THE RELATIVE MAGNITUDE OF THE 1986 PACIFIC SARDINE SPAWNING BIOMASS OFF CALIFORNIA

PATRICIA WOLF
California Department of Fish and Game
245 West Broadway
Long Beach, California 90802

PAUL E. SMITH
National Marine Fisheries Service
Southwest Fisheries Center
P.O. Box 271
La Jolla, California 92038

CHERYL L. SCANNELL
California Department of Fish and Game
245 West Broadway
Long Beach, California 90802

ABSTRACT

The spawning biomass of the Pacific sardine off southern California during 1986 remains at or above 20,000 short tons[1]. This determination was made using an egg production area method, which estimates the area over which eggs of a specified spawning biomass (20,000 short tons) would be expected to occur. The area method was developed from the egg production method, which estimates adult biomass from measurements of egg production in the spawning area and from the egg production rate of the adult population. From estimates of components of egg production rate and specific fecundity for sardines, we expected that 20,000 tons of spawning biomass would cover a spawning area of about 500 n.mi^2.

The August 1986 survey extended from Point Conception to San Diego and ranged from the 10-fathom isobath to offshore approximately 25 miles. A total of 266 sardine eggs was collected at 59 of 330 stations. Spawning extended from Santa Barbara to Dana Point and out to the Santa Barbara Channel Islands and Santa Catalina Island, and covered an estimated 955 n.mi^2. This spawning area is 43% larger than the spawning area observed in 1985.

RESUMEN

En 1986, la biomasa de desove de la sardina del Pacífico frente a California del Sur se mantuvo en o por encima de las 20,000 toneladas cortas[1]. Esta determinación fue hecha mediante el método del área de producción de huevos, el cual estima el área en la cual se espera encontrar los huevos correspondientes a una determinada biomasa de desove (20,000 toneladas cortas). El método del área se baso en la método de producción de huevos el cual estima la biomasa de los adultos a partir de las mediciones de producción de huevos en el área de desove y de la tasa de producción de huevos de la población adulta. Dadas las estimaciones de componentes de la tasa de producción de huevos y la fecundidad específica de las sardinas, esperábamos que 20,000 toneladas de biomasa de desove cubrieran un área de desove de aproximadamente 500 millas náuticas^2.

El muestreo realizado en agosto de 1986 se extendió desde Point Conception hasta San Diego y cubrió desde la isóbata de 10 brazas hasta 25 millas mar adentro. Un total de 226 huevos de sardina fue colectado en 59 de las 330 estaciones. El desove abarcó desde Santa Barbara hasta Dana Point y, mar adentro, hasta las islas del canal de Santa Barbara y la isla Santa Catalina y, se estimó que cubrió 955 m.n^2. Este área de desove es un 43% más extensa que la observada en 1985.

INTRODUCTION

In this report we evaluate the magnitude of the 1986 spawning biomass of the Pacific sardine relative to 20,000 tons. The California Department of Fish and Game (CDFG) is required to determine annually whether the spawning biomass is above or below this level. Earlier assessments of the spawning biomass were based on ichthyoplankton surveys, incidental landings in mackerel and live bait fisheries, trawl surveys, and aerial observations. From 1974 through 1985, a moratorium on the fishing of sardines was in effect because the biomass remained below 20,000 tons.

The egg production area technique was developed (Wolf and Smith 1985) and applied to sardines in 1985 (Wolf and Smith 1986). This technique allows an objective determination of whether the spawning biomass has exceeded 20,000 tons. The Pacific sardine fishery was reopened in 1986 with a 1,000-ton quota, since regulations permit a low rate of mortality due to fishing (.05) when the spawning stock recovers to 20,000 tons.

We used the egg production area technique to assess the relative magnitude of the sardine spawning biomass during 1986. Details of the method, including procedures for estimating egg production parameters, are described in Wolf and Smith (1986). An adult survey was conducted simultane-

[1]Commercial landings, tonnages specified in legislation, and tonnages in this paper are reported in short tons.

[Manuscript received February 5, 1987.]

ously with the egg area survey, in order to develop current estimates of adult parameters for Pacific sardines. Results from this survey, however, are not yet available.. Design and results of the 1986 egg survey are presented in the following sections.

