THE 1985 SPAWNING BIOMASS OF THE NORTHERN ANCHOVY

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ABSTRACT

The 1985 spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*) is 522,000 metric tons (MT). This estimate was made using the egg production method, which computes the spawning biomass as the ratio of the daily egg production rate (eggs per day for the entire population) and the daily specific fecundity (eggs per day per metric ton). For the entire population, the egg production rate was 16.95×10^{12} eggs/day, and the daily specific fecundity was 37.00×10^{6} eggs/day/MT. In 1985 anchovy eggs were found farther offshore than in any survey since the egg production method was first employed in 1980. A significant number of eggs spawned far offshore may have been missed by the survey, thus biasing the estimate downward.

RESUMEN

En 1985, la biomasa de desove de la subpoblación central de la anchoveta norteña (*Engraulis mordax*) es 522,000 toneladas métricas (TM). Esta estimación fue calculada por medio del método de producción de huevos, él cual calcula la biomasa de desove como la proporción entre la tasa diaria de producción de huevos (huevos por día para toda la población) y la fecundidad específica diaria (huevos por día por tonelada métrica). La tasa de producción de huevos de la población total fue 16.95×10^{12} huevos/día, y la fecundidad específica diaria 37.00×10^{6} huevos/día/TM. Los huevos de anchoveta fueron encontrados más alejados de la costa en 1985 que en cualquiera de los estudios anteriores desde que el método de producción de huevos fuera inicialmente empleado en 1980. Es posible que un número significativo de los huevos puestos mar afuera haya sido obviado por el presente estudio implicando una subestimación de la biomasa.

INTRODUCTION

This estimate of the 1985 spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*) fulfills the requirements of the Anchovy Management Plan adopted by the Pacific Fishery Management Council (PFMC 1983). In the past, anchovy biomass has been estimated using a larval census method (Smith 1972; Stauffer and Parker 1980; Stauffer and Picquelle 1981) and an egg production method (Parker 1980; Stauffer and Picquelle 1980; Picquelle and Hewitt 1983, 1984; Hewitt 1984; Lasker 1985). In 1985 only the egg production method was used to estimate the anchovy spawning biomass.

With the egg production method (EPM), we compute the spawning biomass as the ratio of the daily production of eggs (eggs per day for the entire population) and the daily specific fecundity (eggs per day per metric ton) of the adult population. The daily production of eggs is estimated from the density and embryonic developmental stages of egg samples from an ichthyoplankton survey. The developmental rates of anchovy eggs are measured in the laboratory under various temperature regimes. The daily specific fecundity of the anchovy population is estimated from adult fish sampled during a trawl survey. The parameters used to produce the average specific fecundity are average female weight, batch fecundity, sex ratio, and the proportion of females spawning each night. Variance and covariance values are also produced for the parameters.

The survey results, the EPM estimate of spawning biomass, and the variance of the estimate are presented in the following sections.

DESCRIPTION OF THE SURVEY

The 1985 EPM survey of the central subpopulation of northern anchovy was conducted with the NOAA ship *David Starr Jordan* from January 28 through March 8, 1985. The survey (Figure 1) ran from north to south starting approximately 50 miles south of Monterey, California, (CalCOFI line 71.7) and ending at Bahía del Rosario, Baja California, (CalCOFI line 110.0). Several survey lines were extended farther offshore than planned because of the unexpected extent of positive samples. The survey lines directly north of the greatest concentration of anchovy eggs (northwest of San Diego) may not have extended far enough offshore to sample the northern extent of this concentration. Thus a significant number of anchovy eggs may have been missed.

