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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 the Pacific sardine (*Sardinops sagax*) in April 2012 was estimated using the daily egg production method (DEPM) calculated by two methods: 1) the traditional method where the egg production (P_0) was a weighted mean while each adult parameter was an unstratified estimate, and 2) a stratified procedure where the estimate of total spawning biomass is the sum of the estimated spawning biomass in each of two regions representing high and low spawning activity. The two estimates of the spawning biomass were 282,110 mt (CV = 0.43) and 255,391 mt (CV = 0.32), respectively, for the standard DEPM survey area of 270,991 km^2 off the west coast of North America from north of San Francisco to San Diego, California, California (CalCOFI line 60.0-95.0). The daily egg production estimate (P_0, an average weighted by area) was 0.84/.05m^2 (CV = 0.27). In the standard DEPM area, the estimates of female spawning biomass calculated by the two methods were 120,902 mt (CV = 0.36) and 113,178 mt (CV = 0.27), respectively. Samples taken north of CalCOFI line 60 found no eggs in either CalVET tows or CUFES collections, and one trawl out of three caught sardines north of CalCOFI line 60 during the *R/V Ocean Starr* cruise. Hence, coastwide estimates of sardine spawning biomass and female spawning biomass were not calculated.

The estimated daily specific fecundity was 16.14 (number of eggs/population weight (g)/day) using the following estimates of reproductive parameters from 126 mature female Pacific sardines collected from 16 positive trawls: F, mean batch fecundity, 38,682 eggs/batch (CV = 0.06); S, fraction spawning per day, 0.138 females spawning per day (CV = 0.24); W_f, mean female fish weight, 141.6 g (CV = 0.04); and R, sex ratio of females by weight, 0.429 (CV = 0.12). Since 2005, trawling has been 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. During the 2012 survey, the number of tows positive for mature female sardines was the same in Regions 1 and 2 (8 trawls in each region). In addition, two tows in each region contained a sole male sardine.

The estimates of spawning biomass of the Pacific sardine off California in 1994 – 2012 based on the traditional method 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, 392,000 mt, 117,000 mt, 185,000 mt, 108,000 mt, 383,000 mt, and 282,000 mt (for the standard DEPM area), respectively. These estimates of spawning biomass indicate that there has been considerable fluctuation during this time (the peaks occurred in 2000 and 2006) and that biomass has declined in 2008-2010, increased in 2011 and declined in 2012 to the level of 2004 (about 300,00 mt). The time series of spawning biomass was one of the fishery-independent inputs to the annual stock assessment of the Pacific sardine from 1985 – 2008. Since 2009, the time series of spawning biomass was replaced by female spawning biomass for years when sufficient trawl samples were available and the total egg production for other years was used as inputs to the stock assessment of Pacific sardines.

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INTRODUCTION

The spawning biomass of the Pacific sardine (*Sardinops sagax*) was estimated using the daily egg production method (DEPM: Lasker 1985) in 1986 (Scannel et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), and 1996 (Barnes et al. 1997). 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 on sardine eggs collected with CUFES have been incorporated in various ways into the estimation procedures for 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 on 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 sardine egg stages from CUFES samples are representative of the entire vertical distribution of stages. 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 pre-assigned if sardine egg densities in CUFES collections exceeded a threshold value of 1 egg/minute.

Since 2001, a cost-effective alternative has been adopted to calculate the DEPM index that reduces effort in calculation and egg staging of the CUFES collections. This revised DEPM index only uses CalVET samples of eggs and yolk-sac larvae and Bongo samples of yolk-sac larvae, all from the high-density area (Region 1), to provide an estimate of P_0 (daily egg production), the variance of which may be large due to small sample size (fewer than 100 plankton tows in some years). Adult samples were collected sporadically in 1997, 2001, and 2002 (Lo et al. 2005).

Starting in 2004, full-scale surveys have been conducted for collection of Pacific sardine eggs, larvae, and adults to better estimate the spawning biomass in the area off California between San Diego and San Francisco (Lo and Macewicz 2004; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2006a, b; Lo et al. 2007a, b, 2008, Lo et al. 2009, 2010b, 2011). In 2004 the adult samples were taken primarily in the high-density area, but beginning in 2005 adult Pacific sardine samples for reproductive output were taken in both high and low sardine egg density areas. The ichthyoplankton samples taken during regular April CalCOFI cruises were also included in the spawning biomass computation. During 2006, 2008, and 2010-2012, the survey area was extended north to the US-Canadian border. The spawning biomass was computed for both the whole survey area (Cape Flattery, WA to San Diego, CA) and the

standard DEPM survey area, (from San Diego to San Francisco) in 2006, 2008 and 2010. Since 2011, because few eggs and adults were observed in the area north of CalCOFI line 60.0, the daily egg production (P_0) was estimated for the standard DEPM survey area between CalCOFI lines 60.0 and 95.0. Note in some years, the most southern CalCOFI line occupied was 93.3, as in this year (line 93.8).

Since 2009, in addition to the estimates of spawning biomass based on the past procedure where P_0 was weighted by the size (km^2) of each region and the adult parameters were estimated from all trawl samples in the entire survey area, an alternative estimator based on stratified sampling for each parameter was also included (Hill et al. 2009, 2010) for years when adequate adult samples were available (1986, 1987, 1994, 2004, 2005, 2007-present). As such, the original time series of spawning biomass may not be comparable due to slightly different estimation procedures and the refined survey designs over time. This alternative method was also used to estimate the female spawning biomass that is now used as a data time series for stock assessment computations. Here, we report the time series of spawning biomass, female spawning biomass, and total egg production based on both the traditional method and the stratified estimation procedure.

MATERIALS AND METHODS

Data

The spring 2012 CPS-Sardine DEPM survey was conducted aboard one NOAA research vessel, *Bell M. Shimada* (April 11-April 30) and a chartered research vessel, the R/V *Ocean Starr* (March 26-April 29). The *Ocean Starr* covered the area off the west coast of US from Cape Flattery, Washington to Point Conception, California with most of the stations off California located within the area from north of San Francisco to Point Conception (CalCOFI lines 56.3 to 80.0 from April 5 to April 28) (Figure 1 and 2). The *Shimada* covered the area from San Diego, California (CalCOFI line 93.8) to Monterey Bay (CalCOFI line 68.3). The NOAA ship *Shimada* also occupied the primary CalCOFI lines, 76.7 to 93.3, from March 23 to April 7 for the spring CalCOFI cruise. During the DEPM and CalCOFI surveys, CalVET tows, Bongo tows, and CUFES were conducted aboard both vessels while surface trawls were conducted only during the DEPM surveys. Data from DEPM surveys on both ships were included in the estimation of spawning biomass of Pacific sardines. Data from the CalCOFI survey during March, 2012, were not used due to the low number of sardine egg or larval catches from all nets.

All ichthyoplankton tows follow specific protocols developed within the CalCOFI program and are conducted as follows. CalVET tows are fished vertically from 70 meters depth to the surface at a retrieval rate of 70 meters/minute. The mesh size of the net body and the codend are 150 µm and the frame opening diameter is 25 cm. Water flow through the net opening is measured using a GO digital flowmeter. Bongo tows consist of paired 71 cm rings connected by a central swivel. With depth permitting, the Bongo nets fish to a depth of 210 m through an oblique trajectory. The paired nets have a mesh size of 505 µm and the codends have a 333 µm mesh. The amount of water strained during a tow is measured by a GO digital flowmeter. For a more detailed description please refer to Smith and Richardson (1977).

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), 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 sardine 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 embryonic mortality in the high density area and the daily egg production, P_0, for the whole survey area.

During the 2012 CPS-Sardine DEPM survey, twenty-one distinct transects were occupied by the vessels. The *Shimada* occupied 8 lines and the *Ocean Starr* occupied 15 lines (two lines above CalCOFI line 50). Both vessels occupied CalCOFI lines 68.3, and 78.3. For the CPS-Sardine DEPM 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. The catch ratio of egg densities from CUFES (egg/min) to that by CalVET tow (eggs/0.05m^2) depends on the degree of water mixing. This adaptive allocation sampling was similar to that used in the 1997 survey (Lo et al. 2001). Because the threshold changed in 2002, caution should be taken when comparing the size of the area of Region 1.

In 2012, the entire survey area (344,174 km^2) was mostly south of CalCOFI line 53.4 (lat 39.01^{o}N). The standard DEPM survey area is south of CalCOFI line 60.0 (37.94°N latitude) with an area size of 270,991 km^2 in 2012 that was smaller than the area in 2011 (314,481 km^2) and similar to that in 2010 (271,773 km^2). This standard DEPM survey area was used to estimate the initial P_0, because none of the CUFES collections included sardine eggs from north of CalCOFI line 60.0. The standard DEPM area was post-stratified into two regions: Region 1 (high sardine egg density) and Region 2 (low egg density). Region 1 was largely between CalCOFI lines 60.0 and 76.7(Figure 1) where the egg density in CUFES collections was at least 1 egg per minute. The sizes of Region 1 and the standard DEPM survey area were calculated using both the formula for a trapezoid area (based on the distance between CalCOFI lines and the distance between CalCOFI stations) and the R function, areaPolygon in the geosphere-package (http://cran.r-project.org/web/packages/geosphere/geosphere.pdf). Region 1 was 32,322 km^2 (12% of the standard DEPM area) and Region 2 was 238,669 km^2. Over the years, although the standard DEPM survey area has varied in size, it has been approximately between CalCOFI line 60 (near San Francisco) and line 95 (near San Diego). In 2012, the spawning biomass estimated in the standard DEPM area was considered to be the spawning biomass for the entire survey area (Figure 1).

A total of 964 CUFES samples were collected in the *Ocean Starr* (618) and *Shimada* (346) cruises over the whole survey area. For the standard DEPM area (CalCOFI line 60.0 to 93.8), 769 CUFES samples were taken by the *Shimada* (346) and *Ocean Starr* (423). For *Ocean Starr*, CUFES sampling intervals ranged from 3 to 125 minutes with a mean of 37.53 minutes and median of 30 minutes, and for *Shimada*, CUFES sampling intervals ranged from 2 to 168

minutes with a mean of 34.7 minutes and a median of 30 minutes depending on egg densities observed onboard. The total number of CalVET tows was 129 for the entire survey area, with 128 in the standard DEPM survey area. A total of 50 CalVET samples caught at least one egg (Table 1), all in Region 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 *Shimada* and the *Ocean Starr* to conduct 3 – 5 trawls a night either near regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections. At night a Nordic 264 rope trawl with 3.0 m^2 foam core doors was towed for 30 minutes at the surface (0 – 11 meters). The trawl was modified for surface trawling with Polyform floats attached to the head rope and trawl wings. The trawl was modified with a marine mammal excluder device placed midsection just forward of the codend. In addition, on both vessels, the first trawl of the night (about a half hour after sunset) was towed without the Polyform floats to depths about 15 to 35 meters to potentially catch fish that might still be moving up toward the surface from daytime depths since darkness had not fully descended. For the whole CPS-Sardine DEPM survey, trawling occurred from April 5 to April 30, 2012 and 21 of the 95 trawls conducted at night were positive for Pacific sardines. A single trawl in northern California just above CalCOFI line 56.7 collected sardines. The other 20 trawls with sardines were located in the south below latitude 37.4°N (Figure 1, Table 2).

