SOUTHWEST FISHERIES CENTER

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JULY 1985

THE 1985 SPAWNING BIOMASS OF THE NORTHERN ANCHOVY

By

Andrew G. Bindman

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National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center
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ABSTRACT

The 1985 spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*) is 521,000 mtons. This estimate was made using the egg production method which computes the spawning biomass as the ratio of the daily egg production rate and the daily specific fecundity. 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-mton.

In 1985 anchovy eggs were found further offshore than have been seen in any survey since the egg production method was first employed in 1980.

INTRODUCTION

This is a report of the estimate of the 1985 spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*). This estimate 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 and 1984, Hewitt 1984, Lasker 1984). Only the egg production method was used in 1985 to estimate the anchovy spawning biomass.

The egg production method computes the 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 estimated from the density and embryonic developmental stages of egg samples from an ichthyoplankton survey. The developmental rates of anchovy eggs have been measured in the laboratory under various temperature regimes. The daily specific fecundity of the anchovy population was estimated from adult fish sampled during a trawl survey. The components of the daily specific fecundity were computed from the trawl survey. The parameters that were 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 were also produced for the parameters.

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

DESCRIPTION OF THE SURVEY

The 1985 egg production survey of the central subpopulation of northern anchovy was conducted with the NOAA Ship DAVID STARR JORDAN during the period of January 28 through March 8, 1985. The survey ran from north to south starting approximately 50 miles south of Monterey, California (CalCOFI line 71.7) and ending at Bahia del Rosario, Baja California (CalCOFI line 110.0). Several survey lines were extended further offshore than planned due to the unexpected offshore extent of positive samples. Plankton samples were taken using a 25 cm diameter vertical egg net from 70 m in depth or 210 m in depth at 492 and 417 stations, respectively. 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 Flerx (1985, Cruise Report 8502-JD, April 29, 1985, Southwest Fisheries Center, La Jolla, California.)

The geographic distribution of anchovy eggs was much further 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 Pt. Conception spawning was generally constrained between the 13.5°C and 15°C isotherms. North of Pt. Conception spawning occurred in colder water. The Union of Soviet Socialist Republics' research vessel MYS BABUSHKINA (D. Abramenkoff 1985, Cruise Report 8503-MB, June 7, 1985, 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. On the Soviet cruise ichthyoplankton samples were visually "scanned" to estimate the number of anchovy larvae taken at each station. The scanned estimates were used to estimate the anchovy spawning biomass in the non-surveyed area north of our survey area (Figure 3).

In summary, in the late winter of 1985 anchovies were spawning from Baja California to the San Francisco Bay. There was a large concentration of spawning anchovies in the southern California Bight that were further offshore than usual. Elsewhere the population was closer to shore but they were generally not present in the colder upwelled water adjacent to the coast.

BIOMASS MODEL

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

$$B = P_0 A \frac{k\,W}{R\,F\,S}, \qquad (1)$$

where B = spawning biomass in metric tons

P_0 = 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

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

An estimate of an approximate variance for the biomass estimate, derived using the delta method (Seber 1983), is:

$$\mathrm{var}(B) \cong B^2(\mathrm{var}(P_0)/P_0^2 + \mathrm{var}(W)/W^2 + \mathrm{var}(R)/R^2 + \mathrm{var}(F)/F^2 + \mathrm{var}(S)/S^2 + 2[\mathrm{cov}(P_0W)/P_0W - \mathrm{cov}(P_0R)/P_0R - \mathrm{cov}(P_0F)/P_0F - \mathrm{cov}(P_0S)/P_0S - \mathrm{cov}(WR)/WR - \mathrm{cov}(WF)/WF - \mathrm{cov}(WS)/WS + \mathrm{cov}(RF)/RF + \mathrm{cov}(RS)/RS + \mathrm{cov}(FS)/FS]). \quad (2)$$

DAILY PRODUCTION OF EGGS

The daily production of eggs in the sea, P_0, 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) which assumes that all spawning occurs at 2200 hours each night. An exponential mortality curve for the eggs was fit to the egg age data. The daily production of eggs was estimated as the value of the predicted curve at the origin.

In order to reduce the variance of the estimate of P_0, a two stage sampling scheme with post-survey stratification was used. The first stage was the systematic ichthyoplankton sample of the survey area. Each sample was assigned a weighting factor proportional to the area which the station represented. The second stage 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).

The egg mortality model

$$P_{jt} = P_0^1 e^{-Zt} \qquad (3)$$

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

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

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_0^1 = 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:

$$P_0 = (A_1/A)\ P_0^1 \qquad (4)$$

$$\mathrm{var}(P_0) = (1+1/n)[(A_1/A)\ \mathrm{var}(P_0^1)] \qquad (5)$$

where n = the total number of stations

A_1 = the area of stratum 1

A = the total survey area

The estimates which were used to compute P_0 and their variances are given in Table 1. The estimate of P_0 is 4.777 eggs per day per $0.05 m^2$ for the entire 51,720 nm^2 survey area, with an approximate variance of 0.326. This gives a coefficient of variation of 11.96%.

ADULT PARAMETERS W, F, S, AND R

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

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

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

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 = $\sum_j y_{ij}/m_i$ 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. Average female weight was computed by selecting 25 females from each trawl; however this was not always possible since 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 water (hydrated). The extra weight of the hydrated eggs was corrected by regressing the whole body weight of mature females without hydrated eggs against their ovary-free weight and then estimating the whole body weight of the hydrated females as if they did not contain hydrated eggs. The following regression equation was found:

$$\hat{W} = -0.3030 + 1.09\ W^* \tag{8}$$

where $\hat{W}$ = estimated whole body weight in grams

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 85 fish were selected so the ovary-free weight of the sample was similar to the ovary-free weight of all mature females (Figure 8). The estimated regression equation was:

$$\hat{F} = -2035.6 + 682.1\ W^* \tag{9}$$

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 of the fish from its ovary-free weight and the above regression. The average batch fecundity for the entire survey area was estimated using equation (6) where $y_{ij} = \hat{F}_{ij}$, the estimated batch fecundity; the desired 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):

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

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

$\hat{\mathrm{var}}(b)$ = 2453, variance of the slope of the regression

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 $\bar{y} = S_i$ 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 over-sampled by the trawl (Picquelle and Hewitt 1983). To account for this, m_i was adjusted by removing day-0 spawners and assuming that there was an equal incidence of day-0 and day-1 spawning fish. 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 fraction of the population by weight that is female is the parameter R, the female fraction. Equations 6 and 7 were used where $\bar{y}$ = R_i, the total weight of females in a subsample of approximately 50 male and female fish divided by the total weight of the male and female fish. 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). The frequency distribution of R is given in Figure (10) and its estimate and variance are shown in Table 2.