We used a 25-cm-diameter vertical egg net with a 0.15-mm mesh to take plankton samples from 70-m-

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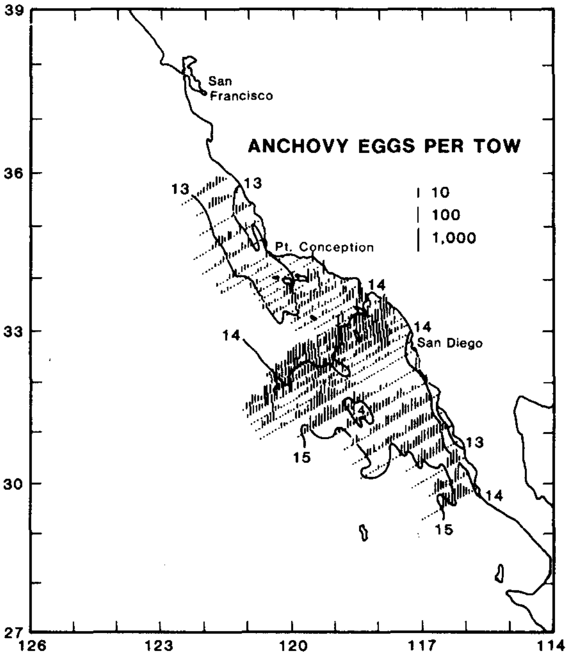

Figure 1. Geographic distribution of ichthyoplankton stations, anchovy eggs, and surface isotherms.

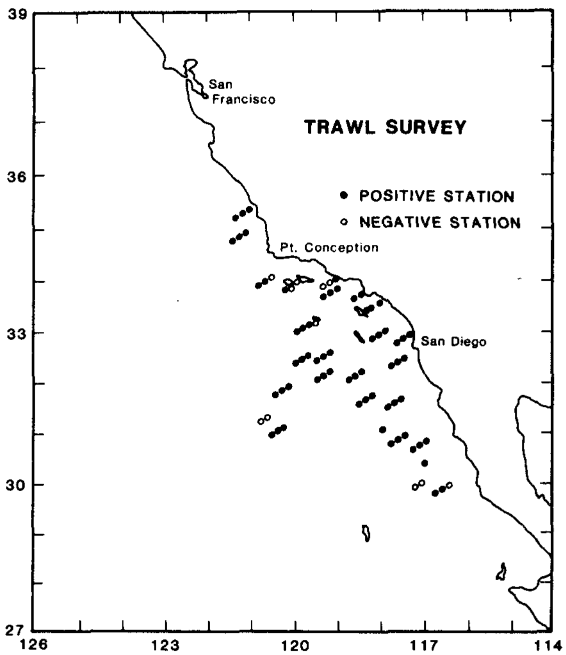

Figure 2. Geographic distribution of trawl stations.

deep water at 492 stations, and 210-m-deep water at 417 stations. Of these 809 samples, 547 contained anchovy eggs (Figure 1). A 15-m^2 pelagic trawl with a 2-mm-mesh liner was towed at 74 stations. Adult anchovies were caught at 64 stations (Figure 2). (For a more complete description of the field operations, see Cruise Report 8502-JD, dated April 29, 1985, William Flerx, Southwest Fisheries Center, La Jolla, California.)

Anchovy eggs extended much farther offshore than in any other year since egg production surveys began in 1980. Spawning activity, as in previous years, was correlated with sea-surface isotherms (Lasker et al. 1981) (Figure 1). South of Point Conception, spawning was generally constrained within the 15°C isotherm. North of Point Conception, spawning occurred in colder water. The cruise report of the USSR research vessel *Mys Babushkina* (Cruise Report 8503-MB, dated June 7, 1985, D. Abramenkoff, Southwest Fisheries Center, La Jolla, California) gave quantitative evidence of spawning in the area north of our survey area up to the San Francisco Bay area (Figure 3). On the Soviet cruise, ichthyoplankton samples were visually "scanned" (the number of larvae per tow roughly estimated) to estimate the number of anchovy larvae taken at each station. We used the scanned estimates to estimate the anchovy spawning biomass in the area north of our survey.

In summary, in the late winter of 1985, anchovies were spawning from Baja California to the San Francisco Bay. This spawning was concentrated in the Southern California Bight and extended farther offshore than usual. Because some of our survey lines may not have extended far enough offshore, many anchovy eggs may not have been counted. This would bias our biomass estimate downward. South of San Diego and north of Point Conception the population was closer to shore, but generally not present in the colder, upwelled water adjacent to the coast.