Up to 50 sardines were randomly sampled from each positive trawl with more than 75 fish, or all were sampled if fewer than 76 fish were captured (Table 2). After the random subsample, additional mature females were randomly processed, if necessary, from the trawl catch to obtain 25 mature females per trawl for reproductive parameters or to obtain females 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, 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 latitude 39.01°N (CalCOFI line 53.4), the spawning biomass was most likely distributed in the survey area south of San Francisco, the standard DEPM survey area. Therefore, the estimate of P_0, and thus spawning biomass for the standard DEPM survey area (i.e., the area between CalCOFI line 60.0 and 95) were also used for the entire survey area which differed from some of the previous years, e.g. 2006, that had separate area estimates. Appropriate parameter estimates required by the DEPM were obtained

for each region.

Similar to the 2001-2005 procedure (Lo 2001), we used a 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 10 transects (Figure 1 and 2). In Region 1, a total of 34 out of 37 CalVET samples contained at least 1 sardine egg (Table 1); these eggs were examined for their developmental stages (Figure 3). In the total Region 2 (North plus DEPM), 16 out of 92 CalVET tows caught sardine eggs.

Based on laboratory counts of sardine eggs in CUFES samples, 272 of the 964 collections were positive for sardine eggs over the entire survey area. For the DEPM area (south of CalCOFI line 60.0), 272 of 769 collections caught sardine eggs. In Region 1, there were 130 positive CUFES collections out of 137 total collections. In the DEPM Region 2, 142 of the total 632 collections were positive. No CUFES samples taken north of CalCOFI line 60.0 were positive (Figure 1 and Table 1).

To model the embryonic mortality curve, we included yolk-sac larvae (preserved larvae $\leq$ 5 mm notochord length), assuming that 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). 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, 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/0.05m^2 was then computed for each tow and termed daily larval production/0.05m^2.

In the entire survey area, 7 of 129 CalVET and 16 of 90 Bongo samples had at least one yolk-sac larva (Table 1). In Region 1 (Figure 2), 5 of 37 CalVET and 6 out of 10 Bongo samples were positive for yolk-sac larvae (all within the DEPM area), and in Region 2, 2 of 92 CalVET and 10 of 80 Bongo samples were positive for yolk-sac larvae. In the DEPM survey area (area south of CalCOFI line 60), 7 out of 128 CalVET and 16 out of 89 Bongo samples had at least one yolk-sac larvae. In Region 1, 5 of 37 CalVET and 6 of 10 Bongo samples were positive for yolk-sac larvae, and in Region 2, 2 of 91 CalVET and 10 of 79 Bongo samples were positive for yolk-sac larvae (Table 1).

Daily egg production for the whole survey area (31.22°N – 48.02°N)

Because no eggs were collected in the area north of CalCOFI line 53.4 (lat 39.01 ^{o}N) (Figure 1), and most stations were south of CalCOFI line 60.0, P_0 (daily egg production/0.05m^2) was computed based on the area south of CalCOFI line 60.0, the standard DEPM survey area.

Daily egg production in Region 1 ($P_{0,1}$) for the standard DEPM survey area (south of CalCOFI line 60.0)

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 3). The distribution of overall density of eggs by egg development stage in 2012, with peaks at stage 3 and 5, was different from those in recent years when stage 6 or stages 6-9 had the highest density (Lo et al. 2009 and 2010b). The average sea surface temperature for CalVET tows with ≥1 egg in this DEPM survey area was 13.6°C, which is similar to 2011 and lower than in recent years (Lo et al. 2010b). 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 ≤ 3h old and eggs older than 2.5 days were excluded because of possible bias. The average sea surface temperature for all CalVET tows from *Ocean Starr* was 13.4°C, while from the *Shimada* it was 13.6°C for the tows in the standard DEPM survey area.

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

$$P_t = P_0 e^{-zt} \qquad [1]$$

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, t is the age (days) of eggs or yolk-sac larvae from each tow and z is the daily instantaneous mortality rate. 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 4.93, 6.47, and 1.9, for day-one, day-two and day-three age groups from CalVET samples, respectively, and the SD for yolk-sac larvae was 0.15 and 0.21 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 as $P_{0,1,c} = P_{0,1}$ * (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 standard DEPM survey area

Although 91 CalVET samples were taken in Region 2 (Table 1), only 16 tows had ≥ 1 sardine egg, ranging from 1 to 67 eggs per tow with most of the catches containing fewer than 15 eggs. 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:

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

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

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

where q is the ratio of eggs/min between the low density and high density areas, m_i was the total CUFES time (minutes) in the i[th] transect, $\bar{x}_{j,i}$ is eggs/min of the i[th] transect in the j[th] Region, and $q_i = \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}}$ is the catch ratio in the i[th] transect. The estimates of q were computed from a total of 9 transect lines occupied by the *Ocean Starr* and/or the *Shimada* in Region 1.

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

The above P_0 was computed for the DEPM area between CalCOFI line 60.0 and 90.0. The estimate of egg production for the 'whole' survey area (south of CalCOFI line 53.4) $P_{0,\mathrm{WHOLE}}$ would be equal to P_0 in the DEPM survey area times the ratio of the DEPM area to the 'whole' area $P_{0,\mathrm{WHOLE}} = \sum P_{0,\mathrm{i,\ WHOLE}}\ W_{\mathrm{i,WHOLE}}$. For the DEPM area, $P_{0,\mathrm{DEPM}} = \sum P_{0,\mathrm{i,\ DEPM}}\ W_{\mathrm{i,DEPM}}$ where the weights are $W_{\mathrm{i,DEPM}} = A_{\mathrm{i,DEPM}} / A_{\mathrm{DEPM}}$ for i = 1, or 2. $A_{\mathrm{DEPM}} = A_{1,\mathrm{DEPM}} + A_{2,\ \mathrm{DEPM}}$ where $A_{\mathrm{i,DEPM}}$ is the area for the ith region in the standard survey area (32,322 km^2). For Region 1, $P_{0,1,\mathrm{WHOLE}} = P_{0,1}$. For Region 2, $P_{0,2,\mathrm{WHOLE}} = P_{0,2}$ x $A_{2,\ \mathrm{DEPM}} / A_{2,\ \mathrm{WHOLE}} = P_{0,\mathrm{I,c}}$ x q x (238,669/311,815) where $A_{2,\ \mathrm{DEPM}}$ was the area of the DEPM Region 2. CV ($P_{0,\mathrm{WHOLE}}$)= se ($P_{0,\mathrm{WHOLE}}$)/ $P_{0,\mathrm{WHOLE}}$ where se ($P_{0,\mathrm{WHOLE}}$) = sqrt [(se ($P_{0,1}$) * $W_{1,\mathrm{WHOLE}})^2$ + (se ($P_{0,2,\mathrm{WHOLE}}$) * $W_{2,\mathrm{WHOLE}})^2$]. The area of Region 1 for the whole survey area ($A_{1,\mathrm{WHOLE}}$) was equal to Region 1 in the DEPM survey area (A_1) and CV($P_{0,2,\mathrm{WHOLE}}$) = CV($P_{0,2}$) . The size of the standard DEPM survey area (area between CalCOFI lines 60.0 and 95.0) is 270,991 km^2 . The total egg production (TEP) is the numerator of equation (4) or = P_0 * (A_1+A_2).

Adult parameters

Four adult parameters are needed for estimation of spawning biomass: 1) daily spawning fraction or the number of spawning females per mature female per day (S), 2) the average batch

fecundity (*F*), 3) the proportion of mature female fish by weight (sex ratio, *R*), and 4) the average weight of mature females (g, W_f). Population values for *S*, *R*, *F* and W_f were estimated using the methods of Picquelle and Stauffer (1985). Daily specific fecundity (number of eggs per population weight (g) per day) is $(RSF)/W_f$. The parameters were estimated for the DEPM area and separately for sardine females caught in each egg-density region. Correlations among all pairs of adult parameters were calculated for computing the variance of the estimate of spawning biomass (Parker 1985). In the past, the predicted batch fecundity for each female fish was calculated as y = a + bx where x is the female weight (without ovary) and y is the predicted value. In reality, most of the batch fecundities we estimated gravimetrically are scattered around the regression line and not on it. Therefore, to account for the deviation of batch fecundity from the regression line, we added an error term to the predicted value as y = a + bx + *e* where error term *e* was a random number generated from a normal distribution with mean zero and a variance of the error terms from the regression analysis. An MS[1] Visual Basic program (Chen et al. 2003) was modified to more accurately describe batch fecundity variance and 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). In total, 148 mature female sardines were analyzed and considered to be a random sample of the population in the area (126 were in the DEPM area). 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 using the number of females 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 spawned two nights before capture (A) since 2009 plus the adjusted number of mature females caught in each trawl (Table 2) to estimate the 2012 population spawning fraction (S_{12}) and variance (Picquelle and Stauffer 1985, Hill et al. 2009).

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 40 females caught during the April 2012 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = -12724 + 402.33W_{of}$,where $r^2 = 0.609$, variance of the slope was 2737.4, and W_{of} ranged from 79 to 178 g (Figure 4); the intercept did not differ from zero ($p = 0.081$). We used the equation $F_b = -12724 + 402.33W_{of} + e$ where the error term, *e*, was generated from a normal distribution with mean zero and variance of 64,507,697 to estimate batch fecundity for each of the 126 mature Pacific sardine females that were analyzed to estimate spawning frequency.

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

Female weight (W_f). The observed female weight was adjusted downward for females with hydrated ovaries, because their ovary weights were temporarily inflated. We obtained the adjusted female weight by the linear equation $W_f = -7.29 + 1.127W_{of}$ where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated mature females taken during the April 2012 CPS-Sardine DEPM 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 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 also calculated (Picquelle and Stauffer, 1985).

Spawning biomass (B_s)

The spawning biomass was computed:

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

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 using Taylor expansion and in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

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

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

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

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.

The survey area was post-stratified into two regions based on the presence of sardine eggs: Region 1 (high-density area) and Region 2 (low-density area). Thus, equation (5) can be applied to the whole survey area and/or to each of the two regions depending on the availability of data. For the female spawning biomass (fs.biomass), one of the inputs to the stock assessment, the sex ratio (R), was excluded from equations (5) and (6). The estimate of female spawning biomass was the sum of the estimate from each of the two regions, which is referred to as the stratified procedure. The traditional method is to obtain a weighted mean for P_0 (equation 4), while each of the adult parameter was an un-stratified estimate.

RESULTS

Daily egg production (P_0) for the standard DEPM survey area and the 'whole' survey area

In Region 1, the initial daily egg production ($P_{0,1}$) from the mortality curve was 5.07/0.05 m^2/day (CV = 0.27; equation 1 and Figure 5). The bias-corrected egg production, ($P_{0,1,c}$) was 5.28 (CV = 0.27) (Table 3) for an area of 32,322 km^2 (south of CalCOFI line 60.0). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.046 (CV = 0.22) (equation 3). The egg production ($P_{0,2}$) in Region 2 of the standard survey area was 0.24 (CV = 0.34), compared to 0.914 /0.05m^2/day (CV = 0.5) in 2011, for an area of 238,669 km^2. Egg mortality (0.66 (CV = 0.10)) was higher than in many years (Table 3 and 4). The P_0 for the standard DEPM survey area was 0.84/0.05m^2 (CV = 0.27) (equation 4) for 270,991 km^2. For the 'whole' area, south of CalCOFI line 53.4, P_0 = 0.66/0.05m^2/day (CV = 0.22) in an area of 344,137 km^2.

