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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 of Pacific sardine (*Sardinops sagax*) in April - May 2006 was estimated by the daily egg production method (DEPM) to be 1,682,260 mt (CV = 0.47) for an area of 885,523 km^2 off the west coast of North America from San Diego, U.S.A. to northern Vancouver Island, B.C. Canada (30°-51°N). For the entire survey area, the daily egg production estimate (P_0) was 0.98/.05m^2 (CV = 0.23), although no eggs were collected in the area north of latitude 44°N. The daily specific fecundity was calculated as 10.32 (number of eggs/population weight (g)/day) using the estimates of reproductive parameters from 132 mature female Pacific sardine collected from 10 positive trawls: F, mean batch fecundity, 21163 eggs/batch (CV = 0.114); S, fraction spawning per day, 0.083 females spawning per day (CV = 0.37); W_f, mean female fish weight, 76.72 g (CV = 0.089); and R, sex ratio of females by weight, 0.449 (CV = 0.047). The standard survey area off California, from San Diego to San Francisco (CalCOFI lines 95 to 60), in 2006 was 336,774 km^2. For the standard area, using the egg production estimate of 1.936/0.05m^2 (CV = 0.26) and the daily specific fecundity of 8.62 (number of eggs/population weight (g)/day), the spawning biomass was estimated to be 1,512,882 mt (CV=0.47). The mature female Pacific sardine reproductive parameters in the standard survey area estimated from 7 positive trawls and 86 mature females were: F, mean batch fecundity, 18474 eggs/batch (CV = 0.106); S, fraction of females spawning per day, 0.0698 (CV = 0.33); W_f, mean female fish weight, 67.41 g (CV = 0.0658); and R, sex ratio of females by weight, 0.451 (CV = 0.073). The spawning biomass north of CalCOFI line 60, near San Francisco, was calculated by difference to be 169,378 mt. In 2006, trawling was conducted at pre-assigned 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 Pacific sardine off California in 1994 - 2006 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, 300,000 mt, 600,000 mt, and 1.5 million mt respectively. Therefore, the estimates of spawning biomass have been fluctuating and have been high last three 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 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 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 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 taken 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 (P_0) may be large due to small sample size (fewer than 100 plankton tows). Adult samples were collected sporadically between 1994 and 2004 (in 1997, 2001, and 2002).

Beginning in 2004, trawl and ichthyoplanton surveys were conducted for collection of 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; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2005 and 2006). The 2006 survey was extended to the northern coast of Vancouver Island, B.C., Canada to cover the majority of the area occupied by the sardine population off the west coast of North America. Two NOAA ships were used: the NOAA ship *Oscar Dyson* sailed from B.C., Canada to San Diego and the NOAA ship *David Starr Jordan* sailed from San Diego to San Francisco. Trawl and ichthyplankton samples were taken aboard the *Oscar Dyson* while only ichthyoplankton samples were taken aboard the *David Starr Jordan*, due to malfunction of trawl equipment. In addition, the routine April CalCOFI cruise aboard the Scripps Institution of Oceanography (SIO) R/V *New Horizon* provided additional ichthyplankton samples from CalCOFI lines 93.3 to 76.7.

MATERIALS AND METHODS

Data

Ichthyoplankton sampling differed among the vessels and trawls were taken only aboard the NOAA ship *Oscar Dyson*. CalVET tows, Bongo tows and CUFES were conducted aboard the *Oscar Dyson* (April 11-May 8) and the NOAA ship *David Starr Jordan* (April 5-28). CalVET and Bongo tows were taken during the routine CalCOFI cruise aboard SIO R/V *New Horizon* (April 1-18). 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 2006 survey, twenty seven distinct transects were occupied by the research vessels, with CalCOFI lines 93.3, 86.7, 76.7 and 66.7 occupied by at least two vessels (Figure 1). The *New Horizon* occupied the six regular CalCOFI lines (93.3 - 76.7) taking CalVET and Bongo tows only at regular CalCOFI survey stations. The *Oscar Dyson* occupied 17 transects from latitude 51°N to 30.7°N. Except for the first four lines which were 40 nm apart, the distance between lines was 80 nm. CUFES and trawl samples were taken during the entire *Oscar Dyson* cruise while CalVET and Bongo samples were taken in the area north of 40°N latitude, on CalCOFI line 53.3, and an inside station of CalCOFI line 60. The *David Starr Jordan* occupied ten CalCOFI lines (95.0 - 51.7) with most spaced 60 nm apart except for a 40 nm distance between CalCOFI lines 95.0 and 91.7. During the *David Starr Jordan* cruise Bongo samples were taken only at regular CalCOFI survey stations on CalCOFI line 95.0 and the four CalCOFI lines from 71.7 to 57. For both the *Oscar Dyson* and *David Starr Jordan* cruises, 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 the 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 885,523 km^2. Only the area south of 44°N latitude (568,831 km^2) was used to estimate the initial P_0 because no eggs were collected north of 44°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 standard

CalCOFI lines and the distance between standard CalCOFI stations. The area of Region 1 was 149,074 km^2 and was 26% of the area south of 44°N (568,831 km^2). The rest of the area south of 44°N was Region 2 (419,757 km^2, Figure 1). For comparison purposes, we also estimated the standard DEPM survey area off California which was surveyed in the past for estimation of the annual spawning biomass of Pacific sardine. 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 2006 this area was calculated as 336,774 km^2.

A total of 1385 CUFES samples was collected from both the *Oscar Dyson* (705) and *David Starr Jordan* (680) cruises over the whole survey area. For the area south of 44°N, 1161 CUFES samples were taken by both the *Oscar Dyson* (481) and *David Starr Jordan* (680). CUFES sampling intervals ranged from 1 to 60 minutes with a mean of 26.18 minutes and median of 30 minutes. A grand total of 174 (154 S of 44°N) CalVET samples was collected, of which 71 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 eggs/min and x is eggs/tow.

For adult samples, the initial survey plan was to use two NOAA ships, the *David Starr Jordan* and the *Oscar Dyson*, to conduct trawls at pre-assigned stations and to conduct additional adaptive trawls at other random locations or where acoustic signals or CUFES observations indicated potential sardine schools. 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. The survey plan was changed to only occupy the pre-determined stations due to the mechanical difficulties encountered by the *David Starr Jordan*. The trawl survey was conducted from April 11 to May 8, 2006 on the *Oscar Dyson*. Trawling was conducted at night near the surface (0-6 fathoms) or in the daytime at depths of 40 to 140 meters at pre-assigned, regularly-spaced stations, which is different from the adaptive trawling conducted in 2004 and 2005 where the presence of sardine eggs in CUFES collections identified potential trawl sites. For the whole survey, 40 trawls were taken: none of the daytime trawls contained Pacific sardines and the 10 nighttime trawls positive for sardines were located in the area south of 44°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 44°N, the spawning biomass was most likely distributed in the survey area south of 44°N. For continuity 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 26 transects with 20 of these in the area south of 44°N. Note there were 33 transects with 26 distinctive transects from San Diego to north of Vancouver Island, B.C. (Figure 1). In Region 1, a total of 62 out of 79 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, 477 of the 1385 collections were positive for sardine eggs over the whole survey area (477 of 1161 collections S of 44°N). In Region 1, there were 198 positive CUFES collections out of 240 total collections. In Region 2, 279 of the total 1145 collections (279 of 921, S of 44°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, 53 of 174 (of 154, S of 44°N) CalVET and 25 of 136 (of 111, S of 44°N) Bongo samples had at least one yolk-sac larva (Figure 3). In Region 1, 47 of 79 CalVET and 16 of 20 Bongo samples were positive for yolk-sac larvae. In Region 2, 6 of 95 (of 75, S of 44°N) CalVET and 9 of 116 (of 91, S of 44°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 - 51°N)

Because no eggs were collected in the area north of latitude 44°N, the overall P_0 (daily egg production/0.05m^2) was first computed for the area south of 44°N and then prorated to the whole survey area simply by multiplying P_0 by the area north of 44°N divided by the size of the whole survey area.

