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# THE 1984 SPAWNING BIOMASS OF THE NORTHERN ANCHOVY

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## ABSTRACT

The 1984 estimate of the spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*) is 309,000 metric tons (MT). The estimate was obtained using the egg production method, where biomass is defined as the ratio of the daily production of eggs found in the sea and the daily specific fecundity of the population.

In 1984, as in 1983, the central subpopulation of northern anchovy was geographically distributed more offshore and northerly than in previous years. Spawning was apparent throughout the southern portion of the Southern California Bight as far south as the latitude of Ensenada; no spawning was evident within 50 km of the coast between San Diego and Ensenada. A small amount of spawning was detected adjacent to the coast between San Francisco and Monterey bays, California, and between Cape Colnette and Punta Baja, Baja California.

## RESUMEN

El valor estimado de la biomasa de desove de la subpoblación central de la anchoveta del norte (*Engraulis mordax*), para 1984, es de 309.000 toneladas métricas (TM). Esta estimación se obtuvo utilizando el método de la producción de huevos, en el cual la biomasa se define como el cociente entre la producción diaria de huevos colectados en el océano y la fecundidad específica diaria de la población.

En 1984, al igual que en 1983, la subpoblación central de la anchoveta del norte estuvo distribuída más lejos de la costa y más al norte que en años anteriores. A lo largo de la parte sur de la Bahia del Sur de California y, hacia el sur, hasta la latitud de Ensenada, hubo señales de desove. No se observaron evidencias de aquél hasta 50 km mar adentro entre San Diego y Ensenada. Pequeñas cantidades de desove se detectaron en la vecindad de la costa entre las bahías de San Francisco y Monterey, California, y entre Cabo Colnette y Punta Baja, Baja California.

## INTRODUCTION

This report documents the 1984 spawning biomass estimate of the central subpopulation of the northern anchovy (*Engraulis mordax*), as required by the most recent version of the Anchovy Management Plan adopted by the Pacific Fishery Management Council (PFMC 1983). In recent years the anchovy biomass has been assessed using two ichthyoplankton-based methods: larval census (Smith 1972; Stauffer and Parker 1980; Stauffer 1980; Stauffer and Picquelle 1981) and egg production (Parker 1980; Stauffer and Picquelle 1980; Picquelle and Hewitt 1983, 1984). The larval census method assumes a constant proportionality between larval abundance and spawning biomass, whereas the egg production method measures and incorporates variability in the proportionality parameter. Only the egg production method was used to calculate the 1984 spawning biomass.

The egg production method defines spawning biomass as the ratio of the daily production of eggs and the daily specific fecundity of the adult population. The daily production of eggs was derived from the density of eggs sampled in an ichthyoplankton survey, and from egg development rates as measured in the laboratory. The daily specific fecundity of the anchovy population was derived from adult fish sampled during a trawl survey, which yielded estimates of average female weight, batch fecundity, sex ratio, and the proportion of females spawning each night. The two samples were obtained concurrently on a survey conducted during the seasonal peak of spawning.

This report describes the survey results, the egg production estimate of spawning biomass, and the variance of the estimate.

## DESCRIPTION OF THE SURVEY

The 1984 survey was conducted by the NOAA ship *David Starr Jordan* from February 7 through March 30, 1984. The survey area extended from San Francisco, California (38°N), to Punta Baja, Baja California (30°N), approximately 250 km offshore in the main spawning region. The station pattern (Figure 1) was occupied from north to south, with the exception of the area between San Diego and Punta Baja. During the last portion of the survey, five station lines, spaced 40 miles apart and extending offshore, were occupied while the ship worked to the south, and twelve inshore lines, spaced 10 miles apart, were occupied while northbound to San Diego.