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 47 pairs of CalVET tows and CUFES collections from the *Ocean Starr* and *Shimada* 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, 0.0338 (CV = 0.34), was lower than that in 2011 (0.0589, CV = 0.21) and 2010 (0.077, CV = 0.14). A ratio of 0.0338 means that one egg/tow from a CalVET tow was equivalent to approximately 0.0338 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 29.5 eggs/tow from the CalVET sample.

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). It is needed 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 2012 survey, q was obtained from transects in Region 1 that had at least five CUFES collections taken. A total of 9 transect lines, all north of CalCOFI line 80.0, were used to compute q. The estimate was 0.046 (CV = 0.22).

Adult parameters

Over the whole survey area trawled (31.3° – 93.62°N) during the April 2012 CPS-Sardine DEPM survey, one out of 3 tows caught sardines north of CalCOFI line 60 at 37.61°N (Figure 1) . Although this trawl caught mature female sardines (Table 2), no sardine eggs were found by CalVET or CUFES, and the 'whole' area spawning biomass was estimated by that in the standard DEPM area. In the DEPM survey area off California (from CalCOFI lines 93.8 to 60), Pacific sardines were found in 20 tows: mature females were caught in 16 tows, and 4 tows contained only a single male (Table 2). Standard length (SL) of the randomly obtained sardines in each trawl ranged from 172 to 252 mm for 158 males and from 191 to 261 mm for 106 females. The smallest mature female was 191 mm SL. Since only six immature female sardines (size range 189 to 201 mm SL) were captured during the 2012 survey, the length at which 50% of females are mature (ML_{50}) was not calculated.

The DEPM survey area off California in 2012 was 270,991 km^2. Estimates of reproductive parameters of sardines for the individual trawls (up to 25 mature females analyzed per trawl) are given in Table 2. The mature female sardine reproductive parameters in the standard DEPM survey area, estimated from 16 positive trawls (Table 2) and 126 mature females, were F, mean batch fecundity, 38,682 eggs/batch (CV = 0.06); S, fraction spawning per day, 0.1376 females spawning per day (CV = 0.24); W_f, mean female fish weight, 141.6 g (CV = 0.04); and R, sex ratio of females by weight, 0.429 (CV = 0.12) (Table 5). The average interval between spawning bouts (spawning frequency) was about 7 days (inverse of spawning fraction or 1/0.1376), and the daily specific fecundity was 16.14 eggs/population weight (g)/day (Table 5). The correlation matrix for the adult parameter estimates for the DEPM Region 1 and Region 2 and the whole DEPM area is shown in Table 5. We also provide estimates of each adult parameter in each region (Table 5), primarily because they are used to compute female spawning biomass, which is the input of fishery-independent spawning biomass time series to the stock assessment (Hill et al. 2011).

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardines in 2012 using the traditional method (equation 1 and 4, Tables 3, 4, and 6) was 282,110 mt (CV = 0.43) for the standard DEPM survey area of 270,991 km^2 (79,179 nm^2) off California. The yearly point estimates of spawning biomass of Pacific sardine off California in 1994 – 2012 were, 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; 117,426; 185,084; 108,280; 383,286 and 282,110 mt (Table 4). Based on the stratified procedure, the estimate of the 2012 spawning biomass was 255,391 mt (CV = 0.32) (Table 3).

The estimate of the female spawning biomass for the DEPM survey area was 113,178 mt (CV = 0.27) and 120,902 mt (CV = 0.36) based on the stratified procedure and the traditional method respectively (Table 6). The former with estimates of previous years was used as one time series input to the Pacific sardine stock assessment (Table 6). Note the spawning biomass estimates prior to 2009 could be different between Tables 4 and 6 due to the different estimation procedure for the spawning fraction. Beginning in 2009, the spawning fraction was the average of spawning fraction one night before and 2 nights before the capture (S_{12}) (Table 6) while before 2009, the spawning fraction was based on female spawning one night before capture (S_1) (Table 4).

DISCUSSION

Sardine eggs

Sardine eggs in April 2012 were concentrated in the expanse between CalCOFI lines 60.0 and 76.7 and as far offshore as CalCOFI station 83.5 in Region 1, an area of close to 32,000 km^2, which is a much smaller area compared to 2011 (Figure 1, Lo et al. 2011) but similar to the high density area in 2010 when eggs were distributed between CalCOFI lines 63.3 and 73.3, and further north than in 2009 when eggs were distributed between CalCOFI lines 81.7 and 95.0 (Lo et al. 2010b and 2009)(Figure 7). Similar to 2011, no sardine eggs were caught north of CalCOFI line 60.0 (Figure 1) whereas in 2006 and 2008, some sardine eggs were collected in the northern area. The daily egg production rate of 5.28/0.05m^2 in the high-density area was lower than that of 2011, but was much higher than in 2007-2010 (Table 6). As in 2011, the high-density area was 12% of the standard DEPM survey area, much lower than in most previous years (e.g., 27% in 2009). The spawning area which has been in the center of California waters since 2010, shifted from a more southerly area of California between 2006 and 2009 (Figures 7 and 8). In the past, eggs were concentrated north of Point Conception in 1999, 2004 and 2005. The relatively small size of Region 1 in 2010 and 2012, and its northern location (between CalCOFI line 60.0 and 76.7) which was somewhat more north compared to 2011 (Figure 7), could be due to a minor La Niña year and/or other environmental conditions. Moreover, in the 2006 CCE survey, eggs were observed around latitudes 40°N to 43°N, which was not true for the 2008 and the 2011 California Current Ecosystem (CCE) surveys.

The adaptive allocation sampling procedure was used aboard the *Ocean Starr* and the *Shimada* (excluding March CalCOFI survey data). A total of 128 CalVET tows were taken in the standard DEPM survey area. The number of tows was higher than in some previous years (84 in 2007, 123 in 2006, 74 in 2005, and 124 in 2004), but smaller than in other recent years (217 in 2002, 192 in 2003, 151 in 2008, 136 in 2009, 129 in 2010, and 151 in 2011). Due to the low egg densities south of CalCOFI line 78.3, no extra CalVET tows were taken. Starting in 2011, adaptive sampling was used during the April CalCOFI survey. Even though the data from the

2012 March CalCOFI survey were not used to compute the daily egg production (P_0) due to low catch of sardine eggs and larvae, we still highly recommend that adaptive allocation sampling be applied during the spring (March-April) routine CalCOFI survey in the future to enhance the quality of the estimate of the spawning biomass.

Embryonic mortality curve

The estimates of the daily egg production at age 0 ($P_0/0.05m^2$ = 5.28 with CV = 0.27) and the daily embryonic mortality (0.66, CV = 0.11) from the mortality curve (Figure 5) in Region 1 were much higher than in recent years from 2007-2010. In many past years, the peak egg developmental stage was stage 6. In 2012, however, the peak egg development stage was stage 3 and 5 (Figure 3). Another extreme case was in 2010, when the peak densities spread from stage 6 to 9 (Lo et al. 2010b). The latter phenomenon is not understood and needs thorough investigation. The overall P_0 in the DEPM (0.84 eggs/$0.05m^2$) was higher than in most previous years (Table 3 and 4), despite the relatively small size of the high density area (Figure 2). The spatial distribution of yolk-sac larvae was similar to that in years prior to 2011(Figure 2). Those yolk-sac larvae in Region 2 were not used in the computation of spawning biomass.

Catch ratio between CUFES and CalVET (E)

The 2012 catch ratio between CUFES and CalVET (0.0338) computed from data obtained from the *Ocean Starr* and *Shimada* appeared to be the lowest among all years: 2011(0.058), 2010 (0.077), 2009 (0.15), 2008 (0.14), 2007 (0.15), 2006 (0.32(CV = 0.12)), 2005 (0.18 (CV = 0.28)), 2004 (0.22 (CV = 0.09)), 2003 (0.39 (CV = 0.11)), 2002 (0.24 (CV = 0.06)), 2001 (0.145 (CV = 0.026)), 2000 (0.27), 1999 (0.34), and 1998 (0.32). This continuous decreasing of catch ratio since 2006 indicated that relatively fewer eggs were in the upper 3 meters of the water column, possibly due to weakly mixed ocean water. In particular, the current catch ratio was much lower than 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 of 0.046 (CV = 0.22) (ratio of eggs/min in Region 2 to eggs/min in Region 1) (equation 2) was lower than in 2011 (0.164 (CV = 0.23)) and other previous years for the standard DEPM sampling area. The *q* values have ranged from 0.036 to 0.085 in 2001-2006 with an increasing trend until 2012. The low *q* value indicated that the egg densities in Region 1 were much higher than in Region 2 and sardine eggs were more concentrated in Region 1 than Region 2. Otherwise the difference of densities of eggs between these two regions would be less.

Adult parameters

The April 2012 CPS-Sardine DEPM survey attempted to again cover a large area off the west coast of the U.S. from Cape Flattery, WA to San Diego, CA. Previous trawling off the

whole west coast was conducted in the spring during 2006, 2008, 2010, and 2011 (Lo et al. 2007a, 2008, 2010b, 2011). We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in three subareas off the coast: Washington and Oregon, north of CalCOFI line 60 and the standard DEPM area (Figure 1 and Table 7). Due to weather and time constraints no trawls were conducted off Washington-Oregon (WA-OR) and only 3 trawls were conducted in northern California water. Temperatures recorded during CUFES sampling (8.8–10.0^{o}C) off WA-OR in 2012 were similar to the cold 2008 survey and no sardine eggs found in the CUFES samples which indicated that sardines might not have been caught off WA-OR even if trawling had occurred. The trawl (at 11.5°C) off northern CA caught immature and mature sardines. Two of the mature females had spawned two nights earlier and some fish may have moved slightly north after spawning since some sardine eggs and adults were found about 40 nm to the south on CalCOFI line 60. In the standard DEPM area waters during 2012 (9.9–15.7^{o}C), sardine adults and eggs were collected as in past surveys. In 2012 the size of sardines caught increased yet both the size of Region 1 (high sardine egg density) and P_0 (daily egg production) decreased, which is similar to the trend of 2006-2010 (Table 7) but opposite to 2011 (in 2011, sardines were smaller and both P_0 plus the area of Region 1 were larger than in 2010). This may indicate possible lower recruitment in 2012 than in 2011.

During the April 2012 survey in the standard DEPM survey area, we were again able to collect trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) sardine egg densities which is beneficial to better the 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) in Region 2 (147.7 grams, SE = 5.03) was higher than in Region 1 (131.1 grams, SE = 7.57) but was not statistically significant at 5% level (t = 1.83, $0.05<p<0.10$). This difference is opposite to most years 2005-2011 when females in the regions were either similar in weight or slightly heavier in Region 1 (Table 8). The fraction of females spawning per day, S_{12}, (based on the average of females that spawned the night before capture and 2 night before capture or "average of day 1+day 2") was higher in Region 1 (0.159 females/day (CV = 0.16)) than Region 2 (0.128 females/day (CV = 0.39)) (Table 5) although the values are not significantly different (t = 0.56, $p>0.5$). This regional difference in the fraction of females spawning (high in 1 and lower in 2, Table 8) was similar to that in past DEPM surveys in 2005, 2006 (Lo and Macewicz 2006, Lo et al. 2007a), 2007 (when one unusual trawl is removed, Lo et al. 2007b), 2008, 2009, 2010, and 2011 (Lo et al. 2008, 2009, 2010b, 2011). Although there were more trawls conducted in Region 2 (76 trawls) than in Region 1 (16 trawls), the reduction of positive sardine trawls in Region 2 (8 in 2012 from 16 in 2011) may be due to surveying and sampling far offshore on four of the transect lines without evidence of presence of sardine, e.g. eggs (Figure 2). In fact, most of the surveys from 2004 to 2011 (Figure 7 and 8) generally trawled closer to CalCOFI station 90 while the 2012 survey conducted 12 trawls beyond CalCOFI station 95. Most trawls taken in Region 2 failed to catch any sardines. In the future, we recommend reducing the extent of transect lines far offshore and we may reduce number of trawls in Region 2 when the egg density is zero or consistently less than 1 egg/min. However, because more females were 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.