EGG PRODUCTION METHOD

The egg production method (Lasker 1985) was developed by Parker (1980) and applied by Picquelle and Hewitt (1983, 1984) and Hewitt (1984) to estimate northern anchovy biomass. This method estimates spawning biomass as

$$B = P_o A \frac{kW}{RFS}$$

where B = spawning biomass (MT),
P_o = daily egg production, number of eggs produced per 0.05 m² of sea-surface area,
W = average weight of mature females (g),
R = sex ratio, fraction of population that is female, by weight (g),
F = batch fecundity, number of eggs spawned per mature female per batch,
S = fraction of mature females spawning per day,
A = total area of survey (0.05 m²), and
k = conversion factor from grams to metric tons.

EGG PRODUCTION AREA METHOD

In the egg production area method, the spawning biomass is specified and the equation solved for A_1:

$$A_1 = \frac{B_1 RFSm}{P_o k_1 W}$$

where A_1 = spawning area of biomass B_1 in nautical miles²,
B_1 = spawning biomass, in short tons,
k_1 = conversion factor from grams to tons,
m = conversion factor from 0.05 m² to nautical miles².

In the egg production method, daily egg production and population fecundity parameters are measured during the survey. Daily production of eggs, P_o, is estimated from the density and embryonic developmental stages of eggs collected in an ichthyoplankton survey. Daily specific fecundity parameters W, F, S, and R are estimated from samples of adult fish collected during the survey.

In the egg production area method, we adapted existing information from previous studies (Table 1) concerning sardines and related species to estimate parameters P_o, W, F, S, and R for sardines. This range of parameter estimates—presented and described in Wolf and Smith (1986)—was used in the egg production area equation to produce a range of estimates of A_1. We selected 500 n.mi² from the range of values as a useful estimate of spawning area.

SURVEY DESIGN

The 1986 survey was conducted in August, rather than in May, as in 1985. Several sources of information, including nearshore egg and larval surveys in the Southern California Bight (R.J. Lavenberg, Los Angeles County Museum of Natural History, pers. comm.) indicated that sardine spawning in recent years has occurred in late summer and fall rather than in spring. CDFG surveys of young fish did not detect evidence of sardine recruitment until September 1985. Adult sardines captured in these sea surveys and incidentally in

TABLE 1
Values of Parameters Used to Estimate Spawning Area, and Resulting Estimates

B_1	W	R	F	P_o	S	A_1
Spawning biomass (short tons)	Average female weight (g)	Sex ratio (females/total)	Batch fecundity (eggs/batch female)	Egg production (eggs/.05m²-day)	Spawning fraction (spawning females/ total females)	Spawning area (nautical miles²)
20,000	120	0.5	32,000	5.0	0.02	141
					0.05	353
					0.10	706
					0.15	1,058
				1.5	0.02	470
					0.05	1,176
					0.10	2,352
					0.15	3,528

the mackerel fishery were in progressively more advanced prespawning states in summer and fall during 1985.

The location of the survey area was based on results of the 1985 survey, which indicated that sardine spawning took place relatively close to shore and was prevalent in the eastern portion of the Santa Barbara Channel. Stations were more concentrated in 1986, and were spaced 4 n.mi. apart offshore and 4 n.mi. alongshore, in an attempt to obtain a greater number of positive stations to improve information on the sampling distribution of eggs. The survey covered approximately 5,000 n.mi^2. As in 1985, the critical spawning area, A_1, was estimated to be 500 n.mi^2., or approximately 10% of the 1986 survey area. Because each station represented 16 n.mi^2., the calculated spawning area that 20,000 tons of sardines would cover was expected to produce at least 31 stations with eggs present.

SURVEY DESCRIPTION

The survey was conducted aboard the Occidental College research vessel *Vantuna*, from August 4 through August 12, 1986. Stations were occupied north to south from Point Conception to the Mexican border, from the 10-fathom isobath to approximately 25 n.mi. offshore (Figure 1). Samples were collected at all hours, and, in contrast to the 1985 survey, stations occurring within shipping lanes were occupied. Plankton samples were collected at 330 stations using a 25-cm-diameter CalVET net (vertical egg tow) of 150-micron mesh. The net was retrieved vertically from 70 meters where depth allowed. Plankton samples were preserved in 5% buffered Formalin solution at sea. In the laboratory, sardine and anchovy eggs and larvae were identified, sorted, and counted.