Daily egg production in Region 1 ($P_{0,1}$) for the area south of 44°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 2006 was lower than previous years (Lo 2003; Lo and Macewicz 2002, 2004, and 2005). Unlike most past years when the density of eggs in stage 6 was highest among all stages, the densities of eggs in stage 3 and stage 6 were highest in 2006. 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* and *New Horizon* was 14.5°C while from the *Oscar Dyson* it was 10.7°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 10.44, 5.26, and 8.89 for day one, day two and day three age groups from CalVET samples respectively and SD for yolk-sac larvae was 2.43 and 1.70 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- 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 44°N

Although 95 CalVET samples were taken in Region 2, only 9 tows had ≥ 1 sardine egg, ranging from 1 to 4 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 is 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 13 transect lines: three lines occupied by the *Oscar Dyson* between 39°N - 44°N latitudes and 10 lines between CalCOFI line 51.7 and 95 (Figure 1) occupied by the *David Starr Jordan*; most lines occupied by *Oscar Dyson* south of 38°N had very low eggs/min.

Daily egg production (P_0) for the area south of 44°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 ($P_{0,1,c}$) = v($P_{0,1}$) + bias^2 = v($P_{0,1}$) + ($P_{0,1}$ 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 44°N. The estimate of P_0 for the whole survey area is P_0 times (the area S of 44°N divided by the total survey area) = P_0 x (568,831/885,523) = P_0 x 0.64.

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

***$P_{0,1}$*:**

Sardine egg density for each developmental stage was computed based on CalVET samples between CalCOFI lines 60-95 taken aboard both the *David Starr Jordan* and *New Horizon* (Figure 2). Similar to 2005 and unlike most of the past data where the density of eggs in stages 6 was highest among all stages, the densities of eggs in stage 3 was highest in 2006. The average sea surface temperature for CalVET tows with ∃1 egg from the *David Starr Jordan* and *New Horizon* was 14.95°C which is higher than other years (Table 4). To fit equation (1), the weight is 1/SD where SD's were 11.77, 5.92, and 9.92 respectively for day one, day two and day three age groups for eggs, and 2.76 and 1.82 for yolk-sac larvae from CalVET and Bongo samples respectively.

P_{02}

Although 64 CalVET samples were taken in Region 2, only 6 tows were positive for sardine with 1 egg each (Table 1).

The P_0 for the standard DEPM survey area off California (from about San Diego to San Francisco) was obtained based on equation (4) without further adjustment.

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 132 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

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

spawning on one night, an average of several nights, or all nights. We used the average of the number of females identified as having spawned the night before capture (B) and those having spawning two nights before capture (A) with the number of mature females caught in each trawl (Table 2) to estimate the population spawning fraction and variance (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-May 2006 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was F_b = -396 + 293.39W_{of} where r^2 = 0.829 and W_{of} ranged from 46.4 to 200 grams (Figure 4). We used this equation to predict batch fecundity for each of the 132 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 = -1.79 + 1.07W_{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 2006 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 $0.05m^2$ (e.g $1.77x10^{17}$ $0.05m^2$ = (885523 km^2)(20 $0.05m^2/1m^2$)(10^6 $m^2/1km^2$)), 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

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

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) *for the whole survey area*

In Region 1, the daily egg production ($P_{0,1}$) was 4.32/0.05 m^2/day (CV = 0.23; equation 1 and Figure 5). The bias-corrected egg production, ($P_{0,1,c}$) is 4.49 (CV = 0.23) (Table 3). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.105 (CV=0.23) (equation 3). In Region 2, the egg production ($P_{0,2}$) was 0.47 /0.05 m^2/day (CV = 0.32) for an area of 419,757 km^2 (122,646 nm^2). The estimate of the daily egg production for the area south of 44°N was 1.53/0.05 m^2 (CV = 0.23) (equation 4) for 568,831 km^2 (166,203 nm^2) (Table 3). Egg mortality (0.28 (CV=0.25)) was lower than most years (Table 4). The P_0 for the whole survey area (30°N-51°N) was 1.53 x 0.64 = 0.98/0.05 m^2/day.

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

In Region 1 in the standard DEPM survey area, the daily egg production ($P_{0,1}$) was 5.32/0.05 m^2/day (CV = 0.25; equation 1 and Figure 5) compared to 7.84 /0.05 m^2/day in 2005 (CV = 0.40), egg mortality was Z = 0.31 (CV=0.25) compared to 0.58 (CV = 0.2) in 2005, and the area was 98,034 km^2 (28,644 nm^2) compared to 46,203 km^2 (13,500 nm^2) in 2005 and to 68,203 km^2 (19,928 nm^2) in 2004 (Table 4).The bias-corrected egg production, ($P_{0,1,c}$) is 5.52 (CV = 0.25) (Table 3). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.084(CV = 0.32) (equation 3). In Region 2, the egg production ($P_{0,2}$) was 0.46/0.05 m^2/day (CV = 0.41) for an area of 238,740 km^2 (69,756 nm^2). The estimate of the daily egg production for this area of 336,774 km^2 (98,400 nm^2) was 1.936/0.05 m^2 (CV = 0.26) (equation 4 and Table 3). Egg mortality (Z = 0.31 with CV=0.25) was similar to the estimate of Z the area south of 44°N (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 62 pairs of CalVET tows and CUFES collections from both the *Oscar Dyson* and *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 0.32 (CV=0.12) in comparison to 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 0.32 means that one egg/tow from a CalVET tow was equivalent to approximately 0.32 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 3.12 eggs/tow from the CalVET sample.

Adult parameters

Over the whole survey area, standard length (SL) of the first 50 randomly selected sardine in each trawl ranged from 111 to 258 mm for 163 males and from 137 to 268 mm for 132 females. The smallest mature female was 163 mm SL and because only nine of the females were immature (size range of 137 - 210 mm SL), the length at which 50% of females are mature (ML_{50}) was not calculated.

Reproductive parameters of 132 mature female sardines (up to 25 mature analyzed per trawl) for the individual trawls, over the whole survey area, are given in Table 2. The April - May 2006 population sex ratio (R), was 0.449 (CV = 0.047) (Table 5). Estimates of the other female sardine parameters were: F, mean batch fecundity, 21163 eggs/batch (CV = 0.114); S, spawning fraction, 0.083 per day (CV = 0.37); and W_f, mean female fish weight, 76.73 grams (CV = 0.089). The average interval between spawning (spawning frequency) was about 12 days (inverse of spawning fraction or 1/0.083), and the daily specific fecundity was 10.32 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.

The standard DEPM survey area off California, from San Diego to San Francisco in 2006 was 336,774 km^2. The mature female Pacific sardine reproductive parameters in the standard survey area, estimated from 7 positive trawls and 86 mature females, were: *F*, mean batch fecundity, 18474 eggs/batch (CV = 0.106); *S*, fraction spawning per day, 0.0698 females spawning per day (CV = 0.33); W_f, mean female fish weight, 67.41 g (CV = 0.0658); and *R*, sex ratio of females by weight, 0.451 (CV = 0.073). The daily specific fecundity was 8.62 eggs/population weight (g)/day (Table 6). The correlation matrix for the adult parameter estimates for the standard DEPM survey area is shown in Table 6

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardine in 2006 (equation 5, Table 5) was 1,682,260 mt (CV=0.47) or 1,850,486 short tons (st) (=1,682,260 x 1.1) for the entire survey area of 885,523 km^2 (258,736 nm^2) from San Diego to Vancouver Island, BC, Canada. For the area of 336,774 km^2 (98,400 nm^2) off California, the estimate of spawning biomass was 1,512,882 mt (CV=0.47) or 1,664,170 st. The point estimates of spawning biomass of Pacific sardine off California in 1994-2006 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 and 1,512,882 mt (Table 4).