BIOMASS ESTIMATE AND VARIANCE

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

The results of the cruise of the MYS BABUSHKINA show that, as in past years, there is spawning off San Francisco. The Soviet cruise covered the area from Pt. Conception (CalCOFI line 80.0) north to line 70.7, the northern extent of our biomass survey (region 1) as well as the region not covered by our biomass survey north of line 70.7 to the San Francisco area (region 2). The Soviet cruise collected anchovy eggs and larvae by means of a bongo net. Because larvae are less patchy than eggs, "scanned" larvae counts (Figure 3) were used 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 equal. The biomass of region 2 was calculated as:

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

where B2 = estimated spawning biomass of region 2

B1 = 29,090 mtons is the spawning biomass of region 1 (biomass equation)

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

$L2_i$ = " " " " " region 2

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 mtons. This estimate has no associated estimate of variance, and the coefficient of variation is necessarily larger than the 19% associated with B1.

DISCUSSION

The 1985 egg production method estimate of the spawning biomass of the central sub-population of the northern anchovy is up by 61% from its all time low (since 1980) in 1984. Table 4 lists the historical time series of the parameters. The increase in spawning biomass is caused by a 31% increase in egg production and a 21% increase of female weight. The increase in batch fecundity is strongly related to the increase in female weight since the two are highly correlated (Table 3). The ratio of the batch fecundity and the mean weight (F/W) gives an indication of the specific batch fecundity (Table 4). The increase in this ratio is less than the increase in batch fecundity. This implies that much of the increase in batch fecundity is due to a larger average female weight. The spawning fraction has dropped since last year to a level that is average for the previous years. Female fraction remained at a very high level compared to the years before 1984. The daily specific fecundity is down a little but is still high compared to most years. This is due to the unusually large female fraction.

The spawning biomass estimate can be compared to an annual acoustic survey which provided an estimate 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 (K.F. Mais 1985, Cruise Report 85-X-1, CDFG, Long Beach, California). The cruise was restricted to the area between Pt. 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 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 estimated the total biomass of anchovies (not spawning biomass) to be 627,000 to 753,000 mtons in the U.S. waters off Southern California. This is up 30.8 to 34.5 percent from his estimate of 1984. He concludes that the 1985 estimate is the largest in 5 years and it would have been higher had the proportion of the anchovy population located in Mexican waters been included.

In previous year's 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 in those years 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.

ACKNOWLEDGEMENTS

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Table 1: Parameters for computing the daily production of eggs.

	Stratum 0	Stratum 1	Total Survey
P_0 (eggs/day-0.05m^2)	0	6.41	4.77
var(P_0)	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}
P_0A (eggs/day)			16.95×10^{12}
var(P_0A)			4.11×10^{24}

Table 2: Estimates of egg production parameters, their variances, and coefficients of variation.

Parameter		Value	Variance	Coefficient of Variation
Daily egg production (eggs/day)	(P_0A)	16.95×10^{12}	4.11×10^{24}	15.6%
Average female weight (g)	(W)	14.4940	0.10519	2.2
Batch fecundity (eggs)	(F)	7343.	114518.	4.6
Spawning fraction (day^{-1})	(S)	0.1198	0.00024	12.9
Female fraction	(R)	0.6093	0.00038	3.2
Daily specific fecundity (10^6 eggs/day-mton)		37.003		
Spawning biomass (mtons) (not including San Francisco area)	(B)	458,024	7,374,058,390	18.7
Spawning biomass (mtons) (including San Francisco area)	(B)	521,742		

Table 3: Covariances between adult parameters.

	F	S	R
Female Weight (W)	66.25495	0.00076	0.00064759
Batch Fecundity (F)		0.53235	0.44352668
Spawning Fraction (S)			0.00005531
Female Fraction (R)			

Table 4: Time series of egg production parameters (1980-85)

		1980	1981	1982	1983	1984	1985[a]
Daily egg production (10^{12} eggs/day)	(P_0A)	26.34	20.96	13.51	17.25	12.98	16.95
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-mton)		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 mtons)	(B)	870	635	415	652	309	522[b]
Coeff. 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 mtons)		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 area.

[c] Does not include Mexican portion of anchovy population.

FIGURE CAPTIONS

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

Figure 2. Geographic distribution of trawl stations.

Figure 3. Geographic distribution of ichthyoplankton stations and anchovy larvae from the Soviet cruise (MYS BABUSHKINA).

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

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 line) is indicated.