The 1986 survey collected a total of 266 sardine eggs from 59 stations, with the number of eggs per station ranging from 1 to 18 (Figure 2). The mean number of eggs per station was 4.51 (standard error = 0.548) (Table 2). Positive stations occurred along the coast between Santa Barbara and Ventura; in the eastern portion of the Santa Barbara Channel out to and around Santa Cruz Island; in Santa Monica Bay and offshore in the Santa Monica Basin to approximately 30 miles; and between Seal Beach and Dana Point, along the coast and out to Santa Catalina Island in the San Pedro Channel. A total of 413 sardine larvae was collected at 113 stations, from approximately the same areas as sardine eggs (Figure 3). The number of sardine larvae per positive tow ranged from 1 to 22.

Evidence of anchovy spawning was much less

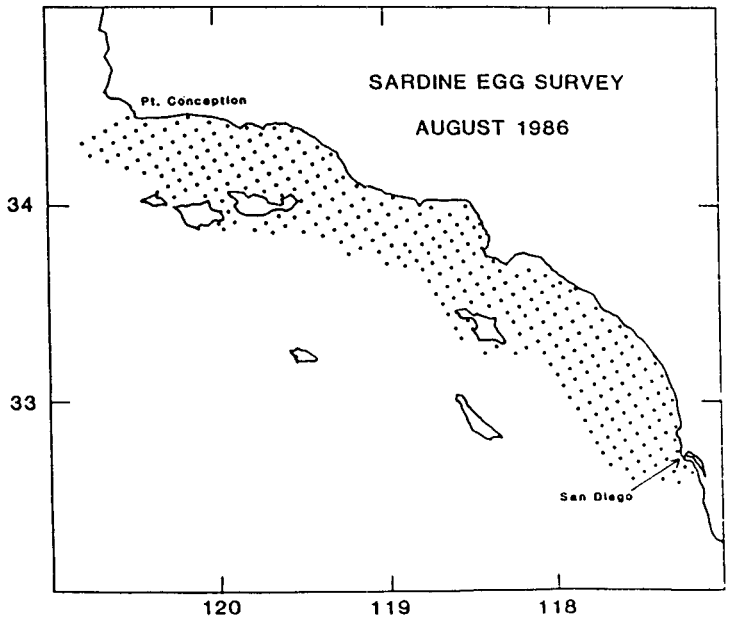

Figure 1. Stations occupied during sardine survey, August 1986.

TABLE 2
Pacific Sardine Egg Sample Frequency Distributions at Different Levels of Estimated Spawning Biomass[a]

#/10 m²		Net types and years						
		CalVET	CalVET	CDFG 2-m	1-m	0.5-m	Hi-speed	1-m
x	ln (x)	1986	1985	1931–32	1941	1941	1950	1959
.125	−2.08	—[b]	—	2	—	—	—	—
.5	−0.69	—	—	4	—	—	—	—
2	0.69	—	—	6	21	—	—	28
8	2.08	—	—	7	22	8	—	28
32	3.47	—	—	14	16	15	—	30
128	4.85	19	4	12	31	29	77	23
512	6.24	22	4	13	27	14	20	12
2,048	7.62	18	2	5	17	10	7	5
8,192	9.01	0	1	2	3	2	1	4
Estimated mean		902	1,564	544	569	619	406	410
(Biomass (10^6 MT)[c])		0.02	0.02	3.9	2.7	2.7	1.0	0.2

[a](Smith and Richardson 1977)
[b]Value below sampler threshold
[c](Murphy 1966)

common, probably because most anchovy spawning occurs in February and March. Only 39 eggs and 240 larvae were collected, from 27 and 106 stations, respectively. Furthermore, anchovy eggs and larvae were more concentrated in the southern portion of the survey area, between Point Fermin and San Diego.

SPAWNING AREA

The spawning area was determined by multiplying the number of positive egg stations by the area represented by each station (16 n.mi²). Slight adjustments were made by including half of the unsampled areas that were adjacent to positive stations, averaged along lines by order of occupation.

