fisheries

SUMMARY

The spawning biomass of the Pacific sardine (*Sardinops sagax*) in April - May 2008 was estimated by the daily egg production method (DEPM) to be 135,301 mt (CV = 0.43) for an area of 667,162 km^2 off the west coast of North America from San Diego, U.S.A. to Cape Flattery, Washington (30°- 48.47°N), primarily for the area south of 39.5°N. For the entire survey area, the daily egg production estimate (P_0) was 0.218/.05m^2 (CV = 0.22), although no eggs were collected in the area north of latitude 39.5°N. The daily specific fecundity was calculated as 21.82 (number of eggs/population weight (g)/day) using the estimates of reproductive parameters from 187 mature female Pacific sardine collected from 12 positive trawls: *F*, mean batch fecundity, 29802 eggs/batch (CV = 0.06); *S*, fraction spawning per day, 0.118 females spawning per day (CV = 0.31); W_f, mean female fish weight, 102.21 g (CV = 0.06); and *R*, sex ratio of females by weight, 0.631 (CV = 0.09). The standard survey area off California, from San Diego to San Francisco (CalCOFI lines 95 to 60), in 2008 was 297,949 km^2. For the standard area, using the egg production estimate of 0.43/0.05m^2 (CV = 0.21) and the daily specific fecundity of 21.82 (number of eggs/population weight (g)/day), the spawning biomass was estimated to be 117,426 mt (CV=0.43). Only a single sardine was caught north of CalCOFI line 60. The spawning biomass north of CalCOFI line 60, near San Francisco, was 17,041 mt. In 2008, trawling was conducted randomly or at CalCOFI stations, which resulted in sampling adult sardines in both high (Region 1) and low (Region 2) sardine egg density areas.

The estimates of spawning biomass of the Pacific sardine off California in 1994 - 2008 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, 485,000 mt, 300,000 mt, 600,000 mt, 837,000 mt, 392,00 mt and 117,000 mt (for the standard DEPM area), respectively. Therefore, the estimates of spawning biomass have been fluctuating, peaked in 2000 and 2006 and have been declining in the recent three years. 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

INTRODUCTION

The spawning biomass of the 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 from ichthyoplankton survey data, 2) estimating the reproductive parameters 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. Adult fish were sampled in various ways prior to 1996 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 for 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 for 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 the 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 may 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 of Pacific sardine in the area off California from San Diego to San Francisco (Lo and Macewicz 2004, 2006; Lo et al. 2005,2006, 2007a and 2007b; Hill et al. 2005, 2006, 2007). The 2008 April survey was extended to Cape Flattery, Washington, to cover the majority of the area occupied by the sardine population off the west coast of North America. To better understand the spatial distribution of the population, length distribution and movement of Pacific sardines along the west coast of the United States (U.S.), through the year, a coast-wide California Current Ecosystem (CCE) survey was conducted in spring and summer of 2008. During March-April 2008 two NOAA ships were used: the *David Starr Jordan* covered the area from San Diego to San Francisco and the *Miller Freeman* covered the northern part from Cape Flattery, WA to San Francisco, CA while during July-August 2008 the *David Starr Jordan* covered the whole area. In this report, we provided the estimate of the spawning biomass and related biological information for the Pacific sardine off the west coast of the U.S. based on the 2008 April CCE survey.

MATERIALS AND METHODS

Data

The spring 2008 CCE survey was conducted aboard two NOAA research vessels: the *David Starr Jordan* (March 24-May 1) to cover the area off California from San Diego to San Francisco (CalCOFI lines 93.3 to 62.3) and the *Miller Freeman* (April 1-30) to cover the area from Cape Flattery, Washington to San Francisco (48.47°N to 36.6°N, down to CalCOFI line 63.3). During the CCE surveys, CalVET tows, Bongo tows and CUFES and trawls were conducted aboard both vessels. Prior to the CCE survey, the routine April CalCOFI survey was carried out aboard *David Starr Jordan* from March 24-April 9 to cover six lines from 93.3 to 76.6 and only CalVET and Bongo tows were taken. Data from both CCE and CalCOFI suryes were included in estimation of spawning biomass of Pacific sardines.

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 have been 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, P_0, for the whole survey area.

During the 2008 survey, thirty three distinct transects were occupied by the research vessels. The David Starr Jordan occupied 15 lines out of 17 lines planned and the Miller Freeman occupied 18 lines. The distance between lines ranged from 20 to 40 nm. Due to weather condition, some lines were not fully occupied by the Jordan, e.g. line 80, 70, 60, and others. For the CCE survey, 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 of 1 egg/min was reduced from the number used in years prior to 2002 (2 eggs/min) to increase the area identified as the high density area and, subsequently, to increase the number of CalVET samples. One egg/min is equivalent to two to seven eggs/CalVET tow, depending on the degree of water mixing. This adaptive allocation sampling was similar to that used inthe 1997 survey (Lo et al. 2001). As the threshold changed beginning in 2002, caution should be taken when the size of the area of Region 1 is compared.

The size of the whole survey area was 677,162 km^2. Only the area south of 39.5°N latitude (396,517 km^2) was used to estimate the initial P_0 because no eggs or adults were collected north of 39.5°N. This area was post-stratified into two regions: Region 1, the high egg density area, and Region 2, the low egg 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 entire survey area were calculated using the formula for a trapezoid area based on the distance between CalCOFI lines and the distance between CalCOFI stations. The area of Region 1 was 53,514 km^2, 13.5% of the area south of 39.5°N (396,517 km^2). The rest of the area south of 39.5°N was Region 2 (343,003 km^2, Figure 1). We also estimated the spawning biomass in the standard DEPM survey area off California to be compared with the past years. Over the years, although the standard DEPM survey area has varied in size, it is approximately from San Francisco (about 37.8°N) to San Diego or between CalCOFI lines 60 and 95. For 2008, this area was calculated as 297,949 km^2.

A total of 1643 CUFES samples were collected from both the *Miller Freeman* (591) and *David Starr Jordan* (1052) cruises over the whole survey area. For the area south of 39.5°N, 1190 CUFES samples were taken by both the *Miller Freeman* (138) and *David Starr Jordan* (1052). CUFES sampling intervals ranged from 1 to 60 minutes with a mean of 27.84 minutes and median of 30 minutes. The total number of CalVET tows was 240 for the entire survey area, 170 south of 39.5^{o}N and 151 in the regular DEPM survey area, south of line 60. A total of 85 CalVET samples caught at least one 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 (eggs/tow). 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 eggs/min and *x* is eggs/tow.

For adult samples, the survey plan was to use the *Miller Freeman* and the *David Starr Jordan* to conduct 2-4 trawls a night either at pre-assigned stations, or near regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections from April 1-May 1, 2008. This survey design would have enabled us to obtain an estimate of biomass from trawl catches using the swept trawl area method as well as spawning biomass using the DEPM and is different from the adaptive trawling conducted in 2004 and 2005 where the presence of sardine eggs in CUFES collections identified potential trawl sites. On both ships trawling was conducted at night near the surface (0-6 fathoms) using a Nordic 264 mid-water trawl. The *Miller Freeman* completed 42 trawls. Bad weather encountered by the *David Starr Jordan* reduced the amount of survey time, and hence the number of trawls completed was only 29. For the whole CCE survey, 71 trawls were conducted and the 13 nighttime trawls positive for Pacific sardines were located in the area south of 39.5°N (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).]

Daily egg production (P_0)

Because no eggs or adults were collected north of 39.5°N, the spawning biomass was most likely distributed in the survey area south of 39.5°N. For continuity and comparison purposes, we also estimated the spawning biomass for the standard DEPM survey area (i.e., the area from CalCOFI line 60 to San Diego) which has been surveyed for estimation of the annual spawning biomass of Pacific sardine in the past. For each area, appropriate parameter estimates required by the DEPM were obtained.

Similar to the 2001-2005 procedure (Lo 2001), we used the net tow as the sampling unit. Sardine eggs from CalVET tows and sardine yolk-sac larvae from both CalVET and Bongo tows in Region 1 were used to compute egg production, primarily based on data from 12 transects (Figure 1). In Region 1, a total of 65 out of 76 CalVET samples contained at least 1 sardine egg; these eggs were examined for their developmental stages (Figure 2 and Table 1).

Based on aboard-ship counts of sardine eggs in CUFES samples, 556 of the 1643 collections were positive for sardine eggs over the whole survey area (556 of 1190 collections S of 39.5°N). In Region 1, there were 232 positive CUFES collections out of 243 total collections. In Region 2, 324 of the total 1400 collections (324 of 947, S of 39.5°N) 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 whole survey area, 61 of 240 (of 170, S of 39.5°N) CalVET and 25 of 155 (of 85, S of 39.5°N) Bongo samples had at least one yolk-sac larva (Figure 3). In Region 1, 47 of 76 CalVET and 10 of 10 Bongo samples were positive for yolk-sac larvae. In Region 2, 27 of 180 (of 110, S of 39.5°N) CalVET and 15 of 145 (of 75, S of 39.5°N) Bongo samples were positive for yolk-sac larvae (Table 1). For the standard DEPM survey area (CalCOFI line 95 to CalCOFI line 60), please see Table 1.