In 2012 the CV (0.24) of the spawning fraction estimate in the DEPM area was higher

than in 2011 (CV = 0.18), 2010 (CV = 0.22), and 2009 (CV = 0.15) but lower than in earlier years (CVs of 0.33 in 2007 and 0.31 in 2005 and 2008) (Lo et al. 2006, 2007b, 2008, 2009, 2010b, and 2011). The high CVs in the previous years were most likely due to the low number of sardine positive trawls (12-14) and high variance of spawning (Table 9). A factor in improvement of the CV was the change in the calculation of daily spawning fraction. In the past (1994, 1997, 2004, 2005, 2007, and 2008), calculation of the original daily spawning fraction (S_1) was based on the number of females that spawned the night before capture (night B, "day 1") and followed the procedure for northern anchovies (Picquelle and Hewitt, 1983) to replace the number of females spawning the night of capture (night C, "day 0") with the number of night B spawning females to adjust the number of total mature females. By contrast, since 2009 we calculated the daily spawning fraction (S_{12}) using the mean number of night-B and night-A (two nights before capture, "day 2") spawning females for each trawl and replaced the night-C females by this mean to adjust the number of total mature females. Another factor accounting for the lower CV of the 2011 and 2009 spawning fraction estimate was an increase in the number of trawls with sardines (30 in 2011 and 29 in 2009). 2012 and 2010 had fewer sardine positive trawls (16 and 17 respectively) (Table 9) and hence slightly higher CVs (0.24 in 2012 and 0.22 in 2010). Therefore for continued improvement of spawning fraction precision, we recommend using S_{12} to calculate daily spawning fraction and that at least 17 trawl samples be obtained or the number of trawls sampled be increased, in both high and low egg density areas, for future biomass surveys.

We did not estimate the size at which 50% of the female sardines were mature (ML_{50}) in 2012 because only 6 immature females, between 186 mm and 201 mm SL, were caught. Considering that the smallest mature female in 2012 was 191 mm SL, it is possible that the size at ML_{50} in 2012 may be similar to the values in 2011 (186.47 mm) or 2004 (193 mm) and higher than the values in 2007, 2005, and 1994 (Figure 9). The variation in ML_{50} could be real due to change in maturity or it may be the result of sample bias if any one of the following is true: a) the trawls are located in a partial area of the survey (e.g., high egg density area only, offshore only, inshore or near islands only), b) migration of sardine subpopulation occurred, and/or c) the age and length relationship changed. We recommend continued evaluation of maturity to eliminate any biases.

We examined the relative frequency of length of sardines taken in 2012 and compared that to those taken during a similar period in the standard DEPM area in previous years (Figure 7 and 8). The mean size of sardines (male and females) was the largest since 2004. The length distribution of sardine caught during 2012 continues to show two size modes but with peaks at larger sizes than those seen in 2011: one peaking at about 210 mm (185 mm in 2011) and the other at about 240 mm (230 mm in 2011) with a dip in the 220 mm length class (Figure 7). These size modes may be due to strong recruitment from 2003-2005 and in 2009 (Hill et al. 2012). The smaller size mode seen in 2011 is again almost absent in 2012, as it was in 2010 and (low in quantity) in 2008 and 2009 surveys, while the larger lengths are consistent with increasing size of an aging fish population during 2008-2011. We believe that a likely explanation for the lack of smaller fish in 2012 is poor recruitment of the recent year class. It could possibly also be due to 1) the lack of trawls positive for sardines inshore, where sardines are known to be small relative to offshore (Lo et al. 2007a), or 2) not conducting trawls in inshore areas that are known (because they have been commercially fished) to have sardines, e.g. around Catalina Island or

the Channel Islands. We recommend that to improve the whole population adult parameter analyses more trawls should continue to be added in the inshore areas or samples taken on commercial vessels during fishing to obtain spawning and maturity information to avoid possible bias against smaller fish

Spawning biomass

In the DEPM survey area, the 2012 estimate of spawning biomass using the traditional method was 282,110 mt, based on the egg production of 0.84 eggs/0.05m$^{2/}$day, and the daily specific fecundity of 16.14 eggs/g/day. This production was mostly in the area between CalCOFI line 60.0 and 76.7 (32.6°N and 36.03°N). The spawning biomass was higher than for most previous years except 2011 (Table 3 and 4). Note that the egg production rate of 5.28 eggs/0.05m^2 in the high-density area was higher than in 2010: 1.70 eggs/0.05m2, and 2009: 1.69 eggs/.05m^2 (Lo et al. 2009). The overall daily egg production, 0.84 eggs/0.05m2, is much higher than in most recent years: 0.36 eggs/0.05m^2/day in 2010, 0.59 in 2009, 0.43 in 2008, and lower than 1.16 in 2011, 1.936 in 2006, and 1.916 eggs/0.05m^2 in 2005. The area of Region 1 of 32,000 km^2 was larger than 27,462 km^2 in 2010 and smaller than in other years. The adult daily reproductive output (daily specific fecundity) was similar to that in the previous year. The higher values in early years were due to the fact that trawl samples were taken in the high-density area only. Since 2005, trawl samples have been taken in both Region 1 and Region 2. The daily specific fecundity (16.14) is lower than recent years. The difference between the estimates of spawning biomasses between 2012 and 2011 was not statistically significant (t = 0.71, p>0.05). This insignificant difference of spawning biomass indicated that the spawning biomass of Pacific sardine did not decline much from 2011 to 2012. For the stock assessment, we provided the estimates of female spawning biomass for years where adequate adult samples were available (Table 6).

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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[a] in Region 1 (eggs/min ≥ 1), Region 2 (eggs/min < 1) for *Ocean Starr* , and *Shimada* cruises of 2012 April Sardine DEPM survey. Both *Shimada* and *Ocean Starr* occupied part of the standard DEPM survey area: *Shimada* occupied the area from San Diego (CalCOFI line 90) to Monterey Bay (CalCOFI line 68.3), California. *Ocean Starr* occupied the area from Cape Flattery, Washington to Point Conception, California with most stations between CalCOFI lines 80.0 to 56.3. The area north of CalCOFI line 60.0 is referred to as 'North' and the standard DEPM survey area is within CalCOFI lines 95.0 – 60.0.

		Region 1			**Region 2**			**Grand Total**		
		Total	North	DEPM	Total	North	DEPM	Total	North	DEPM
CalVET Eggs	Positive	34	0	34	16	0	16	50	0	50
	Total	37	0	37	92	1	91	129	1	128
CalVET Yolk-sac	Positive	5	0	5	2	0	2	7	0	7
	Total	37	0	37	92	1	91	129	1	128
Bongo Yolk-sac	Positive	6	0	6	10	0	10	16	0	16
	Total	10	0	10	80	1	79	90	1	89
CUFES Eggs	Positive	130	0	130	142	0	142	272	0	272
	Total	137	0	137	827	195	632	964	195	769
Trawls	Positive	10	--	10	11	1	10	21	1	20
	Total	16	--	16	79	3	76	95	3	92

[a] All sardines were captured at night, 4 trawls contained only a single male each (2 in each region).

Table 2. Sardine egg density region, individual trawl information, sex ratio[a], and parameters for mature female *Sardinops sagax*, used in the estimation of the April 2012 west coast spawning biomass. Collection 2789 is north of CalCOFI line 60 and the other 20 trawls are in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES							
				Location										Number spawning		
Region 1=high 2=low	No.	Month-Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	No. of fish	Sex Ratio	No. analyzed	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	Adj. No.[b]	Night of capture	Night before capture	2 Nights before capture
2(N)	2789	4-05	2:07	37.608	125.561	11.5	61	0.579	22	101.50	97.02	25460	22.5	0	0	1
1	2791	4-08	20:41	36.954	125.038	12.9	50	0.427	25	120.33	114.28	30614	16.5	11	2	3
1	2792	4-09	1:01	36.673	124.836	12.7	1[c]	0.000	0	0	0	0	0.0	0	0	0
1	2799	4-11	19:23	36.073	123.554	12.3	1	1.000	1	120.50	114.58	23256	1.0	0	0	0
1	2800	4-11	22:08	35.985	123.702	12.3	18	0.372	6	140.50	130.92	35071	0.0	6	0	0
1	2894	4-27	20:34	35.926	123.263	13.2	16	0.621	9	151.86	141.07	45885	9.0	2	2	2
1	2895	4-28	19:50	35.918	123.216	12.7	1	1.000	1	115.50	108.44	29066	1.5	0	0	1
1	2832	4-24	19:28	35.312	122.762	13.8	2	0.659	1	172.00	159.00	30227	1.0	0	0	0
1	2833	4-24	21:58	35.234	122.932	13.7	1[c]	0.000	0	0	0	0	0.0	0	0	0
1	2834	4-25	1:10	35.204	122.749	13.8	7	0.266	2	114.50	105.85	29230	2.5	0	1	0
2	2810	4-15	19:38	34.942	122.699	12.2	18	0.341	6	120.08	113.21	39767	6.5	0	0	1
2	2885	4-24	19:52	34.763	122.199	13.6	10	0.648	6	154.50	143.22	40928	7.5	0	2	1
1	2813	4-16	23:32	34.128	122.766	13.1	8	0.436	3	145.67	133.01	44921	3.0	0	0	0
2	2812	4-16	19:27	34.042	122.942	13.2	14	0.542	7	121.43	114.24	31041	7.5	0	0	1
2	2720	4-12	23:10	33.467	120.141	13.0	50	0.229	25	156.96	144.44	46120	16.0	9	0	0
2	2723	4-14	23:33	33.046	120.176	12.1	1[c]	0.000	0	0	0	0	0.0	0	0	0
2	2722	4-14	19:32	32.972	120.376	12.5	50	0.492	25	151.58	140.80	41052	29.5	2	7	6
2	2871	4-20	2:02	32.609	120.722	13.4	1	1.000	1	88.00	83.82	15059	1.0	0	0	0
2	2734	4-18	23:02	32.420	120.667	14.5	8	0.403	3	170.19	156.24	48998	1.0	2	0	0
2	2735	4-19	1:16	32.378	120.653	13.9	1[c]	0.000	0	0	0	0	0.0	0	0	0
2	2733	4-18	20:31	32.264	120.661	14.6	6	0.864	5	142.10	130.59	33319	5.5	0	1	0
									126				109	32	15	15
all									148				131.5	32	15	16

[a] Sex ratio, proportion of females by weight, based on average weights from subsamples and number of fish sampled in each trawl (Picquelle and Stauffer 1985).
[b] Mature adjusted by the average number of females spawning the night before capture and females spawning 2 nights before capture
[c] Only a male captured

Table 3. Egg production (P_0) of the Pacific sardine in 2012 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 *Ocean Starr* (March 26 - April 29), and *Shimada* (April 11 - 30) cruises, adult parameters from positive trawls (April 5 – 28), and 2012 spawning biomass estimates.