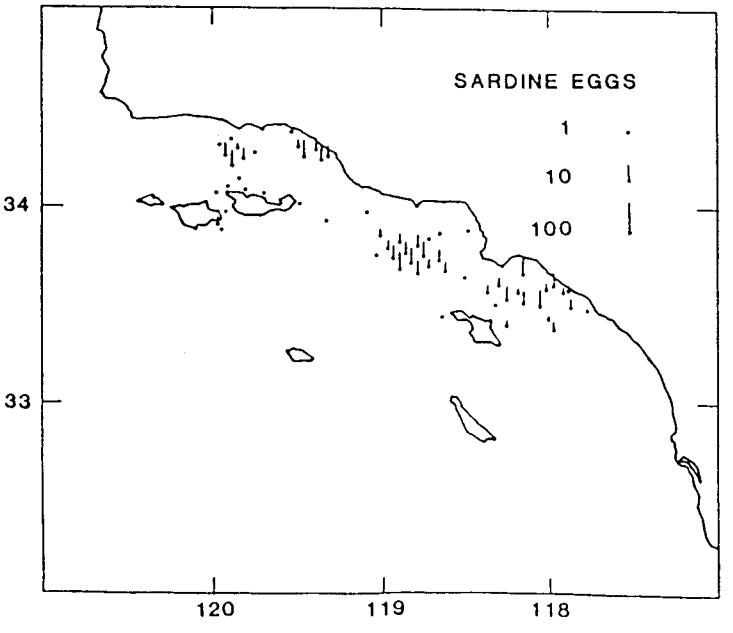

Figure 2. Stations with sardine eggs.

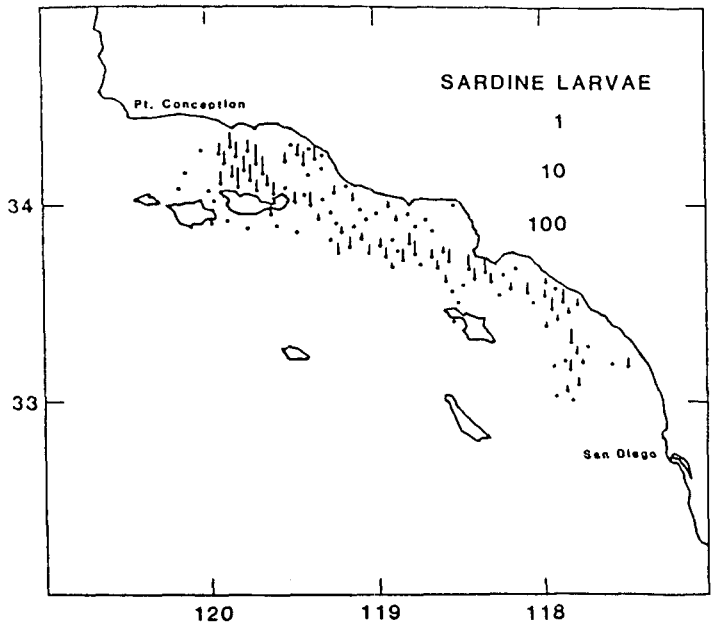

Figure 3. Stations with sardine larvae.

The area of positive stations too near to shore to include an entire 16 n.mi². was also adjusted to include only the portion actually sampled (Figure 4). The adjusted estimate of the 1986 spawning area is 955 n.mi²., which is within the range of spawning area calculated for 20,000 tons of spawning biomass, and greater than the selected estimate of 500 n.mi². for A_1. This year's spawning area is 43% larger than the spawning area determined in May 1985.

DISCUSSION

Because the spawning area detected during the survey exceeds that predicted for 20,000 tons of adult sardines, the spawning biomass of sardines off California is considered to be at least 20,000 tons. As a result, the 1,000-ton fishery for sardines was reopened on January 1[1987. This is the second year of a limited fishery for sardines, and is a continuation of the first directed harvest of sardines allowed in California since the moratorium was enacted 12 years ago.

Although a substantial (43%) increase in spawning area was observed in 1986 compared to the spawning area detected in 1985, the estimate of spawning area for 1986 is probably conservative. Our observations were limited to the survey area, and additional spawning probably occurred elsewhere. We observed evidence of spawning at the offshore edge of the survey, and spawning could have extended beyond those bounds. Fishermen reported large schools of sardines near Santa Barbara Island at the time of the survey. The offshore banks (Tanner and Cortez) were historical spawning grounds for sardines and, although we saw no evidence of spawning there in 1985, it is not known whether spawning occurred in those areas during the 1986 survey. CDFG young-fish surveys in October 1986 detected juvenile sardines near Tanner Bank. Young-of-the-year sardines were observed in Monterey Bay in 1985, and in San Francisco Bay in 1986, indicating that some spawning occurred north of Point Conception in both years.