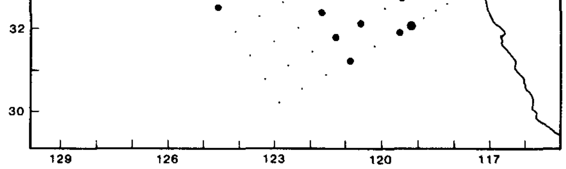

Figure 3. Geographic distribution of ichthyoplankton stations and anchovy larvae from the Soviet cruise (*Mys Babushkina*).

BIOMASS MODEL

The egg production method estimate of spawning biomass (Parker 1980; Stauffer and Picquelle 1980) is:

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

where B = spawning biomass in metric tons,
P = daily egg production rate in number of eggs per day per 0.05 m^2,
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 m^2, and
k = conversion factor from grams to metric tons (10^{-6} MT/g).

An estimate of an approximate variance for the biomass estimate, derived using the delta method (Seber 1982), is:

$$\mathrm{var}(B) \cong B^2\{\mathrm{var}(P)/P^2 + \mathrm{var}(W)/W^2 + \mathrm{var}(R)/R^2 + \mathrm{var}(F)/F^2 + \mathrm{var}(S)/S^2 + 2[\mathrm{cov}(PW)/PW - \mathrm{cov}(PR)/PR - \mathrm{cov}(PF)/PF - \mathrm{cov}(PS)/PS - \mathrm{cov}(WR)/WR - \mathrm{cov}(WF)/WF - \mathrm{cov}(WS)/WS + \mathrm{cov}(RF)/RF + \mathrm{cov}(RS)/RS + \mathrm{cov}(FS)/FS]\}.$$

DAILY PRODUCTION OF EGGS

The daily production of eggs in the sea, P, is the number of eggs spawned per night per unit area (0.05 m^2, the area of the ichthyoplankton net) averaged over the range and duration of the survey. The density of eggs was determined from an ichthyoplankton survey, and the embryonic developmental stage of each egg was determined by microscopic inspection. The ages of the eggs in hours from spawning were computed from the embryonic developmental stage by a FORTRAN program (Hewitt et al. 1984; Lo 1985) which assumes that the daily spawning of anchovy eggs occurs at 2200 hours. An exponential mortality curve for the eggs was fit to the egg age data. I estimated the daily production of eggs as the value of the predicted curve at the time of spawning.

In order to reduce the variance of the estimate of P, I used a two-step sampling scheme with postsurvey stratification. The first step was the systematic ichthyoplankton sample of the survey area. Each sample was assigned a weighting factor proportional to the area the station represented. The second step was to divide the survey area into two strata: stratum 1 was defined as the area where eggs were found or were likely to be found based on incidence in surrounding locations, and stratum 0 was the area devoid of eggs (Figure 4).

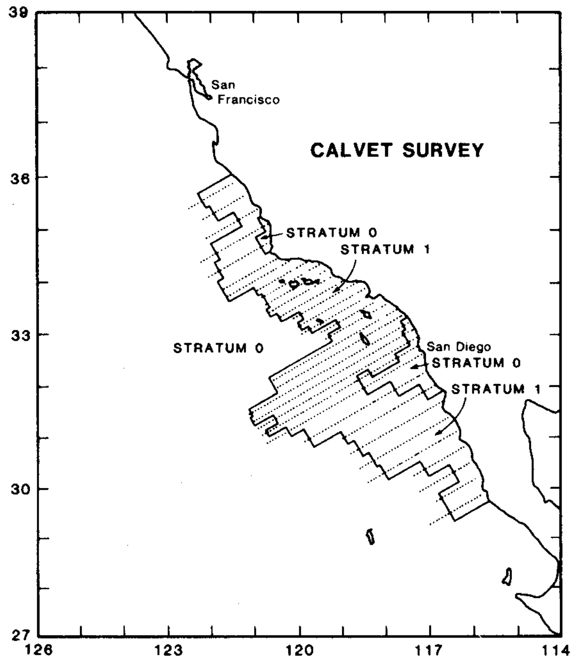

Figure 4. Subdivision of 1985 survey into strata (stratum 1 is the spawning area; stratum 0 is devoid of eggs).