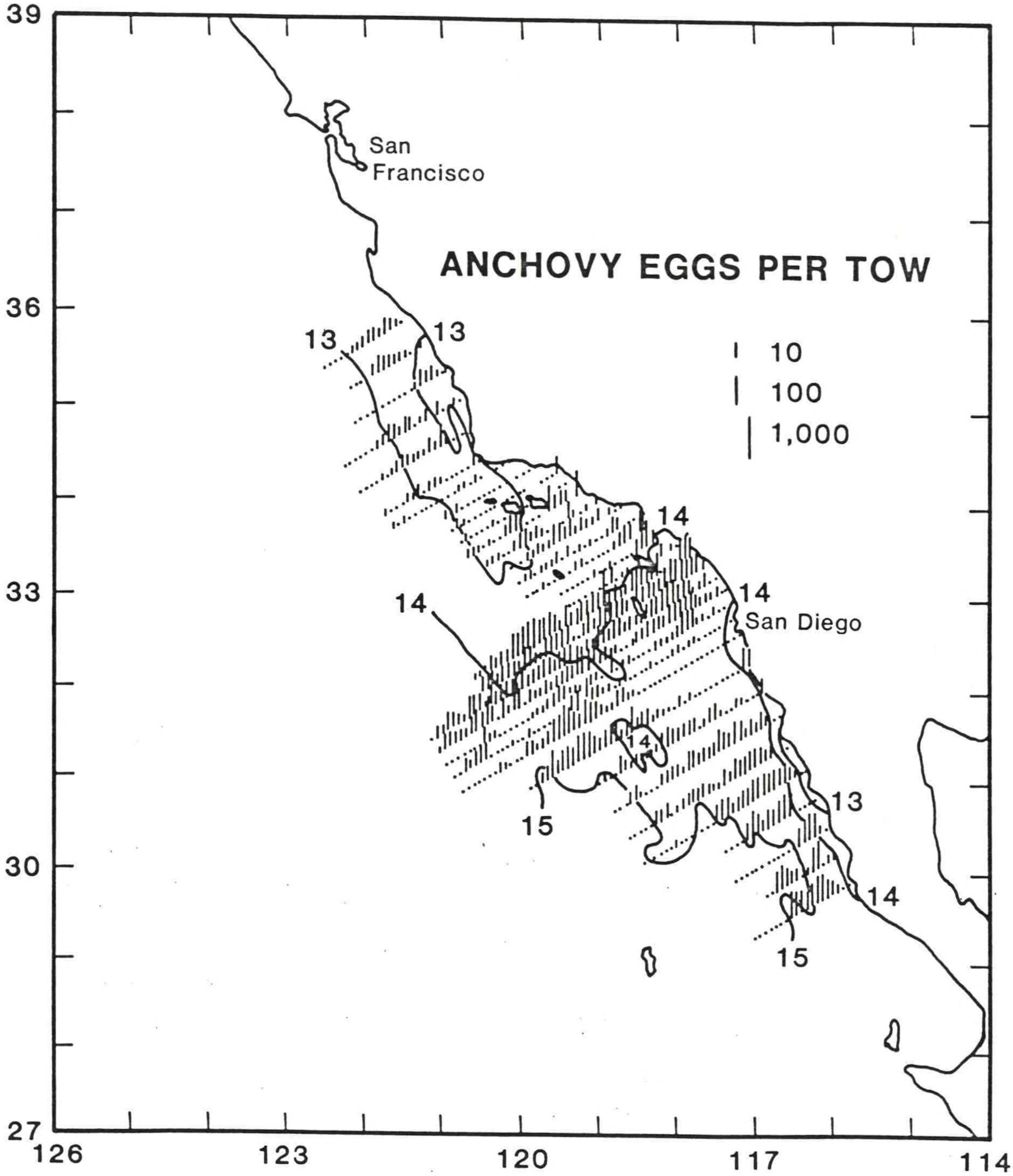
Figure 6. Frequency distribution of average mature female weight per trawl.

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

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.

Figure 10. Frequency distribution of female fraction by weight.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ANCHOVY EGGS PER TOW
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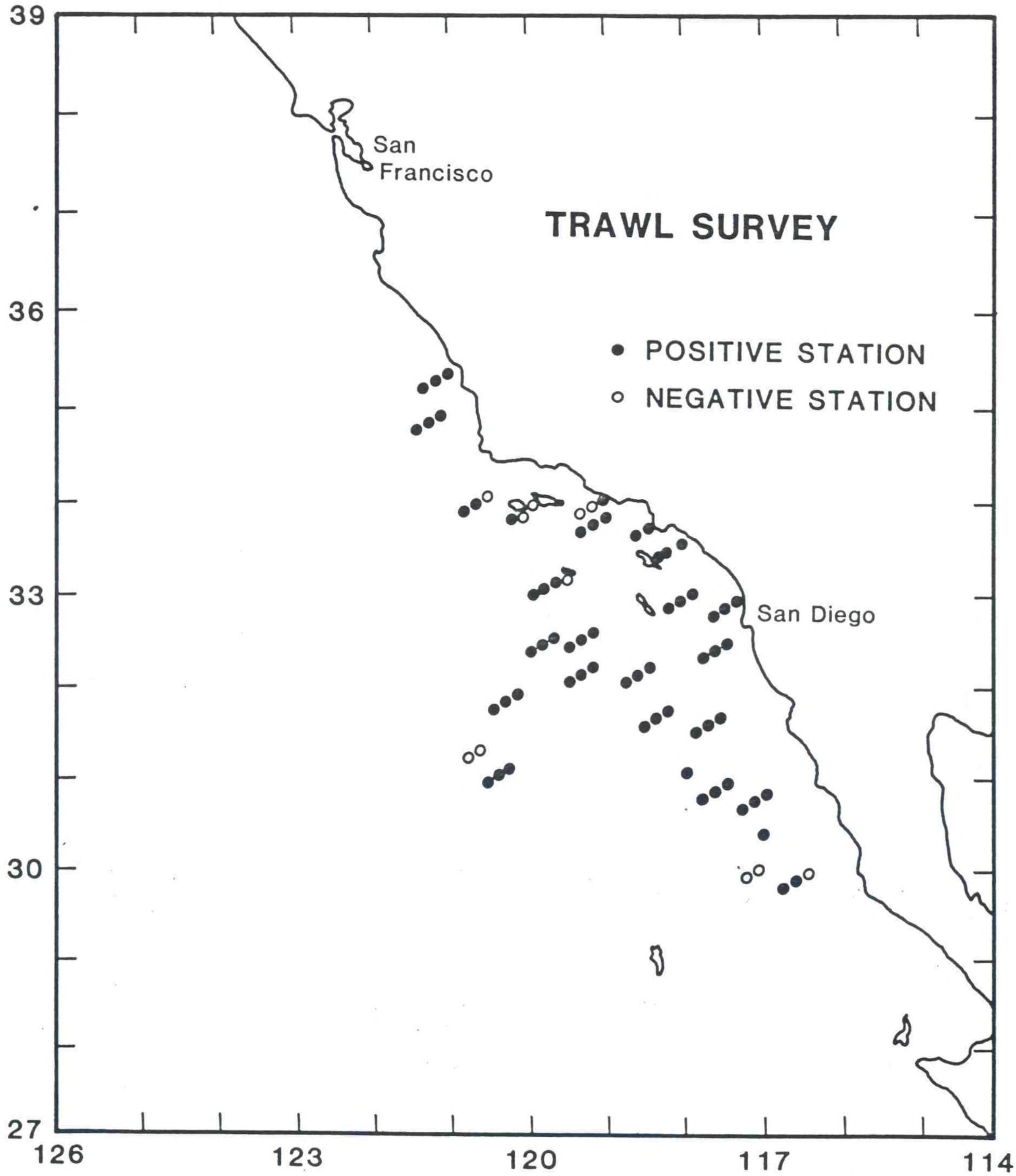
figure 1.