Daily egg production for the whole survey area (30°N – 48.47°N)

Because no eggs were collected in the area north of latitude 39.5°N, the overall P_0 (daily egg production/0.05m^2) was first computed for the area south of 39.5°N and then prorated to the whole survey area simply by multiplying P_0 by the area south of 39.5°N divided by the size of the whole survey area.

Daily egg production in Region 1 ($P_{0,1}$) for the area south of 39.5°N

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 2008 was lower than in previous years (Lo 2003; Lo and Macewicz 2002, 2004,2005 and 2006, Lo et al. 2007a and 2007b). Like most past years, the density of eggs in stage 6 was highest among all stages, followed by the densities of eggs in stage 3 and stage 11. The average sea surface temperature for CalVET tows with ≥ 1 egg from the *David Starr Jordan* was 13.3°C which is low compared with other years (Lo et al. 2007b). A temperature-dependent stage-to-age model (Lo et. al. 1996) was used to assign age to each stage. Sardine eggs 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 from the *David Starr Jordan* was 13.1°C while from the Miller Freeman it was 9.6°C for all tows.

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, 3.7, and 3.8 for day one, day two and day three age groups from CalVET samples, respectively, and SD for yolk-sac larvae was 0.67 and 1.03 from CalVET and Bongo samples, respectively.

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 is calculated: $P_{0,1,c} = P_{0,1} * (1- \text{RB}) = P_{0,1} *(1.04)$, and SE ($P_{0,1,c}$) = SE($P_{0,1}$) * 1.04.

Daily egg production in Region 2 ($P_{0,2}$) for the area south of 39.5°N

Although 94 CalVET samples were taken in Region 2, only 20 tows had ≥ 1 sardine egg, ranging from 1 to 8 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 (q) of egg density in Region 2 to Region 1 from CUFES samples, assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET was the same for the whole survey area:

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

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

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

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. The estimates of q were computed from a total of 11 transect lines occupied by the *David Starr Jordan*; most lines occupied by the *Miller Freeman* south of 39.5°N had very low eggs/min.

Daily egg production (P_0) for the area south of 39.5°N and for the whole survey area

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

$$\begin{aligned} P_0 &= \frac{P_{0,1,c}A_1 + P_{0,2}A_2}{A_1 + A_2} \\ &= P_{0,1,c}w_1 + P_{0,2}w_2 \\ &= P_{0,1,c}[w_1 + qw_2] \end{aligned} \qquad [4]$$

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

The above P_0 was computed for the area S of 39.5°N. The estimate of P_0 for the whole survey area is P_0 times (the area S of 39.5°N divided by the total survey area) = P_0 x (396,517/677,162) = P_0 x 0.59.

Daily egg production for the standard DEPM survey area off California.

$P_{0,1}$ for the region 1 and **P_{02}** region 2 were the same as the estimates for the area up to N.39.5

with area size of region 2 (244,435 km^2) smaller than that (343,003 km^2) for the area up to 39.5°N.

A total of 75 CalVET samples were taken in Region 2, and 20 tows were positive for sardine (Table 1). The number of positive tows was higher than any of the previous surveys.

The P_0 for the standard DEPM survey area off California (from about San Diego to San Francisco) was obtained based on equation (4). All estimates of egg production were adjusted for bias-correction.

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 female fish mature 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 estimate spawning biomass and its coefficient of variation.

Spawning fraction (S). A total of 187 mature female sardines were 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 47 females caught during the April-May 2008 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = 14118 + 172.04W_{of}$,where $r^2 = 0.111$ but the intercept did not

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

differ from zero (P = 0.071). Therefore we forced the regression through 0, yielding the relationship $F_b = 305.14W_{of}$ where W_{of} ranged from 64.6 to 127.6 grams (Figure 4). We used this equation to predict batch fecundity for each of the 187 mature Pacific sardine females that had been analyzed for the estimation of spawning frequency.

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 $W_f = 1.04W_{of}$ where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated females taken during the April 2008 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).

Spawning biomass (B_s)

The spawning biomass was computed according to:

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

where A is the survey area in units of 0.05m^2, S is the fraction of mature females spawning per female per day, F is the batch fecundity (number of eggs per mature female released per spawning), 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):

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

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

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

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

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

where k refers to k^{th} tow, and $k = 1,\ldots,n$. 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 (P₀) for the whole survey area

In Region 1, the initial daily egg production ($P_{0,1}$) from the mortality curve was 1.39/0.05 m^2/day (CV = 0.18; equation 1 and Figure 5). The bias-corrected egg production, ($P_{0,1,c}$) is 1.45 (CV = 0.18) (Table 3) for an area of 53,514 km^2 (south of CalCOFI line 73.3). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.139 (CV=0.27) (equation 3). In Region 2 (South of 39.5°N) , the egg production ($P_{0,2}$) was 0.202 /0.05 m^2/day (CV = 0.32) for an area of 343,003 km^2 (100,220 nm^2). The estimate of the daily egg production for the area south of 39.5°N was 0.37/0.05 m^2 (CV = 0.22) (equation 4) for 396,517 km^2 (115,856 nm^2) (Table 3). Egg mortality (0.13 (CV=0.29)) was lower than most years (Table 4). The P_0 for the whole survey area (30°N-51°N) based on the ratio of area sizes was 0.37 x 0.59 = 0.218/0.05 m^2/day.

Daily egg production (P_0) for the standard DEPM survey area off California

The estimates of the egg production and egg mortality in the region 1 and the q value are the same as those for the whole survey area because region 1 was south of CalCOFI line 73.3. In Region 2, the egg production ($P_{0,2}$) was 0.202/0.05 m^2/day (CV = 0.32) for an area of 244,435 km^2 (71,420 nm^2). The estimate of the daily egg production for this area of 297,949 km^2 (87,056 nm^2) was 0.43/0.05 m^2 (CV = 0.21) (equation 4 and Table 3).

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 150 pairs of CalVET tows and CUFES collections from *David Starr Jordan* cruises (Figure 6). 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 0.19 (CV=0.06) in comparison to the 2007 estimate of 0.15 (CV=0.09), the 2006 estimate of 0.32(CV=0.12) , the 2005 estimate of 0.18 (CV = 0.28), the 2004 estimate of 0.22 (CV = 0.09) and the 2003 estimate of 0.39 (CV = 0.11). A ratio of 0.19 means that one egg/tow from a CalVET tow was equivalent to approximately 0.19 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 5.3 eggs/tow from the CalVET sample.

Adult parameters

Over the whole survey area (30°- 48.47°N) in April 2008, one Pacific sardine was taken at 39.98°N and 353 sardines were taken in the standard DEPM survey area off California (from San Diego to San Francisco). Standard length (SL) of the first 50 randomly selected sardine, in each trawl ranged from 163 to 246 mm for 135 males and from 167 to 253 mm for 219 females. The smallest mature female was 167 mm SL. The length at which 50% of females are mature (ML_{50}) was not calculated because immature female sardines were not captured in the survey. Since the single sardine taken north of the standard DEPM area was a male (236 mm), female reproductive parameters were calculated for the standard DEPM area and used for estimating spawning biomass in both the whole survey and standard DEPM areas.

Reproductive parameters of 187 mature female sardines (up to 25 mature analyzed per trawl) for the individual trawls are given in Table 2. The April 2008 population sex ratio (*R*), was 0.631 (CV = 0.098) (Table 5). Estimates of the other female sardine parameters were: *F*, mean batch fecundity, 29,802 eggs/batch (CV = 0.07); *S*, spawning fraction, 0.1186 per day (CV = 0.31); and W_f, mean female fish weight, 102.2 grams (CV = 0.06). The average interval between spawning (spawning frequency) was about 8 days (inverse of spawning fraction or 1/0.1186), and the daily specific fecundity was 21.82 eggs/population weight (g)/day (Table 5). The correlation matrix for the adult parameter estimates over the whole survey area is shown in Table 5.

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardine in 2008 (equation 5, Table 4 and 5) is 135,301 mt (CV=0.43) or 148,831 short tons (st) (=135,301 x 1.1) for the entire survey area of 677,162 km^2 (258,736 nm^2) from San Diego to Cape Flattery, Washington. For the standard DEPM area of 297,949 km^2 (87,056 nm^2) off California, the estimate of spawning biomass is 117,426 mt (CV=0.43) or 129,169 st. The point estimates of spawning biomass of Pacific sardine off California in 1994-2008 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; 392,492 and 117,426 mt (Table 4).