The egg mortality model

$$P_{ijt} = P_i e^{-Zt} \qquad (3)$$

was fit to the data by a weighted nonlinear least-squares regression, with station-weighting factors used as the weights,

where P_{ijt} = the number of eggs of age t from the j^{th} station in the i^{th} stratum,
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,
P_0 = the daily egg production rate in stratum 0; it is zero by definition, and

P_1 = the daily egg production rate in stratum 1.

Mean half-day frequencies for the age data along with the fitted curve and a 95% confidence region for the regression line are described in Figure 5. By definition, the number of eggs produced in stratum 0 is zero. The daily egg production rate for the total survey area and its variance (Jessen 1978) is:

$$P = (A_1/A)\,P_1 \qquad (4)$$

$$\mathrm{var}(P) = (1 + 1/n)[(A_1/A)\ \mathrm{var}(P_1)] \qquad (5)$$

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

The estimates used to compute P, and their variances are given in Table 1. P was found to be 6.41 within stratum 1. For the entire 51,720 n.mi.^{2} survey area, the estimate of P is 4.78 eggs per day per 0.05 m^2 with an approximate variance of 0.33. This gives a coefficient of variation of 12.0%

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

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

$$\bar{\bar{y}} = \sum_i\ [(m_i/\bar{m})\bar{y}_i]/n \qquad (6)$$

$$\mathrm{var}(\bar{\bar{y}}) = \sum_i\ [(m_i/\bar{m})^2(\bar{y}_i-\bar{\bar{y}})^2]/[n(n-1)] \qquad (7)$$

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,

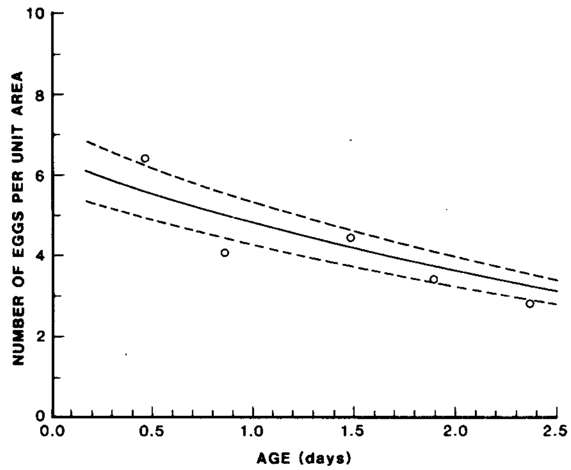

Figure 5. Egg mortality curve. The data are summarized as the mean abundance by half-day intervals, although the regression was fit to the individual data points. A 95% confidence region for the regression (*broken lines*) is indicated.

$\bar{y}_i$ = the average value for the i^{th} trawl = $\sum_j y_{ij}/m_i$, and
y_{ij} = the observed value for the j^{th} fish in the i^{th} trawl.

Average Female Weight

The average weight of an adult female, W, and its variance were estimated using equations 6 and 7, where $\bar{y}_i$ was the average female weight in the i^{th} trawl. I computed average female weight by selecting 25 mature females from each trawl; however, this was not always possible because some trawl samples were too small or were dominated by immature fish.

