# SPAWNING BIOMASS OF THE NORTHERN ANCHOVY IN 1988

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## ABSTRACT

The spawning biomass estimate of the northern anchovy in 1988 is 1,009,000 MT. The estimate was made with the stock synthesis (SS) model, which uses time series of abundance data and age composition data, anchovy landings from the United States and Mexico, and sea-surface temperature. New data incorporated in the 1988 estimate were an egg production index derived from CalCOFI plankton samples of January–February 1988, monthly sea-surface temperatures taken at the pier of the Scripps Institution of Oceanography, and the age composition from the Mexican fishery in Ensenada during 1987. The spawning biomass of anchovy in 1988 remained at a level similar to that in 1987.

## RESUMEN

La estimación de la biomasa del desove de la anchoveta del norte es de 1,009,000 toneladas métricas para 1988. Esta estimación se realizo por medio del modelo de síntesis del stock ("stock synthesis", SS), que utiliza una combinación de datos distribuídos en el tiempo de abundancia y composición por edad, datos de desembarque de capturas de los Estados Unidos y Mexico, y datos de temperatura de la superficie del mar. Se incorporaron a la estimación de la biomasa del desove para 1988 datos nuevos, tales como el índice de producción de huevos obtenido de las muestas de plancton recolectadas en los meses de enero y febrero de 1988 por la campaña de la CalCOFI, los valores de temperatura de las aguas de superficie obtenidos desde el muelle del Scripps Institution of Oceanography, y los datos de composición por edad obtenidos por la pesquería de Ensenada durante el año 1987. La biomasa del desove de la anchoveta para 1988 es similar a la del año 1987.

## INTRODUCTION

This is a report on the estimate of the 1988 spawning biomass of the central subpopulation of the northern anchovy (*Engraulis mordax*). The Southwest Fisheries Center is required to estimate the spawning biomass according to the provisions of the Anchovy Management Plan of the Pacific Fishery Management Council (PFMC 1983). In 1980–85, the spawning biomass was estimated by the egg production method (EPM) (Lasker 1985). Beginning in 1986, the estimate was computed by the stock synthesis (SS) model (Methot 1986; Methot and Lo 1987). The SS model integrates the EPM observation with other data. These data include other biomass indexes, age composition from U.S. and Mexican fisheries, age composition from California Department of Fish and Game surveys, and environmental data. Although four time series of abundance data are used in the historical model, the new data points in 1988 are only (1) the modified historical egg production computed from plankton samples in the California Cooperative Oceanic Fisheries Investigation (CalCOFI) survey; (2) the 1987 age composition data from the Mexican fishery in Ensenada (pers. comm. Walterio Garcia Franco, Centro Regional Investigación de Pesquera [CRIP], Instituto Nacional de Pesca); and (3) the sea-surface temperature at the pier of the Scripps Institution of Oceanography.

## MODEL

The SS model (figure 1) developed by Methot (1986) and revised by Methot and Lo (1987) and Methot (in press) used data on age composition and various biomass time series to construct time series of age-structured populations. The age-composition data provide information on recruitment variability and describe year-to-year changes in relative abundance; biomass time series establish the trend in abundance. The population from the model is characterized by a set of biological parameters, e.g., recruitment, natural mortality, age-specific availability to the fishery, and temperature-dependent fraction of age 1 anchovy that are mature. Other parameters are associated with fishery-independent biomass estimates. Parameter estimates are chosen so that the age compositions and biomass indexes

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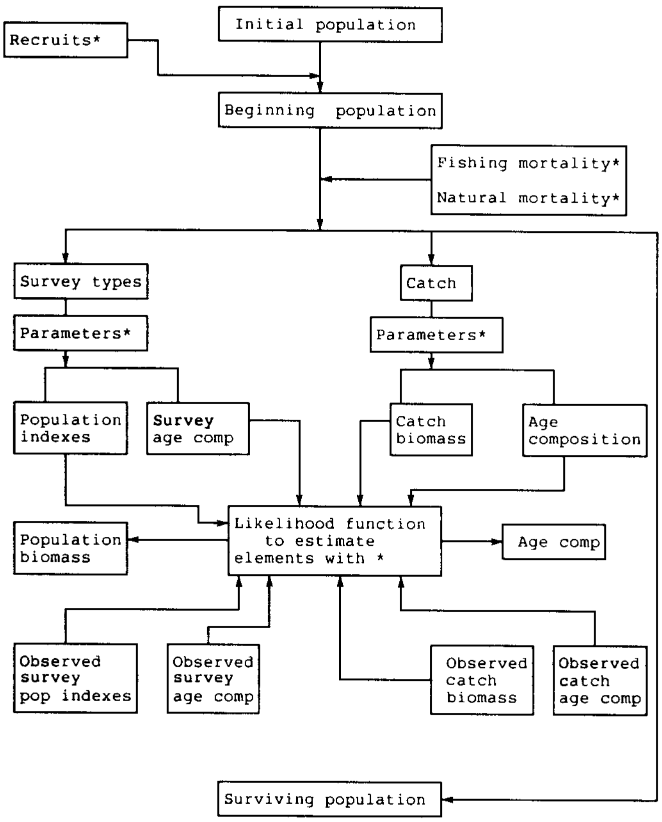


Figure 1. Schematic stock synthesis model. Asterisks indicate parameters to be estimated by the model.

computed from the model closely match the "observed" values. The best estimates are those that maximize a composite likelihood function. These estimates are then used in the population model to compute biomass at age and the spawning biomass (figure 1).

The observed age compositions are obtained from commercial catches of the U.S. and Mexican fisheries and from U.S. sea surveys. The observed biomass may be any existing biomass time series. The current SS model uses spawning biomass time series (table 1) from the egg production method (Lasker 1985; Bindman 1985), historical egg production (HEP) (Lo 1985), sonar (Mais 1974), and modified HEP (Methot and Lo 1987). The environmental variable, sea-surface temperature (George Anderson, SIO, pers. comm.), is included to model the availability to the fishery, the fraction of one-year-olds that are mature, and the fraction of one-year-olds that are actively spawning (Methot, in press). The natural mortality was fixed at the value 0.6, which is consistent with the literature (MacCall 1974) and earlier investigation with the SS model (Methot 1986).

TABLE 1
**Fishery-Independent Spawning Biomass Estimate for Northern Anchovy**

| Year | EPM | HEP | MHEP | *Z* | Sonar |
|---|---|---|---|---|---|
| 1951 | – | 0.012 (0.12) | 0.011 (0.06) | 0.23 (2.18) | – |
| 1952 | – | 0.017 (0.11) | 0.024 (0.14) | .09 (1.27) | – |
| 1953 | – | 0.066 (0.18) | 0.035 (0.08) | .19 (0.54) | – |
| 1954 | – | 0.168 (0.19) | 0.177 (0.18) | .12 (0.24) | – |
| 1955 | – | 0.316 (0.34) | 0.360 (0.41) | .07 (0.26) | – |
| 1956 | – | 0.146 (0.65) | 0.476 (2.21) | .33 (0.88) | – |
| 1957 | – | 0.364 (0.42) | 0.444 (0.47) | .20 (0.25) | – |
| 1958 | – | 1.274 (1.18) | 1.718 (1.23) | .43 (0.23) | – |
| 1959 | – | 0.992 (0.82) | 1.777 (1.31) | .23 (0.20) | – |
| 1960 | – | 1.765 (0.77) | 2.443 (1.20) | .24 (0.10) | – |
| 1961 | – | 0.653 (0.64) | 0.706 (0.61) | .29 (0.22) | – |
| 1962 | – | 1.314 (1.17) | 2.248 (1.66) | .19 (0.18) | – |
| 1963 | – | 2.275 (0.99) | 2.967 (1.39) | .28 (0.09) | – |
| 1964 | – | 4.147 (2.68) | 8.643 (4.59) | .42 (0.13) | – |
| 1965 | – | 4.019 (1.18) | 8.177 (2.91) | .19 (0.06) | – |
| 1966 | – | 5.256 (1.80) | 12.851 (5.12) | .42 (0.07) | – |
| 1967 | – | – | – | – | – |
| 1968 | – | – | – | – | – |
| 1969 | – | 3.821 (1.06) | 5.431 (1.55) | .19 (0.06) | 438 |
| 1970 | – | – | – | – | 275 |
| 1971 | – | – | – | – | 233 |
| 1972 | – | 1.657 (0.80) | 3.450 (0.83) | .25 (0.11) | 822 |
| 1973 | – | – | – | – | 1671 |
| 1974 | – | – | – | – | 947 |
| 1975 | – | 19.691 (10.36) | 16.707 (3.96) | .44 (0.11) | 3086 |
| 1976 | – | – | – | – | – |
| 1977 | – | – | – | – | 1984 |
| 1978 | – | 2.33 (4.48) | 14.657 (6.53) | .59 (0.10) | 392 |
| 1979 | – | 5.426 (2.62) | 5.070 (2.19) | .48 (0.10) | 292 |
| 1980 | 870 | 2.671 (1.26) | 2.548 (0.99) | .36 (0.08) | 604 |
| 1981 | 635 | 4.376 (2.08) | 4.738 (1.78) | .38 (0.08) | 567 |
| 1982 | 415 | 3.29 (1.36) | 1.684 (2.03) | .36 (0.09) | 250 |
| 1983 | 652 | 3.91 (1.17) | 1.654 (1.27) | .46 (0.06) | 532 |
| 1984 | 309 | 2.85 (1.06) | 2.567 (1.76) | .36 (0.08) | 573 |
| 1985 | 521 | 2.62 (0.67) | 5.160 (2.16) | .28 (0.05) | 1015 |
| 1986 | – | – | 7.558 (3.34) | .34 (0.12)[a] | – |
| 1987 | – | – | 7.234 (2.57) | .19 (0.08)[a] | – |
| 1988 | – | – | 6.891 (3.42) | .53 (0.09)[a] | – |

[a] *Z* for 1986–88 computed from the condensed CalCOFI area.

EPM is spawning biomass (thousand MT) estimated by the egg production method; HEP is the historical egg production index of spawning biomass (Lo 1985); MHEP is HEP as modified to account for the reduced CalCOFI sampling pattern. *Z* is the daily egg mortality associated with the HEP estimate and was used in making the MHEP estimate. Sonar is based on the acoustic surveys conducted by CDFG. Standard errors are in parentheses.