DISCUSSION

Sardine eggs

Sardine eggs were concentrated in two areas: between CalCOFI lines 95-86.7, and a narrow strip between 40°N and 42°N latitude (Figure 1). The area with low density of eggs north of CalCOFI line 86.7 had high density of eggs in 2005 (Lo and Macewicz 2006) and the distribution of sardine eggs in 2006 differed from the past two years because very few were collected between CalCOFI lines 73.3 and 60 (Figure 1). This could be due to the shift of the spawning grounds, or to the delay of coverage of the central California area by the *David Starr Jordan* because of malfunction of equipment aboard (in port April 1-5 and 11-14). The area north of 40°N latitude has been sampled relatively little using ichthyoplankton net tows. The high concentration of sardine eggs in this area was an indication of a spawning ground for sardine. In the standard DEPM survey area, the egg density 1.07 eggs/min (Table 3) in 2006 was higher than 2005 (0.62 egg/min, Lo and Macewicz 2006) and 2004 (0.78 egg/min, Lo and Macewicz 2004) and lower than that in 2003 (1.57 egg/min, Lo 2003). In addition, unlike recent years, in 2006 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*, which covered the area between CalCOFI lines 95 and 51.7, and aboard the *Oscar Dyson*, north of CalCOFI line 53.3, but not aboard the *New Horizon* because the latter was conducting the routine CalCOFI survey. During the *New Horizon* cruise, 10 out of 42 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 123 total CalVET tows were taken in the standard DEPM survey area. This was higher than the 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) and the daily embryonic mortality were higher than in previous years. These high values were not caused by high abundance of eggs, but by the distribution of egg developmental stages (Figure 2). In 2006, the peak density among egg developmental stages was that of stage 3, rather than the older stages 5 or 6 seen in past years. The latter phenomenon is not understood and needs thorough investigation.

Catch ratio between CUFES and CalVET (E)

The 2006 catch ratio between CUFES and CalVET (0.32) appeared to be higher than those obtained in 2005 (0.18), 2004 (0.22 (CV = 0.09)), 2002 (0.24 (CV = 0.06)), 2001 (0.145 (CV = 0.026)), and 2000 (0.277), while similar to those obtained in 1998 (0.32), 1999 (0.34), and 2003 (0.39 (CV = 0.11)). This 2006 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 (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 catch ratio was computed separately for data collected by the *David Starr Jordan* and *Oscar Dyson*: 0.34 (CV = 0.15) and 0.13 (CV = 0.14) respectively; the ratios were statistically different ($p < 0.05$). The low ratio from the *Oscar Dyson* could have been due to the low density of sardine eggs in the area occupied or the possible poor performance of the CUFES system aboard the *Oscar Dyson*.

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 2006 survey, two q values were obtained: 0.084 (CV = 0.32) and 0.105 (CV = 0.23) for the standard DEPM sampling area and the area south of 44°N respectively. Both values are higher than those 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, possibly due to the increasing size of the sardine population.

Adult parameters

In April-May 2006, for the first time, trawls were taken during day and night in the area of 30.7° N to 51° N off the west coast of North America at pre-assigned stations (Figure 1). Pacific sardine adults were captured only in the night-time trawls south of 44°N latitude (between 32.95°N and 40.24°N), including three positive samples north of about 38°N which is the northern extent of standard sardine DEPM surveys. Three positive trawls in Region 1 and seven positive trawls in Region 2 were taken (Table 2). The average mature female weight (*W*) was similar in both regions (76.5 g in Region 1 and 76.93g in Region 2). The difference in the fraction of females spawning per day was similar to 2005 (Lo and Macewicz 2006) with a higher fraction in Region 1 (0.145 females/day) than Region 2 (0.028 females/day). Because more females are spawning per day in Region 1 than Region 2 (Table 3), it is necessary to take trawls in both regions to ensure an unbiased estimate of spawning biomass for the whole population.

The daily spawning fraction (*S*) was low in 2006 (0.083) for the entire survey. In the standard DEPM survey area (Table 7), the spawning fraction in 2006 (*S* = 0.0698) was low compared to the years1997-2005 (range of 0.111 - 0.174) and similar to 1994 (0.074). If we assume little inter-annual variation in the duration and peak of the sardine spawning season, then from Table 7, peak spawning may occur from late March to late April (highest spawning fractions per day). Hence, in 2006 our positive trawls with sardine adults may have occurred nearer to the end of the spawning season (early May) and that may have been the main cause of the low spawning fraction measured in the standard DEPM survey area. Other possible factors influencing the low estimate of the fraction of females spawning in 2006 besides timing are also apparent from examination of the time series of adult parameters since 1994 (Table 7). The low ratio in the number of positive trawls in Region 1 to all positive trawls, together with the presence of postbreeding mature females seems to result in a lower estimate of spawning fraction. This is especially evident during 1994 and 2006 when less than 30% of the trawls were in Region 1 where as in 2005 over 40% of the trawls were in Region 1. It is also possible that postbreeding females migrate after final spawning because no postbreeding females were collected and all samples came from the high sardine egg density area during 1997, 2001, 2002, and 2004, when *S* was higher. Lastly, low (or high) spawning fraction estimates may be the result of variability in small sample sizes. In 2006 only seven trawls were positive for a total of 86 mature female sardines collected, which is half the number of trawls or females analyzed in 2004 and 2005 (Table 7). The small number of positive trawls may have been the reduction of the potential number of trawls as a result of the unforeseen changes to the survey plan, i.e. one ship trawled the entire survey area (30.7°N to 51°N) at only the pre-determined locations, and none of the daytime trawls caught sardines.

We recommend future biomass surveys include some adaptive sampling of adults to ensure sufficient adult samples and to balance the ratio of samples in high and low sardine egg density areas. In addition, trawl operations for sardines should be conducted only from dusk to dawn and better synchronized with egg sampling (< about 15 days apart).

During the 2006 survey we collected samples of sardines north of the standard DEPM survey area. We examined the sardines taken in 2006 (north and within the standard DEPM sampling area) and compared them to those taken during a similar period in 2005 (within the standard DEPM survey area). We plotted the sardine length distributions from each survey. Although the mean size of sardines (male and female) increased from 166 mm in 2005 to 188 mm in 2006, the surveys appeared similar in range of size classes (Figure 7). The 2005 survey area previously was divided into offshore and inshore (near islands or the coast) areas and the larger sardines were present offshore (Lo and Macewicz 2006). In 2006, we divided our samples into north of and within the standard DEPM sampling area instead of inshore and offshore because only one sample occurred inshore. The largest sardines in 2006 were observed in the three samples north of the standard DEPM sampling area while in 2005 they occurred offshore. This change in observed area could be due to the movement of the large sardines or sample bias due to the low number of positive trawls in the standard DEPM survey area in 2006.

Spawning biomass

The 2006 estimate of spawning biomass is considerably higher than any previous years for the standard DEPM survey area (Table 4). The high spawning biomass is primarily due to the adult reproductive output. The egg production, 1.936 eggs/0.05m^2/day, was similar to 1.916 eggs/0.05m^2 in 2005 but higher than 0.96 eggs/0.05m^2 in 2004, 1.52 eggs/0.05m^2 in 2003 and 0.728 eggs/0.05m^2 in 2002, while the area of Region 1 of 98,034 km^2 was larger than recent years: 46,203 km^2 in 2005, 68,204 km^2 in 2004, 83,578 km^2 in 2003 and 88,403 km^2 in 2002 (Table 4). The low value of the daily specific fecundity was driven by the spawning fraction of 0.0698 as compared to 0.123 in 2005. The 2006 daily specific fecundity (8.62 eggs/g/day) was lower than 15.64 eggs/g/day in 2005 and 21.86 eggs/g/day in 2004 and was primarily due to the non-synchronization of trawls taken aboard the *OscarDyson* (May 2 – 5) and CalVET samples taken aboard the *David Starr Jordan* (April 6 - 17) in the high density egg area (south of line 76.7) in the standard DEPM sampling area; in particular, on CalCOFI lines 95 and 91.7, CUFES sampled on April 6-10 while trawls were taken on May 3-4 and on line 86.7, CUFES sampled on April 15 - 16 while trawling occurred on May 1 - 2. Therefore there was a time lag of 15 days to one month when some active adult sardines may have begun to migrate northward. If the 2005 estimate of the daily specific fecundity, 15.67, were used, the 2006 estimated spawning biomass in the standard DEPM survey area would be 832,000 mt, a reduction of about half of the current estimate (Table 3).

The estimate of spawning biomass for the entire survey area in 2006 was 1,682,260 mt based on the egg production of 0.98 eggs/0.05m$^{2/}$day and the daily specific fecundity of 10.32 eggs/g/day. As both trawl and CalVET samples were taken during the same time period in the area north of CalCOFI line 60, this estimate is likely to be less biased upward than that for the standard DEPM survey area. The spawning biomass north of CalCOFI line 60 was calculated by difference to be 169,378 mt (1,682,260 - 1,512,882) with no variance obtained. Again, this estimate maybe biased downward.