DISCUSSION

Sardine eggs

Sardine eggs were concentrated most in the area south of CalCOFI line 73.3 in a narrow strip (Figure 1) compared to the egg distribution in 2007 (Lo et al. 2007b). This could be due to low water temperature or other environmental conditions. The area north of 39.5°N latitude has been sampled on all fixed stations using ichthyoplankton net tows. The area of high concentration of sardine eggs was within the standard DEPM survey area, an indication of a spawning ground for sardine. In the DEPM survey area, the daily egg production of 0.43 eggs/0.05m^2 (Table 3) in 2008 was lower than previous years: 0.864 eggs/0.05m^2 in 2007, 1.936 eggs/0.05m in 2006 (Table 4). In addition, similar to recent years, in 2008 spawning activity was strong in the southern part of the survey area, off San Diego. The extent of spawning south of San Diego will not be known without information from Mexican surveys, i.e. IMCECOCAL.

The adaptive allocation sampling procedure was used aboard the *David Starr Jordan* and the *Miller Freeman*, north of CalCOFI line 63.3, except for the six CalCOFI lines of the regular CalCOFI cruise aboard the *David Starr Jordan*: CalCOFI lines 93.3, 90.0,…76.7. For the six regular CalCOFI lines, 14 out of 55 tows were in the high density area, but additional CalVET tows that the adaptive sampling procedure would have allocated were not taken. As a result, only 151 total CalVET tows were taken in the standard DEPM survey area. This was higher than the 84 in 2007, 123 in 2006, and 74 tows in 2005 but smaller than other recent years: 217 in 2002, 192 in 2003 and 124 in 2004. Again, we highly recommend that the adaptive allocation sampling be applied aboard the research vessel that conducts the spring (March-April) routine 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=1.39) and the daily embryonic mortality (0.13) directly from the mortality curve in Region 1 were similar to that in 2007 but lower than previous years. These low values were partially caused by the distribution of egg developmental stages (Figure 2). In 2008, the peak density among egg developmental stages was that of stage 6, as seen in past years. The latter phenomenon is not understood and needs thorough investigation. The overall P_0 or the DEPM (0.43 eggs/0.05m^2) and the entire survey area (0.218 eggs/0.05m^2) were lower than previous years (Table 3 and 4), partially due to the small area size of the high density area (Figure 1).

Catch ratio between CUFES and CalVET (E)

The 2008 catch ratio between CUFES and CalVET (0.139) computed from data obtained from the *David Starr Jordan* appeared to be similar to that of 2007 (0.15) and lower than that of 2006 (0.32(CV=0.12)) , of 2005 (0.18 (CV=0.28)), 2004 (0.22 (CV = 0.09)), 2002 (0.24 (CV = 0.06)), 2001 (0.145 (CV = 0.026)), and 2000 (0.27), in 1998 (0.32), 1999 (0.34), and 2003 (0.39 (CV = 0.11)). This 2008 value is 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 (routine

CalCOFI survey area) while after 1997 CalVET samples were taken in a larger area extending far north of San Diego (Lo et al. 2005). It would be informative to examine the relationship between the catch ratio and the degree of water mixing over the years (Lo et al. 2001).

The ratio of egg densities of two regions from pump samples (q)

The *q* value: ratio of eggs/min in Region 1 to eggs/min in Region 2, serves as the calibration factor to estimate $P_{0,2}$ in Region 2 (equation 2) because low abundance of eggs observed in Region 2 prevents us from using the egg mortality curve to directly estimate $P_{0,2}$. For the 2008 survey, the *q* value was obtained from 11 transect lines between CalCOFI lines 93.3 and 75.0 including transient lines: 0.139 (CV = 0.27) for the standard DEPM sampling area. This value, even though lower than that of 2007 (0.48), was higher than those of previous years. The q values ranged from 0.036 to 0.065 since 2001 with an increasing trend. If this trend continues, it may mean that the spatial distribution of the spawning population is becoming less aggregated.

Adult parameters

Trawling during the April 2008 CCE survey covered a large area off the west coast of the U.S. from Cape Flattery, WA to San Diego, CA. The only previous trawling conducted off the whole west coast was during the April-May 2006 Coastwide Pacific Sardine survey (Lo et al. 2007a). We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in three areas off the coast: Washington and Oregon (8.2-11.6^{o}C), northern CA (7.8-11.6^{o}C), and in the standard DEPM area (11.2-13.9^{o}C). They were lower than those in 2006 (Table 7), and we found that during April 2008 sardine eggs and adults were present only in northern CA and the standard DEPM area while during the warmer April 2006 they were present in all three areas. Off northern CA in 2008 the eggs densities were <1 egg/min (Figure 1) and only a single adult male were taken, while 101 sardine adults (averaging 91g) and eggs at densities ≥ 1egg/min were collected in 2006 (Lo et al 2007b). Although in the standard DEPM area sardine adults and eggs are always collected, in 2008 the area of Region 1 was much smaller than in 2006 (Table 3); in addition, the average sardine female was larger in 2008 (102.2g) than in 2006 (67.4g) (Table 6). We believe that the colder temperatures encountered in 2008 may have delayed/restricted movement of sardines north.

During the April 2008 survey in the standard DEPM survey area, we were again able to collect some trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) egg density to yield a better estimate of Pacific sardine spawning biomass for the whole population in the large oceanic area from San Diego to San Francisco. We found that the average mature female weight (W_f) was similar in both regions (107.3 grams (SE = 6.6) in Region 1 and 100.2 grams (SE =8.4) in Region 2, Table 3) while the fraction of females spawning per day, *S*, (based on females that spawned the night before capture, night *B* or "Day 1") was higher in Region 1 (0.25 females/day (SE = 0.03)) than Region 2 (0.085 females/day (SE = 0.03)). This regional difference in the fraction of females spawning (high in 1 and lower in 2) was similar to the case in past DEPM surveys in 2005, 2006 (Lo and Macewicz 2006, Lo et al. 2007a) and 2007 (when one unusual trawl is removed, Lo et al. 2007b). Because more females are spawning per day in Region 1 than Region 2, it is necessary to continue to trawl in both regions to ensure an unbiased estimate of spawning biomass for the whole population. Additionally, in 2008, when 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, S was similar (0.1186 females/day) to recent point estimates in 1997, 2004, 2005, and 2007 but higher than in 2006, when adults were sampled 15-30 days after egg collection (Table 6). As in the past, spawning fraction in 2008 had a high CV (0.31), most likely due to the low number of trawls with sardines and high variability of spawning. Therefore, we recommend that the number of trawls be increased, in both high and low egg density areas, for future biomass surveys.

We investigated the relationship of batch fecundity and female weight (without ovary) for the 47 females taken in 2008 to that of females taken in 2006 (n = 27) and 2007 (n = 27) because the r^2 was small (0.11) for the simple linear regression in 2008 compared to r^2 values of 0.83 in 2006 (Lo et al. 2007a) and 0.88 in 2007 (Lo et al. 2007b). We plotted the relationships for each female (Figure 7) and used covariance analysis to test for differences in the relation between batch fecundity and female weight (without ovary) in sardine from 2006, 2007, and 2008. No statistical difference existed among slopes from the three data sets (P = 0.094). Assuming that the slopes were equal, covariance analysis indicated that the adjusted group means were not different at the 8% level ($F_{2,\ 100}$ = 2.65, P = 0.076). Combining the data from all three years (Figure 7) yielded the equation: $F_b = -1147 + 307.14W_{of}$ where $r^2 = 0.683$, but the intercept did not differ from zero (P = 0.572). We forced the regression through 0, yielding the equation $F_b = 295.708W_{of}$ where W_{of} ranged from 35 to 200 grams. We feel confident that using the equation ($F_b = 305.14W_{of}$) derived from 2008 females for estimation of the population mean in 2008 was resonable. If advanced females for batch fecundity were not available in a year, the 3 year combined equation would be acceptable to use.

We examined the sardines taken in the standard DEPM area in 2008 and compared them to those taken during a similar period in 2005-2007 (within the standard DEPM area, from surveys, CPS observer sampling, and port sampling (data provided by CDF&G)). We plotted the standard length distributions from each year divided into offshore and inshore (near islands or the coast) areas (Figure 8). The mean size of sardines (male and females) was always larger offshore. CPS or port samples generally are not preserved and can not be used to estimate spawning fraction which requires histological analysis. We recommend that to improve the whole population adult parameter analyses more trawls should be added in the inshore areas to obtain spawning and maturity information on smaller fish.

Spawning biomass

The 2008 estimate of spawning biomass,135,301mt, primarily in the area south of 39.5°N, based on the egg production of 0.218 eggs/0.05m^{2}/day, and the daily specific fecundity of 21.8 eggs/g/day, is considerably lower than for most previous years (Table 4). The low spawning biomass is primarily due to the small size of the high density area (Table 4) and the high adult reproductive output (Table 3). Note that the egg production rate of 1.39 eggs/0.05m^2 in the high density area was similar to that of 2007: 1.27 eggs/.05m^2 (Lo et al. 2007b). For the standard DEPM area, the egg production, 0.43 eggs/0.05m^2/day, was lower than in most years: 0.864 in 2007, 1.936 in 2006, 1.916 eggs/0.05m^2 in 2005. The area of Region 1 of 53,514 km^2 was the 2nd smallest of all years. The low egg production rate and the high value of the daily specific fecundity (21.82) may indicate that the adults were survivors of the strong 2003 year class and low incoming classes since 2003.