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San Francisco
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POSITIVE STATION
NEGATIVE STATION
San Diego

figure 2.

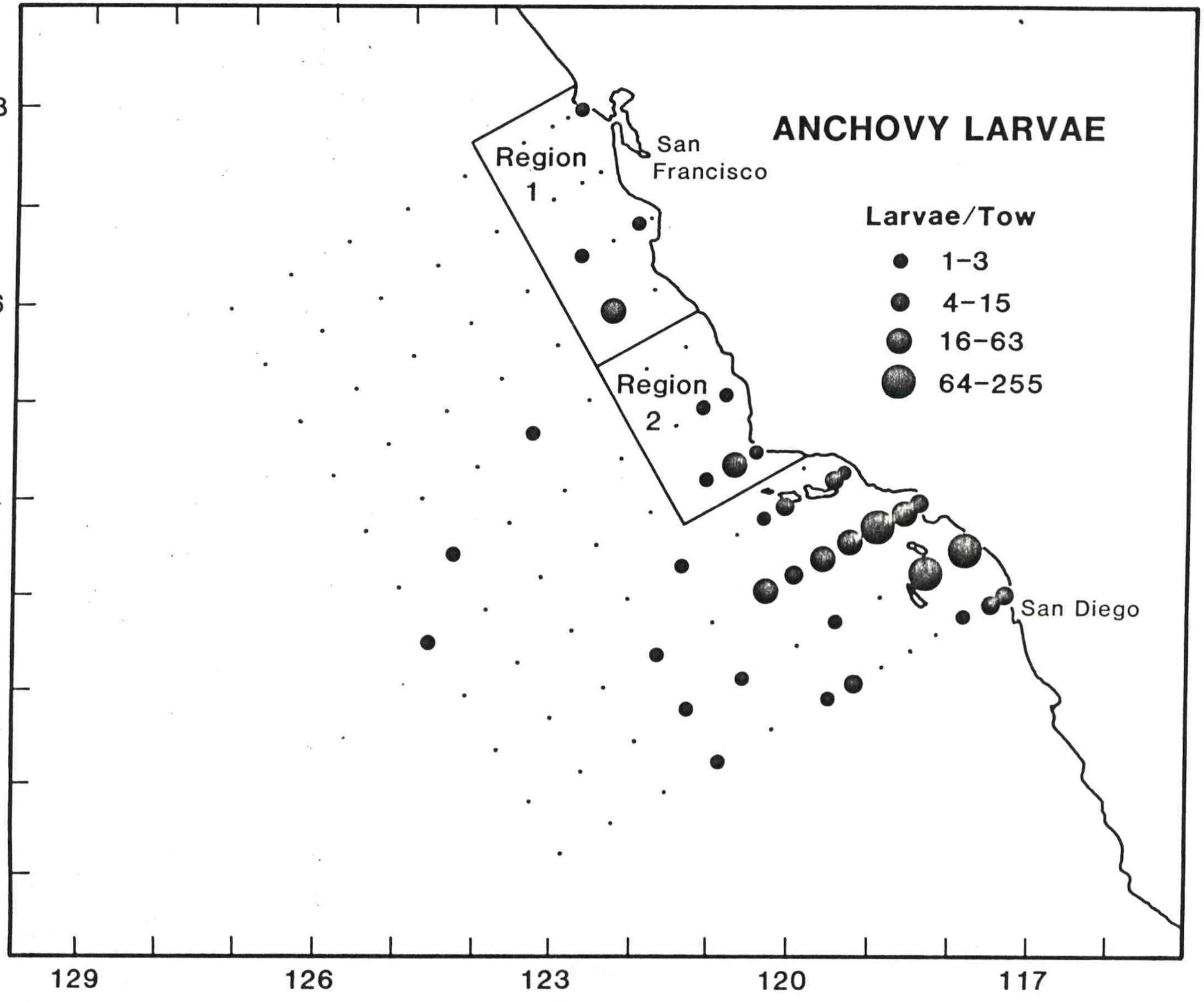
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figure 3.

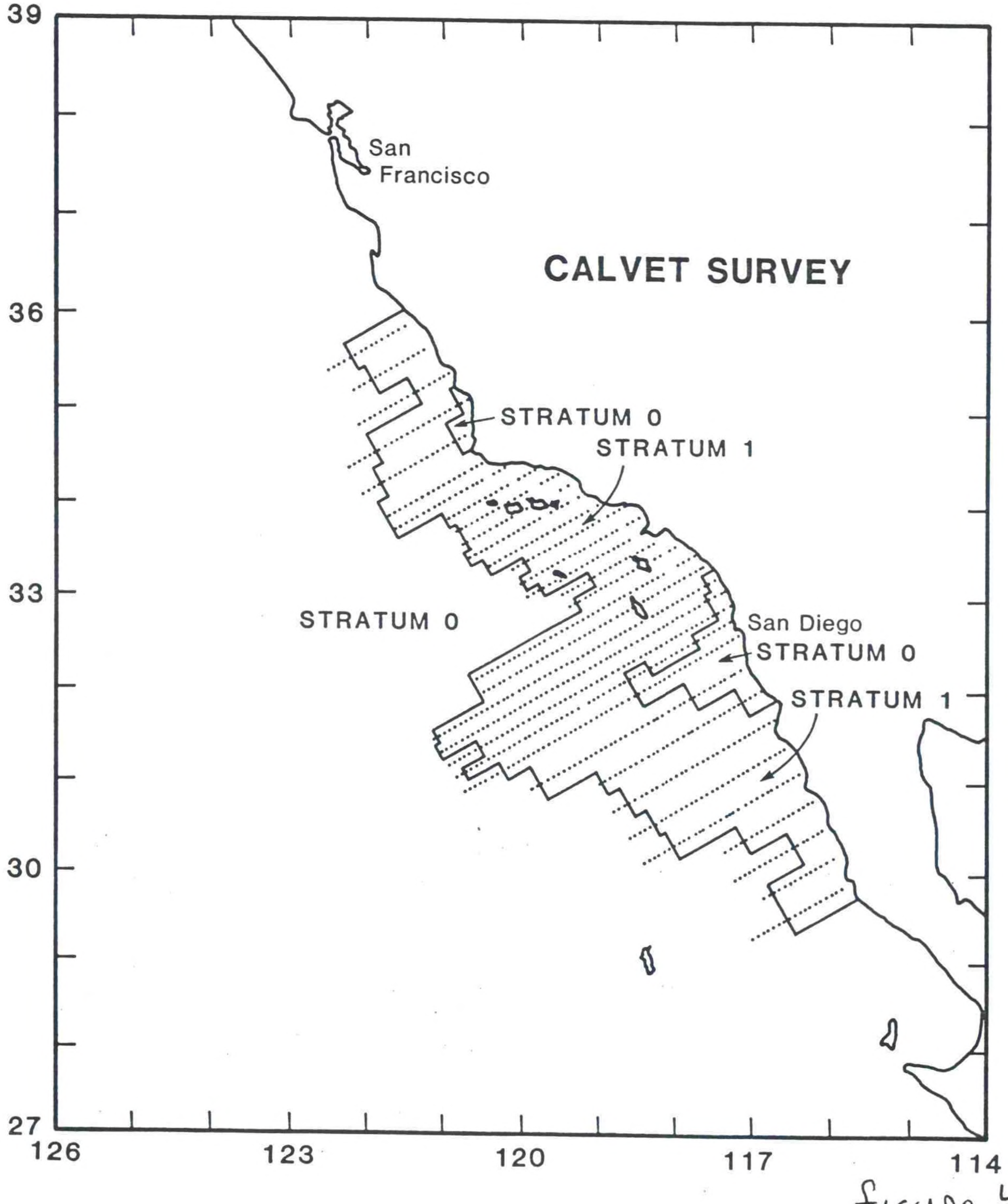
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figure 4.