Planktonic eggs were sampled at 938 stations (Figure 1) using a 25-cm-diameter net of 150-micron

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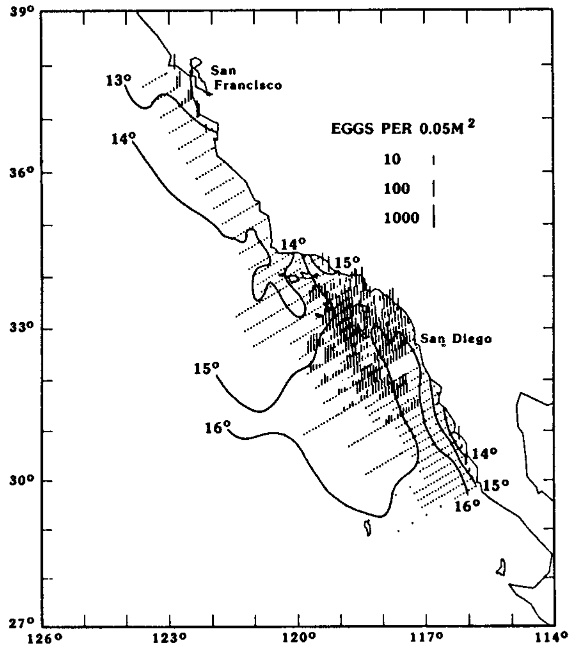


Figure 1. Geographic distribution of ichthyoplankton stations, anchovy eggs, and surface isotherms.

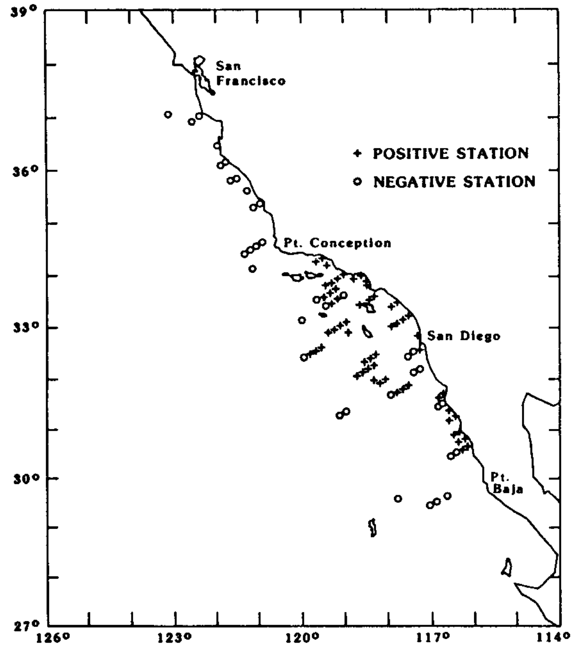


Figure 2. Geographic distribution of trawl stations.

mesh, retrieved vertically to the surface from a depth of 70 m; anchovy eggs were found in 384 of the 938 plankton tows. Planktonic samples were collected at all hours. Adults were sampled between 1800 and 0200 hours at 96 stations (Figure 2) using a 15-m² trawl with a 2-mm mesh liner; anchovies were caught in 66 of the trawl stations. (For a detailed description of field operations, see Cruise Report 8403-JD, dated May 31, 1984, William Flerx, Southwest Fisheries Center, La Jolla, California).

The geographic distribution of anchovy eggs was similar to that observed in 1983 and unlike previous years. In both 1983 and 1984 the range extended farther offshore, and a smaller proportion of eggs was taken off Baja California than in previous years. The distribution in 1984 was unique in that virtually no spawning was evident within 50 km of the northern coast of Baja California, although adult anchovies were caught in this area. Farther south and separate from the main spawning area, a few eggs were found very near shore between Cape Colnette and Punta Baja. Another inshore spawning area, separate from the main area, was detected extending from Monterey Bay to Point Reyes, north of the entrance to San Francisco Bay. This localized area of spawning has been evident in previous years. With the exception of northern Baja California, where the sampled fish were immature, the occurrence of positive trawls agreed well with the distribution of eggs. The egg and trawl surveys appear to have provided good sample coverage of the central subpopulation of northern anchovy in 1984.

There was an apparent correlation between the northern edge of spawning and the 14.5° isotherm; no correlation was evident along the southern boundary. A correlation between the range of the spawning population and temperature isotherms has been noted in previous years (Lasker et al. 1981; Picquelle and Hewitt 1983).

