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STOCK ASSESSMENT AND MANAGEMENT RECOMMENDATIONS FOR PACIFIC SARDINE (*Sardinops sagax*) IN 1997

by Kevin T. Hill, Marci Yaremko, Larry D. Jacobson, Nancy C.H. Lo,
and Doyle A. Hanan

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**STOCK ASSESSMENT AND MANAGEMENT RECOMMENDATIONS
FOR PACIFIC SARDINE (*Sardinops sagax*) IN 1997**

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EXECUTIVE SUMMARY

The primary goal of sardine management as directed by the California Fish and Game Code is rehabilitation of the resource with an added objective of maximizing sustained harvest. Accordingly, the Code states that the annual sardine quota can be set at an amount greater than 1,000 tons, providing that the level of take allows for continued increase in the spawning population.

We estimated the sardine population size to have been 464,000 short tons on July 1, 1997. Our estimate was based on output from a modified version of the integrated stock assessment model called CANSAR (Deriso et al. 1996). CANSAR is a forward-casting, age-structured analysis using fishery-dependent and fishery-independent data to obtain annual estimates of sardine abundance, year-class strength and age-specific fishing mortality for 1983 through the first semester of 1997. Non-linear least-squares criteria are used to find the best fit between model estimates and input data.

Questions about stock structure and range extent remain major sources of uncertainty in assessing current sardine population biomass. Recent survey results and anecdotal evidence suggest increased sardine abundance in the Pacific Northwest and areas offshore from central and southern California. It is difficult to determine if those fish were part of the stock available to the California fishery. In an attempt to address this problem, the original CANSAR model was reconfigured into a Two-Area Migration Model (CANSAR-TAM) which accounted for sardine lost to the areas of the fishery and abundance surveys due to population expansion and net emigration. While the model includes guesses and major assumptions about net emigration and recruitment, it provides an estimate which is likely closer to biological reality than past assessments. The original CANSAR model was also used and estimates are provided for comparison.

Based on the 1997 estimate of total biomass and the harvest formula used last year, we recommend a 1998 sardine harvest quota of 48,000 tons for the California fishery. The 1998 quota is a decrease of 11% from the final 1997 sardine harvest quota for California of 54,000 tons.

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INTRODUCTION

Section 8150.7 of the Fish and Game Code requires the California Department of Fish and Game (Department) to determine annually if the spawning biomass (adult portion) of the Pacific sardine resource is above 20,000 short tons. If spawning biomass exceeds this level, a 1,000-ton fishery for sardine is allowed. As the spawning population increases in excess of 20,000 tons, the Department may increase the seasonal quota, but only at such a rate as to allow continued rehabilitation of the sardine resource.

Our evaluation of the 1997 sardine resource was based on results from a modified version of the CANSAR stock assessment model (Deriso et al. 1996) that has been used by the Department for sardine management since 1993. Significant improvements to this year's assessment included: 1) modified estimates of population weight-at-age based on fishery-independent samples taken offshore from California and Mexico, and 2) modification of CANSAR to include assumptions regarding migration and recruitment and address effects of net emigration on spawning biomass available to the fishery.

The following report summarizes the 1997 sardine fishery, describes trends in biological and fishery-independent input data, and details changes to the recently completed stock assessment work. Based on this work, we recommend the 1998 sardine fishing quota. All weights (*e.g.* biomass and catches) are reported in short tons (2,000 U.S. lbs.).

THE 1997 SARDINE FISHERY

In 1997, 48,251 tons of sardine were landed against the 54,000 ton quota (Table 1, Figure 1), the highest annual total on record since reopening of the directed sardine fishery in 1986. Over half the 1997 landings occurred in the fourth quarter of the year, as the fleet continued to concentrate on wetfish in late fall and winter months due to low availability of market squid.

Section 8150.8 of the Fish and Game Code states that the annual sardine quota shall be divided so that two-thirds are allocated to the southern California directed fishery (south of San Simeon Point, San Luis Obispo County) and one-third to the northern California fishery (north of San Simeon Point). During 1997, that formula resulted in an initial southern fishery quota of 36,000 tons, and a northern fishery quota of 18,000 tons. In October, the Department re-allocated the uncaught portion of the quota and divided it in half between north and south, resulting in a 15,817.5-ton quota for each area to be landed between October 1st and the end of the year.