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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) and Region 2 (eggs/min < 1) for *New Horizon* (NH), *David Starr Jordan* (Jord), and *Oscar Dyson* (OD) cruises of 0604.

For Whole survey (Wh) area and area South of 44°N latitude

		Region 1				Region 2						Grand Total					
		Total	NH	Jord	OD	Total		NH	Jord	OD		Total		NH	Jord	OD	
		Wh and S of 44°			Wh and S of 44°	Wh	S of 44°			Wh	S of 44°	Wh	S of 44°			Wh	S of 44°
CalVET Eggs	Positive	62	5	38	19	9	9	3	3	3	3	71	71	8	41	22	22
	Total	79	10	49	20	95	75	32	33	30	10	174	154	42	82	50	30
CalVET Yolk-sac	Positive	47	3	36	8	6	6	2	3	1	1	53	53	5	39	9	9
	Total	79	10	49	20	95	75	32	33	30	10	174	154	42	82	50	30
Bongo Yolk-sac	Positive	16	13	2	1	9	9	4	3	2	2	25	25	17	5	3	3
	Total	20	15	2	3	116	91	58	20	38	13	136	111	73	22	41	16
CUFES Eggs	Positive	198	--	160	38	279	279	--	142	137	137	477	477	--	302	175	175
	Total	240	--	194	46	1145	921	--	486	659	435	1385	1161	--	680	705	481
Trawls	Positive	3	--	--	3	7	7	--	--	7	7	10	10	--	--	10	10
	Total	10	--	--	10	30	20	--	--	30	20	40	30	--	--	40	30

For Standard DEPM survey area: CalCOFI line 95 to CalCOFI line 60

		Region 1				Region 2				Grand Total			
		Total	NH	Jord	OD	Total	NH	Jord	OD	Total	NH	Jord	OD
CalVET Eggs	Positive	43	5	38	0	6	3	3	0	49	8	41	0
	Total	59	10	49	0	64	32	31	1	123	42	80	1
CalVET Yolk-sac	Positive	39	3	36	0	5	2	3	0	44	5	39	0
	Total	59	10	49	0	64	32	31	1	123	42	80	1
Bongo Yolk-sac	Positive	15	13	2	0	6	4	2	0	21	17	4	0
	Total	17	15	2	0	77	58	18	1	94	73	20	1
CUFES Eggs	Positive	141	--	141	0	192	--	99	93	333	--	240	93
	Total	151	--	174	0	645	--	383	262	819	--	557	262
Trawls	Positive	2	--	--	2	5	--	--	5	7	--	--	7
	Total	8	--	--	8	14	--	--	14	22	--	--	22

Table 2. Individual trawl information, sex ratio[a], and parameters for mature female *Sardinops sagax*, used in the estimation of the April - May 2006 west coast spawning biomass. Trawls 22-40 are in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES						
				Location									Number spawning		
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.	Night of capture	Night before capture	2 Nights before capture
1	15	4-24	22:17	40.241	127.162	11.3	50	0.472	25	100.42	95.26	27552	0	4	6
2	17	4-25	22:50	39.124	123.810	10.8	50	0.414	21	86.69	85.09	24570	0	0	0
2	18	4-26	03:42	38.744	124.462	12.2	1	0.000	0	--	--	--	--	--	--
1	22	5-02	00:08	32.969	120.339	14.4	26	0.508	13	70.19	67.32	19354	0	2	2
1	23	5-02	03:58	33.203	119.845	13.9	50	0.478	24	55.00	52.78	15088	2	1	3
2	34	5-05	20:11	35.288	121.953	14.8	46	0.396	18	64.14	62.18	17847	0	0	0
2	35	5-06	00:55	34.972	122.651	14.8	11	0660	7	79.07	75.45	21740	0	0	2
2	38	5-06	20:17	35.480	124.932	15.1	17	0.401	7	82.07	75.63	21792	0	0	0
2	39	5-06	01:00	35.796	124.199	14.2	32	0.504	15	75.17	70.94	20418	0	1	1
2	40	5-07	03:57	35.929	123.886	13.8	12	0.172	2	77.25	74.32	21410	1	0	0

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

Table 3. Egg production (P_0) of Pacific sardine in 2006 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 *New Horizon* (Apr. 1-18), *David Starr Jordan* (April. 5- 28), and *Oscar Dyson* (April 12- May 8) cruises, adult parameters from positive trawls (April 24- May 7), and 2006 spawning biomass estimate. For comparison, spawning biomass estimates are given using 2005 adult parameter data.

	Area South of 44°N latitude				**Whole**	Standard DEPM survey Area			
Parameter	Region 1	Region 2	Total[a]		**Survey[b]**	Region 1	Region 2	Total[a]	
CUFES samples	240	921	1161	1161	**1385**	174	645	819	819
CalVET samples	79	75	154	154	**174**	59	64	123	123
P_0 / 0.05m^2	4.49	0.47	1.53	1.53	**0.98**	5.52	0.46	1.936	1.936
CV	0.23	0.32	0.23	0.23	**0.234**	0.25	0.41	0.256	0.256
Area (km^2)	149074	419757	568831	568831	**885523**	98034	238740	336774	336774
%	26.21	73.79	100	100		29.11	70.89	100	100
Year for adult samples	2006	2006	2006	2005	**2006**	2006	2006	2006	2005
Female fish wt (W_f)	76.50	76.93	76.73	65.34	**76.73**	60.34	72.74	67.41	65.34
Batch fecundity (F)	21008	21301	21163	17662	**21163**	16587	19899	18474	17662
Spawning fraction (S)	0.145	0.028	0.083	0.1236	**0.083**	0.108	0.041	0.0698	0.1236
Sex ratio (R)	0.48	0.42	0.449	0.468	**0.449**	0.49	0.43	0.45	0.468
(RSF)/W_f	19.17	3.36	10.32	15.67	**10.32**	14.57	4.80	8.62	15.67
Spawning biomass (mt)	698223	1173178	1687104	1110800	**1682260**	741987	457494	1512882	832156
CV	0.36	0.82	0.47		**0.47**	0.42	0.83	0.46	
Daily mortailty (*Z*)	0.28					0.31			
CV	0.25					0.25			
eggs/min	2.81	0.079	0.79			3.51	0.73	1.07	
CV	0.46	0.21	0.43			0.52	0.29	0.50	
q = eggs/min in Reg.2 / eggs/min in Reg.1			0.105					0.084	
CV			0.23					0.32	
E = (eggs.min)/(eggs/tow)			0.32					0.32	
CV			0.12					0.12	
Bongo samples	20	91	111		**136**	17	77	94	
Area in nm^2	43557	122646	166203		**250847**	28644	69756	98400	
S. biomass (short ton)	768045	1290496	1855814	1221880	**1850486**	816486	503243	1664170	915372

a: Two columns under total: one uses estimates of adult parameter from 2006 survey and the other one uses 2005 estimates

b 20 CalVET and 25 Bongo tows above 44°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 sardine and average sea surface temperature for the years 1994 to 2006.

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[f]	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	8.62	1,512,882 (0.46)	14.95	14.5
2006[g]	0.98 (0.234)	0.28 (0.25)	885,523 (149,074)	10.32	1, 682,220 (0.47)	13.9	13.4

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 allotherCOV² 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, calculated from new parameters (table 6 of Lo and Macewicz 2005); estimated spawning biomass is 371,725 mt 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 standard DEPM sampling area off California from San Diego to CalCOFI line 60
g whole 2006 survey area off west coast of North America from about 31°N to 51°N latitude.