## BIOMASS MODEL

The egg production estimate of anchovy spawning biomass and its variance is defined as:

$$B = P_o A \frac{k\,W}{R\,F\,S} \qquad (1)$$

$$\mathrm{Var}(B) \cong B^2 \times \left\{ \frac{\mathrm{Var}(P_o)}{P_o^2} + \frac{\mathrm{Var}(W)}{W^2} + \frac{\mathrm{Var}(R)}{R^2} + \frac{\mathrm{Var}(F)}{F^2} + \frac{\mathrm{Var}(S)}{S^2} + 2\left[ \frac{\mathrm{Cov}(P_o W)}{P_o W} - \frac{\mathrm{Cov}(P_o R)}{P_o R} - \frac{\mathrm{Cov}(P_o F)}{P_o F} - \frac{\mathrm{Cov}(P_o S)}{P_o S} - \frac{\mathrm{Cov}(WR)}{WR} - \frac{\mathrm{Cov}(WF)}{WF} - \frac{\mathrm{Cov}(WS)}{WS} + \frac{\mathrm{Cov}(RF)}{RF} + \frac{\mathrm{Cov}(RS)}{RS} + \frac{\mathrm{Cov}(FS)}{FS} \right] \right\} \qquad (2)$$

where $B$ = spawning biomass in metric tons,

$P_o$ = daily egg production rate in number of eggs per day per 0.05 m²,

$W$ = average weight of mature females in grams (g),

$R$ = female fraction of the population by weight,

$F$ = batch fecundity in number of eggs,

$S$ = fraction of mature females spawning per day,

$A$ = area of survey in units of 0.05 m², and

$k$ = conversion factor from grams to metric tons ($10^{-6}$ MT/g).

These expressions were developed by Parker (1980) and Stauffer and Picquelle (1980) and were used by Picquelle and Hewitt (1983, 1984).

## DAILY PRODUCTION OF EGGS

The parameter $P_o A$, the daily production of eggs, is the survey area multiplied by the number of eggs spawned per night per unit area, averaged over the range and duration of the survey. Eggs were enumerated by stage of embryonic development, and were aged using temperature-dependent development rates and assuming that spawning occurs at 2200 hours each night. An exponential mortality model was fit to the egg data by assuming constant instantaneous rate of mortality. The daily egg production rate was estimated as the value of the predicted curve at the time of spawning.

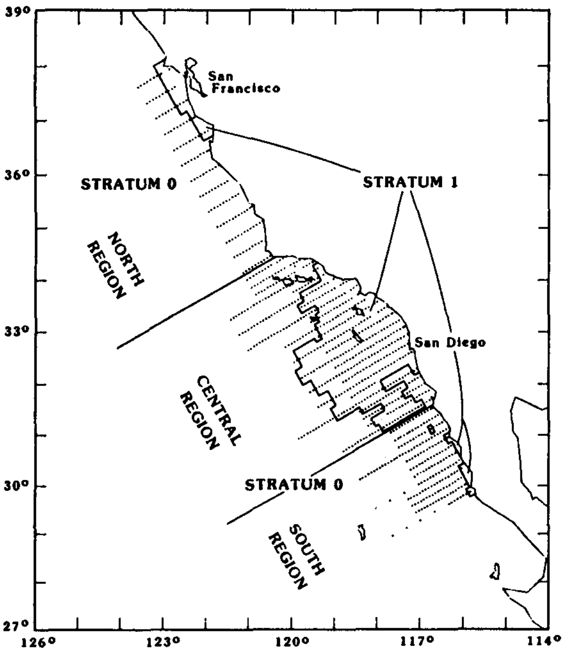


Figure 3. Subdivision of 1984 survey into strata (stratum 1 is the spawning area, and stratum 0 is devoid of eggs) and geographic regions (north, central, and south).

The egg counts were analyzed using a two-stage systematic sampling scheme (Picquelle and Hewitt 1983). First, each station was assigned a weight proportional to the area the station represents; second, the stations were stratified by location, where stratum 1 was defined as the geographic area of spawning, and stratum 0 was that area devoid of eggs (Figure 3). The exponential mortality model

$$P_{jt} = P_o' e^{-Zt} \quad (3)$$

was fit to the data by a weighted nonlinear least squares regression,

where $P_{jt}$ = the number of eggs from the $j$th station of age $t$,

$t$ = the age in days measured as the elapsed time from the time of spawning to the time of sampling at the $j$th station (because spawning occurs once a day and because the incubation period was 3 days or less, as many as 3 cohorts of eggs could be found at each station),

$Z$ = the instantaneous rate of mortality on a daily basis, and

$P_o'$ = the daily egg production rate in stratum 1.