The southern California fishery filled its portion of the reallocation in mid-December. However, the Department did not recommend closing the southern California fishery as there were only a few weeks remaining in the year and several thousand tons remained on the northern allocation. At year's end, the southern allotment was exceeded by 1,805 tons while the northern quota still had 8,518 tons remaining. Consequently, 6,713 tons of the total 1997 quota was not landed.

Purse seine vessels commonly known as the "wetfish fleet" account for nearly all directed fishing for sardines in California. Other important target species of the wetfish fleet are Pacific

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mackerel, market squid, tunas, and Pacific herring. Seventy-five percent of 1997 statewide sardine landings were made south of Pt. Conception, by approximately 17 wetfish vessels based in the San Pedro area. In Monterey 12 wetfish vessels accounted for most of the northern California sardine landings.

Ex-vessel revenue generated by the directed sardine fishery during 1997 is projected to total approximately \$3.51 million (Table 2, Figure 2), up from \$3.11 million in 1996. The ex-vessel price for sardine remained consistent from 1996 to 1997 at \$70-90 per ton, averaging \$72.6 for January through September 1997. Preliminary market reports indicate the average price for sardine increased to approximately \$90 in the last quarter of the year. In addition to the wetfish fishery for sardine, a small bait fishery exists which is not subject to a quota and usually takes less than 5,000 tons per year. Live bait ex-vessel prices (over \$600 per ton in 1996) were roughly nine times greater than for the directed fishery, currently giving an overall value for the sardine live bait fishery which nearly equals that of the directed fishery. In 1996 the ex-vessel value of the live bait fishery exceeded the value of the directed fishery by approximately one million dollars.

The 1996 southern California directed sardine fishery was closed on November 5, 1996 when projected total landings equaled the revised quota of 38,350 tons. Once the directed fishery closes, only incidental catch of sardines (35 percent or less by weight) may be taken. Once the southern California fishery closed, an additional 434 tons of sardine were landed incidentally to the Pacific mackerel fishery in the south, while the northern California directed sardine fishery remained open through the year's end. In total, 37,540 tons were landed for the year.

In both 1996 and 1997 sardine landings varied by month due to availability, demand, and wetfish fleet participation in other fisheries. Alternative target species such as market squid (\$140-300 per ton), tuna (\$600-1400 per ton), and Pacific herring were often preferred over sardine.

In recent years, landings from Mexico (Ensenada) have equaled or exceeded those of California, except in 1995 (Figure 3). Total sardine landings from all sources (California and Mexico) will be in excess of 80,000 tons for calendar year 1997.

During 1997 about 90 percent of sardines landed in southern California were sold to market processors and the remaining amount was canned for human consumption or pet food. This ratio has changed dramatically since 1991, when canneries purchased about 75 percent of the landings.

In 1996 about 6 percent of all sardines landed in California were canned domestically for human consumption. In 1997 the only existing southern California cannery operation that packs fish for human consumption continued intermittent canning of sardines. Although no annual totals were available, cannery management reported 1200 tons of sardine were purchased between September and November 20, 1997, with the primary purpose of canning it for human consumption. In northern California there were two canneries producing fish for human consumption, one of which has been in operation since the 1940's.

Sardine exports in 1997 will likely approach those of 1996 (approximately 12,800 tons) but fall short of the 1995 export total because of decreased landings. To date, 7,911 tons have been

shipped abroad. The top three exports of frozen blocks of California sardine in 1997 were to Australia, Japan, and Thailand. Exports to the Philippines declined significantly in 1997, despite ranking first in 1995 and second in 1996. Australian demand increased in 1997, ranking first for the second consecutive year with 6,162 tons exported from California to date. Sardine are used for feed in Australian aquaculture facilities. Japan supplemented its catch with California sardine to meet consumer demand following the recent collapse of their sardine resource and implementation of a harvest quota system.

SARDINE BIOMASS ESTIMATES

BACKGROUND

CANSAR is an extension of methods used in the CAGEAN model for halibut (Deriso et al. 1985) and is tailored to the characteristics of information currently available for sardine including landings, size and age composition of landings, egg and larval abundance, spawning area, observations by aerial fish spotters, and daily egg-production method (DEPM; Lasker 1985) spawning biomass estimates. CANSAR provides confidence intervals for annual abundance estimates, which improves the usefulness of the estimates for fishery managers.