Table 5. The 2006 output for the whole survey area from “frmBIOMASS” form in the EPM program after input of 2006 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	4345
Enter last collection number	4370
Enter first collection number of 2nd set	
Enter last collection of 2nd set	
Mean gonad-free weight used in regression	80.3
Number of fish used in regression	27
Variance about regression	16562151
Variance of regression slope	677.56
Po (eggs/day - 0.05m2)	0.98
Variance of Po	0.0526
Area (square kilometers)	885523

Statistic Results:

	Average	Variance
Whole Body Weight	76.727272727	46.959595485
Gonad Fee Weight	73.483416667	42.12522511
Batch fecundity	21163.299616	4666225.3778
Spawners, Day 0	0.0227272727	0.0002581978
Spawners Day 1	0.0833352273	0.0009854363
Sex Ratio	0.4488492870	0.0004439682
Daily specific fecundity	10.317222172	
Number of Sets	9	

Enter the name of DBSET table: DBSETn6a1n2

Estimate Average and Variance only [Estimate]

Estimate Correlation and Biomass also [Estimate]

EGG PRODUCTION VALUES

Po (eggs/day - .05 m2):	0.98
CV of Po:	0.23402744778
Area (square kilometers):	885523

BIOMASS ESTIMATE

Biomass (m - tons) =	1682260.06094
CV (biomass) =	0.46878980112

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.87938108	0.48442432	0.05741097
Batch Fecundity (F)			0.3907475	0.02215547
Fraction Spawning (S)				0.60366993
Sex Ratio (R)				

Table 6. The 2006 output for the standard DEPM survey area from "frmBIOMASS" form in the EPM program after input of 2006 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	4345
Enter last collection number	4370
Enter first collection number of 2nd set	
Enter last collection of 2nd set	
Mean gonad-free weight used in regression	80.3
Number of fish used in regression	27
Variance about regression	16562151
Variance of regression slope	677.56
Po (eggs/day - 0.05m2)	1.936
Variance of Po	0.246
Area (square kilometers)	336774

Statistic Results:

	Average	Variance
Whole Body Weight	67.406976744	19.651077679
Gonad Fee Weight	64.318151163	16.141271754
Batch fecundity	18474.30237	2580303.2166
Spawners, Day 0	0.0348837209	0.0005064154
Spawners Day 1	0.0697703488	0.0005360949
Sex Ratio	0.4507489718	0.0010777755
Daily specific fecundity	8.6192372959	
Number of Sets	7	

Enter the name of DBSET table: DBSETn6s1n2

Estimate Average and Variance only — Estimate

Estimate Correlation and Biomass also — Estimate

EGG PRODUCTION VALUES

Po (eggs/day - .05 m2):	1.936
CV of Po:	0.25619001586
Area (square kilometers):	336774

BIOMASS ESTIMATE

Biomass (m - tons) =	1512882.03728
CV (biomass) =	0.46594135852

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.7317992	-0.0001332	0.06864276
Batch Fecundity (F)			-0.0069508	0.03880396
Fraction Spawning (S)				0.68431838
Sex Ratio (R)				

Table 7. 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
Midpoint date of trawl survey		April 22	March 25	May 1	April 21	April 25	April 13	May 2
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
N collections with mature females		37	4	2	6	16	14	7
N collection within Region 1		11	4	2	6	16	6	2
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451
Average mature female weight (grams):								
with ovary	**W_f**	82.53	127.76	79.08	159.25	166.99	65.34	67.41
without ovary	**W_{of}**	79.33	119.64	75.17	147.86	156.29	63.11	64.32
Average batch fecundity[a] (all mature females, oocytes estimated)	**F**	24283	42002	22456	54403	55711	17662	18474
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274
N mature females analyzed		583	77	9	23	290	175	86
N active mature females		327	77	9	23	290	148	72
Spawning fraction of mature females[b]	**S**	0.074	0.133	0.111	0.174	0.131	0.124	0.0698
Spawning fraction of active females[c]	**S_a**	0.131	0.133	0.111	0.174	0.131	0.155	0.083
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.9	21.3	22.91	27.04	15.67	8.62

[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) and 2005 used $F_b = -6085 + 376.28\ W_{of.}$ (Lo and Macewicz 2006).
[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.

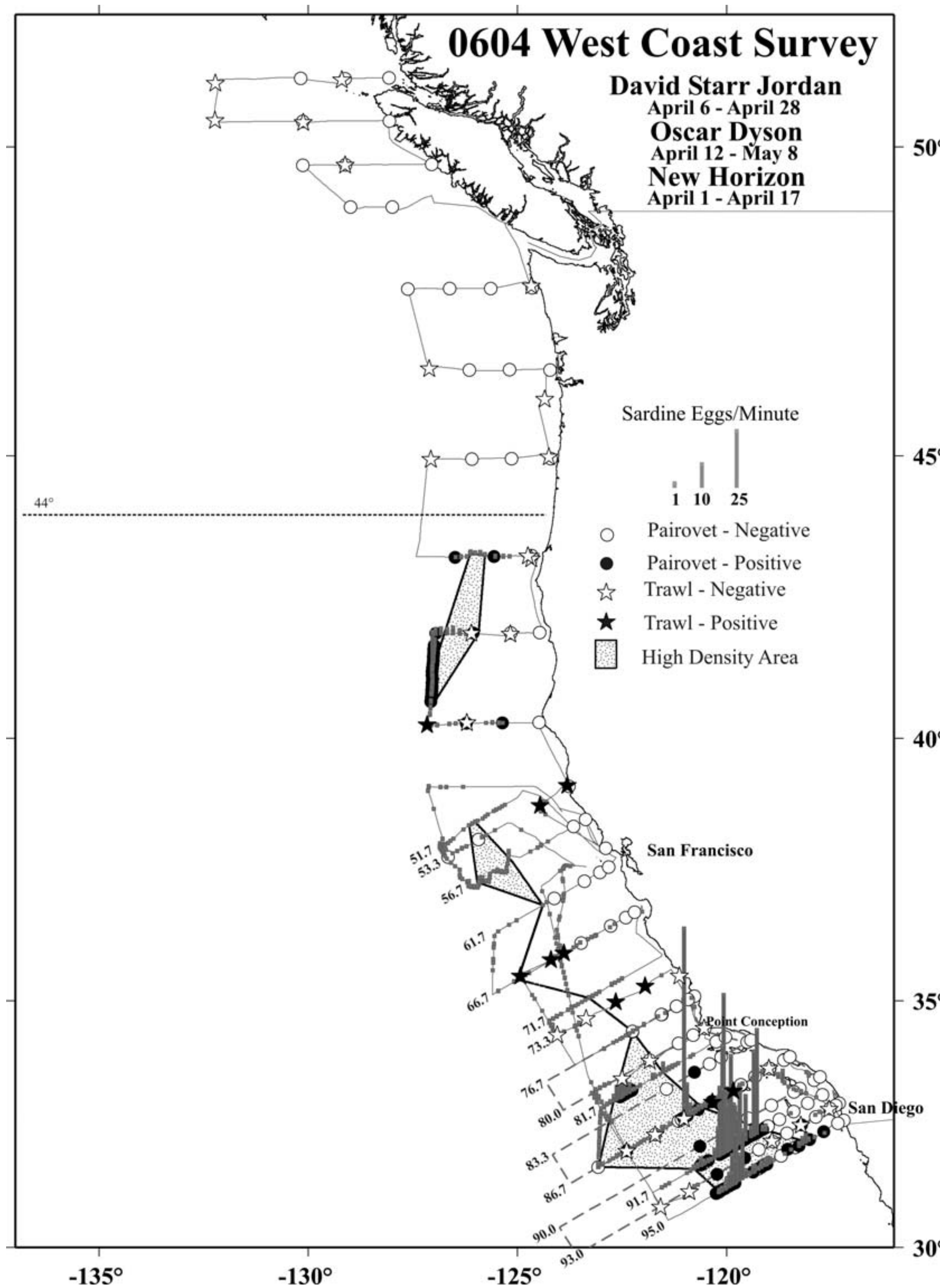


Figure 1. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2006 survey. Region 1 is high density area. Dates of cruises refer to the first and last tow.