The data and fitted curve are described in Figure 4. The daily egg production rate in stratum 0 is zero, and the daily egg production rate for the total survey area

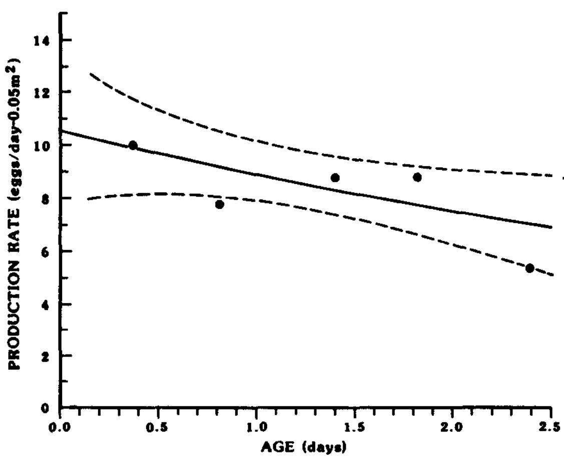


Figure 4. Egg production curve. The data is summarized as the mean abundance by half-day intervals, although the regression was fit to the individual data points. A 95% confidence region for the regression (broken line) is indicated.

TABLE 1
**Parameters for Computing the Daily Production of Eggs**

| | Stratum 0 | Stratum 1 | Total survey |
|---|---|---|---|
| $P_o$ | 0 | 10.55 | 3.79 |
| var ($P_o$) | 0 | 1.66 | 0.60 |
| Z | 0 | 0.17 | 0.17 |
| var (Z) | 0 | 0.008 | 0.008 |
| $A$ | $2.195 \times 10^{12}$ | $1.231 \times 10^{12}$ | $3.426 \times 10^{12}$ |
| $P_o A$ | | | $12.98 \times 10^{12}$ |
| var ($P_o A$) | | | $7.02 \times 10^{24}$ |

and its variance (adjusted for postsurvey stratification; Jessen 1978) is:

$$P_o = \frac{A_1}{A} P_o' \quad (4)$$

$$\mathrm{Var}(P_o) = (1 + 1/n)[(A_1/A)\ \mathrm{Var}(P_o')] \quad (5)$$

where $n$ = the total number of stations,
$A_1$ = the area of stratum 1, and
$A$ = the total survey area.

The estimates for computing the daily production of eggs and their variances appear in Table 1.

## ADULT PARAMETERS *W*, *F*, *S*, AND *R*

The parameters *W*, *F*, *S*, and *R* were estimated from a sample of adult anchovies collected by the midwater trawl. Each parameter was estimated by a weighted sample mean ($\bar{\bar{y}}$) with a weighted variance (Cochran 1963):

$$\bar{\bar{y}} = \sum_{i=1}^{n} \left(\frac{m_i}{\bar{m}n}\right) \bar{y}_i \quad (6)$$

$$\mathrm{Var}(\bar{\bar{y}}) = \frac{\sum_{i=1}^{n} \left[\left(\frac{m_i}{\bar{m}}\right)^2 (\bar{y}_i - \bar{\bar{y}})^2\right]}{n(n-1)} \quad (7)$$

where $m_i$ = the number of fish subsampled from the $i$th trawl,
$\bar{m}$ = the average number of fish subsampled per trawl,
$n$ = the number of positive trawls,
$\bar{y}_i$ = the average value for the $i$th trawl = $\sum_{j=1}^{m_i} y_{ij}/m_i$ and
$y_{ij}$ = the observed value for the $j$th fish in the $i$th trawl.

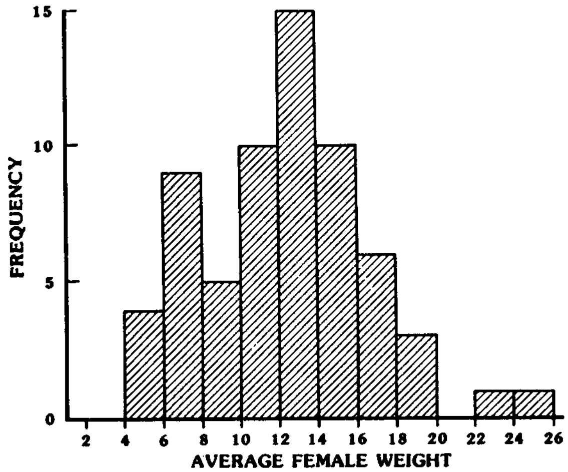


Figure 5. Frequency distribution of average mature female weight per trawl.