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Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, eggs from CUFES and positive sardine trawls in Region 1 (eggs/min ≥ 1), Region 2 (eggs/min < 1) for *David Starr Jordan* (Jord), and *Miller Freeman* (MF) cruises of 0804. Jordan occupied the standard DEPM survey area from CalCOFI line 93.3-66.7, including routine CalCOFI (CC) survey. Miller Freeman occupied the area north of CalCOFI line of 66.7 (Wh).

For Whole survey (W) area and area South of 39.5°N latitude

		Region 1			**Region 2**					**Grand Total**				
		Total	Jord	MF	Total		Jord	MF		Total		Jord	MF	
		W and S of 39.5°N		W and S of 39.5°N	W	S of 39.5°N		Wh	S of 39.5°N	W	S of 39.5°N		W	S of 39.5°N
CalVET Eggs	Positive	65	65	0	20	20	20	0	0	85	85	85	0	0
	Total	76	76	0	164	94	75	89	19	240	170	151	89	19
CalVET Yolk-sac	Positive	47	47	0	14	14	14	0	0	61	61	61	0	0
	Total	76	76	0	180	94	75	89	19	240	170	151	89	19
Bongo Yolk-sac	Positive	10	10	0	15	15	15	0	0	25	25	25	0	0
	Total	10	10	0	145	75	56	89	19	155	85	66	89	19
CUFES Eggs[1]	Positive	232	232	0	324	324	310	14	14	556	556	542	14	14
	Total	243	243	0	1400	947	809	591	138	1643	1190	1052	591	138
Trawls	Positive	4	4	0	9	9	8	1	1	13	13	12	1	1
	Total	11	11	0	60	22	18	42	4	71	33	29	42	4

For Standard DEPM survey area: CalCOFI line 95 to CalCOFI line 66.7

		Region 1			**Region 2**			**Grand Total**		
		Total	CC	DEPM	Total	CC	DEPM	Total	CC	DEPM
CalVET Eggs	Positive	65	12	43	20	12	8	85	24	61
	Total	76	14	62	75	41	34	151	55	96
CalVET Yolk-sac	Positive	47	7	40	14	12	2	61	19	42
	Total	76	14	62	75	41	34	151	55	96
Bongo Yolk-sac	Positive	10	10	0	15	12	3	25	22	3
	Total	10	10	0	56	45	11	66	55	11
CUFES Eggs	Positive	232	93	139	310	145	165	542	238	304
	Total	243	94	149	809	363	446	1052	457	595
Trawls	Positive	4	--	4	8	--	8	12	--	12
	Total	11	--	11	18	--	18	29	--	29

[1] Cufes for Jordan includes samples from Calcofi line 66.7 to San Francisco.

Table 2. Individual trawl information, sex ratio[a], and parameters for mature female *Sardinops sagax*, used in the estimation of the April 2008 west coast spawning biomass. Collections 2302-2304 are in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES							
				Location										Number spawning		
Sardine egg density regions 1=high 2=low	No.	Month-Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	Number of fish sampled	Proportion of females	No. anal-yzed	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	Adj. No.	Night of capture	Night before capture	2 Nights before capture
2	2409	4-26	2:28	38.984	125.4585	11.5	1	0.000	0	-	-	-	-	-	-	-
2	2328	4-27	3:27	35.469	121.624	11.8	2	1.000	2	97.50	92.58	28250	2	0	0	0
2	2327	4-26	21:09	35.297	121.963	11.2	25	0.559	13	115.73	110.51	33720	13	0	0	2
2	2326	4-26	2:22	34.558	123.500	12.8	26	0.678	17	109.68	104.99	32036	16	5	4	0
1	2319	4-22	19:10	34.511	122.781	12.4	2	1.000	2	143.00	137.50	41958	3	0	1	1
2	2325	4-25	20:01	34.278	124.081	13.0	50	0.591	25	126.98	120.14	36661	28	0	3	3
2	2316	4-21	20:01	34.085	122.028	11.8	11	0.822	9	122.33	116.47	35539	11	0	2	3
1	2323	4-24	21:24	33.822	123.379	12.8	2	0.458	1	116.00	106.87	32612	1	0	0	0
2	2311	4-17	23:46	33.430	120.177	11.4	50	0.618	25	83.44	80.66	24612	26	0	1	0
2	2309	4-17	3:13	32.861	119.806	11.6	30	0.610	18	68.92	65.34	19938	18	0	0	0
2	2307	4-16	18:57	32.478	120.615	12.8	50	0.282	25	90.42	86.77	26477	27	0	2	2
1	2302	4-13	19:58	31.764	120.414	13.6	55	0.794	25	97.49	93.69	28587	3	22	0	1
1	2304	4-14	2:58	31.505	120.882	13.9	50	0.783	25	113.94	108.78	33193	29	4	8	7
									187				187	26	21	19

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

Table 3. Egg production (P_0) of the Pacific sardine in 2008 based on egg data from CalVET and yolk-sac larval data from CalVET and Bongo in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1) from *David Starr Jordan* (March 24-May 1), and *Miller Freeman* (April 1-30) cruises, adult parameters from positive trawls (April 13-27), and 2008 spawning biomass estimate. For comparison, spawning biomass estimates are given using 2007 adult parameter data.

	Area South of 39.5°N latitude				**Whole**	Standard DEPM survey Area			
Parameter	Region 1	Region 2	Total[a]		**Survey[b]**	Region 1	Region 2	Total[a]	
CUFES samples	243	1400	1643	1643	**1643**	243	809	1052	1052
CalVET samples	76	164	240	240	**240**	76	75	141	141
P_0 / 0.05m^2	1.45	0.202	0.37	0.37	**0.218**	1.45	0.202	0.43	0.43
CV	0.18	0.32	0.22	0.22	**0.22**	0.18	0.32	0.21	0.21
Area (km^2)	53,514	343,003	396,517	396,517	**677,162**	53,514	244,435	297,949	297,949
%	13.50	86.50	100	100		17.96	82.04	100	100
Year for adult samples	2008	2008	2008	2007	**2008**	2008	2008	2008	2007
Female fish wt (W_f)	107.32	100.20	102.22	81.62	**102.22**	107.32	100.20	102.22	81.62
Batch fecundity (F)	31340	29194	29802	21761	**29802**	31340	29194	29802	21761
Spawning fraction (S)	0.250	0.085	0.1186	0.114	**0.1186**	0.250	0.085	0.1186	0.114
Sex ratio (R)	0.786	0.558	0.631	0.515	**0.631**	0.786	0.558	0.631	0.515
(RSF)/W_f	57.40	13.84	21.82	15.68	**21.82**	57.40	13.84	21.82	15.68
Spawning biomass (mt)	27,037	100,083	134,467	187,127	**135,301**	27,037	71,323	117,426	163,412
CV	0.23	0.49	0.43	0.43	**0.43**	0.23	0.49	0.43	0.42
Daily mortality (Z)	0.13					0.13			
CV	0.29					0.29			
eggs/min	1.87	0.28	0.49			1.87	0.28	0.49	
CV	0.13	0.341	0.03			0.13	0.341	0.03	
q = eggs/min in Reg.2 / eggs/min in Reg.1			0.139					0.139	
CV			0.27					0.27	
E = (eggs/min)/(eggs/tow)			0.19					0.19	
CV			0.06					0.06	
Bongo samples	10	75	85		**155**	10	56	66	
Area in nm^2	20,447	131,058	151,505		**258,736**	20,447	93,396	87,056	
Spawning biomass (short ton)	29,741	110,091	147,914		**148,831**	29,741	78,455	129,169	

a: Two columns under total: one uses estimates of adult parameter from 2008 survey and the other one uses 2007 estimates
b 70CalVET and 70 Bongo tows above 39.5°N latitude were not included in the computation of spawning biomass because they contained zero eggs and larvae.

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 sardines and average sea surface temperature for the years 1994 to 2008.