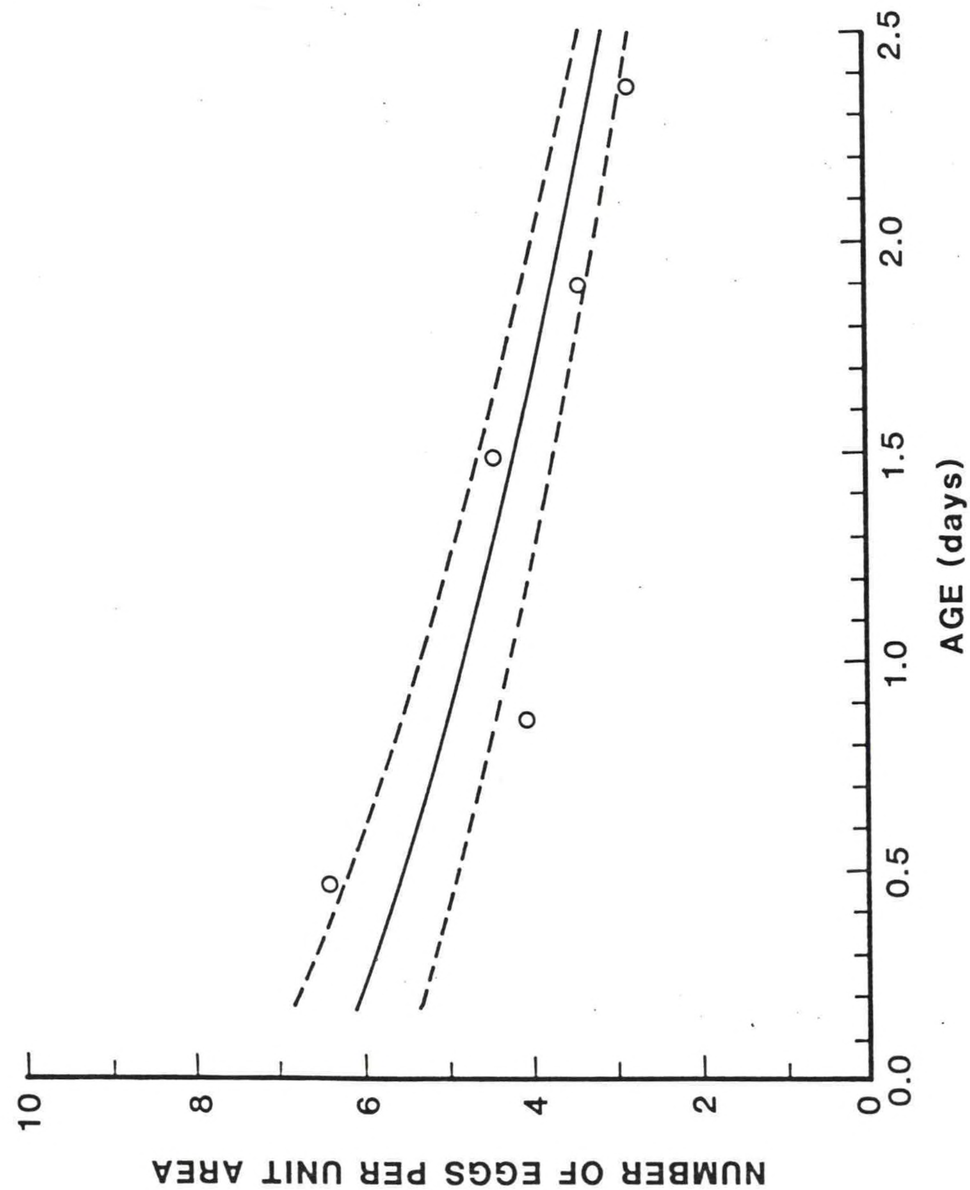
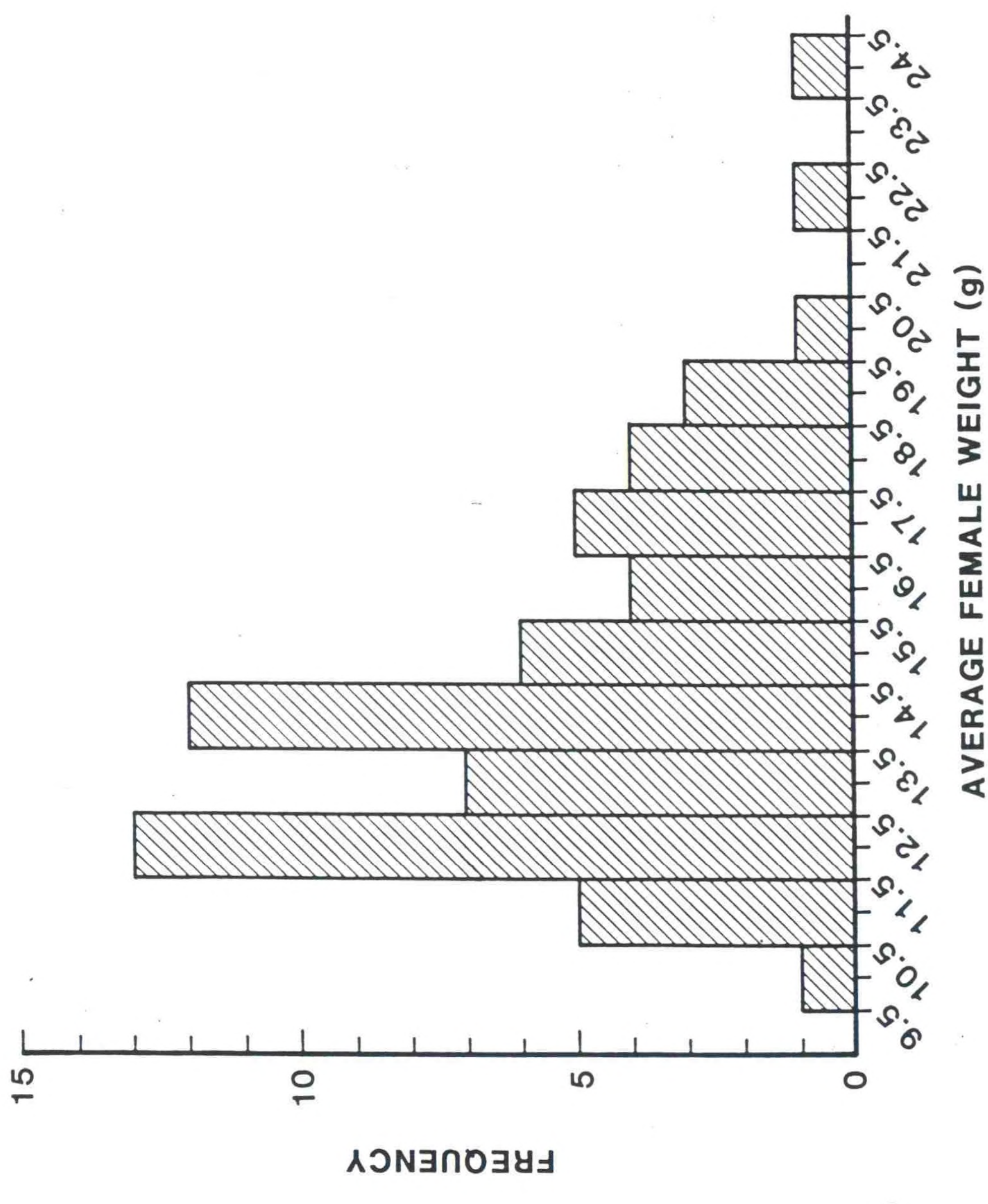