## DATA

### *Fishery Data*

The total landings from the U.S. fishery in 1987 were 5,024 MT, compared to 5,500 MT in 1986 (table 2). The total landings included 149 MT for reduction to oil and meal, and 4,875 MT for live bait and other uses (Thomson et al. 1988). The total landings at Ensenada, Baja California, Mexico, during 1987 were 124,457 MT (Secretaria de Pesca de México 1988; W. Garcia F., pers. comm.) compared to 96,000 MT in 1986. The 1987 landings are

TABLE 2
**United States Fishery Landings and Weight at Age**

| Year | Month | Landings (MT) | Weight at age (g) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5+ |
| 1964 | 1–2 | 0 | | | | | | |
| | 3–6 | 3482 | 0.0 | 12.9 | 17.5 | 21.0 | 24.5 | 28.8 |
| | 7–8 | | | | | | | |
| | 9–12 | 3484 | 11.2 | 16.6 | 19.4 | 21.8 | 24.4 | 26.3 |
| 1965 | 1–2 | | | | | | | |
| | 3–6 | 4122 | 0.0 | 12.9 | 17.5 | 21.0 | 24.5 | 28.8 |
| | 7–8 | | | | | | | |
| | 9–12 | 4124 | 11.2 | 16.6 | 19.4 | 21.8 | 24.4 | 26.3 |
| 1966 | 1–3 | 4518 | 2.7 | 12.1 | 15.8 | 19.4 | 23.4 | 28.5 |
| | 4–6 | 14440 | 6.7 | 13.6 | 17.4 | 20.1 | 22.9 | 28.0 |
| | 7–9 | 4958 | 10.8 | 15.1 | 18.4 | 20.0 | 22.3 | 26.9 |
| | 10–11 | 3851 | 12.3 | 17.1 | 19.4 | 21.7 | 23.9 | 26.3 |
| 1967 | 12–2 | 16982 | 1.8 | 11.4 | 16.6 | 19.5 | 22.4 | 26.0 |
| | 3–6 | 16934 | 5.9 | 11.7 | 17.7 | 22.3 | 28.1 | 33.3 |
| | 7–9 | 3876 | 10.9 | 15.2 | 18.4 | 19.9 | 22.3 | 26.8 |
| | 10–12 | 5307 | 12.1 | 16.9 | 19.5 | 21.8 | 24.1 | 26.8 |
| 1968 | 1–3 | 979 | 2.8 | 12.1 | 15.7 | 19.2 | 23.2 | 28.5 |
| | 4–6 | 3308 | 6.9 | 13.6 | 17.5 | 20.0 | 22.7 | 28.0 |
| | 7–9 | 4487 | 10.9 | 15.2 | 18.4 | 19.9 | 22.3 | 26.8 |
| | 10–1 | 13868 | 14.9 | 17.4 | 20.2 | 23.1 | 27.1 | 31.3 |
| 1969 | 2–3 | 2445 | 3.8 | 14.2 | 16.0 | 21.0 | 20.7 | 24.1 |
| | 4–5 | 10134 | 5.9 | 14.3 | 16.2 | 20.4 | 24.7 | 27.1 |
| | 6–8 | 4676 | 9.1 | 13.7 | 18.3 | 20.1 | 22.1 | 27.8 |
| | 9–12 | 47099 | 12.7 | 17.7 | 21.4 | 25.1 | 29.0 | 32.7 |
| 1970 | 1 | 6089 | 1.3 | 13.8 | 17.8 | 20.0 | 26.1 | 27.8 |
| | 2–5 | 23663 | 5.1 | 12.7 | 17.8 | 20.8 | 27.4 | 33.1 |
| | 6–10 | 30437 | 11.8 | 17.5 | 21.6 | 24.3 | 29.3 | 27.8 |
| | 11–12 | 32664 | 14.1 | 17.6 | 21.9 | 25.3 | 31.7 | 35.4 |
| 1971 | 1 | 9128 | 1.3 | 13.5 | 18.7 | 22.5 | 25.9 | 32.5 |
| | 2–5 | 10881 | 5.8 | 13.9 | 18.2 | 24.9 | 27.3 | 31.4 |
| | 6–9 | 7359 | 9.9 | 14.5 | 18.3 | 20.0 | 22.2 | 27.1 |
| | 10–12 | 19117 | 13.4 | 14.8 | 17.1 | 22.5 | 24.2 | 25.3 |
| 1972 | 1–2 | 11734 | 1.9 | 12.5 | 15.1 | 18.2 | 24.3 | 27.8 |
| | 3–5 | 16426 | 5.7 | 12.2 | 15.5 | 19.0 | 24.8 | 27.1 |
| | 6–9 | 9508 | 9.9 | 14.6 | 18.3 | 20.0 | 22.2 | 27.0 |
| | 10–12 | 30325 | 12.8 | 13.8 | 16.5 | 19.0 | 24.8 | 26.0 |
| 1973 | 1–2 | 3483 | 1.7 | 8.9 | 11.1 | 13.7 | 14.0 | 27.9 |
| | 3–6 | 36629 | 6.2 | 12.8 | 14.3 | 17.0 | 21.1 | 28.5 |
| | 7–10 | 38266 | 8.5 | 14.0 | 16.2 | 18.5 | 21.6 | 29.3 |
| | 11–12 | 47587 | 13.7 | 15.8 | 18.9 | 22.1 | 25.7 | 29.9 |
| 1974 | 1–2 | 11824 | 2.0 | 10.7 | 12.9 | 15.4 | 17.7 | 25.0 |
| | 3–6 | 18989 | 6.1 | 13.0 | 15.6 | 18.3 | 22.0 | 26.4 |
| | 7–9 | 5084 | 11.1 | 15.4 | 18.4 | 19.9 | 22.3 | 26.6 |
| | 10–1 | 61075 | 10.7 | 17.1 | 18.0 | 20.8 | 22.7 | 24.7 |
| 1975 | 2–3 | 13491 | 3.2 | 13.7 | 17.6 | 18.7 | 21.4 | 26.1 |
| | 4–6 | 34132 | 6.1 | 17.1 | 20.7 | 21.7 | 24.2 | 27.4 |
| | 7–10 | 42862 | 15.1 | 18.1 | 19.5 | 20.3 | 22.6 | 23.6 |
| | 11–1 | 60267 | 9.0 | 18.3 | 20.6 | 22.3 | 26.9 | 27.3 |
| 1976 | 2–3 | 12557 | 3.9 | 10.4 | 19.6 | 22.9 | 25.0 | 30.4 |
| | 4–6 | 19887 | 5.7 | 14.5 | 20.5 | 23.0 | 23.9 | 28.0 |
| | 7–9 | 10229 | 11.6 | 17.1 | 19.1 | 20.7 | 22.2 | 24.6 |
| | 10–1 | 61069 | 10.4 | 15.8 | 20.4 | 22.0 | 23.7 | 25.2 |
| 1977 | 2 | 503 | 2.7 | 11.7 | 15.2 | 17.4 | 21.1 | 27.7 |
| | 3–6 | 32294 | 4.7 | 13.9 | 15.5 | 19.1 | 22.5 | 26.5 |
| | 7–9 | 13483 | 12.8 | 18.0 | 19.3 | 21.0 | 22.4 | 25.7 |
| | 10–12 | 58869 | 12.2 | 18.4 | 20.3 | 22.1 | 22.9 | 26.2 |
| 1978 | 1–3 | 832 | 3.0 | 12.1 | 15.7 | 19.2 | 23.2 | 28.5 |
| | 4–6 | 3052 | 6.7 | 13.6 | 17.4 | 20.0 | 22.9 | 28.0 |
| | 7–9 | 6031 | 12.2 | 17.0 | 18.9 | 25.0 | 22.3 | 26.4 |
| | 10–12 | 7556 | 11.0 | 18.3 | 19.8 | 23.7 | 20.3 | 28.6 |
| 1979 | 1–3 | 625 | 2.6 | 12.0 | 15.7 | 19.1 | 23.1 | 28.4 |
| | 4–6 | 41754 | 6.5 | 14.3 | 18.6 | 22.5 | 24.8 | 24.9 |
| | 7–9 | 4563 | 11.3 | 15.6 | 18.4 | 19.9 | 22.3 | 26.4 |
| | 10–1 | 8591 | 8.8 | 19.2 | 23.0 | 20.0 | 24.9 | 26.6 |