CANSAR is a forward-projecting, age-structured analysis that uses both fishery-dependent and fishery-independent data to obtain annual estimates of sardine abundance, year class strength, and age specific fishing mortality. We used it to fit data for 1983 through the first semester of 1997. CANSAR combines a simulation model of the population dynamics of sardine with all or most of the available data. Non-linear least-squares criteria were used to find the best fit or match between model predictions and actual catch-at-age and abundance data for sardine. As described below, CANSAR was modified this year into a Two-Area Migration Model (CANSAR-TAM) which accounts in part for a fraction of the available biomass moving outside the range of the fishery and survey data.

THE DATA

Fishery-based data used in the assessment model include fishery weight-at-age, catch in numbers-at-age, and tons landed by semester for the California and Ensenada fisheries for the period 1983 through 1997. Landings information for the Ensenada fishery in May and June 1997 were not available; the model used average tons landed for those months in 1994 through 1996. The model also requires estimates for landings in California and Ensenada during the second semester 1997. For California the mean of semester 2 (July through December) landings for 1995 and 1996 were applied, the only two recent years in which second semester landings were not severely hampered by quota restrictions. In Ensenada mean landings for the period 1994 through 1996 were applied. Size and age composition data were available for the U.S. fishery for nearly all semesters, but were lacking for the Ensenada fishery since 1992.

Fishery-independent data include an index of sardine egg and larvae abundance in the Southern California Bight, an annual estimate of spawning area, an index of adult sardine abundance from aerial spotter logbooks, and DEPM spawning biomass estimates.

Catch-at-Age Data

For the California fishery, age composition data were available during the study period from all except two semesters but were attained for the Ensenada fishery from only five semesters between July 1990 - December 1992. Approximately 4,904 sardines were collected in 1996 through port sampling programs from Long Beach and Monterey, and another 1,491 were collected in the first semester of 1997 from both locations. Age was determined on these specimens by reading sagittal otoliths for annuli (Yaremko 1996). For the 14-year period covered by this study, a combined sample of 31,241 sardines were aged from California and Ensenada fishery samples. The oldest sardine were age 9. Mean round weight from port samples was used to estimate number of fish in landings by dividing total tons landed by mean fish weight. Total numbers were prorated by age based on the age composition of port samples. Weight-at-age for fish taken in the California fishery has declined by about 50% during the past ten years (Figure 4), to such low levels that it appears the southern California landings no longer represent mean fish size for the whole west coast population (refer to population weight-at-age section).

In 1996 our systematic sampling of the Monterey sardine fishery adopted the protocol established in Long Beach in 1983. This year, we have incorporated age composition and weight-at-age information into fishery-dependent data files that previously reflected landings only in southern California. Both age composition and weight-at-age information were weighted proportionally by semester for commercial landings totals in the north and south beginning with semester 1, 1996.

Age 2 fish were an important component of the catch in all years, and they may be used to explore the least squares fit between observed catch-at-age and model predictions. Catch of age 2 fish during the first semester of each year parallels the upward trend in landings (Figure 5). Regression analysis residuals (observed age 2 catch minus CANSAR-TAM predicted age 2 catch) were not serially correlated, and the model appeared to fit these data. To improve the fit between model predictions and the catch-at-age data, we used different age-specific fishery selectivities: 1) during 1983-1992 when the range of the stock was largely confined to waters south of Point Conception and 2) during 1993-1997 when the directed fisheries became more significant and the stock began to expand beyond the Southern California Bight (Figure 6).

Population Weight-at-Age

Since 1991 size-at-age for sardine taken in southern California was much smaller than previously reported for the population. Therefore, population weights-at-age in 1991-1997 for the whole stock were not assumed to be the same as those of the southern California fishery.

For the period 1983-1990, a better estimate of population weight-at-age was calculated by fitting a von Bertalanffy growth curve ($L_t = L_\infty(1 - e^{-k(t-t_0)})$) to the fishery data (Figure 7) collected each semester in order to improve values that may be impacted by small sample size in each semester and year. Once the curve was fitted, half ages were used to allow for differences in weight-at-age between semesters (*i.e.*, semester 1 = x.5). The curve was generated using the assumption that a fish of age zero in the second semester is 1.5 g in weight (Butler, 1987).