figure 5.


FREQUENCY
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15
AVERAGE FEMALE WEIGHT (g)
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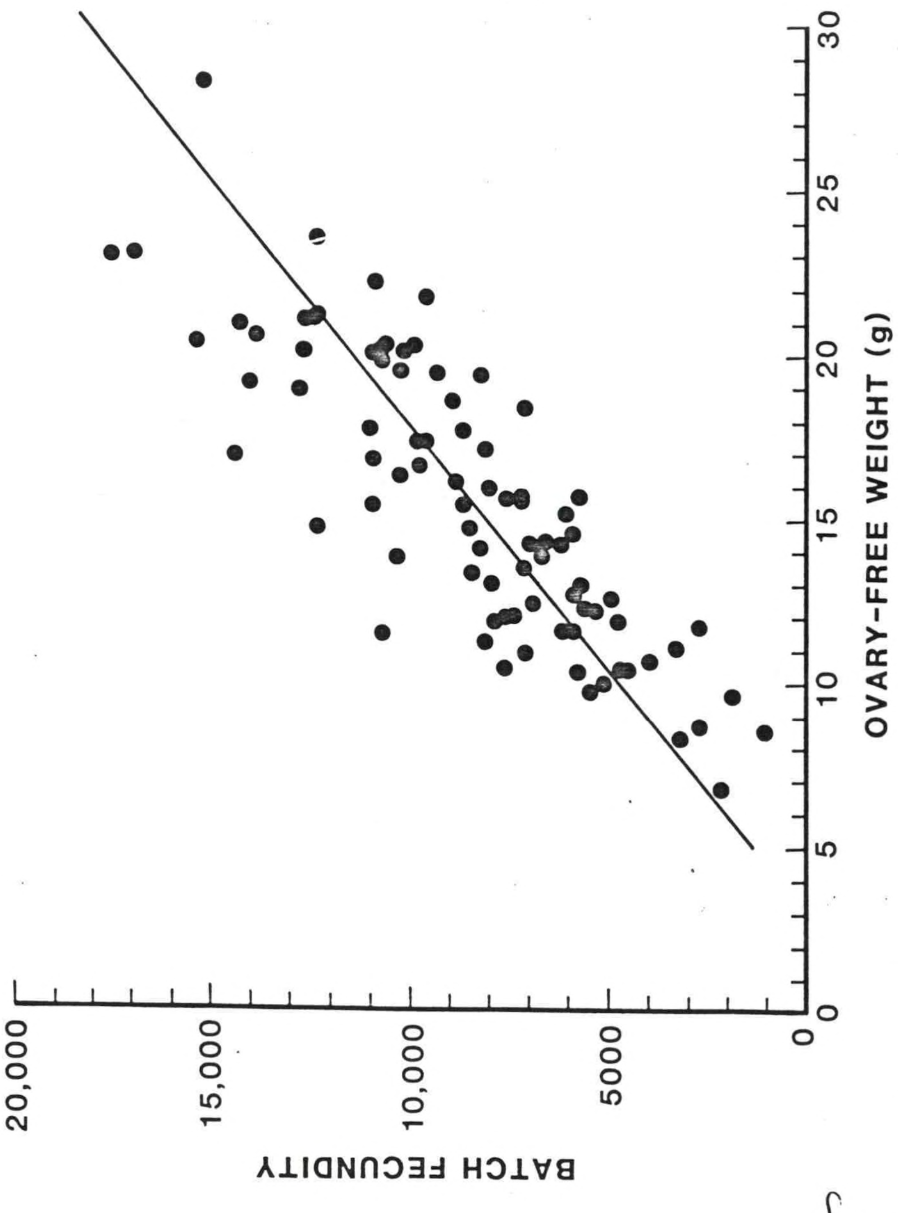
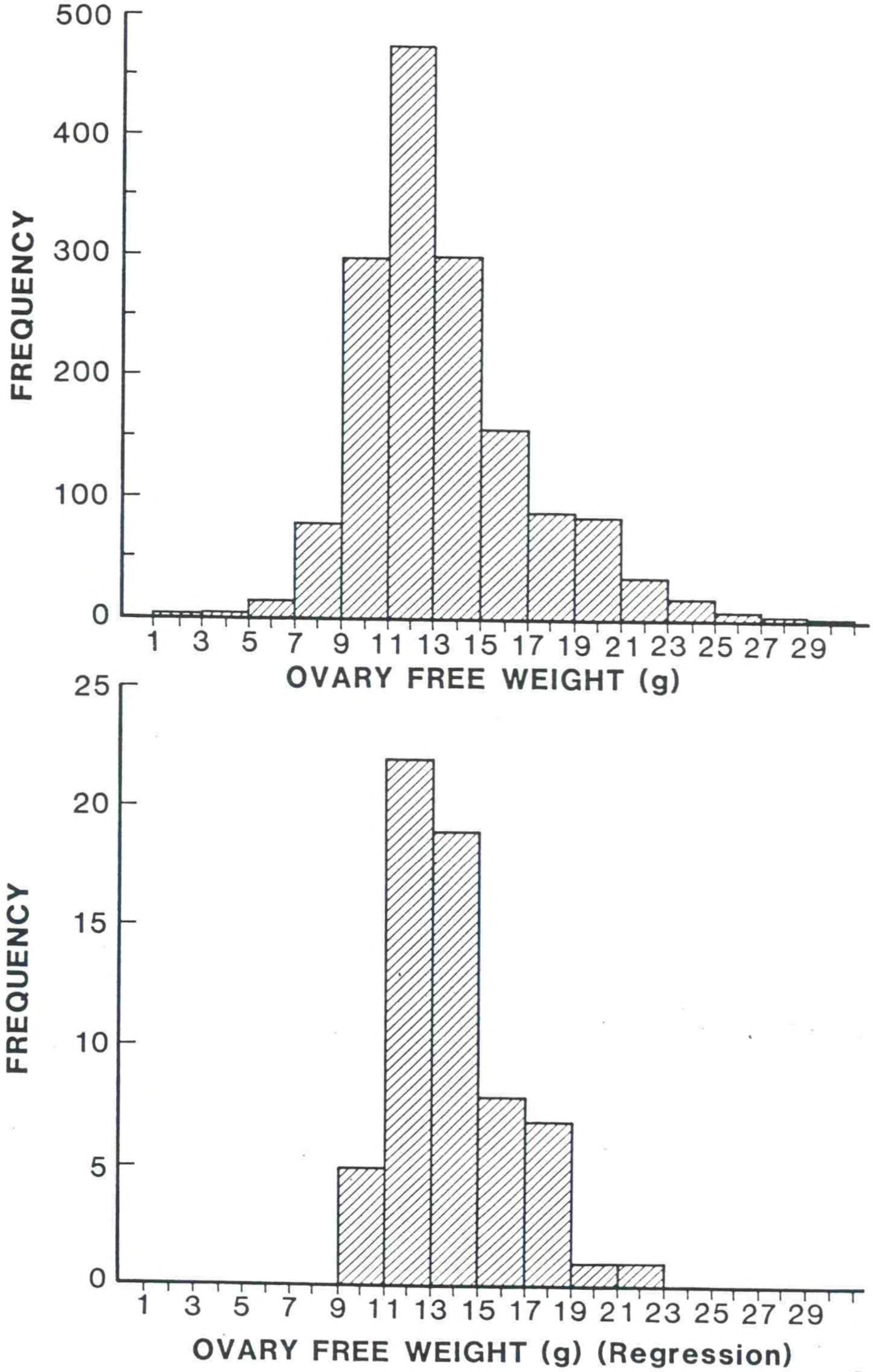
15.5
16.5
17.5
18.5
19.5
20.5
21.5
22.5
23.5
24.5

figure 6.



BATCH FECUNDITY
20,000
15,000
10,000
5000
0
5
10
15
20
25
30
OVARY-FREE WEIGHT (g)

figure 7.



500
400
300
200
100
0
FREQUENCY
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
OVARY FREE WEIGHT (g)
25
20
15
10
5
0
FREQUENCY
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
OVARY FREE WEIGHT (g) (Regression)

figure 8.