*(continued on next page)*

TABLE 2 (*continued*)
**United States Fishery Landings and Weight at Age**

| Year | Month | Landings (MT) | Weight at age (g) 0 | 1 | 2 | 3 | 4 | 5+ |
|---|---|---|---|---|---|---|---|---|
| 1980 | 2–3 | 207 | 3.5 | 12.2 | 15.7 | 19.1 | 23.1 | 28.6 |
| | 4–6 | 26730 | 6.8 | 11.2 | 18.4 | 20.8 | 24.1 | 27.7 |
| | 7–9 | 3374 | 11.0 | 15.2 | 18.4 | 19.9 | 22.3 | 26.8 |
| | 10–1 | 27401 | 9.5 | 14.2 | 19.2 | 21.5 | 22.8 | 27.6 |
| 1981 | 2–3 | 432 | 3.4 | 12.2 | 15.6 | 18.9 | 22.9 | 28.5 |
| | 4–6 | 34699 | 6.5 | 14.0 | 15.8 | 19.7 | 21.9 | 28.6 |
| | 7–9 | 2878 | 11.0 | 15.3 | 18.4 | 19.9 | 22.3 | 26.7 |
| | 10–1 | 9151 | 7.6 | 17.0 | 18.3 | 20.4 | 25.1 | 26.8 |
| 1982 | 2–3 | 375 | 3.4 | 12.2 | 15.6 | 19.0 | 23.0 | 28.6 |
| | 4–6 | 40808 | 7.3 | 14.4 | 18.5 | 20.2 | 22.2 | 25.2 |
| | 7–9 | 3044 | 10.6 | 14.8 | 18.4 | 20.0 | 22.3 | 27.2 |
| | 10–12 | 2872 | 11.9 | 16.8 | 19.4 | 21.5 | 23.7 | 26.5 |
| 1983 | 1–3 | 526 | 3.2 | 12.2 | 15.8 | 19.4 | 23.5 | 28.7 |
| | 4–6 | 4561 | 7.4 | 13.4 | 17.8 | 20.1 | 22.4 | 27.9 |
| | 7–9 | 2218 | 10.6 | 14.9 | 18.4 | 20.0 | 22.3 | 27.2 |
| | 10–12 | 1182 | 12.2 | 17.0 | 19.4 | 21.7 | 23.9 | 26.5 |
| 1984 | 1–3 | 427 | 2.5 | 11.9 | 15.7 | 19.0 | 22.9 | 28.3 |
| | 4–6 | 3680 | 6.8 | 13.6 | 17.4 | 20.0 | 22.8 | 28.0 |
| | 7–9 | 2266 | 10.5 | 14.9 | 18.4 | 20.0 | 22.3 | 27.2 |
| | 10–12 | 929 | 12.0 | 16.8 | 19.4 | 21.5 | 23.8 | 26.5 |
| 1985 | 1–3 | 503 | 2.8 | 12.0 | 15.6 | 18.8 | 22.7 | 28.3 |
| | 4–6 | 1064 | 7.3 | 13.5 | 17.7 | 20.1 | 22.5 | 28.0 |
| | 7–9 | 2727 | 10.7 | 15.0 | 18.4 | 20.0 | 22.3 | 27.1 |
| | 10–12 | 1490 | 12.1 | 16.9 | 19.5 | 21.7 | 24.0 | 26.7 |
| 1986 | 1–3 | 456 | 2.7 | 12.1 | 15.8 | 19.3 | 23.2 | 28.5 |
| | 4–6 | 1648 | 6.4 | 13.8 | 17.2 | 19.9 | 23.1 | 28.1 |
| | 7–9 | 2519 | 10.6 | 14.9 | 18.4 | 20.0 | 22.3 | 27.2 |
| | 10–12 | 881 | 12.1 | 16.9 | 19.4 | 21.6 | 23.9 | 26.6 |
| 1987 | 1–3 | 370 | 2.9 | 12.1 | 15.7 | 19.0 | 23.0 | 28.4 |
| | 4–6 | 1013 | 6.7 | 13.5 | 17.5 | 20.1 | 22.9 | 28.0 |
| | 7–10 | 2965 | 10.9 | 15.4 | 18.6 | 20.2 | 22.5 | 26.9 |
| | 11–12 | 527 | 12.4 | 17.1 | 19.6 | 22.2 | 24.5 | 26.8 |

62% of the 200,000-MT optimum yield. The landings data are necessary for calculating survivorship from the previous year's biomass estimate. Monthly landings, age composition, and weight-at-age data for 1987 were obtained from CRIP (tables 3–5. For data sources for years before 1987, see Methot 1986). The CRIP port sampling program collected monthly anchovy samples from randomly selected fishing boats. Hundreds to thousands of fish were measured, and age was determined from otolith readings (W. Garcia F., pers. comm.). The age composition from the autumn fishery reveals

TABLE 3
**Mexican Fishery Data, 1987**

| Month | Landings (MT) | Age composition 0 | 1 | 2 | 3 | 4 | 5+ | *N* aged | Weight at age (g) × 10 0 | 1 | 2 | 3 | 4 | 5+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0[a] | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 95 | 0 | 468 | 33 | 7 | 4 | 0 | 512 | 0 | 63 | 120 | 120 | 130 | 0 |
| 4 | 4359 | 0 | 684 | 241 | 60 | 12 | 8 | 1005 | 0 | 99 | 104 | 133 | 186 | 178 |
| 5 | 23041 | 0 | 1105 | 189 | 74 | 28 | 15 | 1411 | 0 | 104 | 106 | 174 | 199 | 218 |
| 6 | 16455 | 368 | 491 | 43 | 45 | 11 | 23 | 981 | 40 | 152 | 133 | 221 | 232 | 246 |
| 7 | 22298 | 512 | 476 | 122 | 39 | 3 | 4 | 1156 | 47 | 125 | 128 | 144 | 195 | 214 |
| 8 | 29768 | 338 | 201 | 251 | 14 | 2 | 0 | 806 | 71 | 135 | 130 | 155 | 223 | 0 |
| 9 | 16291 | 1359 | 180 | 668 | 91 | 3 | 0 | 2301 | 67 | 121 | 111 | 118 | 117 | 0 |
| 10 | 11030 | 493 | 33 | 332 | 187 | 36 | 8 | 1089 | 75 | 127 | 134 | 128 | 129 | 159 |
| 11 | 1065 | 253 | 44 | 82 | 12 | 0 | 0 | 391 | 90 | 109 | 127 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[a]In Weight at age section, 0 indicates that no samples were taken.

TABLE 4
**Mexican Fishery Landings and Weight at Age**

| Year | Month | Landings (MT) | Weight at age (g) 0 | 1 | 2 | 3 | 4 | 5+ |
|---|---|---|---|---|---|---|---|---|
| **Yearly data** | | | | | | | | |
| 1964 | 3 | 4599 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1965 | 3 | 9171 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1966 | 3 | 13243 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1967 | 3 | 20104 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1968 | 3 | 14267 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1969 | 3 | 3871 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1970 | 3 | 27977 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1971 | 3 | 20079 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1972 | 3 | 30047 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| 1973 | 3 | 15424 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| **Seasonal data** | | | | | | | | |
| 1974 | 1–3 | 0 | | | | | | |
| | 4–6 | 12552 | 0.0 | 9.5 | 11.2 | 13.4 | 15.0 | 16.5 |
| | 7–9 | 19115 | 8.5 | 12.5 | 14.4 | 16.0 | 17.6 | 18.6 |
| | 10–12 | 11143 | 8.2 | 12.8 | 14.6 | 18.1 | 19.2 | 18.6 |
| 1975 | 1–3 | 6897 | 1.5 | 8.7 | 13.2 | 15.9 | 17.0 | 20.8 |
| | 4–6 | 21191 | 7.0 | 10.8 | 13.9 | 15.5 | 16.8 | 20.8 |
| | 7–8 | 20733 | 6.3 | 11.8 | 14.7 | 15.6 | 17.4 | 20.8 |
| | 9–12 | 8056 | 6.0 | 11.3 | 14.1 | 15.2 | 17.9 | 20.8 |
| 1976 | 1–3 | 253 | 2.2 | 8.9 | 13.3 | 15.8 | 17.0 | 20.8 |
| | 4–5 | 2492 | 5.0 | 10.0 | 13.5 | 15.6 | 16.8 | 20.8 |
| | 6–9 | 36686 | 6.4 | 11.5 | 14.6 | 15.5 | 17.7 | 20.8 |
| | 10–1 | 38745 | 7.7 | 11.3 | 14.3 | 15.6 | 17.5 | 20.8 |
| 1977 | 2–3 | 2204 | 2.7 | 9.4 | 13.4 | 15.8 | 17.0 | 20.8 |
| | 4–5 | 9884 | 5.0 | 10.0 | 13.5 | 15.6 | 16.8 | 20.8 |
| | 6–8 | 90522 | 6.3 | 11.6 | 14.6 | 15.6 | 17.5 | 20.8 |
| | 9–1 | 37692 | 6.5 | 11.5 | 14.2 | 15.7 | 17.7 | 20.8 |
| 1978 | 2–3 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4–5 | 12089 | 5.2 | 10.0 | 13.5 | 15.5 | 16.7 | 20.8 |
| | 6–8 | 72637 | 9.2 | 13.6 | 15.4 | 17.3 | 18.8 | 20.8 |
| | 9–1 | 56261 | 10.4 | 14.6 | 16.3 | 19.2 | 18.0 | 20.8 |
| 1979 | 2–3 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4–6 | 78899 | 6.9 | 11.6 | 12.8 | 15.0 | 17.2 | 20.7 |
| | 7–8 | 45929 | 7.4 | 11.8 | 13.3 | 16.6 | 17.5 | 20.8 |
| | 9–1 | 81238 | 7.1 | 12.0 | 13.6 | 16.9 | 17.9 | 20.8 |
| 1980 | 2–3 | 139 | 2.8 | 9.4 | 13.4 | 15.8 | 17.0 | 20.8 |
| | 4–5 | 4611 | 5.4 | 10.2 | 13.9 | 15.7 | 17.0 | 20.8 |
| | 6–8 | 130810 | 7.7 | 12.9 | 16.1 | 17.0 | 18.7 | 20.8 |
| | 9–1 | 110940 | 8.5 | 13.0 | 16.0 | 17.7 | 18.8 | 20.8 |
| 1981 | 2–3 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4–6 | 71423 | 7.4 | 10.7 | 12.6 | 14.3 | 15.4 | 20.8 |
| | 7–9 | 144543 | 7.6 | 10.7 | 12.6 | 14.0 | 16.2 | 20.8 |
| | 10–1 | 39420 | 8.4 | 11.4 | 13.3 | 14.7 | 14.9 | 20.8 |
| 1982 | 2–3 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4–5 | 27240 | 5.3 | 12.4 | 14.3 | 15.9 | 16.5 | 21.5 |
| | 6–8 | 105296 | 8.2 | 12.1 | 13.5 | 14.8 | 15.3 | 23.4 |
| | 9–10 | 24695 | 7.3 | 11.9 | 13.5 | 14.7 | 15.4 | 22.5 |
| 1983 | 11–3 | 24418 | 1.1 | 6.7 | 9.0 | 10.1 | 12.1 | 18.6 |
| | 4–5 | 35725 | 5.3 | 7.1 | 8.7 | 9.1 | 17.6 | 21.0 |
| | 6–8 | 18308 | 6.7 | 8.7 | 10.2 | 11.0 | 17.8 | 23.8 |
| | 9–2 | 21341 | 3.3 | 7.1 | 8.0 | 9.7 | 13.9 | 22.5 |
| 1984 | 3–4 | 590 | 4.4 | 6.9 | 8.1 | 11.1 | 17.4 | 18.2 |
| | 5–6 | 36495 | 5.6 | 8.6 | 13.7 | 16.0 | 17.5 | 23.7 |
| | 7 | 25465 | 4.9 | 9.2 | 12.7 | 12.1 | 17.3 | 22.5 |
| | 8–1 | 38546 | 5.0 | 8.5 | 12.0 | 15.2 | 15.8 | 22.5 |
| 1985 | 2 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3–6 | 59348 | 5.1 | 14.1 | 15.7 | 18.3 | 18.7 | 20.6 |
| | 7 | 17894 | 6.4 | 18.8 | 20.1 | 26.2 | 25.0 | 22.5 |
| | 8–1 | 44547 | 7.1 | 18.5 | 20.9 | 22.3 | 22.6 | 22.5 |
| 1986 | 2–3 | 211 | 2.7 | 6.5 | 12.4 | 15.4 | 17.0 | 18.2 |
| | 4–5 | 7334 | 4.7 | 8.4 | 13.8 | 16.4 | 16.6 | 20.2 |
| | 6–7 | 36648 | 8.1 | 13.1 | 16.0 | 20.7 | 20.9 | 23.7 |
| | 8–12 | 51478 | 5.3 | 12.9 | 15.5 | 19.7 | 18.6 | 22.5 |