For the 1991-1997 period, fishery weight-at-age values were calculated in the same manner

from three sources of non-fishery data that were collected from within the range of the existing fishery. These sources included weight-at-age data from a) approximately 1,400 fish collected on the 1994 DEPM cruise spanning Monterey, CA, to Cedros Island, Mexico, b) approximately 470 fish collected offshore in the southern California bight during the March 1997 LIDAR cruise, and c) approximately 1,800 fish sampled from 1949 through 1957 (Murphy 1966). We felt these samples provided a better estimate of population weight-at-age than existing fishery weight as they included fish collected offshore, which are likely under represented in fishery samples. Existing weight-at-age information from British Columbia, Humboldt Bay (CA), Halfmoon Bay (CA), and coastal Washington state was not included as those fish were not within the range of existing fisheries. With expansion of CANSAR to include a migration component, it is possible that this information will be included in future assessments.

CalCOFI Egg and Larvae Abundance

We used a generalized additive model (GAM) to standardize California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey data for the period 1984-1997 as a relative measure of egg production and spawning biomass. Bongo net tow data from the standard CalCOFI grid (excluding far offshore stations) during spring and summer cruises were used. The GAM included year, month, CalCOFI line, and inshore/offshore effects and was fit by logistic regression to the proportion of CalCOFI stations positive for eggs or larvae, assuming binomial sampling error.

The CalCOFI index shows a general increasing trend over most of the entire study period, but decreased 29% between the 1996 and 1997 seasons (Table 3, Figure 8). Suspected saturation in the CalCOFI egg/larvae index (Barnes et al. 1997) was dealt with by using an exponent. To estimate the degree of saturation in the index, we regressed log CalCOFI index values on log DEPM spawning biomass estimates. The slope of the regression line ($\beta=0.5$) was used in CANSAR-TAM as an exponent to adjust predicted CalCOFI values for saturation. No trend was apparent in residuals, and the model adequately fits the data (Figure 8).

The geographic area covered by the CalCOFI index extends only from the U.S./Mexico boundary to Point Conception and as far offshore as station 67.5. Sardine spawning area in recent years has clearly expanded beyond the area encompassed by our CalCOFI survey data. As an index of abundance, the CalCOFI egg/larvae data have not been responsive to changes in abundance in recent years. The index exhibits characteristics of saturation because on average it has not increased since 1991 despite a continued upward trend in biomass along the entire west coast. It appears that the area encompassed by CalCOFI surveys (the Southern California Bight) has become fully utilized as spawning habitat, causing the CalCOFI egg/larvae index to increase more slowly than spawning biomass. This problem may be resolved by the planned 1998 northward extension of the current CalCOFI sampling grid.

Spawning Biomass

Spawning biomass was estimated independently during 1986 (Scannel et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), 1996 (Barnes et al. 1997), and 1997 (present study) using the DEPM (Lasker 1985). DEPM estimates spawning biomass by: 1) calculating the daily egg production from ichthyoplankton survey data, 2) estimating the maturity

and fecundity of females from adult fish samples, and 3) calculating the biomass of females that spawned the standing stock of eggs. Before 1996 sardine egg production was estimated from direct CalVET plankton net sampling. For 1996 and 1997 DEPM estimates, Continuous Underway Fish Egg Sampler (CUFES; Checkley, et al. 1997) data were converted to equivalent CalVET egg densities using methods described in Barnes et al. (1997) and the following subsection. Adult fish were sampled in various ways to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average fish weight.

1997 DEPM Estimate

Data collected during the 1997 CUFES cruise 9703 (*R/V David Starr Jordan*, March 11 - April 7) was used to map the spatial distribution of adult sardine population and estimate relative egg density while samples from CalVET tows were used to model the sardine egg mortality curve. The daily egg production together with number of eggs per population weight (23.55 eggs/population weight (gm)/day) modified from the 1994 DEPM cruise was used to estimate the spawning biomass (Macewicz et al. 1996). Because the survey design was different from 1996 (Barnes et al. 1996), different daily egg production (P_0) estimation procedures were used.