### *Average Female Weight*

The average female weight was calculated using the above equations where $\bar{y}_i$ was the average female weight for the $i$th trawl. The desired subsample size was 25 fish from each trawl; however, this was not always possible for small trawl catches or for catches composed predominately of immature fish. The weight of females with hydrated eggs was adjusted for the extra weight of the fluid in their ovaries by measuring their ovary-free weight and estimating the whole-body weight of a female without hydrated eggs. The following regression, estimated from mature females without hydrated eggs, was used:

$$W = -0.176 + 1.06\ W^* \quad (8)$$

where $W$ = estimated whole-body weight in grams, and
$W^*$ = ovary-free weight in grams.

This regression had an $r^2 = 0.998$. The frequency distribution of average weight per trawl is described in Figure 5. the average female weight for the survey and its variance are listed in Table 2.

### *Batch Fecundity*

Batch fecundity for each mature female was estimated from a regression of fecundity on ovary-free weight estimated from a sample of 75 hydrated females. The sample was selected so that the ovary-free weight distribution was similar to the ovary-free weight distribution of all the mature females (Figure 6). The regression model selected was:

$$F = -509 + 523\ W^* \quad (9)$$

TABLE 2
**Estimates of Egg Production Parameters, Variances, and Coefficients of Variation**

| Parameter | | Value | Variance | Coefficient of variation |
|---|---|---|---|---|
| Daily egg production ($10^{12}$ eggs/day) | $(P_o A)$ | 12.98 | 2.51 | 12.2% |
| Average female weight (g) | $(W)$ | 12.0170 | 0.21047 | 3.8 |
| Batch fecundity (eggs) | $(F)$ | 5485. | 96920. | 5.7 |
| Spawning fraction ($day^{-1}$) | $(S)$ | 0.1597 | 0.00026 | 10.0 |
| Female fraction | $(R)$ | 0.5820 | 0.00095 | 5.3 |
| Daily specific fecundity ($10^6$ eggs/dayMT) | | 42.433 | | |
| Spawning biomass (MT) | $(B)$ | 306,000 | 2,547,706,812 | 16.5 |

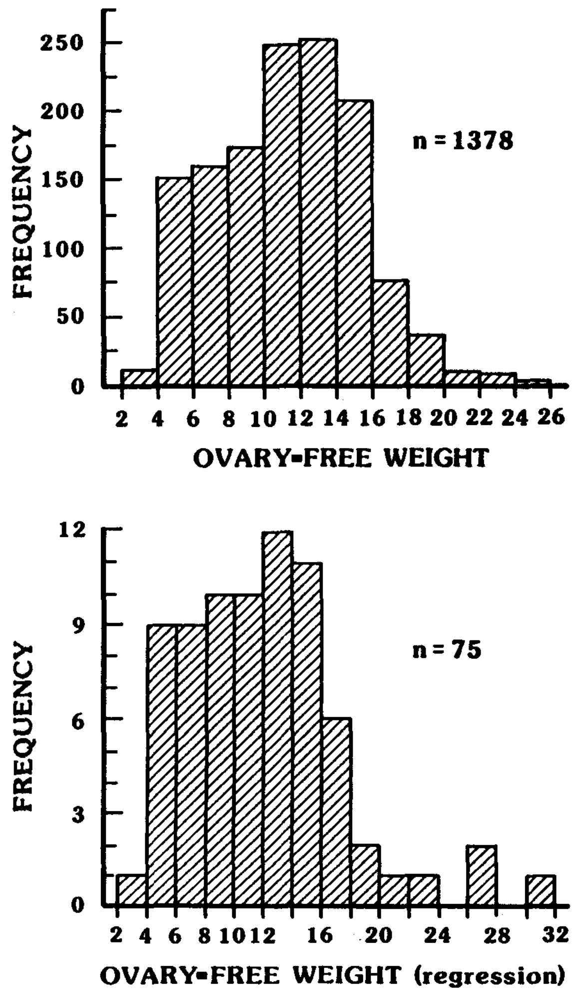


Figure 6. Frequency distributions of ovary-free weight for the entire survey (top) and for the females with hydrated ovaries used to estimate the batch fecundity/ovary-free weight regression.