Our estimate of spawning area for 20,000 tons of adults (500 n.mi².) is based on estimates of the adult reproductive parameters. Daily egg production and spawning fraction are not yet known for Pacific sardines. Two other parameters—average female weight and batch fecundity—were estimated from the historical population. An adult survey, in which sardines were collected by purse seine, was conducted simultaneously with the egg survey during 1986 in order to improve our estimates of these parameters. Results from this survey, however, are not yet available. At low biomass levels, existing techniques for biomass

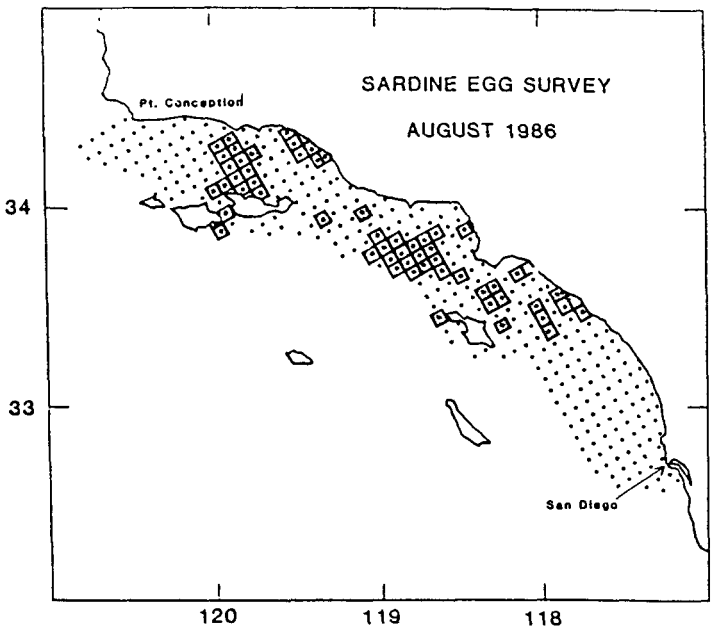

Figure 4. Squares outline the 4-by-4-n.mi. areas represented by each positive station in order to illustrate the spawning area adjustment. Shaded area is the adjusted sardine spawning area.

estimation cannot provide adequate precision. Evaluation of spawning area for biomass assessment is the best available tool where there are low levels of a recovering stock. For sardines, however, the actual relationship between spawning biomass and spawning area is not yet known.

Although the estimated mean of positive samples in the CalVET surveys is high relative to samples taken in the 1930s and 1950s, the 1986 estimated mean appears to be more realistic. This reflects the increased number of positive samples, but still points to technical problems (sampling threshold and scale of integration of the CalVET net relative to other samplers) that cannot be resolved with small numbers of samples.

ACKNOWLEDGMENTS

We thank the crew of the Occidental College RV *Vanduna* and the captain, M. Kibby. B. Flerx and D. Abramenkoff of the National Marine Fisheries Service (NMFS) provided assistance with cruise logistics and equipment. The scientific crew participating in the cruise included A. Enami, G. Lang, J. Patman, and P. Simon of Occidental College. L. Dunn, M.A. Lumpkin, M.E. Farrell, F.R. Pocinich, and M.J. Haddox of Scripps Institution of Oceanography sorted the CalVET plankton samples, and B. Sumida MacCall, E.M. Acuna, E.G. Stevens, and D.A. Ambrose of NMFS staged the sardine eggs under the supervision of Dr. H.G. Moser. C.S. Methot and C. Meyer of NMFS entered and edited the data.

LITERATURE CITED

Hewitt, R.P. 1984. The 1984 spawning biomass of the northern anchovy. SWFC Admin. Rep. LJ-84-18, 17 p.

Lasker, R., ed. 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy (*Engraulis mordax*). U.S. Dep. Commer. NOAA Tech. Rep. NMFS 36, 99 p.

Murphy, G.I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proc. Calif. Acad. Sci. 34:1–84.

Parker, K. 1980. A direct method for estimating northern anchovy, *Engraulis mordax*, spawning biomass. Fish. Bull., U.S. 78:541–544.

Picquelle, S.J., and R.P. Hewitt. 1983. The northern anchovy spawning biomass for the 1982–83 California fishing season. Calif. Coop. Oceanic Fish. Invest. Rep. 24:16–28.

———. 1984. The 1983 spawning biomass of the northern anchovy. Calif. Coop. Oceanic Fish. Invest. Rep. 25:16–27.

Smith, P.E., and S.L. Richardson. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Tech. Paper No. 175, 100 p.

Wolf, P., and P.E. Smith. 1985. An inverse egg production method for determining the relative magnitude of Pacific sardine spawning biomass off California. Calif. Coop. Oceanic Fish. Invest. Rep. 26:130–138.

———. 1986. The relative magnitude of the 1985 Pacific sardine spawning biomass off southern California. Calif. Coop. Oceanic Fish. Invest. Rep. 27:25–31.