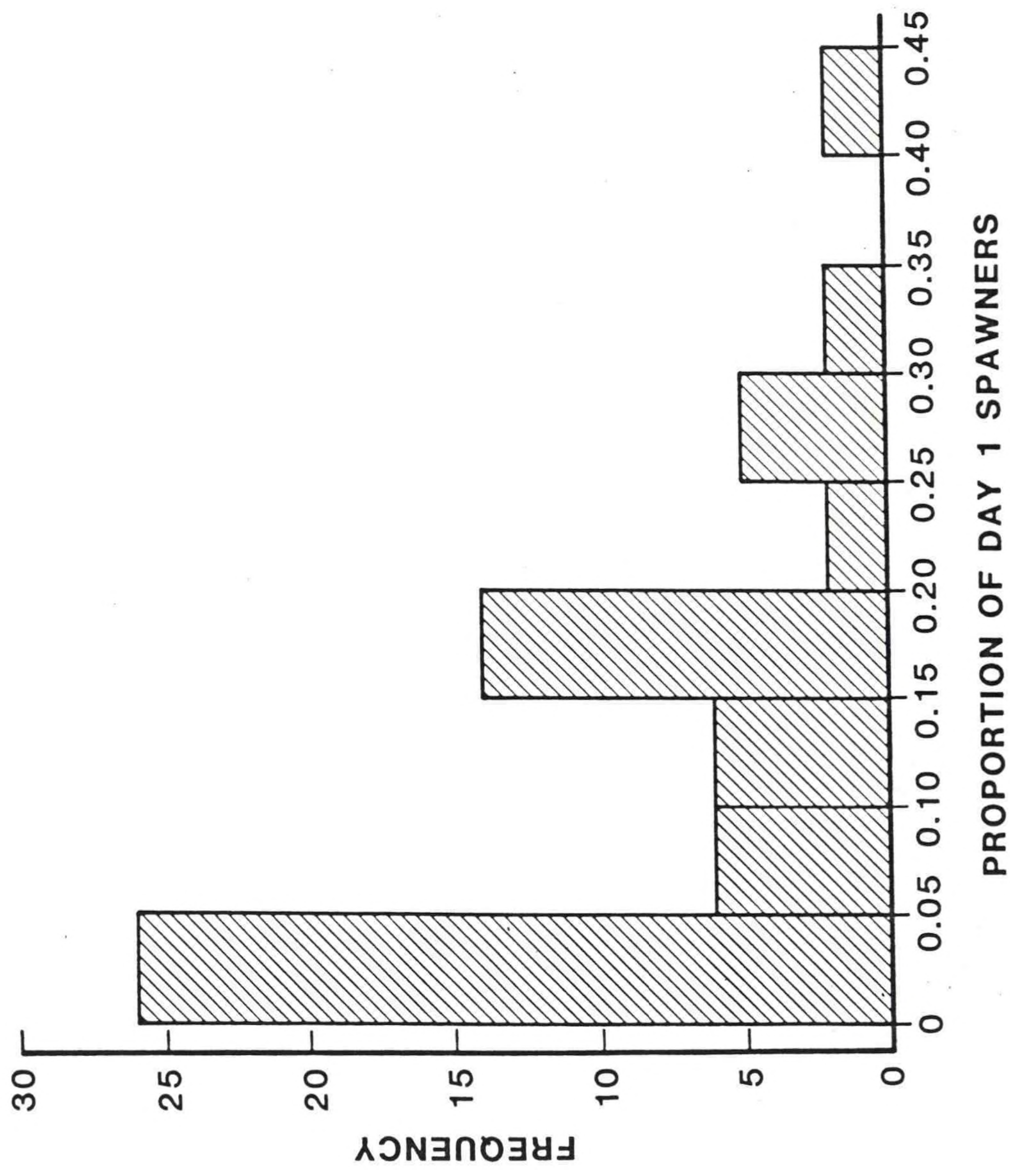
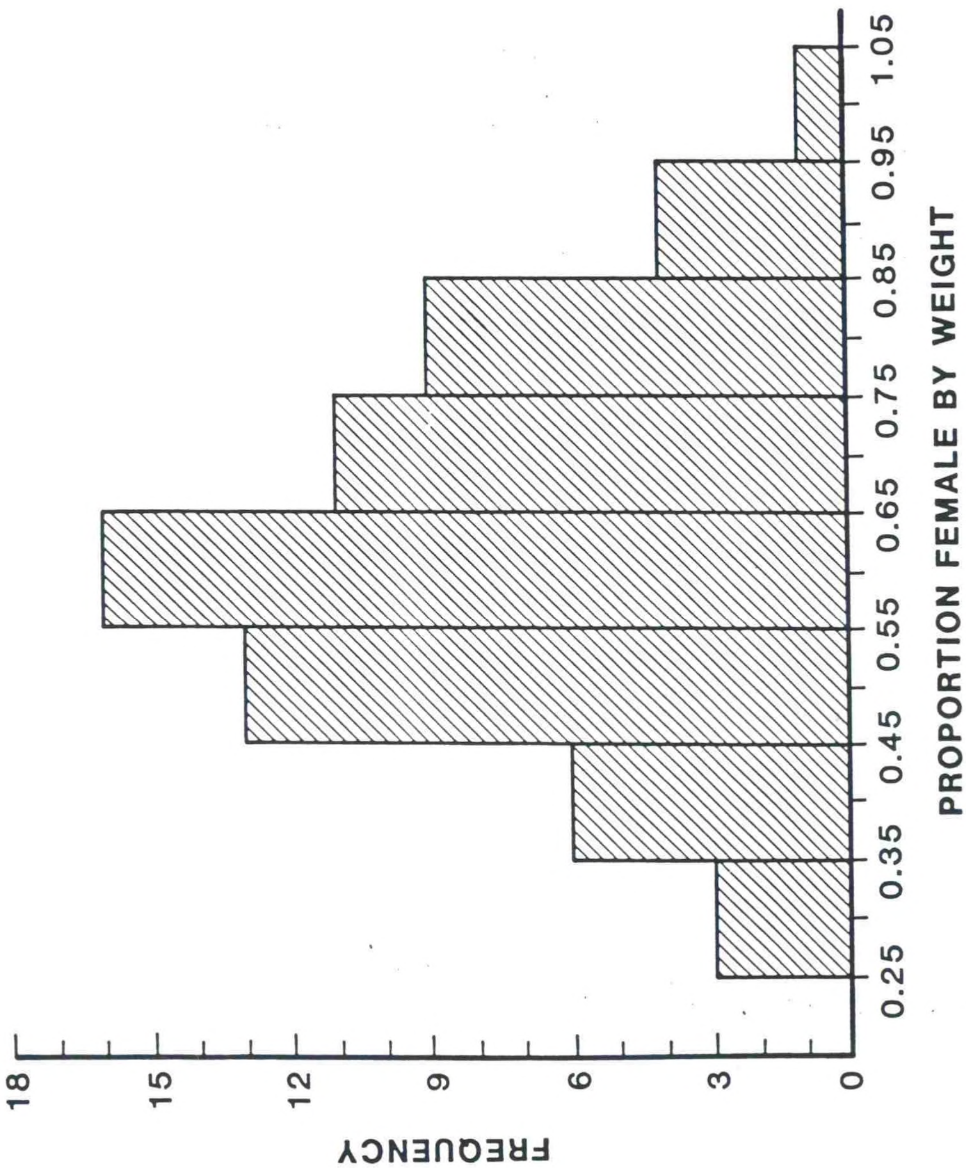

FREQUENCY
0
5
10
15
20
25
30
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
PROPORTION OF DAY 1 SPAWNERS

figure 9.



FREQUENCY
0
3
6
9
12
15
18
0.25
0.35
0.45
0.55
0.65
0.75
0.85
0.95
1.05
PROPORTION FEMALE BY WEIGHT

figure 10.