Parameter	**Region 1**	**Region 2**		**DEPM Area**
		North[a]	DEPM	
CUFES samples	137	195	632	**769**
CalVET samples	37	1	91	**128**
P_0 / 0.05m^2	5.28 [b]	0	0.24	**0.84**
CV	0.27	--	0.27	**0.27**
Area (km^2)	32,322	73,146	238,669	**270,991**
% Whole coast	—	—	—	—
% DEPM area	12	--	88	**100**
Year of adult samples	2012	2012	2012	**2012**
Female fish wt (W_f)	131.08	101.50 [c]	147.69	**141.36**
Batch fecundity (F)	34678	25460	41146	**38682**
Spawning fraction (S)	0.159	0.022	0.1275	**0.1376**
Sex ratio (R)	0.456	0.579	0.412	**0.429**
(RSF)/W_f	19.25	3.32	14.67	**16.14**
Spawning biomass (mt) Traditional method [d]				**282,110**
CV				**0.43**
Spawning biomass (mt) Stratified procedure [e]	177,289	--	78,102	**255, 392**
CV	0.37		0.60	**0.32**
Daily mortality (Z)	0.66			
CV	0.11			
eggs/min	1.60		0.056	**0.24**
CV	0.25		0.19	**0.21**
q = eggs/min in Reg.2 / eggs/min in Reg.1				**0.046**
CV				**0.22**
E = (eggs/min)/(eggs/tow)				**0.0334**
CV				**0.34**
Bongo samples	10	1	79	**90**

[a] North, in 2012, is the area between CalCOFI line 60 and line 53.4 .
[b] 5.28 was corrected for bias of P_0.
[c] single trawl and no eggs collected in North, no biomass estimated for this area
[d] biomass was computed from estimates of parameters in each column, e.g., DEPM area is an average of adult parameters from Region 1 and DEPM Region 2.
[e] biomass was computed by the stratified procedure, i.e., total spawning biomass = the sum of the estimates of spawning biomass in Region 1 and Region 2: 255,392 = 177,289 + 78,102.

Table 4. Estimates of daily egg production (P_0)[a] for the DEPM survey area, daily instantaneous mortality rates (Z) from high-density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardines using the traditional method and average sea surface temperature for the years 1994 to 2012.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	RSF[h] / 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
2009[h]	0.59 (0.22)	0.25 (0.19)	274895 (74,966)	17.53	185,084 (0.28)	13.6	13.5
2010[i]	0.36 (0.40)	0.33 (0.23)	271,773 (27,462)	18.07	108,280 (0.46)	13.7	13.9
2011	1.16 (0.26)	0.51 (0.14)	314,481 (41,878)	19.04	383,286 (0.32)	13.5	13.6
2012	0.84 (0.27)	0.66 (0.11)	270,991 (32,322)	16.14	282,110 (0.43)	13.57	13.3

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 1997 (table 9) 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 2006 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 whole 2008 survey area off west coast of North America from about 31°N to 48.47°N latitude, spawning biomass was estimated as 135,301 mt(CV=0.43)

h RSF/W from 2009 forward is based on S_{12},:average of day1 and day2 females.

i The whole survey area was 477,092 km^2 from San Diego, CA to Cape Flattery, Wa. .Very few sardine eggs were observed north of the DEPM survey area (CalCOFI line 60.0 is the northern boundary of the DEPM area)

Table 5. Estimated 2012 adult parameters and correlations for each region[a] in the DEPM area outputted from the EPM program (Appendix II Chen et al. 2003).

Region 1 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	131.080403688	57.2745836595
Gonad Fee Weight	123.01706875	39.7136392426
Batch fecundity	34677.6412708	10785572.2643
Spawners, Day 0	0.39583333333	0.00957746018
Spawners ave (day1+day2)	0.15942014493	0.00066674165
Sex Ratio	0.45648419894	0.00172835499
Daily specific fecundity	19.2522161161	
Number of Sets	8	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.95864485	0.37984807	0.64887386
Batch Fecundity (F)			0.45188713	0.74047077
Fraction Spawning (S)				0.53799748
Sex Ratio (R)				

Region 2 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	147.694303029	25.3498556151
Gonad Fee Weight	136.856008974	18.6894614547
Batch fecundity	41145.9864055	4378091.83223
Spawners, Day 0	0.16666666667	0.00645982697
Spawners ave (day1+day2)	0.12751680537	0.00254212461
Sex Ratio	0.41289571581	0.00596487173
Daily specific fecundity	14.6680214096	
Number of Sets	8	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.84067004	-0.0321679	-0.4682885
Batch Fecundity (F)			-0.4057750	-0.8287339
Fraction Spawning (S)				0.79607938
Sex Ratio (R)				

DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	141.365198518	37.6429537983
Gonad Fee Weight	131.584031746	26.5204350539
Batch fecundity	38681.8549256	6037743.45521
Spawners, Day 0	0.25396825397	0.00535728278
Spawners ave. (day1+day2)	0.13761465138	0.00112370202
Sex Ratio	0.42856446090	0.00266185002
Daily specific fecundity	16.1378477027	
Number of Sets	16	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.94949389	-0.0569288	-0.3036262
Batch Fecundity (F)			-0.2205228	-0.4558742
Fraction Spawning (S)				0.78029076
Sex Ratio (R)				

[a] Area of Region 1 is 32,322 km^2, Region 2 DEPM area is 238,669 km^2, and the DEPM area is 270,991 km^2

Table 6. The spawning biomass related parameters: daily egg production/0.05m^2 (P_0),daily mortality rate (z), survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); s. biomass, female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2004, 2005 and 2007-2012

Calendar year	Season	Region	[1] P_0/0.05m^2 (cv)	Z (CV)	[2] RSF/W based on S_1	[3] RSF/W based on S_{12}	[3] FS/W based on S_{12}	[4] Area (km^2)	[5] S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temperature (°C) for positive eggs	Mean temperature (°C) from Calvet
1986(Aug)	1986	[6] S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987 (Jul)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5
2010	2009	1	1.70(0.22)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.42)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.29)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9
2011	2010	1	5.57(0.24)	0.51(0.14)	19.03	24.26	41.16	41878	192332 (0.31)	113340 (0.30)		233260.5		
		2	0.487(0.33)		11.40	14.67	25.04	272603	181016 (0.48)	106046 (0.49)		132757.7		
		whole	1.16(0.26)		14.85	19.04	32.40	314481	383286 (0.32)	225155 (0.32)	219386 (0.28)	364798.0	13.5	13.6
2012	2011	1	5.28 (0.27)	0.66(0.11)	17.76	19.25	42.17	32322	177289 (0.37)	80930 (0.33)		170660.16		
		2	0.24 (0.27)		15.34	14.67	35.52	238669	78102 (0.60)	32248 (0.46)		57280.56		
		whole	0.84 (0.27)		16.14	16.14	37.65	270991	282110 (0.43)	120902 (0.36)	113178 (0.27)	227632.44	13.57	13.3

1: P_0 for the whole is the weighted average with area as the weight.

2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008)

3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2,

4. Region 1, since 1997, is the area where the eggs/min from CUFES $\geq$1 and prior to 1997, is the area where the eggs/0.05m^2 >0 from CalVET tows

5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters. The stratified S. biomass not shown is sum of S. biomass in two regions

6. Within southern and northern area, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs)

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, 2008, and 2010-2012 surveys off the west coast of the United States.

Survey Information	**April 2006**	**April 2008**	**April 2010**	**April 2011**	**April 2012**
Washington – Oregon: 48.5° – 42°N					
Sea Temperature Range	9.1-11.8°C	8.2-10.1 °C	9.5-11.4°C	9.4-9.5°C	-**
Mean °C of sardine positive trawls	na	na	na	9.4	-
Number positive trawls (total)	0 (9)	0 (25)	0 (12)	1 (5)	0 (0)
Number of sardine sampled	-	-	-	2	-
Mean body weight (g)	-	-	-	31g	-
Eggs, Region 1	+	-	-	-	-
Eggs, Region 2	+	-	-	-	-
Northern California: 42°N – CalCOFI line 60					
Sea Temperature Range	10.8-12.2°C	7.8-11.6°C *	9.6-13.2°C	-**	11.0-11.7°C
Mean °C of sardine positive trawls	11.4°C	11.5°C	13.2°C	-	11.5
Number positive trawls (total)	3 (4)	1 (15)	1 (17)	0 (0)	1 (3)
Number of sardine sampled	101	1	50	-	61
Mean body weight (g)	91g	148g	152g	-	95g
Eggs, Region 1	+	-	-	-	-
Eggs, Region 2	+	+	+	-	-
standard DEPM: CalCOFI lines 60 – 95 (San Francisco – San Diego)					
Sea Temperature Range	13.3-16.6°C	11.2-15.5°C	12.1-15.9°C	9.9-16.3°C	9.9-15.7°C
Mean °C of sardine positive trawls	14.4°C	12.4°C	13.6°C	13.1°C	13.2
Number positive trawls (total)	7 (22)	12 (31)	18 (68)	36 (100)	20 (92)
Number of sardine sampled	194	353	635	666	264
Mean body weight (g)	67g	105g	127g	108g	134g
Eggs, Region 1 (area, km^2)	+ (98034)	+ (53514)	+ (27462)	+ (41878)	+ (32322)
Eggs, Region 2	+	+	+	+	+
Whole DEPM area P_0	1.96	0.43	0.36	1.16	0.84

* a single negative offshore trawl at 38.4°N recorded 13.2°C

** no trawls were conducted; CUFES recorded temperatures of 8.8-10.0°C in 2012 off WA-OR and recorded 9.9-11.9°C in 2010 off N CA

Table 8. Trawl and mature Pacific sardine female biological data in each sardine egg density region (1 = high, 2 = low) of the DEPM area for surveys conducted 2004-2012.

Survey year and regions	Trawls			Mature Females			
	Sex Ratio	Mean Sea Temp (°C)	Number with Mature Females (total trawls)	Number	Mean Weight (g, W_f)	Relative Batch Fecundity[a]	Daily Spawning Fraction (S)[b]
2012							
1	0.456	13.0	8 (16)	48	131.08	264.55	0.159
2	0.412	13.4	8 (76)	78	147.69	278.60	0.128[c]
2011							
1	0.589	13.4	14 (22)	115	128.36	302.31	0.136
2	0.586	12.9	16 (78)	129	126.92	299.25	0.084
2010							
1	0.466	13.1	3 (11)	60	133.58	311.78	0.165
2	0.608	13.7	14 (58)	253	128.54	301.45	0.088
2009							
1	0.564	13.2	15 (21)	196	94.35	256.87	0.141
2	0.624	12.7	14 (40)	271	125.5	269.37	0.085
2008							
1	0.786	13.2	4 (11)	53	107.32	292.02	0.250
2	0.558	12.1	8 (18)	134	100.20	291.36	0.085
2007							
1	0.488	13.1	8 (10)	136	86.2	266.0	0.093
2	0.615	13.6	6 (8)	67	69.1	268.8	0.151[d]
2006							
1	0.465	14.8	2 (8)	20	74.35	271.79	0.100
2	0.447	14.3	5 (14)	66	65.30	274.87	0.061
2005							
1	0.550	14.7	6 (8)	80	67.02	269.05	0.213
2	0.425	13.8	8 (11)	95	63.93	272.79	0.033
2004							
1	0.618	13.6	16 (24)	290	166.99	333.62	0.131
2	--	--	0	--	--	--	--

[a] oocytes in batch to be spawned per gram of mature female weight

[b] 2006 and 2009-2012 was estimated based on the mean number of females which on two different nights, while 2004, 2005, and 2007 was based on females which had spawned on the night before capture only

[c] fraction is 0.067 without 1 trawl with a high number of spawning females (7 of 25)

[d] fraction is 0.044 without 1 trawl with a high number of spawning females (10 of 22)

Table 9. 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	2009	2010	2011	2012
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr	8-Apr	19-Apr
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	04/17-05/06	04/12-04/27	03/23-04/25	04/08-04/28
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17	30	16
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3	14	8
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	12.93	13.62	13.12	13.18
Female fraction by weight	**R**	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574	0.587	0.429
Average mature female weight (grams): with ovary	W_f	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51	127.59	141.36
without ovary	W_{of}	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34	119.38	131.58
Average batch fecundity[a] (mature females, oocytes)	**F**	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304	38369	38681
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303	301	274
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313	244	126
N active mature females		327	77	9	23	290	148	72	187	177	463	310	244	125
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	0.1098	0.1038	0.1078	0.1376
Spawning fraction of active females[c]	S_a	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048	0.1078	0.1388
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07	19.04	16.14

[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); 2007 used $F_b = 279.23 W_{of}$ (Lo et al. 2007b), 2008 used $F_b = 305.14 W_{of}$ (Lo et al. 2008), 2009 used $F_b = -4598 + 326.78 W_{of} + e$ (Lo et al. 2009), 2010 used $F_b = 5136 + 287.37 W_{of} + e$ (Lo et al. 2010), and 2011 used $F_b = -2252 + 347.6 W_{of} + e$ (Lo et al. 2009).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season). S_1 was used for years prior to 2009 and S_{12} was used staring 2009.