where $F$ = estimated fecundity for a female with $W^*$ ovary-free weight (Figure 7). This regression had an $r^2 = 0.783$. Average batch fecundity for the survey was estimated using equation 6 where $y_{ij} = F_{ij}$ and the desired $m_i$ was 25 mature females. The variance estimate (equation 7) was modified to include the extra source of variance from the batch fecundity/ovary-free weight regression (Draper and Smith 1966):

$$\mathrm{Var}(\bar{\bar{F}}) = \frac{\sum_{i=1}^{n} \left\{ \left( \frac{m_i}{\bar{m}} \right)^2 \left[ \frac{(\bar{F}_i - \bar{\bar{F}})^2}{n-1} + \frac{S_h^2}{75} + (\bar{W}_i^* - \bar{W}_h^*)^2 \, \widehat{\mathrm{Var}}(b) \right] \right\}}{n} \quad (10)$$

where $S_h^2$ = 2,291,706 is the variance about the regression,
$\bar{W}_i^*$ = average ovary-free weight for the $i$th trawl,
$\bar{W}_h^*$ = 11.95 gr, average ovary-free weight of the 75 hydrated females used in the regression,
$\widehat{\mathrm{Var}}(b)$ = 1041, variance of the slope of the regression, and
$n$ = number of positive trawls.

The average batch fecundity for the survey and its variance are listed in Table 2.

### *Spawning Fraction*

The spawning fraction, $S$, and its variance were estimated using equation 6 where $\bar{y}_i = S_i$ was the proportion of mature females in the $i$th trawl that spawned one night prior to capture (day-1 spawners). The desired $m_i$ was 25 mature females. Based on previous experience (Picquelle and Hewitt 1983), it was suspected that females spawning on the night of capture (day-0 spawners) were oversampled by the trawl, thus biasing the proportion of day-1 spawners. To compensate for the potential bias, it was assumed

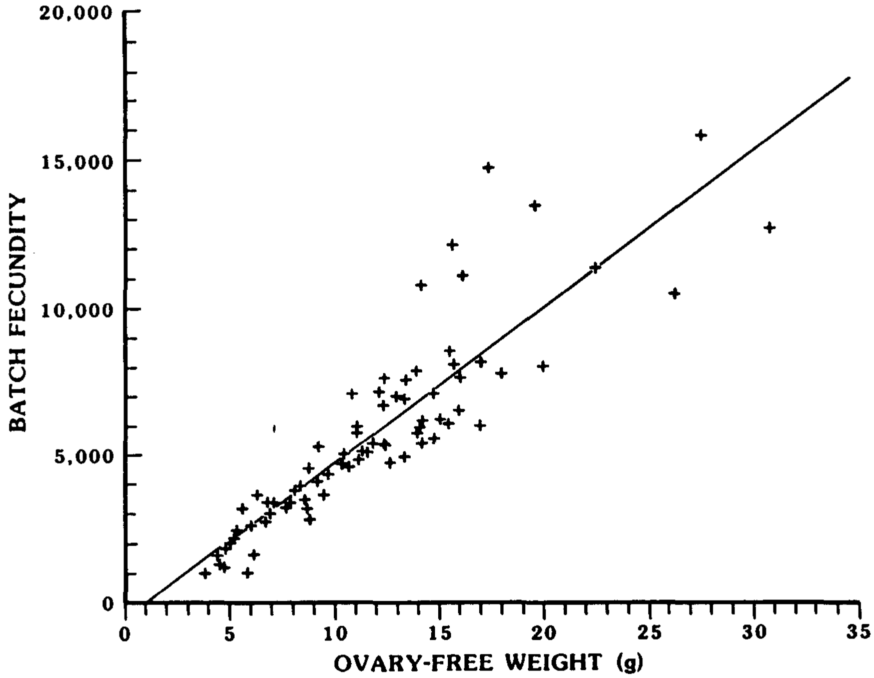


Figure 7. Linear regression of batch fecundity on ovary-free weight fit to 75 females with hydrated ovaries.

that the true proportion of day-0 spawners was equal to the observed proportion of day-1 spawners: the value of $m_i$ in equations 6 and 7 is adjusted by deleting day-0 spawners from the sample and equating the number of day-0 spawners to the number of day-1 spawners, thus reducing the average subsample size, $\bar{m}$. The frequency distribution of the spawning fraction per trawl is described in Figure 8; the estimated spawning fraction for the survey and its variance are listed in Table 2.