Year	P_0 (CV)	Z (CV)	Area (km²) (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
2008[g]	0.43 (0.21)	0.13 (0.29)	297,949 (53,514)	21.82	117,426 (0.43)	13.3	13.1
2008[h]	0.218 (0.22)	0.13 (0.29)	677,162 (53,514)	21.82	135,301 (0.43)	13.1	12.7

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

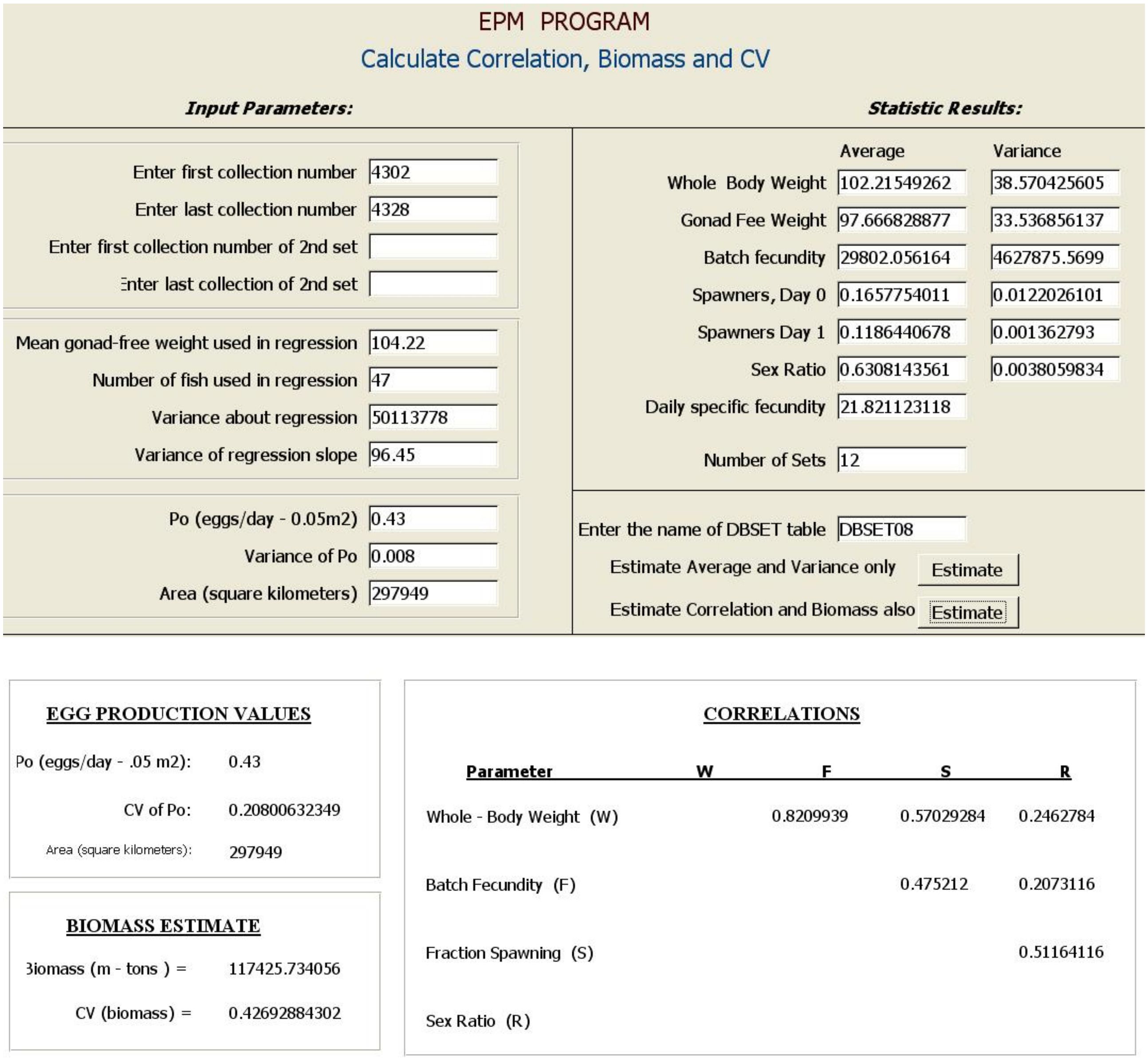
e uses R = 0.5 (Lo and Macewicz 2004); if use actual R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt

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. 2007a), 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

g standard DEPM sampling area off California from San Diego to CalCOFI line 66.7

h whole 2008 survey area off west coast of North America from about 31°N to 48.47°N latitude.

Table 5. The 2008 output for the standard DEPM survey area from "frmBIOMASS" form in the EPM program after input of 2008 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	4302
Enter last collection number	4328
Enter first collection number of 2nd set	
Enter last collection of 2nd set	
Mean gonad-free weight used in regression	104.22
Number of fish used in regression	47
Variance about regression	50113778
Variance of regression slope	96.45
Po (eggs/day - 0.05m2)	0.43
Variance of Po	0.008
Area (square kilometers)	297949

Statistic Results:

	Average	Variance
Whole Body Weight	102.21549262	38.570425605
Gonad Fee Weight	97.666828877	33.536856137
Batch fecundity	29802.056164	4627875.5699
Spawners, Day 0	0.1657754011	0.0122026101
Spawners Day 1	0.1186440678	0.001362793
Sex Ratio	0.6308143561	0.0038059834
Daily specific fecundity	21.821123118	
Number of Sets	12	

Enter the name of DBSET table: DBSET08

Estimate Average and Variance only [Estimate]

Estimate Correlation and Biomass also [Estimate]

EGG PRODUCTION VALUES

Po (eggs/day - .05 m2):	0.43
CV of Po:	0.20800632349
Area (square kilometers):	297949

BIOMASS ESTIMATE

Biomass (m - tons) =	117425.734056
CV (biomass) =	0.42692884302

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.8209939	0.57029284	0.2462784
Batch Fecundity (F)			0.475212	0.2073116
Fraction Spawning (S)				0.51164116
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	2008
Midpoint date of trawl survey		April 22	March 25	May 1	April 21	April 25	April 13	May 2	April 24	April 16
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27
N collections with mature females		37	4	2	6	16	14	7	14	12
N collection within Region 1		11	4	2	6	16	6	2	8	4
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.6	12.4
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631
Average mature female weight (grams):										
with ovary	$\mathbf{W_f}$	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21
without ovary	$\mathbf{W_{of}}$	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67
Average batch fecundity[a] (mature females, oocytes estimated)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292
N mature females analyzed		583	77	9	23	290	175	86	203	187
N active mature females		327	77	9	23	290	148	72	187	177
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186
Spawning fraction of active females[c]	$\mathbf{S_a}$	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187
Daily specific fecundity	$\frac{\mathbf{RSF}}{\mathbf{W}}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82

[a] 1994-2001 estimates were calculated using $F_b = -10858 + 439.53\ W_{of}$ (Macewicz et al. 1996), 2004 used $F_b = 356.46 W_{of}$. (Lo and Macewicz 2004), 2005 used $F_b = -6085 + 376.28\ W_{of}$ (Lo and Macewicz 2006), 2006 used $F_b = -396 + 293.39\ W_{of}$ (Lo et al. 2007a); and 2007 used $F_b = 279.23 W_{of}$. (Lo et al. 2007b).
[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. Temperature range (3m depth) and presence (+) of Pacific sardine eggs collected in CUFES samples and adults taken in trawls during the spring 2006 Sardine Coastwide and 2008 CCE surveys off the west coast of the United States.

	Washington-Oregon: 48.5° - 42°N	Northern California: 42°N- CalCOFI line 60	standard DEPM: CalCOFI lines 60-93 (San Francisco - San Diego)
April 2008			
Sea Temperature	8.2-10.1 °C	7.8-11.6°C [a]	11.2-13.9°C
Number of trawls	25	15	31
positive trawls	0	1	12
Number of adults	-	1	353
Mean body weight (g)	-	148	105
Eggs, Region 1	-	-	+
Eggs, Region 2	-	+	+
April 2006			
Sea Temperature	9.1-11.8°C	10.8-12.2°C	13.3-16.6°C
Number of trawls	9	4	22
positive trawls	0	3	7
Number of adults	-	101	194
Mean body weight (g)	-	91	67
Eggs Region 1	+	+	+
Eggs Region 2	+	+	+