*(continued on next page)*

TABLE 4 (*continued*)
**Mexican Fishery Landings and Weight at Age**

| Year | Month | Landings (MT) | Weight at age (g) 0 | 1 | 2 | 3 | 4 | 5+ |
|---|---|---|---|---|---|---|---|---|
| 1987 | 1–3 | 168 | 2.2 | 6.3 | 12.2 | 13.7 | 15.3 | 18.2 |
| | 4–5 | 27400 | 5.3 | 10.3 | 10.5 | 16.7 | 19.8 | 21.3 |
| | 6–7 | 38753 | 4.4 | 13.8 | 12.9 | 18.3 | 22.3 | 24.1 |
| | 8–12 | 58154 | 7.1 | 13.2 | 12.6 | 13.1 | 14.4 | 21.5 |

TABLE 5
**Age Composition for U.S. Fishery, Mexican Fishery, and U.S. Survey**

| Year | Qtr. | Type | Age 0 | 1 | 2 | 3 | 4 | 5+ | *N* aged |
|---|---|---|---|---|---|---|---|---|---|
| 1967 | 1 | US-F | 0.0 | 39.0 | 224.3 | 662.3 | 704.0 | 239.0 | 1870 |
| | 2 | US-F | 0.0 | 42.3 | 167.0 | 265.6 | 165.7 | 96.4 | 739 |
| 1968 | 1 | US-S | 0.0 | 422.0 | 305.0 | 149.0 | 111.0 | 14.0 | 105 |
| | 2 | US-S | 0.0 | 144.0 | 248.0 | 189.0 | 259.0 | 161.0 | 245 |
| | 4 | US-F | 39.1 | 358.1 | 285.0 | 92.4 | 60.8 | 6.2 | 845 |
| 1969 | 1 | US-F | 0.0 | 62.7 | 73.7 | 26.0 | 6.6 | 10.1 | 179 |
| | 2 | US-F | 0.0 | 200.8 | 389.9 | 119.7 | 50.1 | 30.5 | 789 |
| | 4 | US-F | 101.2 | 722.6 | 1664.8 | 423.3 | 80.1 | 12.0 | 3003 |
| 1970 | 1 | US-F | 0.0 | 167.0 | 352.0 | 207.0 | 44.0 | 16.0 | 786 |
| | 1 | US-S | 0.0 | 359.0 | 322.0 | 250.0 | 47.0 | 22.0 | 206 |
| | 2 | US-F | 0.0 | 1191.0 | 528.9 | 338.3 | 73.7 | 18.1 | 2153 |
| | 3 | US-F | 4.5 | 411.3 | 902.0 | 302.9 | 34.3 | 3.0 | 1657 |
| | 4 | US-F | 42.0 | 682.0 | 756.0 | 480.0 | 57.0 | 9.0 | 2024 |
| 1971 | 1 | US-F | 0.0 | 69.0 | 367.0 | 304.0 | 243.0 | 67.0 | 1050 |
| | 1 | US-S | 0.0 | 196.0 | 301.0 | 307.0 | 164.0 | 33.0 | 173 |
| | 2 | US-F | 0.0 | 54.4 | 89.6 | 95.8 | 51.7 | 20.5 | 312 |
| | 2 | US-S | 0.0 | 223.0 | 281.0 | 300.0 | 132.0 | 64.0 | 171 |
| | 4 | US-F | 62.5 | 477.2 | 365.7 | 94.5 | 24.1 | 0.7 | 1029 |
| 1972 | 1 | US-F | 0.0 | 106.8 | 890.9 | 366.4 | 147.7 | 44.0 | 1557 |
| | 2 | US-F | 0.0 | 154.5 | 424.9 | 192.8 | 79.1 | 15.6 | 867 |
| | 2 | US-S | 0.0 | 122.0 | 412.0 | 253.0 | 119.0 | 94.0 | 190 |
| | 4 | US-F | 74.1 | 500.2 | 1561.2 | 431.6 | 37.8 | 9.1 | 2616 |
| 1973 | 1 | US-S | 0.0 | 43.0 | 377.0 | 457.0 | 112.0 | 11.0 | 249 |
| | 2 | US-F | 0.0 | 425.9 | 864.5 | 1237.8 | 455.6 | 134.1 | 3116 |
| | 2 | US-S | 0.0 | 35.0 | 219.0 | 406.0 | 255.0 | 86.0 | 190 |
| | 3 | US-F | 6.0 | 319.3 | 985.6 | 907.5 | 153.8 | 10.8 | 2383 |
| | 4 | US-F | 27.6 | 269.5 | 935.9 | 1027.4 | 264.5 | 24.0 | 2548 |
| 1974 | 1 | US-F | 0.0 | 263.9 | 607.5 | 471.9 | 260.1 | 37.8 | 1640 |
| | 2 | US-F | 0.0 | 157.0 | 274.7 | 174.2 | 134.0 | 42.1 | 782 |
| | 2 | US-S | 0.0 | 28.0 | 144.0 | 333.0 | 396.0 | 100.0 | 290 |
| | 4 | US-F | 43.2 | 579.7 | 1694.7 | 966.9 | 301.0 | 18.9 | 3611 |
| 1975 | 1 | US-F | 0.0 | 154.9 | 231.0 | 252.1 | 170.2 | 83.8 | 892 |
| | 1 | MX-F | 0.0 | 49.8 | 65.2 | 186.6 | 60.7 | 9.7 | 372 |
| | 1 | US-S | 0.0 | 84.0 | 153.0 | 273.0 | 262.0 | 228.0 | 220 |
| | 2 | US-F | 0.0 | 52.9 | 317.3 | 656.8 | 598.6 | 343.5 | 1970 |
| | 2 | MX-F | 1.3 | 8.0 | 77.2 | 144.4 | 49.5 | 7.7 | 288 |
| | 3 | US-F | 13.0 | 369.7 | 1187.9 | 738.5 | 162.9 | 27.2 | 2498 |
| | 3 | MX-F | 4.3 | 16.5 | 70.9 | 114.0 | 37.5 | 5.7 | 249 |
| | 4 | US-F | 59.9 | 297.0 | 1345.2 | 1342.5 | 531.7 | 46.5 | 3625 |
| | 4 | MX-F | 21.5 | 24.5 | 37.0 | 62.0 | 25.2 | 5.8 | 176 |
| 1976 | 1 | US-F | 0.0 | 52.1 | 57.7 | 180.1 | 263.0 | 257.7 | 809 |
| | 2 | US-F | 0.0 | 7.0 | 89.1 | 299.9 | 467.2 | 286.8 | 1151 |
| | 2 | MX-F | 0.0 | 27.4 | 100.3 | 189.1 | 66.7 | 8.5 | 392 |
| | 2 | US-S | 0.0 | 16.0 | 24.0 | 151.0 | 430.0 | 380.0 | 320 |
| | 3 | US-F | 0.0 | 36.0 | 67.0 | 76.0 | 13.0 | 1.0 | 193 |
| | 3 | MX-F | 170.3 | 144.2 | 151.1 | 175.1 | 78.5 | 10.7 | 730 |
| | 4 | US-F | 306.2 | 255.2 | 579.8 | 1086.1 | 535.3 | 93.3 | 2856 |
| | 4 | MX-F | 376.2 | 59.9 | 81.5 | 36.8 | 10.6 | 0.0 | 565 |

(*continued on next page*)

TABLE 5 (*continued*)
**Age Composition for U.S. Fishery, Mexican Fishery, and U.S. Survey**