*Female Fraction*

The female fraction, $R$, was measured as the fraction of females in the population by weight. Equations 6 and 7 were used by setting $\bar{y}_i = R_i$, where $R_i$ is the estimated total weight of females in a subsample of 50 fish divided by the estimated total weight of the subsample; $m_i$ was set equal to the total weight of the subsample. The average male and female weights for each trawl were estimated from 5 males and 25 females where the weight of any hydrated female was adjusted using equation 8. The frequency distribution of female fraction per trawl is described in Figure 9; the estimated female fraction for the survey and its variance are listed in Table 2.

## BIOMASS ESTIMATE AND VARIANCE

The parameter estimates, their variances, coefficients of variation, and covariances are listed in Tables 2 and 3. The sample covariance terms were calculated only for the adult parameters. Because the daily egg production and the adult parameters were estimated from different samples, it was not possible to estimate their covariances, and they were assumed to be zero. The biomass estimate and its variance were

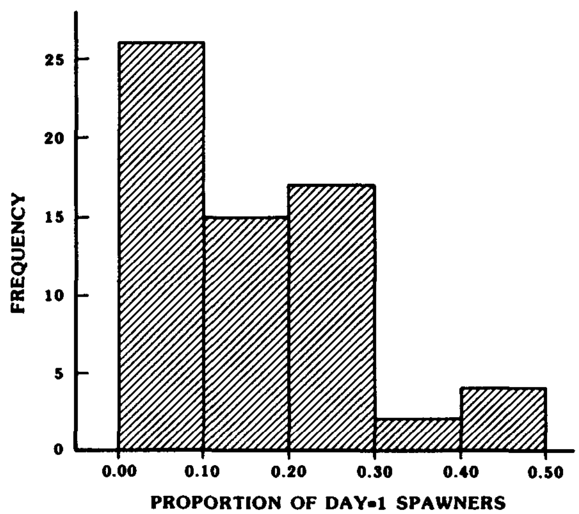


Figure 8. Frequency distribution of spawning fraction. Large portion of lowest class represents nonspawning fish from off northern Baja California.

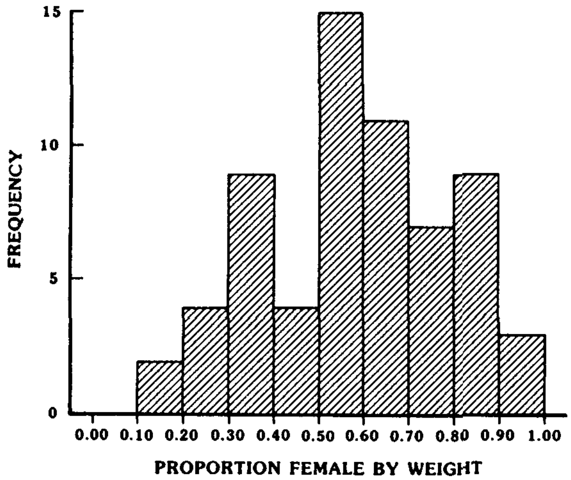


Figure 9. Frequency distribution of female fraction by weight.

calculated using equations 1 and 2. The estimate of spawning biomass was 306,000 MT, with a standard error of 50,475 MT.

The survey was subsequently divided into three geographic regions (Figure 3) corresponding to the three distinct spawning areas. Daily egg production and daily specific fecundity were calculated for each region (Table 4). Because of the small number of trawls in the north and south regions, the estimate of the female fraction by weight ($R$) was unreliable; $R$ was thus estimated for the entire survey and was assumed to be similar among regions. Since the parameter values for the three regions were very different (Table 4), homogeneity could not be assumed. Biomasses were calculated separately for each region and were summed to produce the final estimate of 309,000 MT. This estimate is not very different from the unregionalized estimate but should be more accurate. I was not able to produce a corresponding estimate of the total variance because some of the variances and covariances could not be calculated for the individual regions.