[a] one negative offshore trawl at 38.4°N was an anomalous 13.2°C

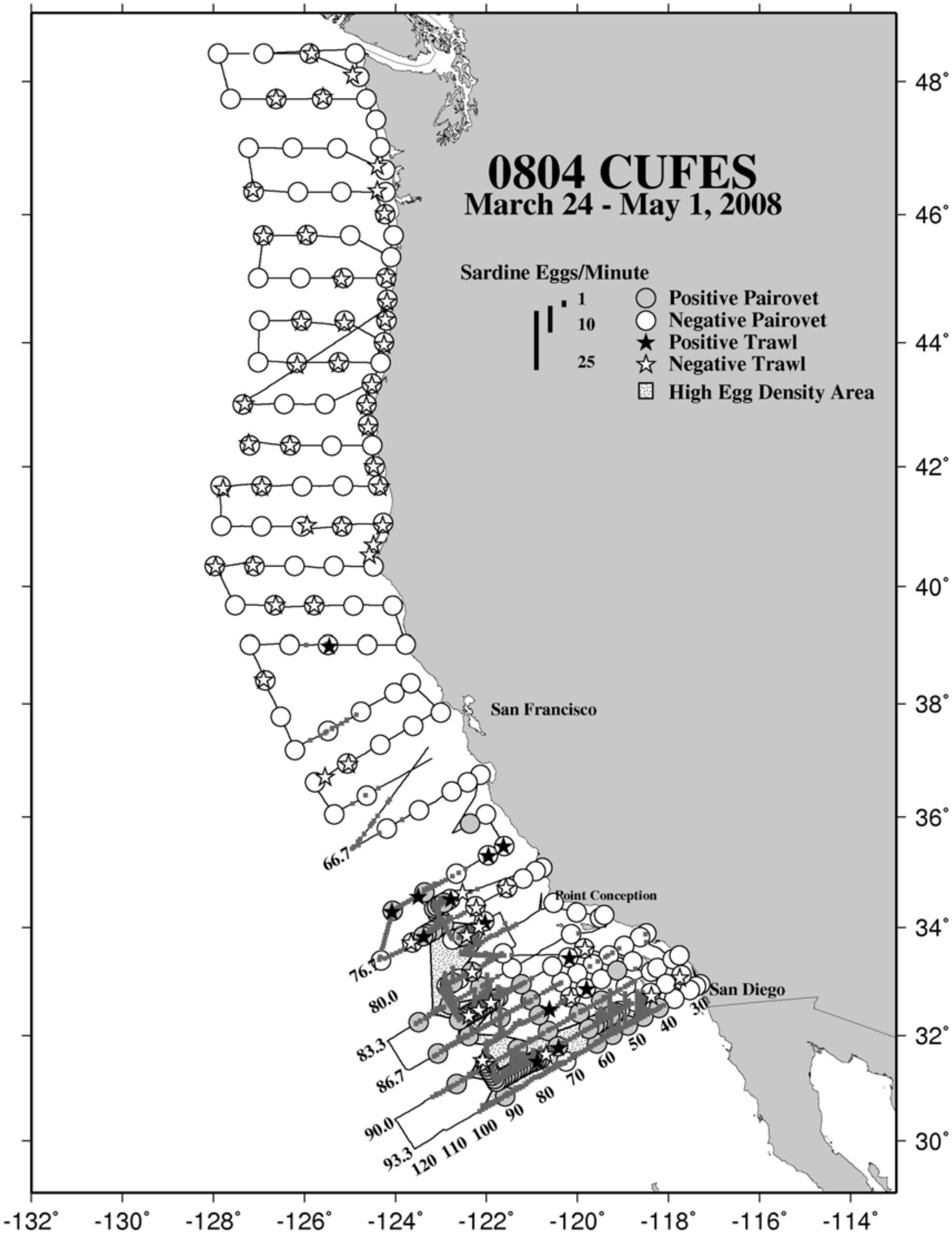


Figure 1. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2008 survey. Region 1 is high density area. Dates of cruises refer to the first and last tow.

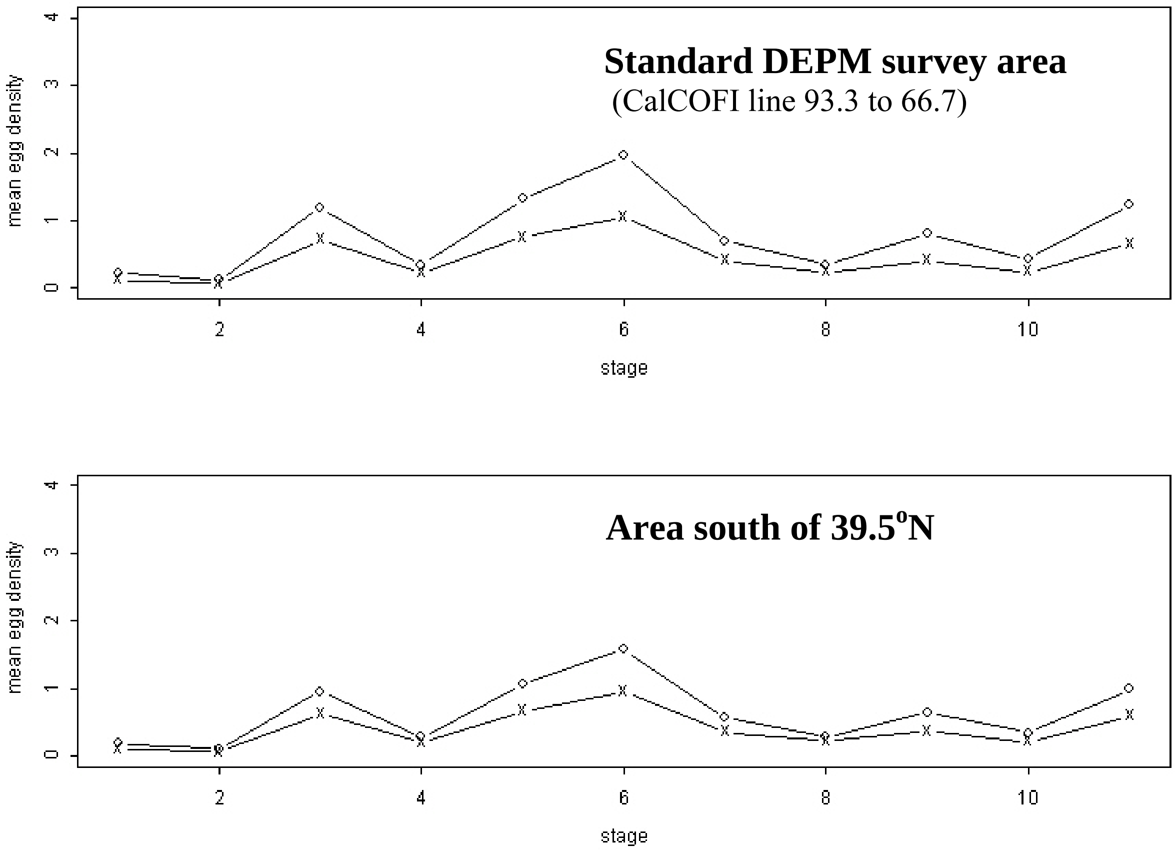
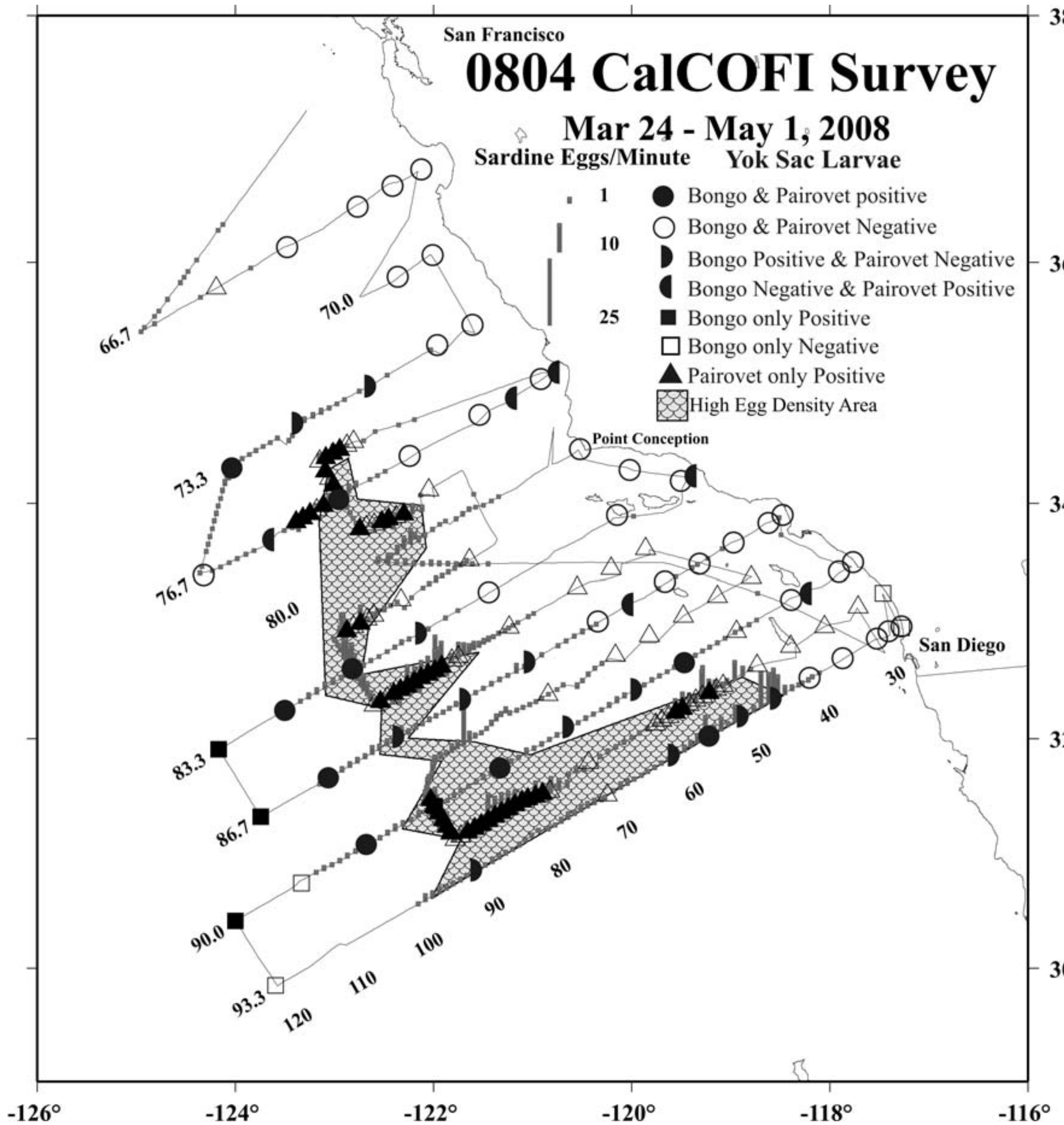


Figure 2. Mean sardine egg density (eggs per 0.05 m^2) for each developmental stage within each area for April - May, 2008. Symbols: o = Region 1 and x = area surveyed. Note that latitude and Calcofi line were used to describe the area sor each of these two graphs due to different orientations of transect lines (Figure 1 and 3).