Just prior to spawning, the eggs in a mature female's ovaries become bloated with fluid (hydrated). I corrected for the extra weight of the hydrated eggs by regressing the weight of mature females without hydrated eggs against their ovary-free weight and then estimating the weight of the hydrated females as if they

TABLE 1
Parameters for Computing Daily Egg Production

	Stratum 0	Stratum 1	Total survey
P (eggs/day-0.05m^2)	0	6.41	4.77
var(P)	0	0.44	0.33
Z (day^{-1})	0	0.29	0.29
var(Z)	0	0.007	0.007
A (0.05m^2)	0.904×10^{12}	2.644×10^{12}	3.548×10^{12}
PA (eggs/day)			16.95×10^{12}
var(P)			4.11×10^{24}

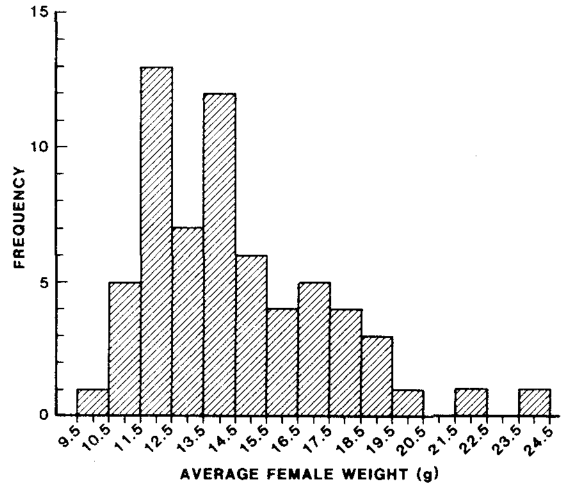

Figure 6. Frequency distribution of average mature female weight per trawl.

did not contain hydrated eggs. The following regression equation was found:

$$\hat{W} = -0.3030 + 1.09\,W^* \qquad (8)$$

where $\hat{W}$ = estimated weight in grams, and
W^* = ovary-free weight in grams.

The regression was highly significant, with a significance level much less than 0.001. The frequency distribution for average weight per trawl is described in Figure 6. The average weight of a female for the entire survey, W, and its variance are listed in Table 2.

Batch Fecundity

The batch fecundity, F, for each mature female is the average number of eggs spawned per female at each spawning event. The batch fecundity was estimated for each female fish by a two-step process. The first step was a regression of batch fecundity versus ovary-free weight from a sample of 85 hydrated females (Figure 7). The ovary-free weight distribution of these 85 fish was similar to the ovary-free weight distribution of all mature females (Figure 8). The estimated regression equation was:

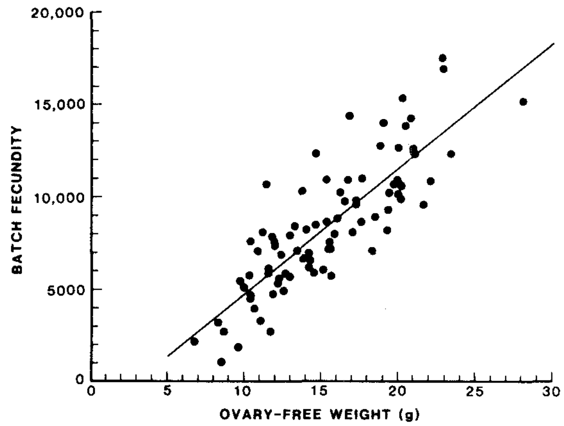

Figure 7. Linear regression of batch fecundity on ovary-free weight fit to 85 females with hydrated ovaries.

$$\hat{F} = -2035.6 + 682.1\,W^* \qquad (9)$$

where $\hat{F}$ = the estimated fecundity for a female with W^* ovary-free weight. The regression was highly significant, with a significance level less than 0.001. The second step was to estimate the batch fecundity for each mature female fish from its ovary-free weight and the above regression. I estimated the average batch fecundity for the entire survey area by using equation 6 where $y_{ij} = \hat{F}_{ij}$, the estimated batch fecundity; the de-

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

Parameter		Value	Variance	Coefficient of variation
Daily egg production (eggs/day)	(PA)	16.95×10^{12}	4.11×10^{24}	15.6%
Average female weight (g)	(W)	14.494	0.105	2.2
Batch fecundity (eggs)	(F)	7,343.	1.145×10^{5}	4.6
Spawning fraction (day^{-1})	(S)	0.120	0.00024	12.9
Female fraction	(R)	0.610	0.00038	3.2
Daily specific fecundity (10^{6} eggs/day -MT)		37.003		
Spawning biomass (MT) (not including San Francisco area)	(B)	458,024	7.374×10^{9}	18.7
Spawning biomass (MT) (including San Francisco area)	(B)	522,000		