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

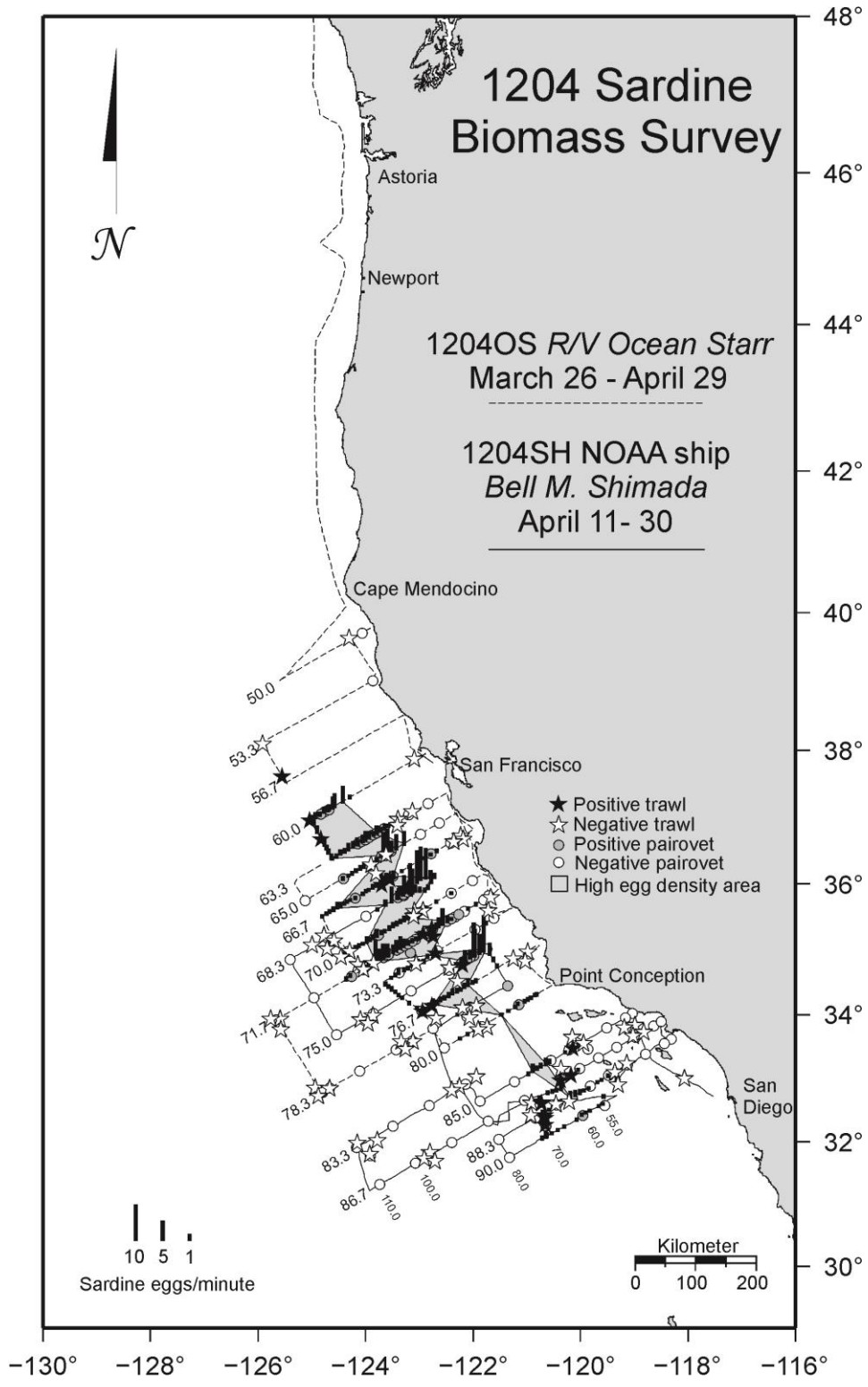

Figure 1. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2012 survey aboard two vessels: the R/V *Ocean Starr* (dash line) and the NOAA ship *Shimada* (solid line). Shaded area is Region 1, the high egg-density area, and the rest of survey area is Region 2.

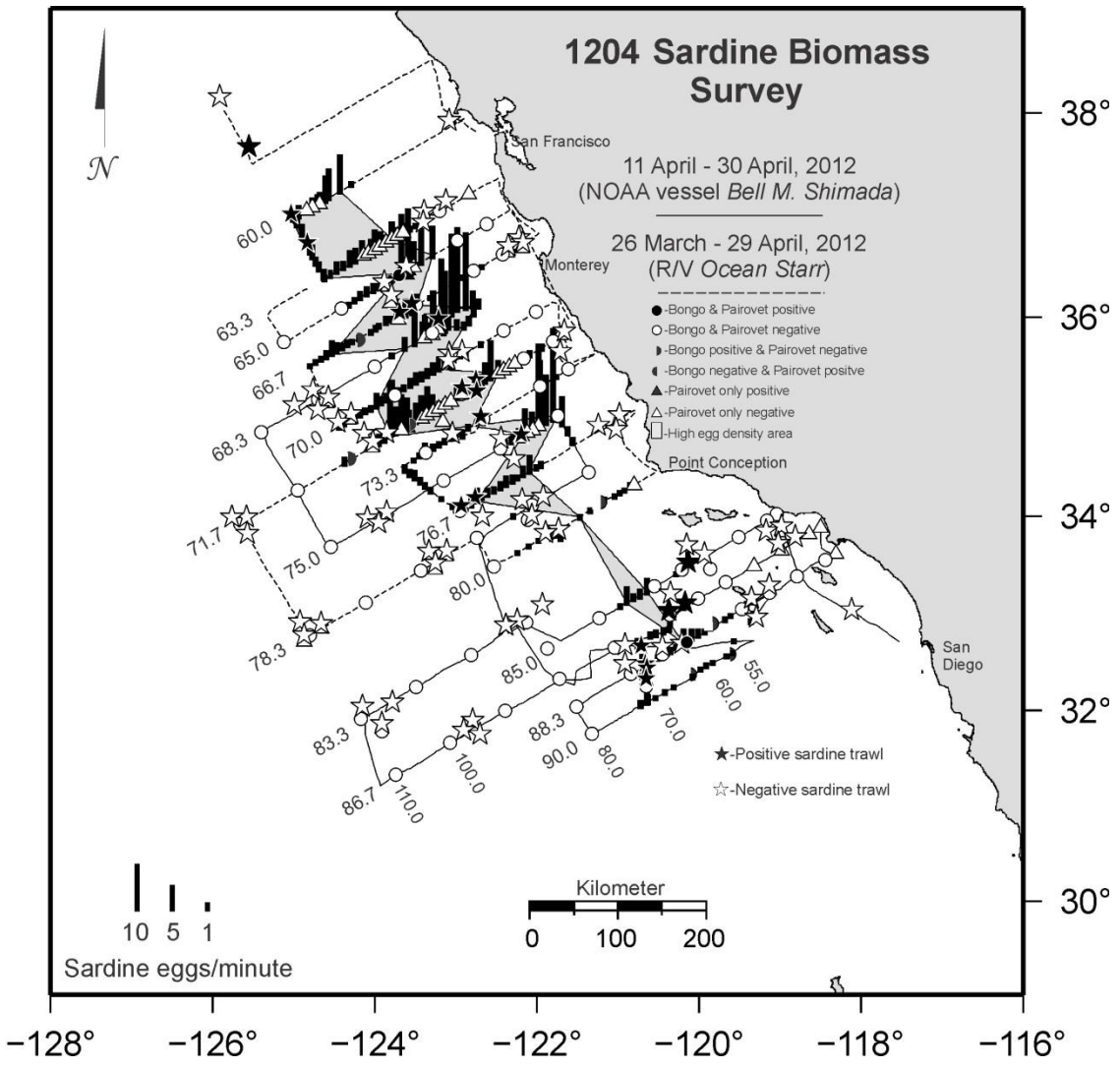

Figure 2. Location of sardine trawls (star), yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) during the 2012 survey aboard two vessels: the R/V *Ocean Starr* (dash line) and the NOAA ship *Shimada* (solid line). Solid symbols are positive and open symbols are zero catch. Few yolk-sac larvae were caught north of CalCOFI line 60.0. The shaded area is Region 1: the high egg-density area. Region 2 in the standard DEPM area includes the rest of the survey area shown between CalCOFI line 95.0 and 60.0.