| Year | Qtr. | Type | Age 0 | 1 | 2 | 3 | 4 | 5+ | *N* aged |
|---|---|---|---|---|---|---|---|---|---|
| 1977 | 1 | MX-F | 0.0 | 93.0 | 39.5 | 113.2 | 51.3 | 0.0 | 297 |
| | 1 | US-S | 0.0 | 450.0 | 47.0 | 96.0 | 216.0 | 191.0 | 470 |
| | 2 | US-F | 0.0 | 908.7 | 250.2 | 187.8 | 264.1 | 212.2 | 1823 |
| | 2 | MX-F | 0.0 | 98.4 | 47.3 | 66.1 | 55.4 | 24.8 | 292 |
| | 3 | US-F | 5.0 | 158.0 | 76.0 | 40.0 | 50.0 | 10.0 | 339 |
| | 3 | MX-F | 34.1 | 215.2 | 166.3 | 233.0 | 182.1 | 40.2 | 871 |
| | 4 | US-F | 262.9 | 886.3 | 506.8 | 379.6 | 358.3 | 77.0 | 2471 |
| | 4 | MX-F | 115.2 | 183.1 | 115.4 | 112.2 | 51.9 | 15.2 | 593 |
| 1978 | 1 | US-S | 0.0 | 96.0 | 459.0 | 160.0 | 149.0 | 135.0 | 396 |
| | 3 | MX-F | 146.5 | 151.4 | 1043.1 | 62.8 | 39.0 | 23.2 | 1466 |
| | 4 | US-F | 71.4 | 107.3 | 114.5 | 4.9 | 7.3 | 1.7 | 307 |
| | 4 | MX-F | 1353.8 | 170.6 | 303.6 | 9.4 | 8.1 | 3.5 | 1849 |
| 1979 | 1 | US-S | 0.0 | 652.0 | 95.0 | 180.0 | 64.0 | 8.0 | 508 |
| | 2 | US-F | 0.0 | 2453.2 | 720.9 | 432.7 | 63.8 | 18.5 | 3688 |
| | 2 | MX-F | 6.9 | 1096.8 | 430.2 | 146.3 | 7.0 | 1.9 | 1689 |
| | 2 | US-S | 0.0 | 727.0 | 132.0 | 97.0 | 25.0 | 18.0 | 328 |
| | 3 | MX-F | 48.1 | 799.9 | 155.1 | 49.6 | 2.2 | 0.0 | 1055 |
| | 4 | MX-F | 744.1 | 1112.4 | 135.7 | 45.1 | 1.6 | 0.0 | 2039 |
| 1980 | 1 | US-S | 0.0 | 348.0 | 501.0 | 120.0 | 22.0 | 8.0 | 610 |
| | 2 | US-F | 0.0 | 915.6 | 1170.1 | 159.6 | 23.2 | 2.4 | 2270 |
| | 2 | MX-F | 0.0 | 241.0 | 202.7 | 21.5 | 14.8 | 0.0 | 480 |
| | 3 | MX-F | 15.9 | 763.2 | 1089.2 | 107.3 | 20.5 | 0.0 | 1996 |
| | 4 | US-F | 135.2 | 1008.6 | 736.6 | 77.6 | 10.0 | 0.0 | 1966 |
| | 4 | MX-F | 750.5 | 723.5 | 607.9 | 57.5 | 3.7 | 0.0 | 2143 |
| 1981 | 1 | US-S | 0.0 | 453.0 | 305.0 | 205.0 | 34.0 | 2.0 | 555 |
| | 2 | US-F | 0.0 | 1177.1 | 902.8 | 583.3 | 59.4 | 2.0 | 2724 |
| | 2 | MX-F | 12.0 | 1490.3 | 789.6 | 282.1 | 24.1 | 0.0 | 2598 |
| | 2 | US-S | 0.0 | 297.0 | 316.0 | 379.0 | 8.0 | 0.0 | 460 |
| | 3 | MX-F | 130.8 | 1246.4 | 583.0 | 215.2 | 21.6 | 0.0 | 2197 |
| | 4 | US-F | 8.3 | 125.5 | 168.8 | 29.4 | 0.0 | 0.0 | 332 |
| | 4 | MX-F | 441.2 | 737.6 | 411.7 | 148.4 | 14.6 | 3.5 | 1757 |
| 1982 | 1 | US-S | 0.0 | 93.0 | 360.0 | 477.0 | 68.0 | 0.0 | 651 |
| | 2 | US-F | 0.0 | 389.7 | 849.9 | 1137.8 | 293.2 | 2.9 | 2672 |
| | 2 | MX-F | 0.0 | 70.1 | 367.4 | 154.2 | 45.0 | 0.2 | 637 |
| | 3 | MX-F | 57.1 | 374.5 | 641.5 | 179.7 | 26.3 | 0.0 | 1279 |
| | 4 | MX-F | 317.3 | 146.9 | 164.2 | 29.6 | 1.9 | 0.0 | 660 |
| 1983 | 1 | MX-F | 0.0 | 399.1 | 223.1 | 54.8 | 3.1 | 0.0 | 680 |
| | 1 | US-S | 0.0 | 742.0 | 112.0 | 108.0 | 38.0 | 0.0 | 582 |
| | 2 | MX-F | 0.0 | 431.6 | 41.3 | 7.1 | 0.0 | 0.0 | 480 |
| | 3 | MX-F | 56.4 | 431.4 | 44.2 | 8.1 | 0.0 | 0.0 | 540 |
| | 4 | MX-F | 393.2 | 369.7 | 49.1 | 7.9 | 0.0 | 0.0 | 820 |
| 1984 | 1 | US-S | 0.0 | 348.0 | 585.0 | 53.0 | 13.0 | 0.0 | 518 |
| | 2 | MX-F | 30.7 | 510.1 | 269.5 | 23.0 | 5.7 | 0.0 | 839 |
| | 3 | MX-F | 93.0 | 217.0 | 29.0 | 1.0 | 0.0 | 0.0 | 340 |
| | 4 | MX-F | 1298.9 | 449.2 | 31.9 | 0.0 | 0.0 | 0.0 | 1780 |
| 1985 | 1 | US-S | 0.0 | 718.0 | 191.0 | 76.0 | 5.0 | 8.0 | 464 |
| | 2 | MX-F | 0.0 | 644.4 | 571.5 | 176.4 | 13.6 | 4.0 | 1410 |
| | 4 | MX-F | 755.6 | 168.1 | 113.0 | 32.9 | 6.4 | 0.0 | 1076 |
| 1986 | 1 | US-S | 0.0 | 170.0 | 598.0 | 203.0 | 24.0 | 5.0 | 790 |
| | 2 | MX-F | 0.0 | 476.9 | 130.0 | 57.2 | 13.2 | 2.6 | 680 |
| | 3 | MX-F | 90.5 | 828.6 | 67.3 | 9.3 | 3.2 | 1.1 | 1000 |
| | 4 | MX-F | 779.2 | 292.7 | 58.6 | 21.6 | 8.0 | 0.0 | 1160 |
| 1987 | 1 | MX-F | 0.0 | 468.0 | 33.0 | 7.0 | 4.0 | 0.0 | 512 |
| | 2 | MX-F | 0.0 | 1852.6 | 364.3 | 129.5 | 44.9 | 24.7 | 2416 |
| | 3 | MX-F | 885.0 | 960.5 | 169.5 | 83.1 | 13.4 | 25.5 | 2137 |
| | 4 | MX-F | 2191.8 | 721.9 | 1387.1 | 243.6 | 36.3 | 6.4 | 4587 |

Fishery age composition is in numbers of fish at age. Fractional fish are due to the weighting of raw monthly age compositions by the monthly landings. Survey age composition is expressed in thousandths and should be scaled by *N* aged.

the level of recruitment and number of age 0 fish. A temperature-dependent fraction of these recruits contributes to the coming winter's spawning biomass (Methot, in press).

Four periods were defined in each year, based on distinct changes in monthly landings, age composition, and weight at age (Methot and Lo 1987) (tables 2–5). Within each period, monthly age composition and weight-at-age data were weighted by the total landings for that month before combining with other months in the period. The U.S. nonreduction fishery landings were similar to 1986, and weights at age were assumed to be equal to the historical mean (table 2) (Methot and Lo 1987). The four periods of the 1987 Mexican fishery are similar to 1986 except for month 4–5, when 1987 landings are higher than for the same period of 1986 (tables 3 and 4). The weight at age in the fourth period is significantly smaller than the long-term average for fish of age >2 (table 4). In particular, the mean weight of four-year-old anchovy was only 14.4 g, whereas the average from 1974–86 was 17.9 (SD = 1.96); these fish were born in the El Niño year of 1983. The fraction of age 0 fish in the Mexican fishery in the last period in 1987 was 0.48 as compared to 0.67 in 1986 (table 5).

### *Modified Historical Egg Production Index*

Spawning biomass of northern anchovy is measured most accurately by the egg production method (EPM), which was used during the period 1980–85. This method measures the abundance of newly spawned eggs and the rate at which mature adults are producing eggs. Estimates of the abundance of newly spawned eggs before 1980 were made by Lo (1985), using data from CalCOFI surveys. This index of historic egg production (HEP) included samples from approximately San Francisco, California, to Punta Baja, Baja California (30°N) during January–April (figure 2). The egg production values and mortality rate were estimated by the solutions to two equations: the abundance of eggs as the integral of mortality curve, and newly hatched larvae as the eggs at hatching time.

Beginning in 1985 the CalCOFI survey pattern changed. The frequency of surveys was increased from almost monthly every three years to quarterly each year, and the geographic extent was restricted to CalCOFI lines 77.0 (rounding off from 76.7, Pt. Buchon, California, north of Pt. Conception) to 93.0 (rounding off from 93.3, Del Mar, California, north of San Diego; figure 2). This change required a recalibration of the HEP index because the mean egg density in this restricted area is not expected to be the same as the mean density in the larger area. Since 1980, only samples collected during February–March have been used for this revised index, because this is the period during which subsequent data are expected to be collected.

The modified historical egg production (MHEP) index was derived from the egg mortality curve: $P_t = P_0 \exp(-zt)$, where $P_t$ is the abundance of some life stage (or size category) corrected for the duration of that stage, and $z$ is the mortality rate. By rearranging the terms in the equation, one obtains $P_0 = P_t \exp(zt)$, and an estimate of $P_0$ can be computed if the egg mortality rate ($z$) and at least one age-specific egg production are known. Because of the reduced sample size in the modified survey area, estimates of $z$ were taken from Lo (1985) for years before 1986, and were computed from staged eggs sampled from the current CalCOFI survey area for years after 1985 (table 1). $P_t$'s can be computed from egg and larval data from the modified survey area. We have for the historical data set two $P_t$'s that are reasonably close in age to the age at spawning; one for the egg stage ($P_{egg}$) and the other for the yolk-sac larvae ($P_{ys}$). The historical anchovy data base provides only the standing stock of anchovy eggs, with no information on the distribution of egg stages. To obtain an average egg production rate, we divided the standing stock by the average temperature-specific incubation time to obtain the egg production rate ($P_{egg}$) at the mid-age ($t_{egg}$ = incubation time /2). From the morality curve fit to sized larvae (Lo 1985), we estimated the larval production rate at the age of yolk absorption ($P_{ys}$). Assuming that eggs and yolk-sac larvae suffer the same mortality, two initial egg production estimates were computed as follows:

$$P_{0\text{-egg}} = P_{egg} \exp(z t_{egg})$$
and
$$P_{0\text{-ys}} = P_{ys} \exp(z t_{ys}).$$

The MHEP egg production index is the average of the above two estimates:

$$\text{MHEP} = (P_{0\text{-egg}} + P_{0\text{-ys}})/2$$

The variance of MHEP was computed as

$$\text{var (MHEP)} = [\text{var}(P_{0\text{-egg}}) + \text{var}(P_{0\text{-ys}})]/4.$$