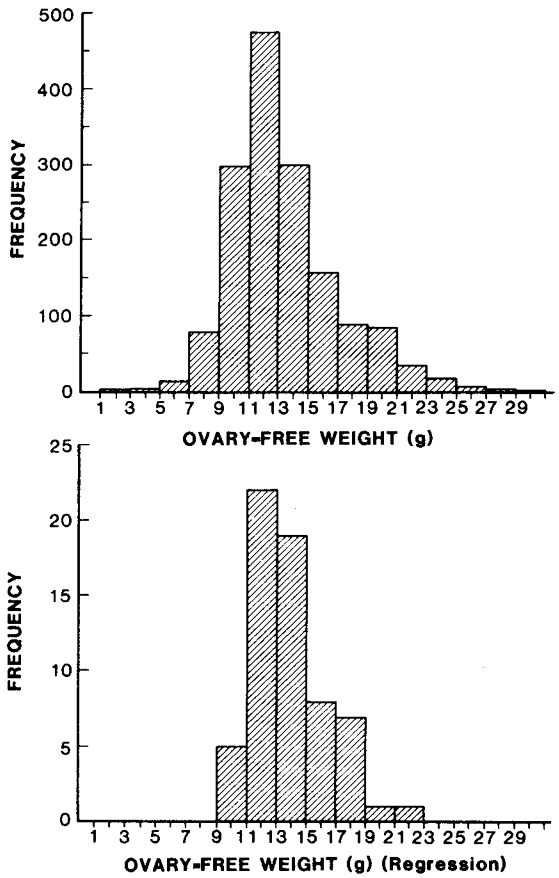

Figure 8. Frequency distributions of ovary-free weight for the entire survey (*top*) and for the females with hydrated ovaries used to estimate the batch fecundity/ovary-free weight regression.

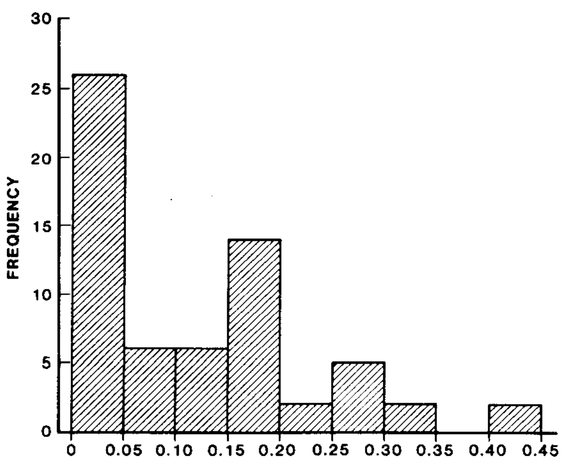

Figure 9. Frequency distribution of spawning fraction.

sired m_i was 25 females. The variance equation (7) was modified because of the extra source of variation from the fecundity/ovary-free weight regression (Draper and Smith 1966):

$$\mathrm{var}(\bar{\bar{F}}) = \sum_i (m_i/\bar{m})^2[(F_i-\bar{F})^2/(n-1) + S_h^2/85 + (\bar{W}_i^*-\bar{W}_h^*)^2\hat{\mathrm{var}}(b)]/n \qquad (10)$$

where S_h^2 = 3,748,191 is the variance about the regression,
$\bar{W}_i^*$ = average ovary-free weight for the i^{th} trawl,
$\bar{W}_h^*$ = 15.43 g, average ovary-free weight of the 85 hydrated females used in the regression,
$\hat{\mathrm{var}}(b)$ = 2,453, variance of the slope of the regression, and
n = 63, the number of positive trawls.

The average batch fecundity and its variance appear in Table 2.