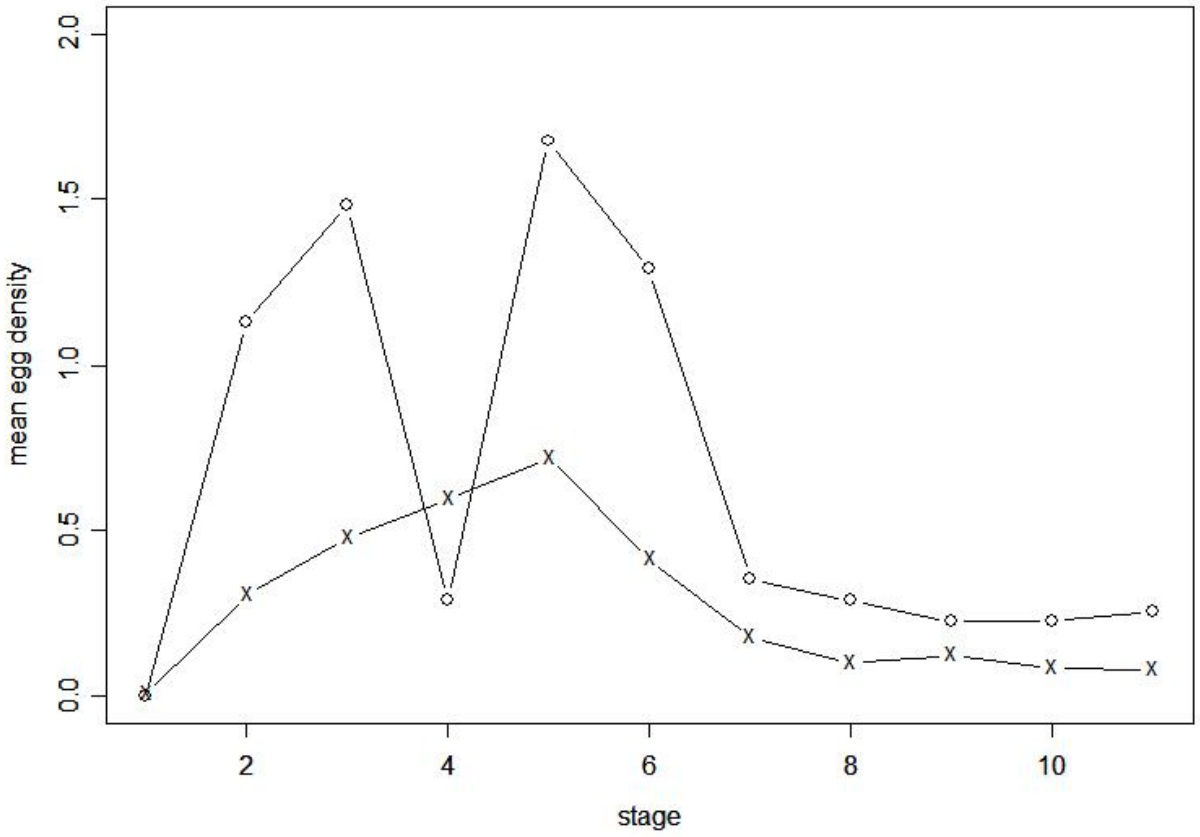

Figure 3. Mean sardine egg density (eggs per $0.05m^2$) for each developmental stage within each area for April 2012. Symbols: o = Region 1 and x = DEPM survey area (CalCOFI lines 90 to 60).

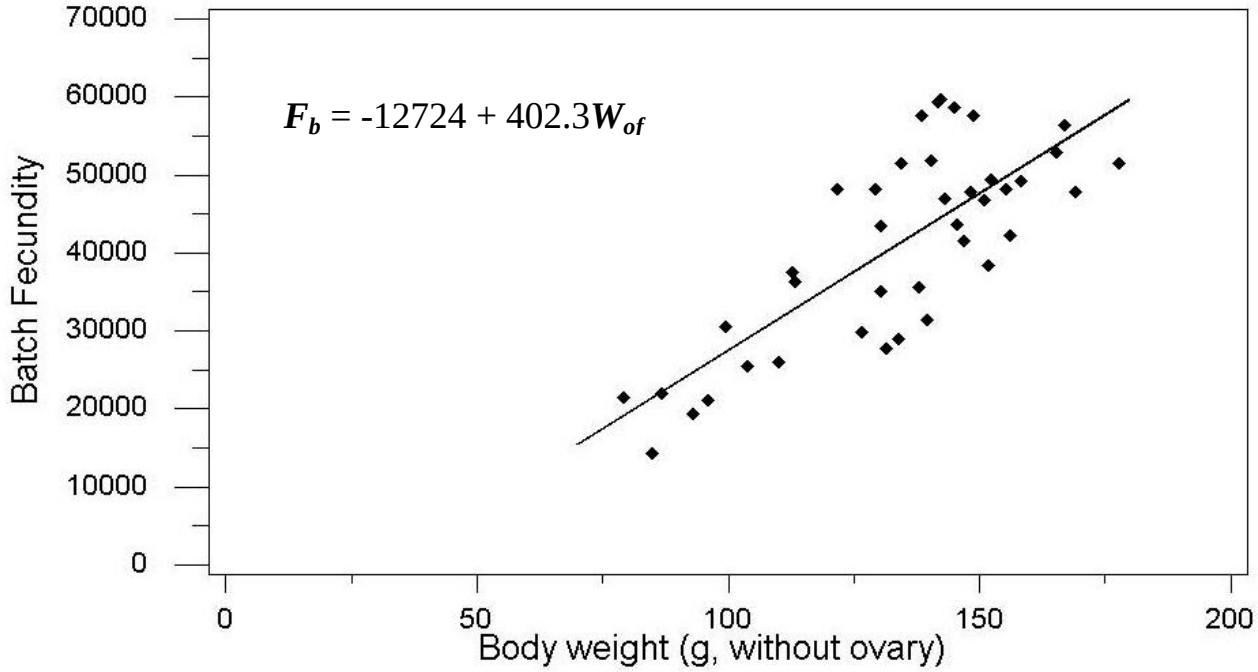

Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 40 females taken onboard the *Shimada* and *Ocean Starr* during April 2012. The batch was estimated from the number of hydrated or migratory-nucleus-stage oocytes.

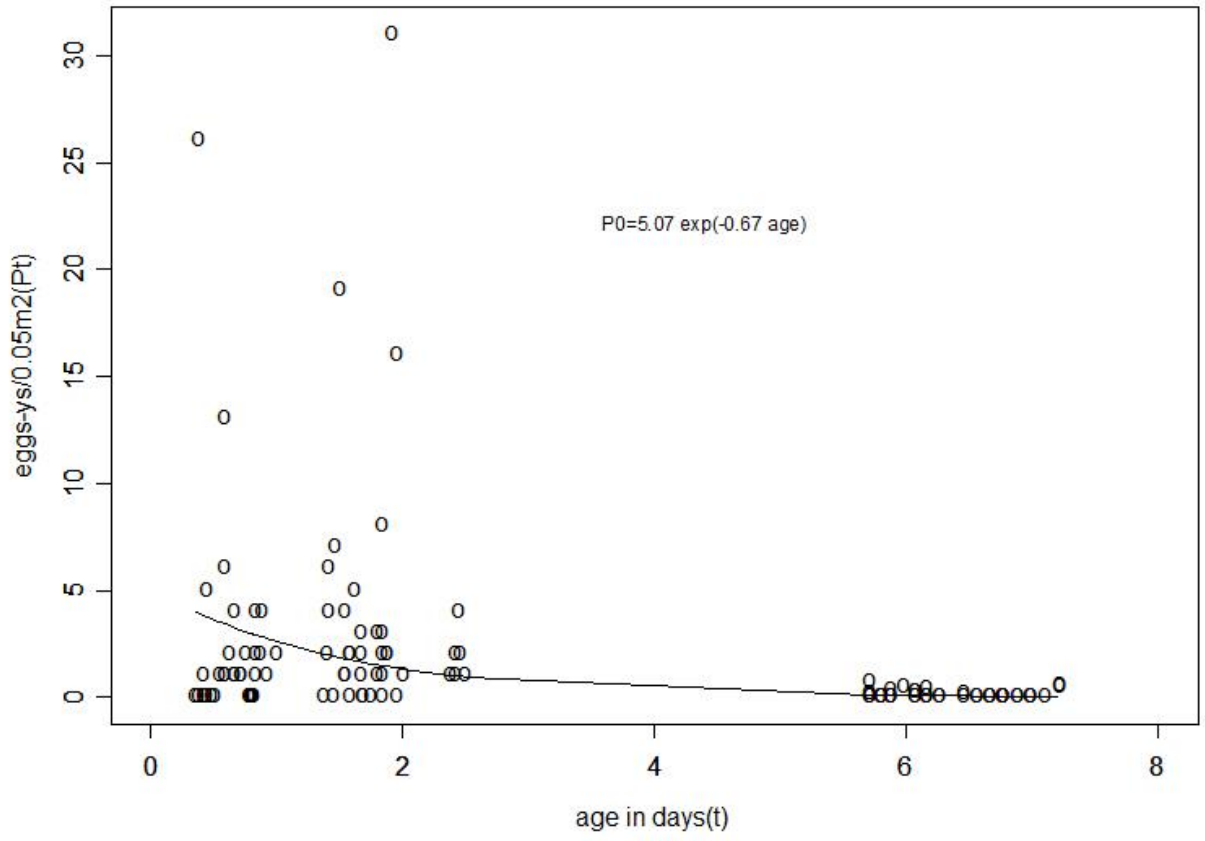

Figure 5. Embryonic mortality curve of Pacific sardines. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April 2012, onboard *Shimada* and *Ocean Starr*. The number, 5.07, is the estimate of daily egg production at age 0 (P_0) before correction for bias.

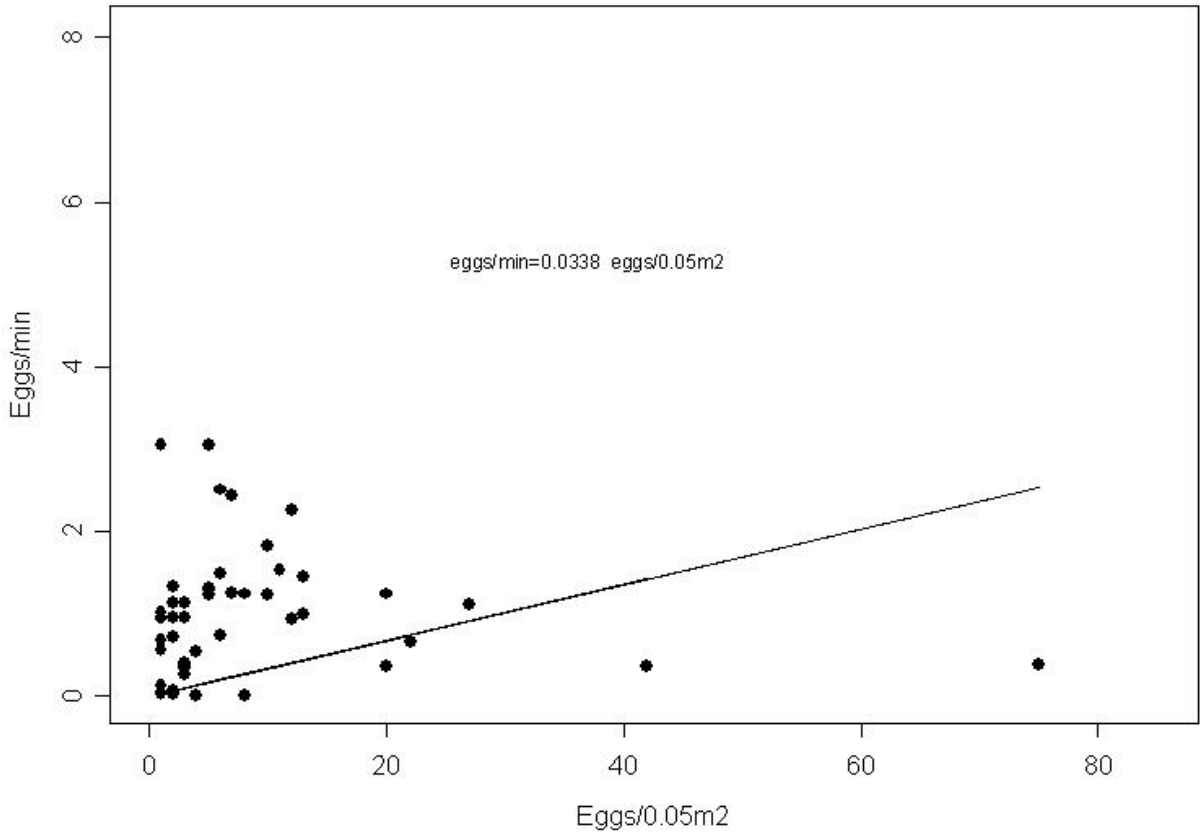

Figure 6. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April 2012 from *Ocean Starr* and *Shimada* collections.