To compute the MHEP index for 1988, we used a total of 58 plankton samples on the Jan. 19–Feb 2, 1988, CalCOFI cruise (Methot and Lo 1987). Anchovy eggs were collected with the CalCOFI vertical egg tow (CalVET) plankton net (Smith et al. 1985). The mouth area of the net is 0.05 m$^2$. The mesh size of 0.15 mm is the maximum size to retain all anchovy eggs. The standard net tow is a vertical cast to 70 m in 1 minute, held at depth for 10 seconds, and retrieved in 1 minute. The larval data were obtained from bongo oblique net tows (figure 2). In the past 30 years, different gears were used to

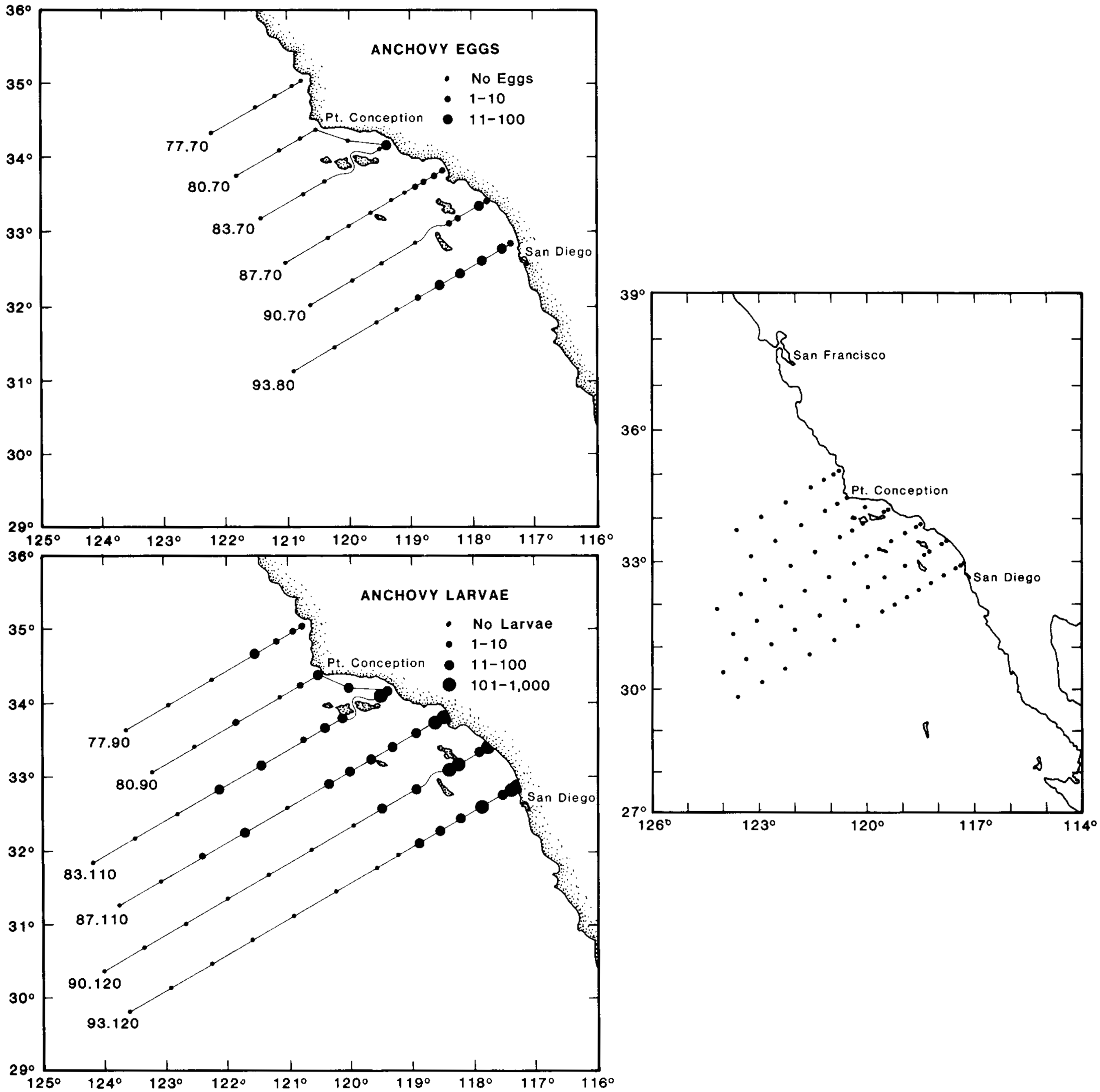


Figure 2. The map on the right shows the CalCOFI survey pattern since 1985 from Point Buchon, north of Point Conception, to Del Mar, north of San Diego, compared to the historical survey area from San Francisco to Punta Baja, Baja California. The maps on the left show the distribution of anchovy eggs and larvae from the 1988 CalCOFI survey. The number at the end of each line is the line and station number. The egg samples cover stations up to 70, except line 93.

collect anchovy eggs and larvae for CalCOFI surveys. Calibration factors were used to standardize egg and larval catch (Lo 1985).

As mentioned earlier, the MHEP takes the average of two daily egg production rates, one based on eggs and the other on yolk-sac larvae. Both egg production rates incorporate the daily egg mortality ($z$), which was computed from staged eggs (table 1). Analysis of the number of eggs and yolk-sac larvae taken during the 1988 CalCOFI cruise indicated a daily egg mortality of $-0.53$ per day in 1988.

The estimated egg production rate for 1988 was 6.9/0.05 $m^2$/day (SE = 3.42), similar to 7.2 (SE = 2.57) in 1986 and 7.6 (SE = 3.34) in 1987. The biomass in 1988 appears to be higher than it was during the 1980–85 period, because in 1980–85 the average

TABLE 6
**Time Series of Environmental Deviations and Weight-at-Age Deviations**

| Year | Qtr. | Temp. | WTDEV-US | WTDEV-MX | Year | Qtr. | Temp. | WTDEV-US | WTDEV-MX |
|---|---|---|---|---|---|---|---|---|---|
| 1964 | 2 | .900 | | | 1976 | 5 | −.412 | 2.77 | |
| | 5 | −.935 | | | | 8 | −.259 | 0.69 | |
| | 8 | −.402 | | | | 11 | 1.539 | 0.03 | |
| | 11 | −.797 | | | 1977 | 2 | 2.144 | — | |
| 1965 | 2 | −1.122 | | | | 5 | −.282 | 0.28 | |
| | 5 | .295 | | | | 8 | −.508 | 1.17 | |
| | 8 | −1.351 | | | | 11 | .474 | 1.12 | |
| | 11 | .020 | | | 1978 | 2 | 1.562 | — | |
| 1966 | 2 | −.074 | | | | 5 | 1.181 | — | |
| | 5 | .274 | | | | 8 | −.422 | 0.91 | 1.13 |
| | 8 | .532 | | | | 11 | .783 | 0.85 | 2.48 |
| | 11 | −.065 | | | 1979 | 2 | −.546 | — | — |
| 1967 | 2 | −.178 | 0.34 | | | 5 | −.301 | 0.95 | 0.44 |
| | 5 | −.680 | 0.56 | | | 8 | .157 | — | 0.33 |
| | 8 | .021 | — | | | 11 | .086 | 2.01 | −0.11 |
| | 11 | 1.050 | — | | 1980 | 2 | .524 | — | — |
| 1968 | 2 | −.005 | — | | | 5 | .296 | −0.18 | 0.37 |
| | 5 | .142 | — | | | 8 | −.999 | — | 0.70 |
| | 8 | −.007 | — | | | 11 | −.883 | −1.26 | 1.26 |
| | 11 | −.040 | 0.79 | | 1981 | 2 | .242 | — | — |
| 1969 | 2 | −.141 | 1.01 | | | 5 | 1.061 | −0.44 | −0.43 |
| | 5 | −.547 | −0.29 | | | 8 | 1.472 | — | −1.03 |
| | 8 | −.563 | — | | | 11 | .073 | −0.74 | 0.19 |
| | 11 | −.283 | 1.99 | | 1982 | 2 | −.093 | — | — |
| 1970 | 2 | −.124 | 1.68 | | | 5 | .282 | 0.51 | 1.30 |
| | 5 | .059 | 0.18 | | | 8 | −.131 | — | −0.20 |
| | 8 | −.403 | 2.37 | | | 11 | .559 | — | 0.53 |
| | 11 | −.107 | 1.95 | | 1983 | 2 | 1.393 | — | −2.29 |
| 1971 | 2 | −.819 | 2.95 | | | 5 | .808 | — | −3.07 |
| | 5 | −1.580 | 1.38 | | | 8 | .200 | — | −2.91 |
| | 8 | .958 | — | | | 11 | 1.965 | — | −3.90 |
| | 11 | −1.022 | −1.23 | | 1984 | 2 | .924 | — | −2.99 |
| 1972 | 2 | −1.716 | −0.25 | | | 5 | 1.091 | — | −1.72 |
| | 5 | −.164 | −1.31 | | | 8 | 2.184 | — | −1.92 |
| | 8 | .451 | — | | | 11 | 2.000 | — | −2.22 |
| | 11 | .156 | −2.90 | | 1985 | 2 | −.427 | — | — |
| 1973 | 2 | 1.051 | −4.67 | | | 5 | .015 | — | 2.94 |
| | 5 | −.354 | −2.62 | | | 8 | .614 | — | 4.59 |
| | 8 | −.489 | −2.37 | | | 11 | .953 | — | 1.63 |
| | 11 | −1.285 | −0.45 | | 1986 | 2 | .602 | — | — |
| 1974 | 2 | −1.114 | −2.30 | | | 5 | 1.258 | — | −1.07 |
| | 5 | −.494 | −1.20 | | | 8 | .130 | — | 1.44 |
| | 8 | −.425 | — | | | 11 | .734 | — | −0.45 |
| | 11 | .185 | −1.06 | | 1987 | 2 | 1.230 | — | 0.00 |
| 1975 | 2 | −1.041 | 1.34 | | | 5 | 1.355 | — | −0.34 |
| | 5 | −1.668 | 2.40 | | | 8 | −.718 | — | 0.48 |
| | 8 | −1.481 | 0.47 | | | 11 | 1.566 | — | −0.01 |
| | 11 | −1.494 | 0.69 | | 1988 | 2 | −.083 | — | — |
| 1976 | 2 | −.646 | 2.12 | | | 5 | 1.198 | — | — |

Deviations are calculated from monthly means, then averaged into quarters. Environmental deviations are lagged −1 month (e.g., quarter 1 contains average Dec.–Feb. deviation). Temp. is the surface temperature at the SIO pier. WTDEV-US and WTDEV-MX are average weight-at-age deviations for ages 2–4 based on data from the commercial reduction fishery at San Pedro in the United States and ages 1–3 at Ensenada in Mexico.

daily egg production rate was only 3.1 if one assumes that the adult reproductive output in 1988 is similar to the average of 1980–85 (table 1).