`**Figure 3**. Location of sardine yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) during the 2008 survey. Solid symbols are positive and open symbols are zero catch. Zero yolk-sac larvae were caught north of CalCOFI line 73.3.

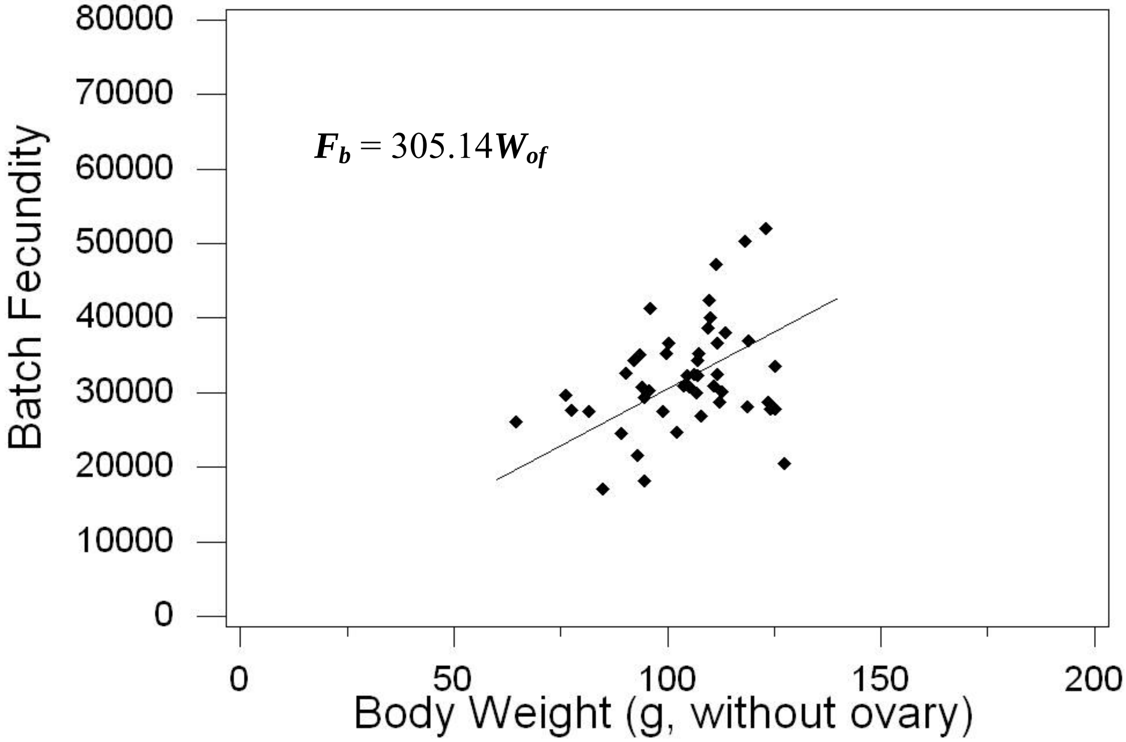


Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 47 females taken during April 2008. The batch was estimated from numbers of hydrated or migratory-nucleus-stage oocytes.

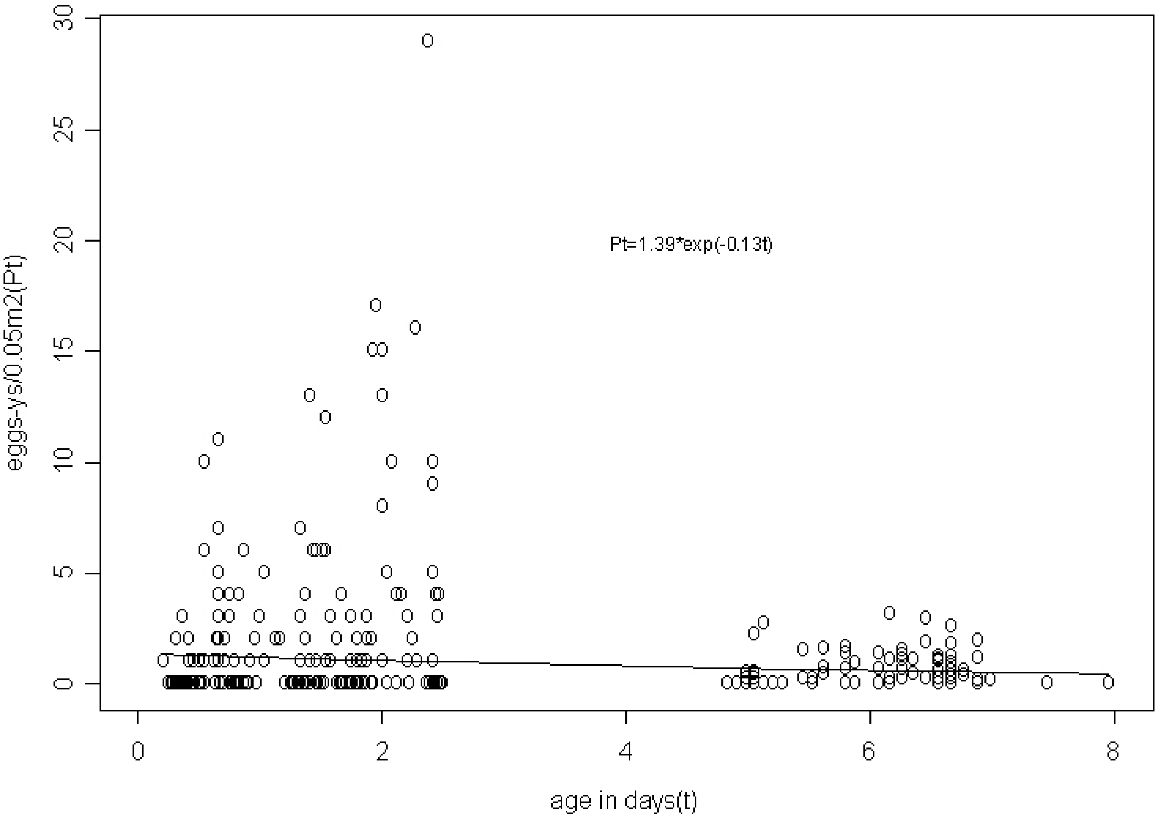


Figure 5. Embryonic mortality curve of Pacific sardines. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April – May 2008, Jordan cruise. The number,1.39 (P_0), is the estimate of daily egg production at age 0 before correction for bias..

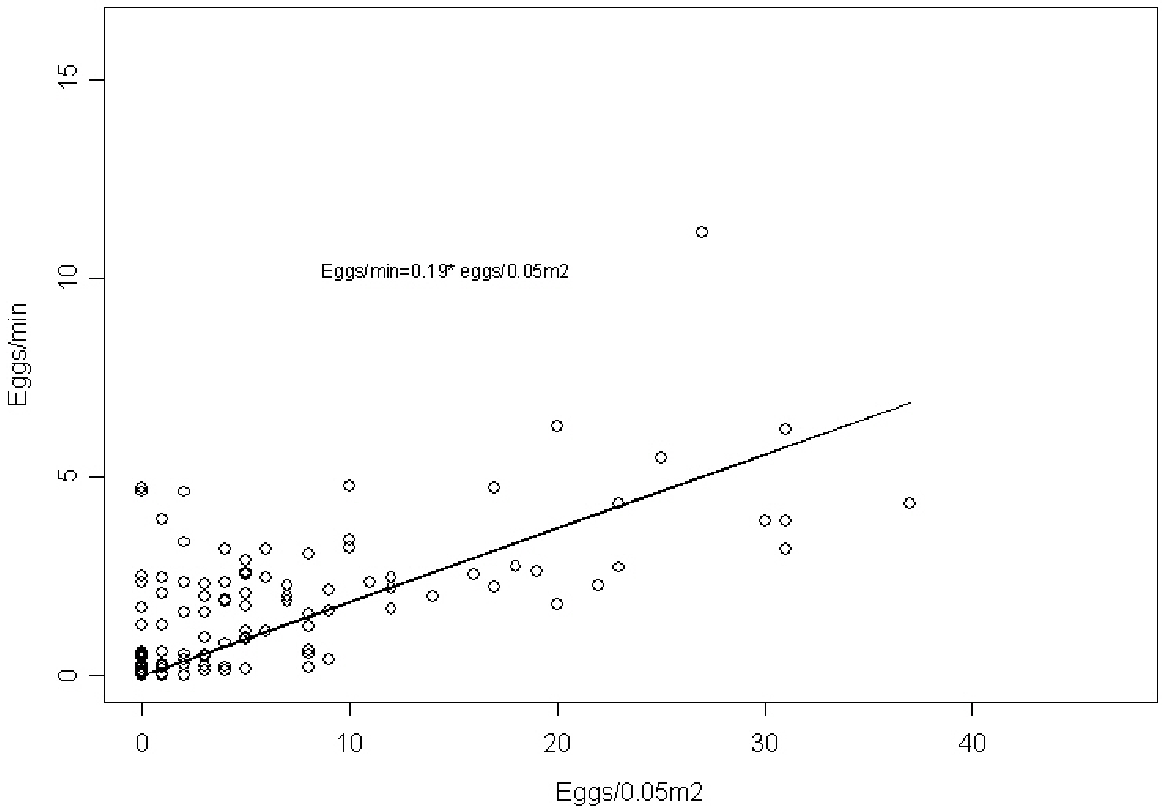


Figure 6. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April – May 2008. from *David Starr Jordan*