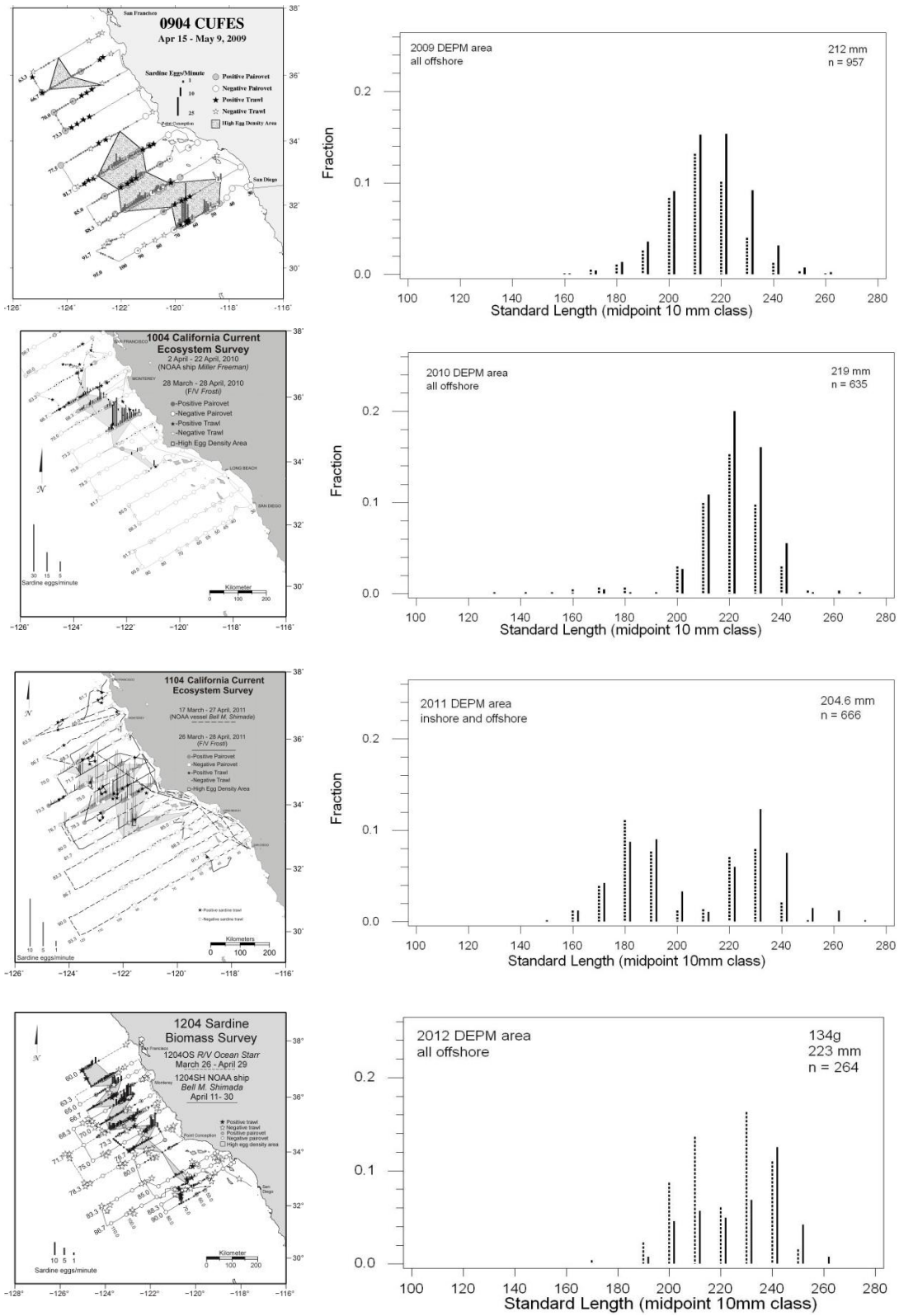

Figure 7. Trawl-egg map, length distribution and mean length of Pacific sardines caught in the 2009, 2010, 2011, and 2012 DEPM survey areas. Males indicated by dotted bars and females by solid bar.

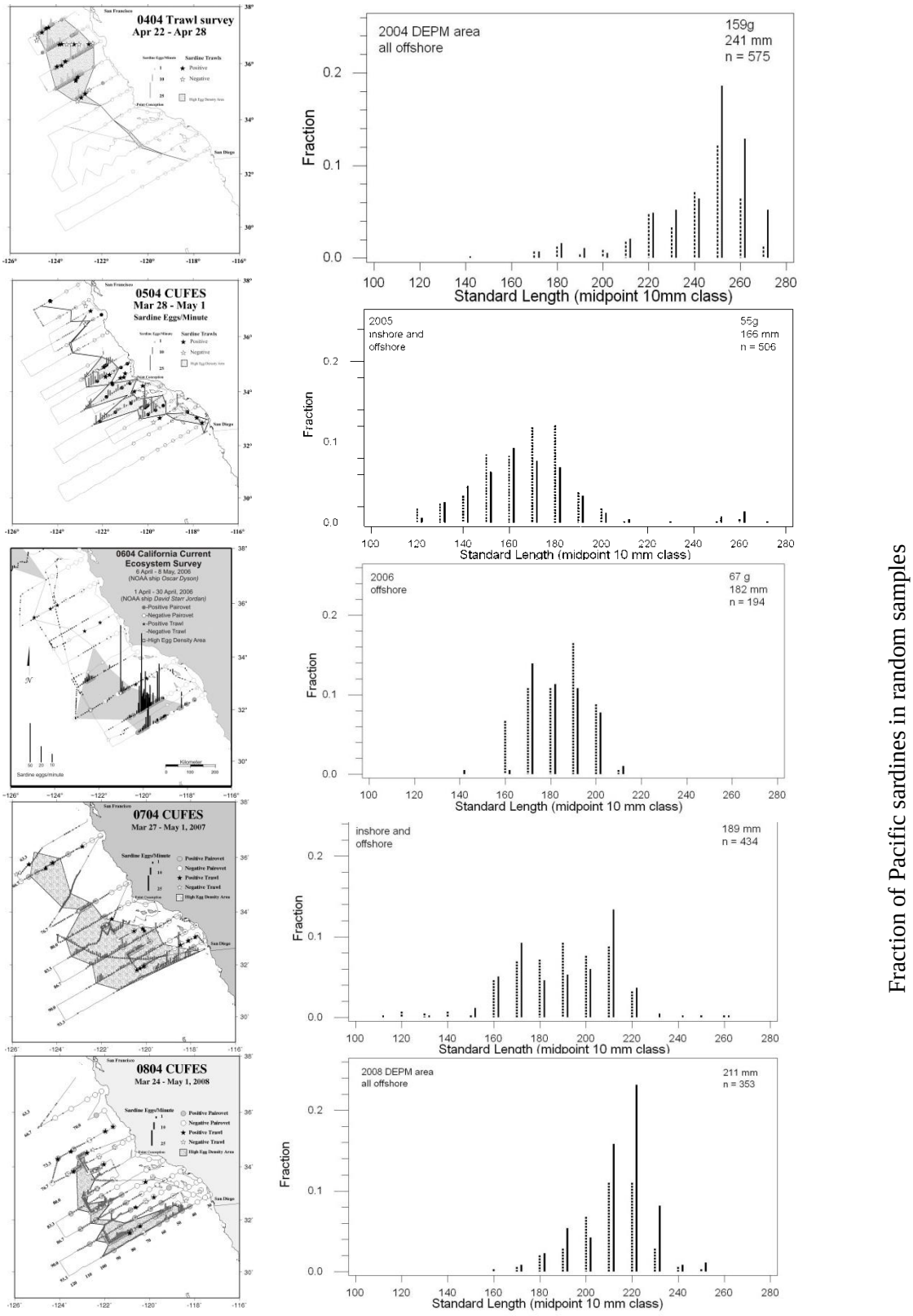

Figure 8. Trawl-egg map, length distribution and mean length and weight of Pacific sardines caught in the 2004, 2005, 2006, 2007 and 2008 DEPM survey areas. Males indicated by dotted bars and females by solid bar.

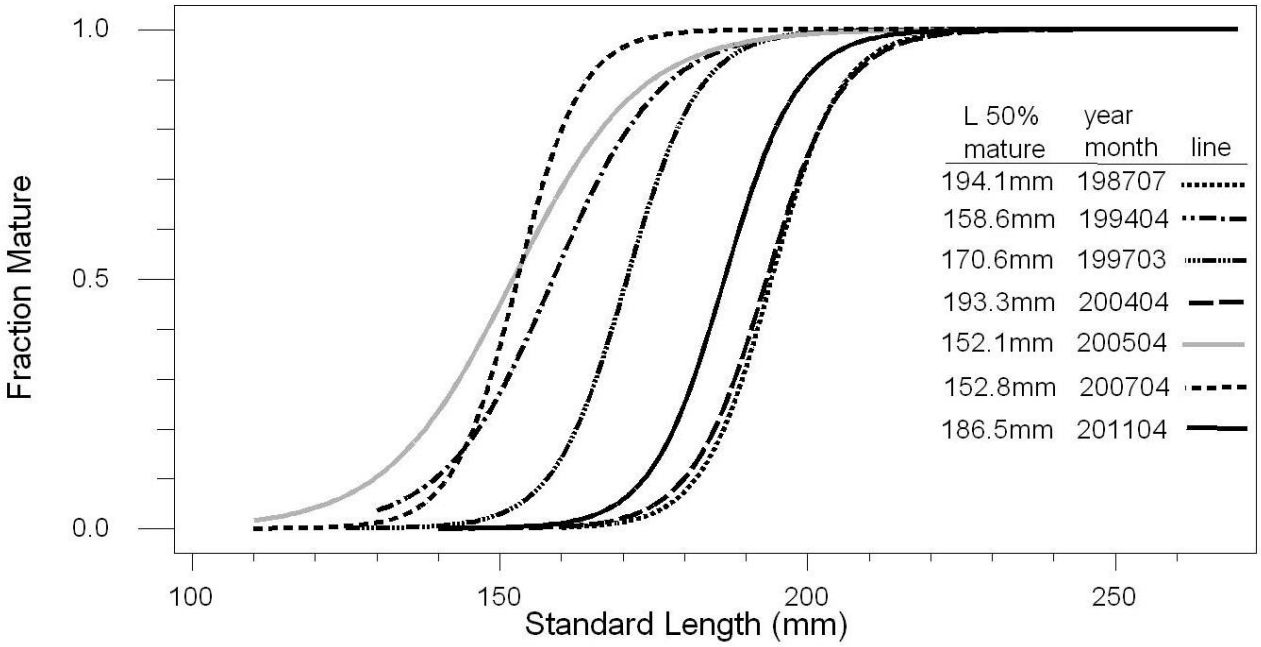

Figure 9. Fraction of Pacific sardine females randomly sampled during seven DEPM sardine surveys that were sexually mature as a function of standard length. The length at 50% maturity from the April 2011 survey was the third largest at 186.5 mm. Insufficient immature females were collected during 2002, 2008, 2009, 2010 and 2012 DEPM surveys to calculate length at 50% mature.

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A.T. MAMULA and J.B. WALDEN
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504 U.S. Pacific Marine Mammal Stock Assessments: 2012.
J.V. CARRETTA, K.A. FORNEY, E. OLESON, K. MARTIEN, M.M. MUTO, M.S. LOWRY, J. BARLOW, J. BAKER, B. HANSON, D. LYNCH, L. CARSWELL, R.L. BROWNELL JR., J. ROBBINS, D.K. MATTILA, K. RALLS, and M.C. HILL
(January 2013)