### *Environmental Data*

Temperature anomalies at the SIO pier were used as an indicator of environmental changes (table 6). During Jan.–Feb. 1988, the mean temperature at the SIO pier was 13.9°C, whereas it was 15°C in 1987 and 15.2°C in 1986 (figure 3). Monthly temperature deviations were averaged into trimonthly periods to be compatible with age-composition data. Two series of temperature indexes were derived from these temperature anomalies. The first series comprised short-term temperature indexes, which averaged the current and previous anomaly, with the

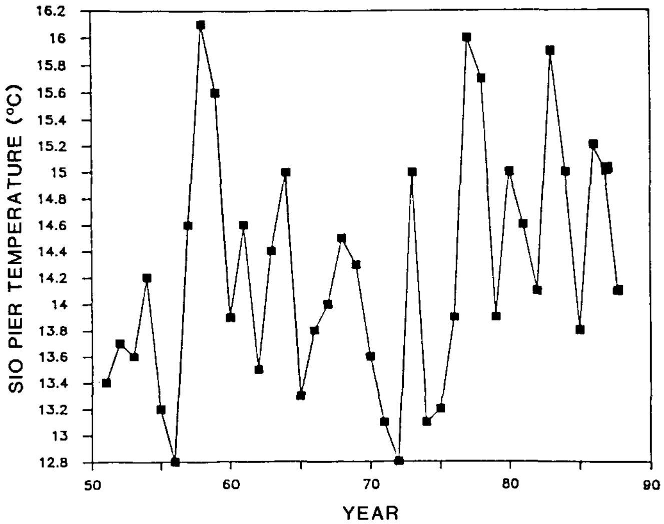


Figure 3. Time series of Jan.–Feb. water temperature (°C) at SIO, 1951–88.

current anomaly having twice the weight of the previous. The second series comprised long-term temperature indexes, which used the current and 15 previous quarters with a linear weighting scheme, with the current value having a weight of 16. The first, high-frequency series was detrended by subtracting the second series from it.

The 1987 SS model also includes time series of weight-at-age deviations, which are used to model the availability to the fishery. Methot and Lo (1987) note that the fraction of age 3+ fish in the Mexican fishery was never greater than 0.02 when the weight of the age 2 fish was less than 12 grams. Appearance of small fish is an indication that the stock has shifted northward, thus a clue that availability to the geographically fixed fisheries should be modified. The weight-at-age deviations for the United States were reproduced from Methot and Lo (1987). The weight-at-age deviations for the Mexican fishery were recomputed by adding 1987 weight at age to the data set (table 6). Availability parameters were modeled as linear functions of environmental and weight deviations.

Methot (1986, in press) presents a relation between percentage of mature fish and temperature at the SIO pier. In 1988, at 13.9°C, the temperature-maturity relation indicates that 63% of the age 1 fish are sexually mature, and 33% of them are actively spawning according to the relationships:

$$\text{Fraction mature at age 1} = \exp(-33.4 + 2.44\ \text{temp})/[1+\exp(-33.4 + 2.44\ \text{temp})]$$

and hence contribute to spawning biomass.

$$\text{Fraction of age 1 spawning} = \exp(-17.51 + 1.21\ \text{temp})/[1+\exp(-17.51 + 1.21\ \text{temp})]$$

and hence contribute to the MHEP index.

One of the major sources of natural mortality of northern anchovy is believed to be predation by Pacific mackerel (Methot 1986). Pacific mackerel biomass was estimated to be 500,000 MT on July 1, 1987 (Methot and Lo 1987), and projected to be 290,000 MT on July 1, 1988 (Patty Wolf, CDFG, pers. comm.). The decrease of biomass was possibly due to the changed estimation procedure. (The historical time series of Pacific mackerel biomass are being reexamined; the results are not available at the time of this writing.) At the level of 290,000 MT of mackerel biomass, the model specifies that natural mortality of anchovy increases from the nominal level of 0.6 to a level of 0.7 per year.

## RESULTS AND DISCUSSION

The spawning biomass in February 1988 is estimated to be 1,009,000 MT (table 7, figure 4). Although this value is a slight decrease from 1,212,000 MT in 1987 (Methot and Lo 1987), it is still higher than the 1985 spawning biomass of 521,000 MT, estimated by the EPM. The high level of spawning

TABLE 7
**Time Series of Estimated Biomass and Recruitment**

| Year | Total biomass | Spawning biomass | Recruitment |
|---|---|---|---|
| 1964 | 782 | 773 | 0.46 |
| 1965 | 705 | 607 | 0.20 |
| 1966 | 537 | 511 | 0.15 |
| 1967 | 369 | 354 | 0.52 |
| 1968 | 353 | 334 | 0.48 |
| 1969 | 374 | 348 | 0.55 |
| 1970 | 391 | 301 | 1.72 |
| 1971 | 723 | 309 | 1.63 |
| 1972 | 1040 | 605 | 2.35 |
| 1973 | 1440 | 1412 | 2.37 |
| 1974 | 1720 | 1148 | 0.80 |
| 1975 | 1432 | 1251 | 0.32 |
| 1976 | 1011 | 970 | 1.12 |
| 1977 | 826 | 825 | 0.25 |
| 1978 | 443 | 442 | 2.12 |
| 1979 | 813 | 536 | 1.72 |
| 1980 | 763 | 756 | 1.52 |
| 1981 | 806 | 768 | 0.57 |
| 1982 | 470 | 428 | 1.70 |
| 1983 | 556 | 538 | 0.71 |
| 1984 | 382 | 376 | 1.53 |
| 1985 | 675 | 529 | 1.01 |
| 1986 | 636 | 630 | 2.27 |
| 1987 | 900 | 878 | 3.00 |
| 1988 | 1297 | 1009 | 0.62 |

Biomass estimates are in units of thousand metric tons as of Feb. 15 of the indicated year. Recruitment estimates are in units of 50 billion age 0 fish as of July 1 of the indicated year.

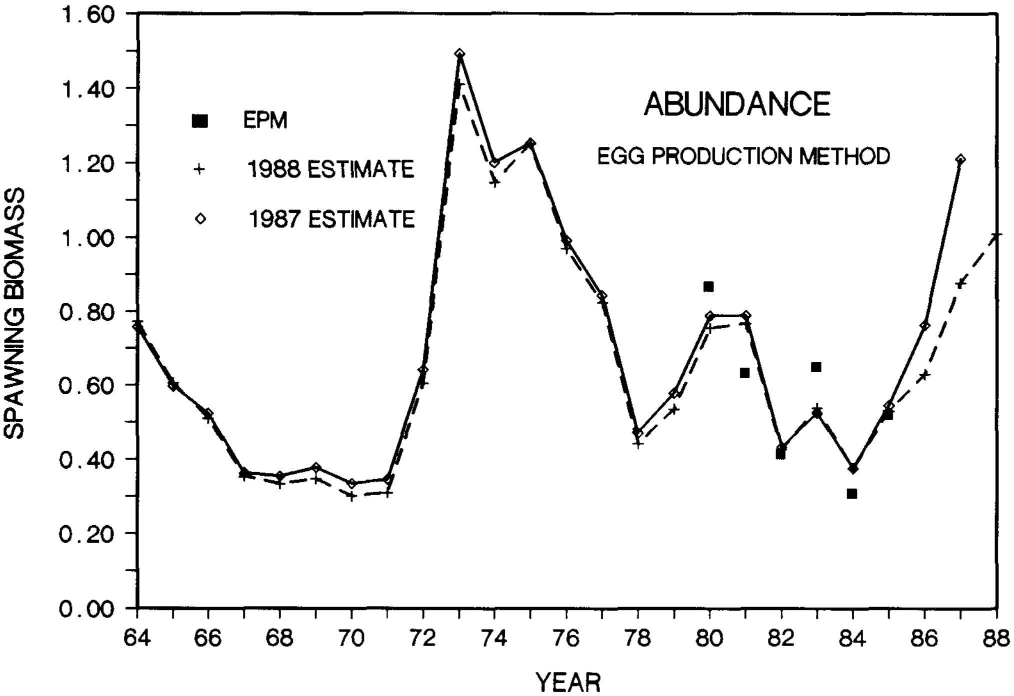


Figure 4. Estimated time series of spawning biomass, using data up to 1987, data up to 1988, and observations made by the egg production method.