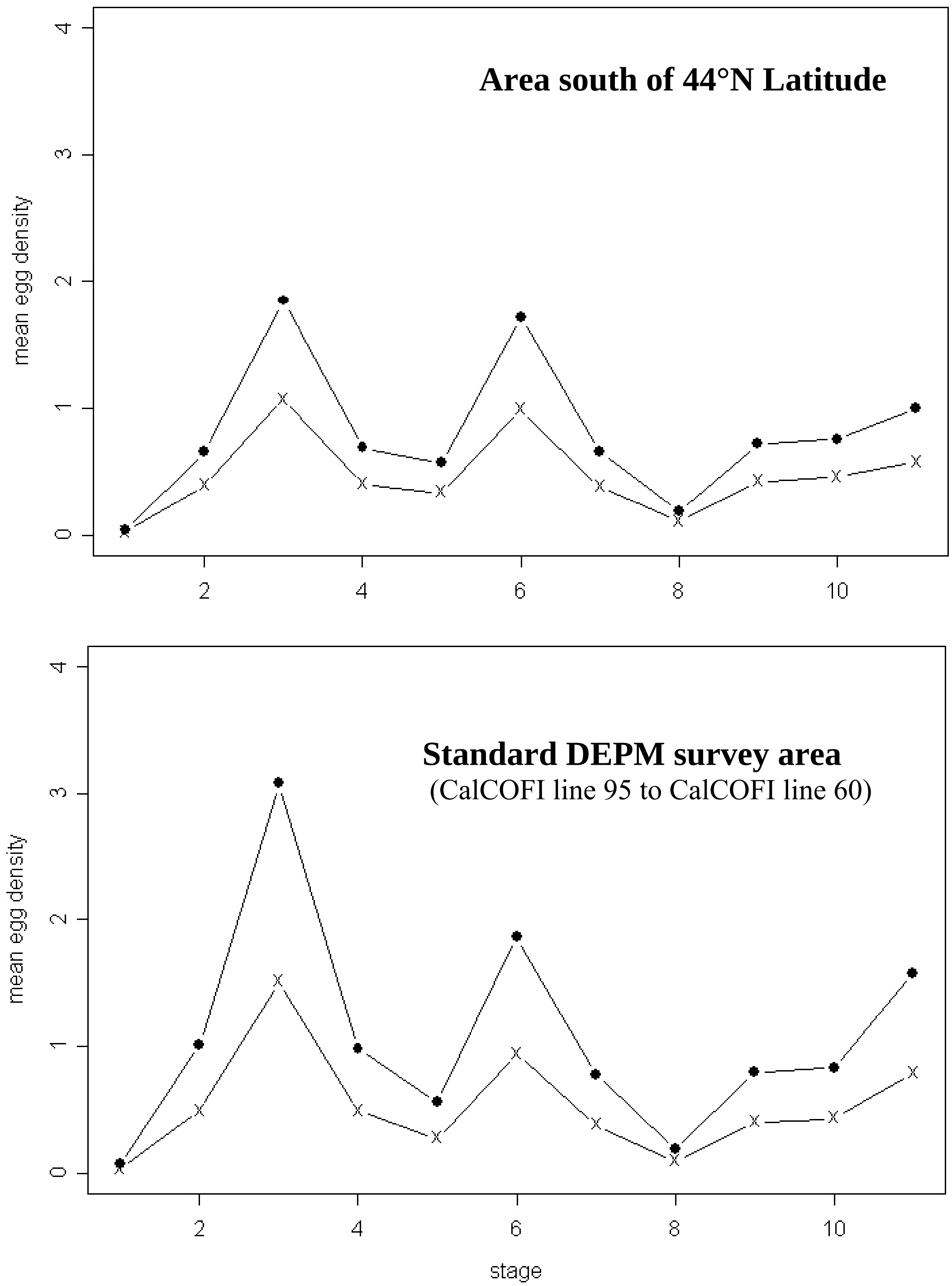
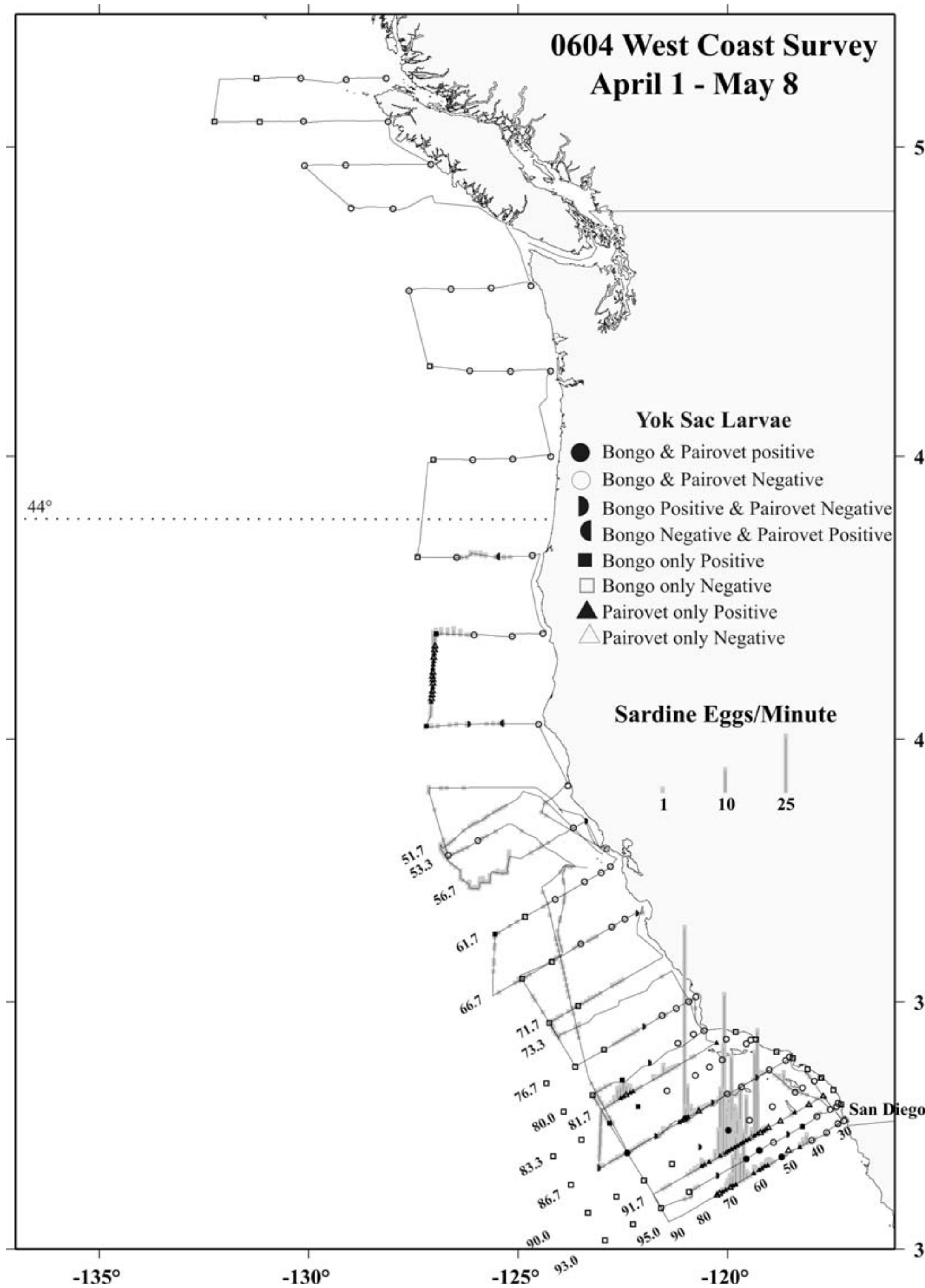


Figure 2. Mean sardine egg density (eggs per 0.05 m^2) for each developmental stage within each area for April - May, 2006. Symbols: ● = Region 1 and x = area surveyed. Note that latitude and Calcofi line were used to describe the area sfor each of these two graphs due to different orientations of transect lines (see Figure 1).



`**Figure 3**. Location of sardine yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) during the 2006 survey. Solid symbols are positive and open symbols are zero catch.