TABLE 3
**Covariances between Adult Parameters**

| | $F$ | $S$ | $R$ |
|---|---|---|---|
| Female weight ($W$) | 103.341133 | 0.00061 | 0.00085401 |
| Batch fecundity ($F$) | | 0.30792 | 0.43871200 |
| Spawning fraction ($S$) | | | −0.00009186 |
| Female fraction ($R$) | | | |

## DISCUSSION

The 1984 estimate of the spawning biomass of the central subpopulation of the northern anchovy is less than half of the 1983 estimate (Table 5). Daily egg production by the population is down 25% from 1983, and the daily specific fecundity is up 75% from 1983. The daily specific fecundity is the highest ever estimated over the last five years and results from a high spawning fraction and a high female fraction by weight. Although the average female weight is slightly larger than the 1983 value, both years are low relative to the previous four surveys. Average batch fecundity is not unusual for the average female weight. This survey indicates that the spawning population comprises predominately small, young females with their center of distribution off southern California.

The geographical distribution of anchovies found in this survey agrees with an earlier report by the California Department of Fish and Game, (CDFG). K.F. Mais (Cruise Report 84-X-1, CDFG, Long Beach, California) conducted an extensive sonar and trawl survey from Point Conception, California, south to Punta Baja, Baja California, in February 1984. He reported that the anchovy central subpopulation was distributed more north and offshore than it was pre-

TABLE 4
**Regional Estimates of Egg Production Parameters**

| Parameter | | North region | Central region | South region |
|---|---|---|---|---|
| Daily egg production ($10^{12}$ eggs/day) | ($P_0 A$) | 2.00 | 5.42 | 0.14 |
| Average female weight | ($W$) | 14.18 | 12.57 | 9.06 |
| Batch fecundity | ($F$) | 6584 | 5752 | 4043 |
| Spawning fraction | ($S$) | 0.1052 | 0.1748 | 0.0891 |
| Female fraction | ($R$) | 0.5820 | 0.5820 | 0.5820 |
| Daily specific fecundity | | 28.44 | 46.57 | 23.15 |
| Spawning biomass | ($B$) | 70,300 | 234,400 | 4,000 |
| Total biomass | | 308,700 | | |

TABLE 5
**Time Series of Egg Production Parameters**

| | | 1980 | 1981 (Feb.) | 1981 (Apr.) | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|
| Daily egg production ($10^{12}$ eggs/day) | ($P_0A$) | 26.34 | 20.96 | 12.59 | 13.51 | 17.25 | 12.98 |
| Average female weight | ($W$) | 17.44 | 13.37 | 16.20 | 18.83 | 11.20 | 12.02 |
| Batch fecundity | ($F$) | 7,751 | 8,329 | 8,846 | 10,845 | 5,297 | 5,485 |
| Spawning fraction | ($S$) | 0.142 | 0.106 | 0.125 | 0.120 | 0.094 | 0.160 |
| Female fraction | ($R$) | 0.478 | 0.501 | 0.495 | 0.472 | 0.549 | 0.582 |
| Daily specific fecundity ($10^6$ eggs/day-MT) | | 30.28 | 33.03 | 33.84 | 32.53 | 24.35 | 42.43 |
| Spawning biomass ($10^3$ MT) | ($B$) | 870 | 635 | 372 | 415 | 652 | 309 |
| Calif. Dept. Fish and Game acoustic biomass estimate ($10^3$ MT) | | 498 to 598 | 493 to 591 | | 233 to 247 | 461 to 504 | 479 to 560 |

vious to 1983. Mais estimated the biomass (including immature nonspawning fish) to be between 479,000 and 560,000 MT (Table 5). He also reported evidence of a relatively strong 1982 year class and weak 1981 and 1983 cohorts; fish of all ages were unusually small. Since 1980, acoustic abundance estimates have tended to be lower than those obtained by the egg production method (Table 5). This year's survey is unusual in that the acoustic survey results are substantially larger than the egg production method estimate. The young, nonspawning fish observed off northern Baja California, which were not included in the egg production method estimate, may account for some of this discrepancy.

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