The 9703 cruise was divided into three legs: leg 1 (San Diego to Port San Luis in March 11-21), leg 2 (Port San Luis to San Francisco March 21 -27) and leg 3 (San Francisco to San Diego in March 28 - April 7)(Figure 9). The survey area extended to 70 to 124 nm miles offshore. Sardine eggs collected in leg 1 and 2 were used to compute the daily egg production since the purpose of leg 3 was to use CUFES as one of the ground-truthing targets to support a LIDAR system. Egg density in leg 3 was drastically different from leg 1 and 2.

The survey area was post-stratified into two regions. Region 1 was a high density area and region 2 was a low density area. Region 1 encompassed the area where at least two eggs/min were sampled with the pump. In this area, CalVET samples were taken at least 4 nm apart. The rest of survey area was Region 2 or the low density area (Figure 9).

A total of 896 (out of 1227) pump samples was collected in legs 1 and 2 at an interval ranging from 1 to 54 minutes with a mean of 30 minutes and median of 15 minutes. A total of 141 CalVET samples was collected, among which 128 CalVET and pump samples were paired collections (Figure 10). Egg counts from these 128 paired samples were used to derive a conversion factor from eggs/minute of pump sample to CalVET catch (R). We used a regression estimator to compute the ratio of eggs/tows from CalVET to eggs/minute from CUFES:

$R = \mu_y / \mu_x$ where y is the eggs/tow and x is eggs/minute.

Daily egg production (p_0)¹

Twelve transects were occupied during legs 1 and 2 of cruise 9703. With the exception of

1

Most of the variance formulas were based on variance of product of two independent random variables (Goodman 1960):

$$v(xy) = v(x)(E_y)^2 + (E_x)^2 v(y) - v(x) v(y)$$

transect 12, all transects were parallel and at least 20 nm apart (Figure 9). Variogram analyses on sardine eggs collected in 9603 leg 2 indicated the range was 5 nm where the range is the distance at which eggs were no longer uncorrelated (Petitgas 1993, Cressie 1991). Because the distance between transects was greater than 5 nm, egg data from transects were uncorrected, and we used transects as the sampling units (Armstrong 1988) to construct the mortality curve from CalVET samples. CalVET tows were taken for the first nine transects, with the exception of transect number eight. The p_0 was estimated for each of two regions using different methods and an weighted average was obtained for the whole survey.

Daily egg production in region 1 ($P_{0,1}$):

Sardine eggs collected from 141 CalVET samples were examined for their development stages (Figure 11). Staged sardine eggs and yolk-sac larvae (5 mm captured size) were used to construct the egg mortality curve (Lo et al 1996):

$$p_t = p_{0,1} \exp(-zt) \quad [1]$$

where p_t is mean eggs-ys/0.05m²(transect is the sampling unit) and t is the mean age for each of 6 half-day age groups of eggs and yolk-sac larvae.

$$p_t = \frac{\sum_i p_{it} m_i}{\sum_i m_i} \quad [2] \quad \text{var}(p_t) = \frac{n/(n-1) \sum_i m_i^2 (p_{it} - p_t)^2}{(\sum_i m_i)^2}$$

where p_{it} is the eggs/0.05m² and m_i is the total pumping time (minute) for the i th transect for $i=1, \dots, 7$, and 9. A weighted nonlinear regression was used to obtain the estimates of $p_{0,1}$ and z , where the weight is $1/\text{var}(p_t)$.

Daily egg production in region 2 ($p_{0,2}$):

Since no CalVET samples were taken in Region 2, we estimated daily egg production ($p_{0,2}$) as the product of the egg production in region 1 ($p_{0,1}$) and the ratio of egg density in region 2 to region 1 (q) from pump samples assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET is the same for the whole survey area:

$$p_{0,2} = p_{0,1} q \quad [3]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,j}}{\bar{x}_{1,j}} m_i}{\sum_i m_i} \quad [4]$$

where q was the ratio of eggs/min between low density area and high density areas, and m_i was the total pump time (minutes) in the i th transect. $\bar{x}_{j,i}$ was eggs/min in the j th region and i th transect.