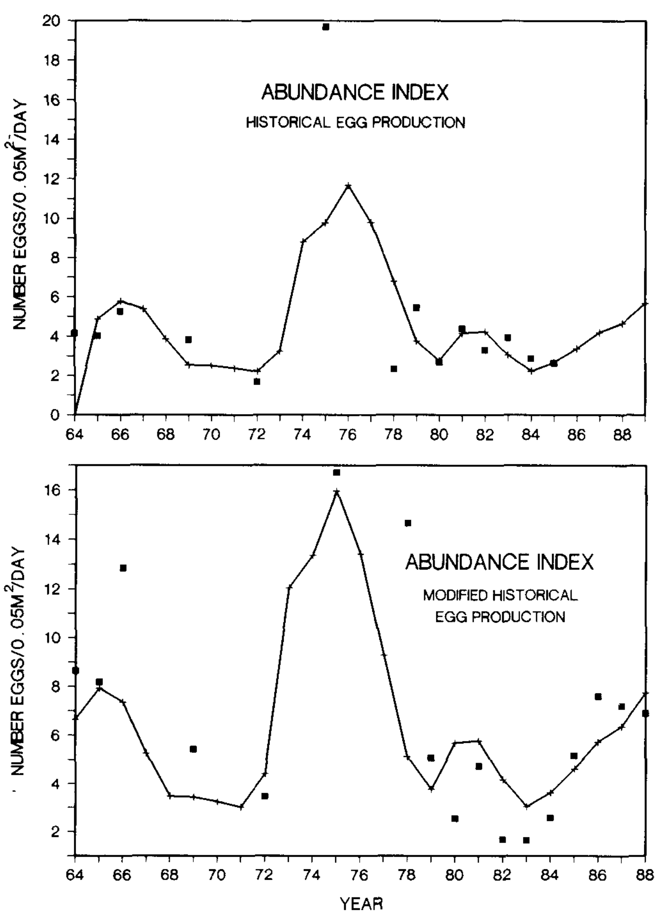


Figure 5. Estimated (squares) and observed (+) time series of historical egg production (Lo 1985) and modified HEP for the current CalCOFI survey area (see figure 2).

biomass was partially due to the high egg production rate estimated from MHEP (figure 5) and partially due to the strong incoming year class in 1987 (figure 6).

The SS model provided a time series of yearly biomass estimates (table 7). The computation of sample variance of the estimates, although it is technically feasible, has not been implemented in the model. Without variance estimates, it is impossible to judge the precision of the biomass estimate for a single year. However, a time series of biomass can indicate long-term change in the population, and it is useful for management.

The current estimate of the 1987 spawning biomass from the SS model using the 1964–88 time series is 880,000 MT; when the 1964–87 time series was used it was 1,212,000 MT (Methot and Lo 1987) (figure 4). Thus some uncertainties exist in estimating the magnitude of the 1986 and 1987 year classes. These year classes seem to be very abundant, because they dominate in the fourth-period Mexican fishery, even though their predicted availability to the fishery is one-third that of the 1984 and 1985 year classes (table 8). It is not surprising that the abundance of the second-year cohort differs from that of the first year, since the cohort in the second year is estimated from an additional year of age-composition data. For this reason, the first year's estimate of cohort biomass in the SS model will always be more uncertain than the subsequent year's estimate.

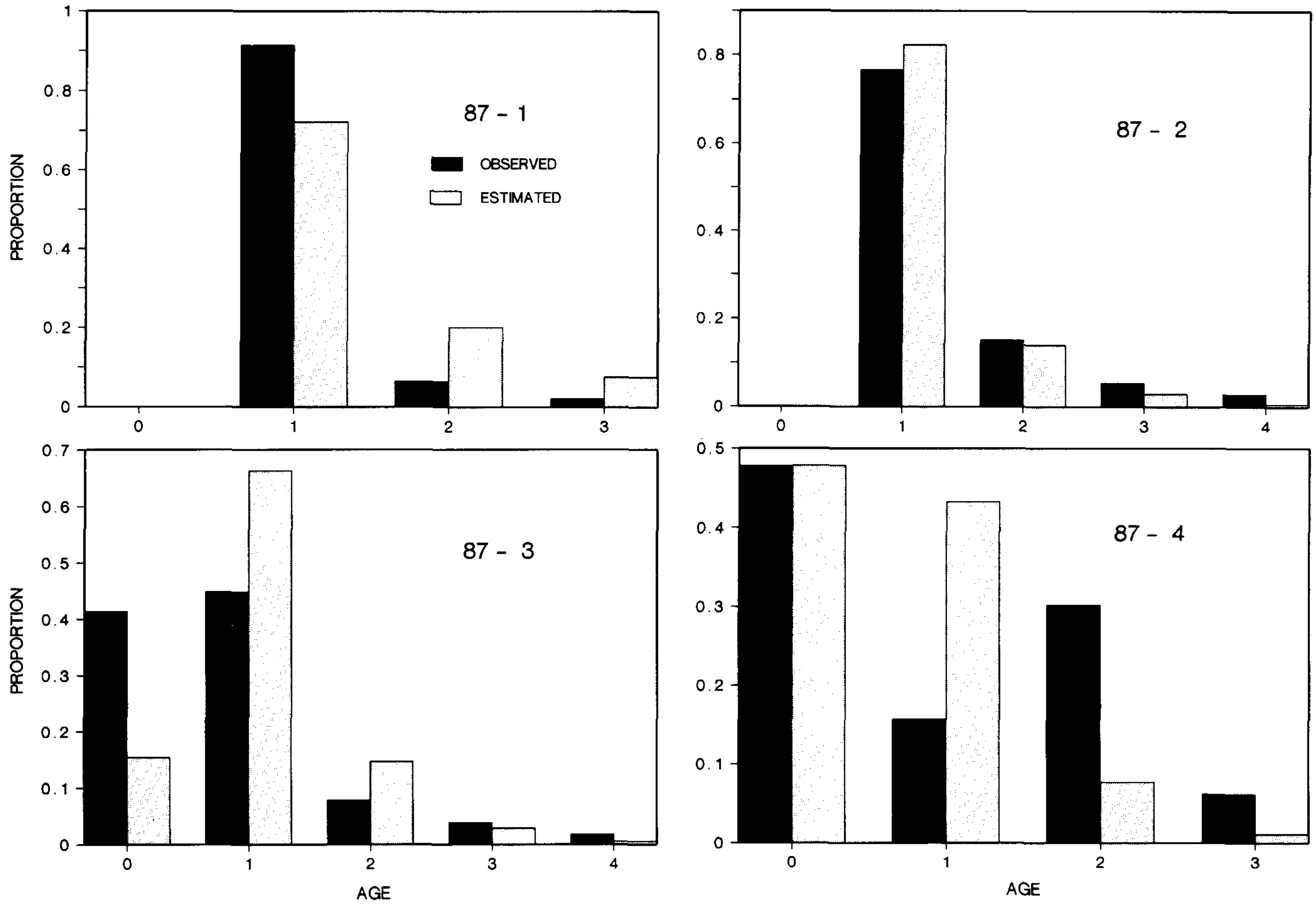


Figure 6. Observed and estimated age composition in 1987 for four periods: period 1, Jan.–Mar.; period 2, April and May; period 3, June and July; period 4, Aug.–Dec. (see table 3).

In the assessment conducted last year with data through the winter of 1987 (Methot and Lo 1987) the 1986 year class was fixed at a high value because when unconstrained, the model assigned an even higher value to the 1986 year class. The same situation occurred in the current assessment, which used data through winter 1988. In this case we fixed the abundance of the 1987 year class at a high value, and estimated the 1986 year class to be somewhat lower than the assumed large 1987 year class. Consequently, the revised estimate of the spawning biomass in 1987 declined when the additional year of data was included. This revised estimate of the 1987 spawning biomass, 880,000 MT, is nearly identical to the alternative estimate, 840,000 MT, made by Methot and Lo (1987) under the assumption that availability to the fourth-period Mexican fishery has been 1.0 since 1983.

The abundance of age 0 fish is difficult to assess because it is affected by two factors: the absolute abundance of age 0 fish in the population and the availability of these fish to the Mexican fishery. The availability of juvenile anchovy to the Mexican fishery is a critical parameter in the SS model. The abundance of juveniles relative to older fish in this fishery fluctuates because of year-to-year changes in the true relative abundance of these new recruits, and because of changes in their availability to the fishery. In the model, temporal changes in age-specific availability were assumed to be a function of long-term temperature trends, deviations from this trend, and deviation in weight at age. Estimated availability of these young fish to the Mexican fishery was very high during, and immediately following, the 1982–83 El Niño (table 8). Consequently, high incidence of young fish during this period is partially explained by their increased availability to the fishery. In the fourth periods of 1985, 1986, and perhaps 1987, the model predicts somewhat lower availability, while the abundance of age 0 fish stayed high. Thus the model indicates that the recruits of these three year classes were very abundant. We

TABLE 8
**Recruitment to the Fishery at Ensenada, Mexico**

| Year class | Age 0 | | | | | | Age 1 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Period 3 | | | Period 4 | | | Period 1 | | | Period 2 | | |
| | O | E | AV | O | E | Av | O | E | Av | O | E | Av |
| 1975 | .017 | .011 | .004 | .122 | .026 | .032 | — | — | — | .070 | .256 | 1.00 |
| 1976 | .233 | .091 | .053 | .666 | .451 | .468 | .313 | .576 | .633 | .337 | .368 | .211 |
| 1977 | .039 | .041 | .007 | .194 | .198 | .205 | — | — | — | — | — | — |
| 1978 | .100 | .152 | .017 | .732 | .690 | .194 | — | — | — | .652 | .692 | .235 |
| 1979 | .046 | .146 | .013 | .365 | .420 | .162 | — | — | — | .502 | .447 | .269 |
| 1980 | .008 | .065 | .008 | .350 | .204 | .048 | — | — | — | 576 | .488 | .349 |
| 1981 | .060 | .103 | .039 | .251 | .231 | .160 | — | — | — | .110 | .338 | .260 |
| 1982 | .045 | .159 | .015 | .481 | .632 | .215 | .587 | .767 | .384 | .899 | .873 | 1.00 |
| 1983 | .104 | .111 | .015 | .480 | .362 | .376 | — | — | — | .631 | .656 | 1.00 |
| 1984 | .274 | .213 | .043 | .730 | .755 | .714 | — | — | — | .457 | .592 | .326 |
| 1985 | — | — | — | .702 | .530 | .725 | — | — | — | .701 | .708 | 1.00 |
| 1986 | .091 | .171 | .028 | .672 | .544 | .230 | .914 | .722 | .549 | .767 | .824 | 1.00 |
| 1987 | .414 | .153 | .027 | .478 | .473 | .234 | | | | | | |

Note: Age 0 anchovy are partially recruited to this fishery in the third period of the year. They typically are fully recruited in the second period of the following year. The symbols indicate the observed ratio of recruits to total numbers in the Mexican fishery (O), the ratio expected by the model (E), and the estimated, environmentally sensitive availability used by the model (Av).

intend to reexamine the submodel that predicts availability from environmental deviations, but it seems unlikely that the generally good fit apparent in table 8 can be substantially improved.

## ACKNOWLEDGMENTS

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