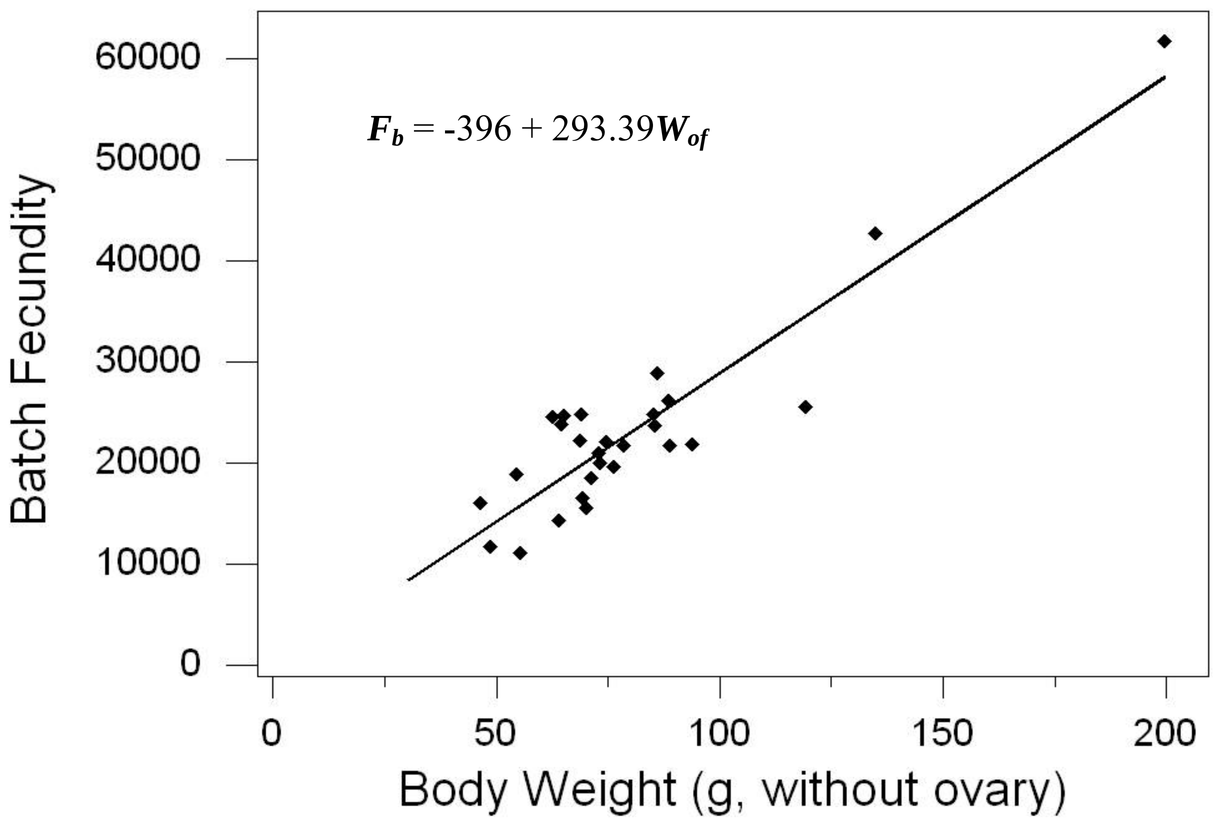
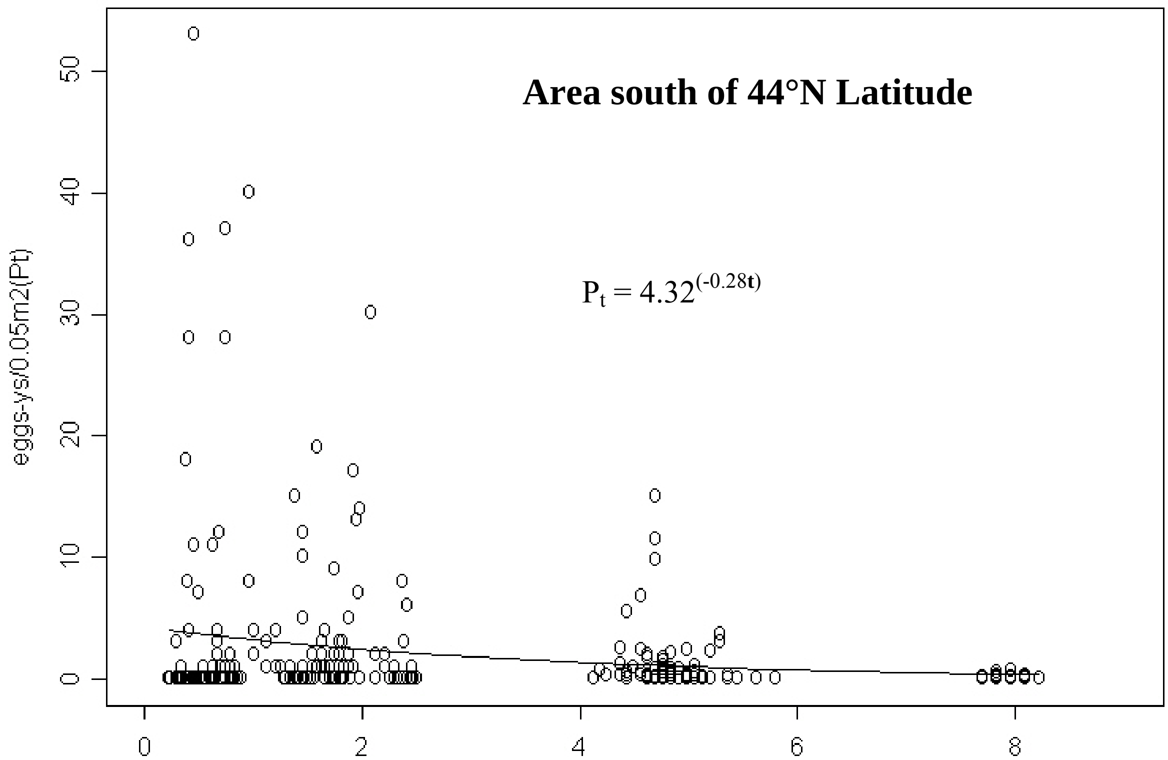


Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 27 females taken during April - May 2006. The batch was estimated from numbers of hydrated or migratory-nucleus-stage oocytes.



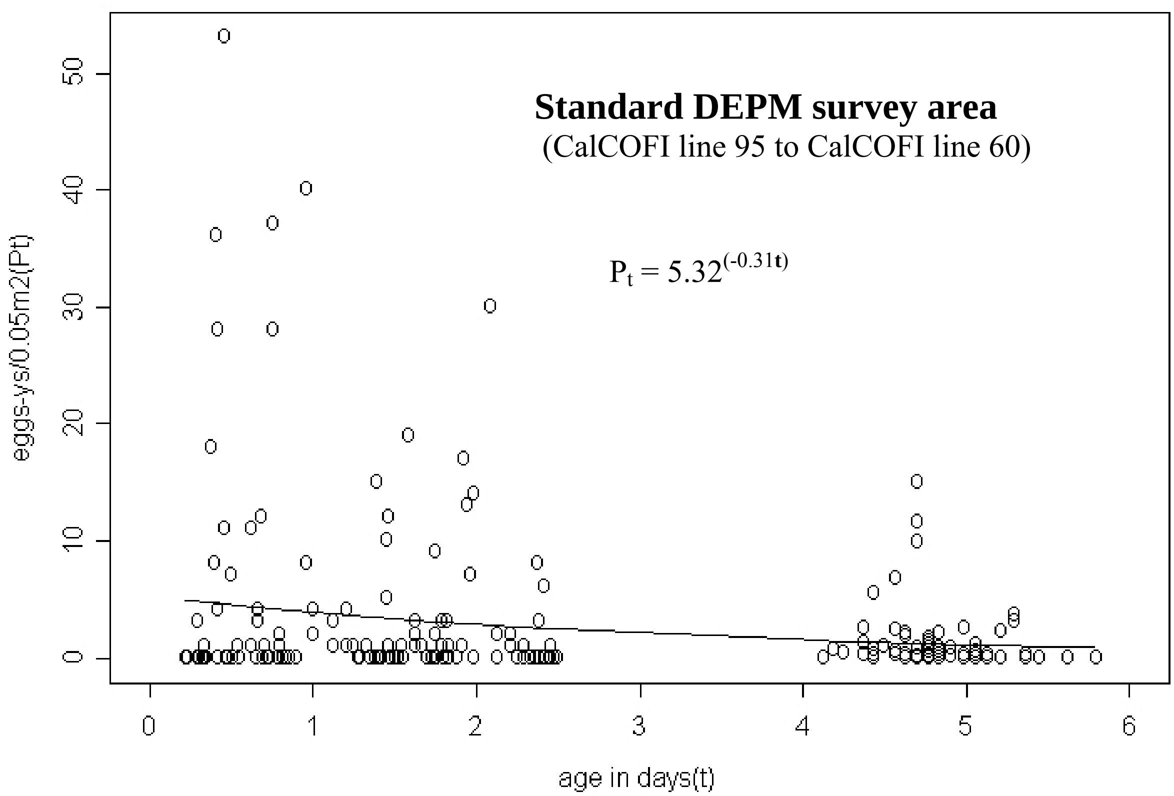


Figure 5. Embryonic mortality curve of Pacific sardine. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April – May 2006. The numbers are the estimate of daily egg production before correction for bias for each area.