Spawning Fraction

The spawning fraction is the proportion of mature females that spawned on the night prior to capture (day-1 spawners). The spawning fraction, S, and its variance were estimated using equations 6 and 7 where $\bar{y}_i = S_i$ was the spawning fraction found from the i^{th} trawl. The desired m_i—the sample size per trawl—was 25. Strong evidence indicates that females spawning on the night of capture (day-0 spawners) are oversampled by the trawl (Picquelle and Hewitt 1983). To account for this, I adjusted m_i by assuming that there was an equal incidence of day-0 and day-1 spawning fish and hence substituting the day-1 spawners for the day-0 spawners. The frequency distribution of the spawning fraction appears in Figure 9. The estimate of S and its variance are found in Table 2.

Female Fraction

The female fraction of the population by weight is the parameter R. Equations 6 and 7 were used where $\bar{y}_i = R_i$, the total weight of females in a subsample of approximately 50 fish divided by the total fish weight. For each trawl, average weights of male (n = 5) and female (n = 25) fish were measured, and the weights of hydrated females were adjusted using the regression given in equation 8. These average weights were used to estimate the total female weight and the total fish weight. The frequency distribution of R is given in Figure 10; the estimate and variance are shown in Table 2.

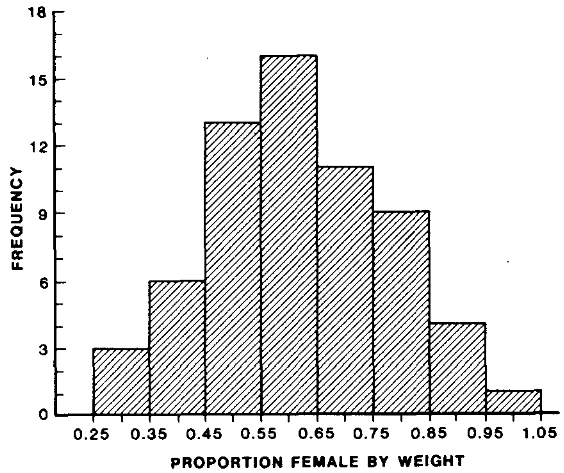

Figure 10. Frequency distribution of female fraction by weight.

BIOMASS ESTIMATE AND VARIANCE

Using equations 1 and 2, I estimated the spawning biomass for the portion of the population range covered by the survey to be 458,025 MT, with a standard error of 85,872 MT. This gives a coefficient of variation of 18.75% The values of the parameters that were used in the estimate, and their variances and covariances appear in Tables 2 and 3. The northern part of the population range was not covered by this survey.

The results of the *Mys Babushkina* cruise show that, as in past years, there is spawning off San Francisco. The Soviet cruise covered the area from Point Conception (CalCOFI line 80.0) north to line 70.7—the northern extent of our biomass survey (region 2)—as well as the region north of line 70.7 (region 1). The Soviets used a bongo net to collect anchovy eggs and larvae. Because larvae are less patchy than eggs, I used "scanned" larvae counts (Figure 3) as an indicator of relative spawning biomass in the two regions. Specific fecundity and subsequent mortality rates of eggs and larvae are assumed to be constant throughout the spawning area. The biomass of region 1 was calculated as:

$$B1 = B2 * \frac{\sum_i (L1_i * A_i)}{\sum_i (L2_i * A_i)} = 63{,}718 \text{ MT}$$

where $B1$ = estimated spawning biomass of region 1,

$B2$ = 29,090 MT is the spawning biomass of region 2 (biomass equation),

$L1_i$ = number of larvae caught at each station in region 1,

$L2_i$ = number of larvae caught at each station in region 2, and

A_i = area represented by station i.

The final biomass estimate for the survey area plus the northern area was 458,025 + 63,718 = 521,742 MT. The variance of this estimate was not computed. However, the coefficient of variation is certainly larger than the 19% associated with the entire region of the EPM survey (Table 2).