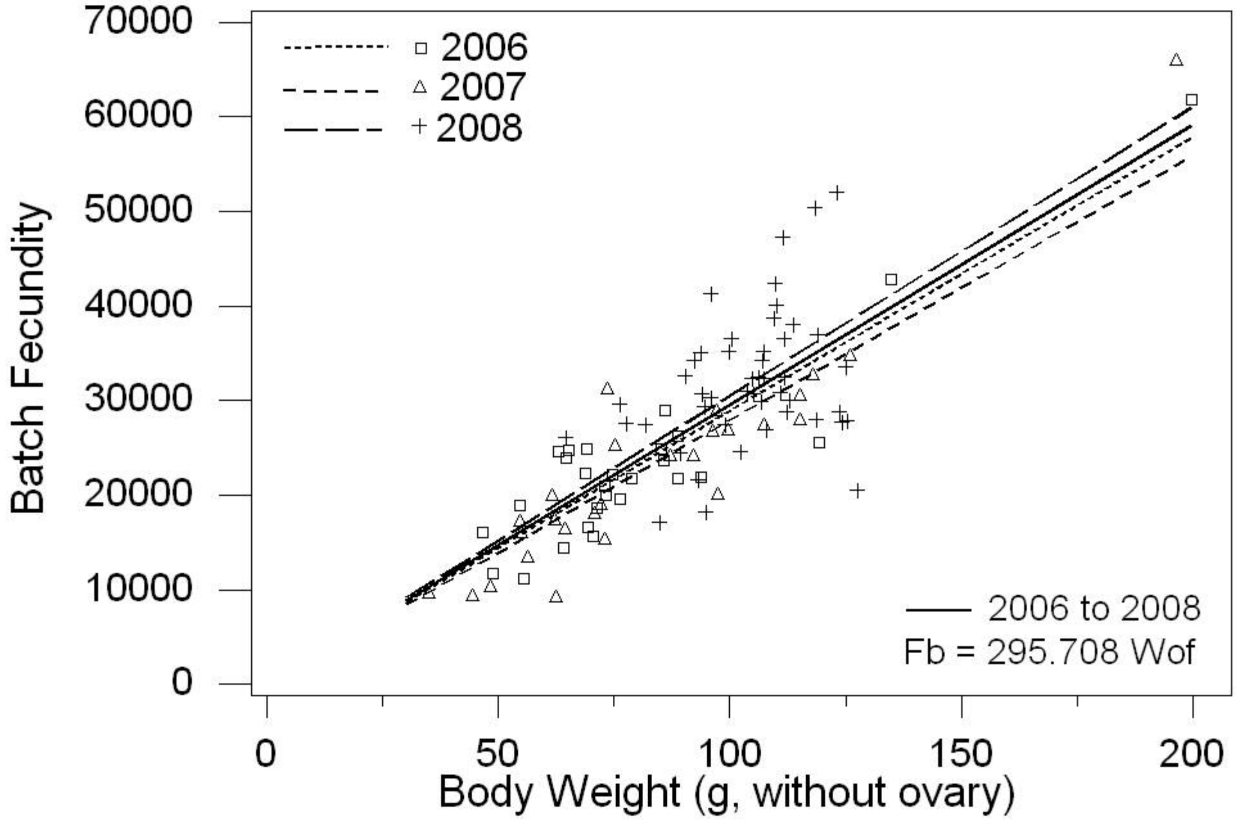


Figure 7. Batch fecundity (F_b) of Pacific sardines as a function of female weight (W_{of}, without ovary) for 101 females from trawl surveys in 2006-2008; where $r^2 = 0.683$ (solid line). 2006 (Lo et al. 2007a), 2007 (Lo et al. 2007b), and 2008 are plotted for comparisons.

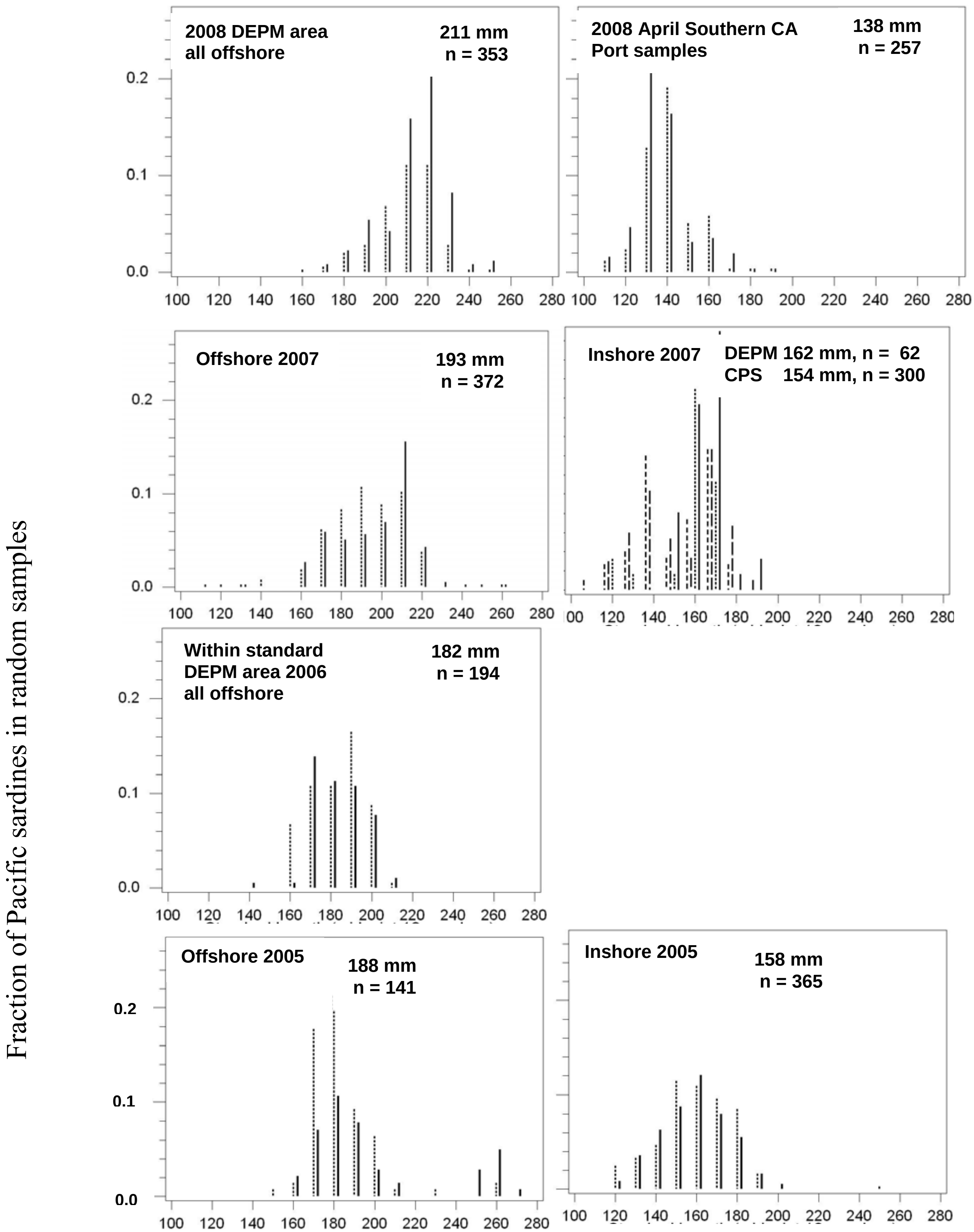


Figure 8. Length distribution and mean length of Pacific sardines caught in the 2005 to 2008 survey by each subarea and for 2007 small pelagic fish (CPS) observer samples and 2008 port samples. Males indicated by dotted bars and females by solid bar.

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