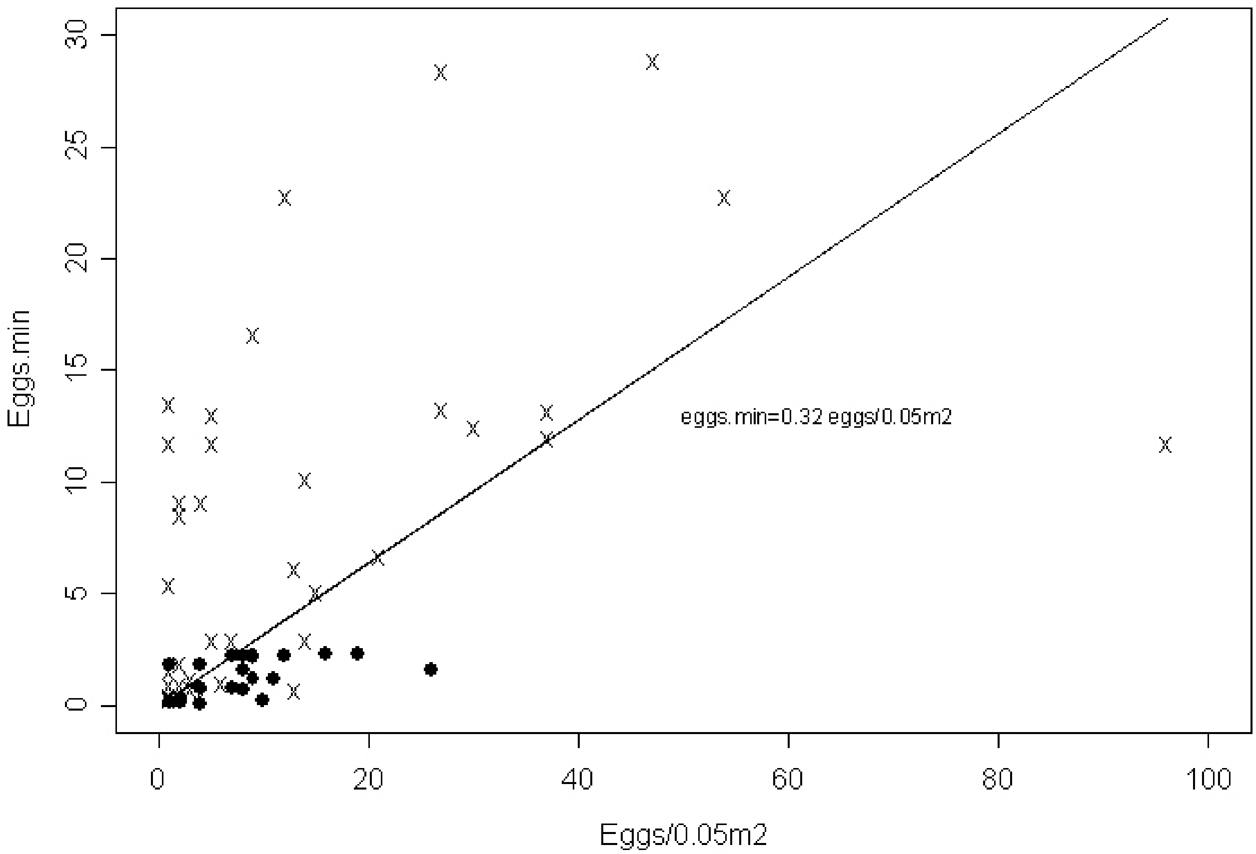


Figure 6. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April – May 2006. Symbols indicate survey ship: ● *Oscar Dyson* and x *David Starr Jordan*

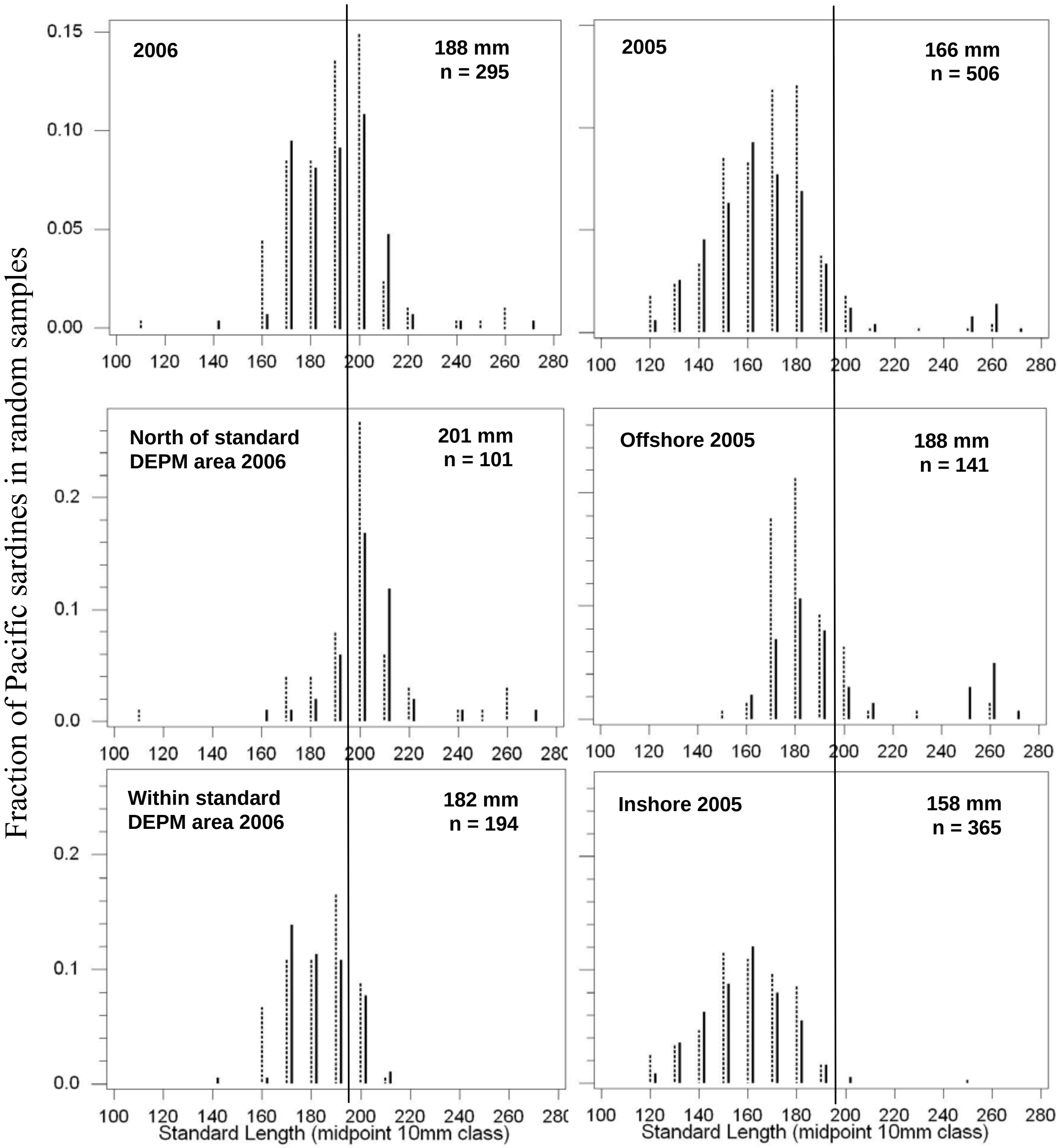


Figure 7. Length distribution and mean length of Pacific sardines caught in the 2006 and 2005 surveys and for each subarea. Vertical line separates 190 and 200 mm classes. Males indicated by dotted bars and females by solid bar.

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