DISCUSSION

The 1985 egg production method estimate of the spawning biomass of the central subpopulation of the northern anchovy is up by 61% from its lowest point (since 1980) in 1984. Table 4 lists the historical time series of parameters. The change in spawning biomass is caused by a 31% increase in egg production and a 13% increase in the daily specific fecundity from 1984. The decrease in daily specific fecundity results from a drop in the spawning fraction to a level average for 1980-84 and an increase in batch fecundity. The larger batch fecundity is strongly related to a 21% increase in female weight, because the two are highly correlated (Table 3). The ratio of batch fecundity and mean weight (F/W) estimates the specific batch fecundity (Table 4). The increase in this ratio is less than the rise in batch fecundity, implying that much of the growth in batch fecundity is due to a larger average female weight. The egg mortality rate Z was higher this year than it has been since 1980. The very large 1980 rate, along with this year's high Z value, demonstrates the variability of Z. Female fraction remained very high compared to the years before 1984. The daily specific fecundity is lower than 1984 but is still above the average for 1980-83.

The EPM spawning biomass estimate can be compared to an annual acoustic survey, which provided a measure of total anchovy biomass. The California Department of Fish and Game conducted an acoustic and midwater trawl survey of the northern anchovy in February 1985 (Cruise Report 85-X-1, K.F. Mais, CDFG, Long Beach, California). The cruise was restricted to the area between Point Conception (CalCOFI line 80.0) and the U.S.-Mexican fishery boundary. In agreement with our results, Mais reports that the geographic distribution of anchovies was more offshore

TABLE 3
Covariances between Adult Parameters

	F	S	Female fraction (R)
Female weight (W)	66.25495	0.00076	0.00064759
Batch fecundity (F)		0.53235	0.44352668
Spawning fraction (S)			0.00005531

TABLE 4
Time Series of Egg Production Parameters (1980-85)

		1980	1981	1982	1983	1984	1985[a]
Daily egg production (10^{12} eggs/day)	(*PA*)	26.34	20.96	13.51	17.25	12.98	16.95
Egg mortality rate	(*Z*)	0.45	0.14	0.16	0.18	0.17	0.29
Average female weight (g)	(*W*)	17.44	13.37	18.83	11.20	12.02	14.50
Batch fecundity (eggs)	(*F*)	7,751	8,329	10,845	5,297	5,485	7,343
Spawning fraction	(*S*)	0.142	0.106	0.120	0.094	0.160	0.120
Female fraction	(*R*)	0.478	0.501	0.472	0.549	0.582	0.609
Daily specific fecundity (10^6 eggs/day/MT)		30.28	33.03	32.53	24.35	42.43	37.00
Specific batch fecundity (eggs/g)	(*F/W*)	444	623	576	473	456	506
Spawning biomass (10^3 MT)	(*B*)	870	635	415	652	309	522[b]
Coef. of variation for (*B*)		0.26	0.22	0.06	0.21	0.17	0.19[a]
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	627 to 753[c]

[a]Does not include San Francisco area
[b]Includes San Francisco
[c]Does not include Mexican portion of anchovy population

and southward than in any other survey year. He also reported that the bulk of the population was "located in an arc of 80 miles west to south, and 30 miles east to south of San Clemente Island." This is where our survey found the greatest density of anchovy eggs (Figure 1). Mais calculated the total biomass of anchovies (not spawning biomass) to be 627,000-753,000 MT in U.S. waters off southern California. This is up 30.8%-34.5% from his results of 1984. He concludes that the 1985 estimate is the highest in five years and that it would have been higher if the proportion of the anchovy population located in Mexican waters been included.

In previous years the survey area was divided into regions in order to reduce the variance of the parameters and the variance of the biomass estimate (Picquelle and Hewitt 1983; Hewitt 1984). The regionalization was indicated because there were significant differences in one or more parameters between regions. There is no indication that regionalization would have reduced the variance of this year's estimates.

Anchovy eggs were found much farther offshore than in any year since the egg production method surveys began in 1980. A large number of eggs far offshore may have been missed by our survey. As mentioned earlier, if a significant number were missed, there would be a downward bias in our biomass estimate.

ACKNOWLEDGMENTS

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