Daily egg production for the whole survey area (p_0):

P_0 was computed as a weighted average of $p_{0,1}$ and $p_{0,2}$, where:

$$\begin{aligned} p_0 &= \frac{p_{0,1}A_1 + p_{0,2} A_2}{A_1 + A_2} \\ &= p_{0,1}w_1 + p_{0,2} w_2 \quad [5] \\ &= p_{0,1}[w_1 + q w_2] \end{aligned}$$

and

$$V(p_0) = V(p_{0,1})(w_1 + w_2q)^2 + p_{0,1}^2 w_2^2 V(q) - V(p_{0,1})w_2^2 V(q)$$

where A_i is the area size and $w_i = \frac{A_i}{A_1 + A_2}$, $i = 1, 2$.

Catch ratio between CUFES and CalVET (R)

The ratio of eggs/minute to eggs/tows was 0.25 (CV= 0.08) from 110 pairs of which at least one sample was positive (Figure 12). This means that one egg/tow from CalVET tow was equivalent to approximately 0.25 egg/min from pump sample, or one egg/minute from the pump was equivalent to 4.00 eggs/tow from the CalVET sample.

The catch ratio between CalVET and CUFES (0.25) was quite different from that obtained in 1996 (0.73). This could be because 1996 CalVET samples were taken only in the southern area near San Diego while 1997 CalVET samples were taken in a larger area north of San Diego. CUFES caught a smaller portion of eggs in 1997 (0.25) compared to 1996 (0.73).

Daily egg production (p_0) results

The daily egg production in region 1 ($p_{0,1}$) was 4.76/0.05m²/day (CV=0.18)(equation 1) and egg mortality was $Z=0.35$ (CV=0.14) for an area of 66,841 km² (19,530 nm²)(Table 4). The ratio (q) of egg density between region 2 and region 1 from pump samples was 0.211 (CV=0.43) (equation 4). Therefore, in region 2, the egg production ($p_{0,2}$) was 1.004/0.05m²/day (CV=0.45) for an area of 107,255 km² (31,338 nm²). The estimate of the daily egg production for the whole survey area was 2.43/0.05m² (CV=0.21)(equation 5) (Table 4).

1997 spawning biomass (B_s) estimate

The spawning biomass was computed according to:

$$B_s = \frac{P_0 A C}{R S F/W_f} \quad [6]$$

where A is the survey area in unit of 0.05 m², S is the proportion of mature females that spawned per day, F is the batch fecundity, R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (gm), and C is the conversion factor from gm to mt. $P_0 A$ is the total daily egg production in the survey area, and the denominator is the daily specific fecundity (number of eggs/population weight (gm)/day).

Assuming the daily specific fecundity was the same as 1994-1996 (23.55), sardine spawning biomass was 396,055 short tons for an area of 174,096 km² (50,868 nm²) from San Diego to San Francisco. In the 1996 pump sardine egg survey, the egg production was 2.86/0.05m² (CV=0.75) and the spawning biomass was 424,052 short tons for an area of 156,717 km². Therefore, the biomass of sardine has been stable in 1996 and 1997, decreasing by only 7% (Table 4, Figure 13).

The CV (0.21) of daily egg production in 1997 was lower than the CV (0.75) of estimate in 1996, partially because the transect line was used as the sampling unit and egg densities among transects were uncorrelated. We think geostatistics (e.g. variogram analysis) are essential in analyzing the spatial structure of eggs based on egg samples from pump. We also believe that the simplest design for future DEPM ichthyoplankton surveys using the egg pump and CalVET will be to use transect lines as sampling units with variogram range as the minimum distance between transects; this design assures that egg counts between transects are uncorrelated and conventional statistical procedures can be applied.

Egg mortality Z (0.35) and its CV (=0.14) were much smaller than values from 1996: $z=0.95$ (CV=0.81). We believe that the estimate of Z in 1997 was better than that of 1996 because CalVET is an unbiased sampler for sardine eggs.

Spawning Area

Methods used for estimating spawning area in past years (1985-96) are described in Barnes et al. (1997). Spawning area for 1997 was calculated from results of the CUFES cruise (9703) described in the previous section (Figure 9). Sampling gear used on the cruise included standard CalVET nets and an 'egg pump', which extracts fish eggs from sea water pumped from 3 m below the surface. Egg pump catch rates were regressed on CalVET tows to give a conversion for egg pump data to equivalent CalVET catch rates. In the 9703 survey, one egg/tow from CalVET was equivalent to approximately 0.38 eggs/min from the pump sample.

We defined the spawning area from pump data for areas where eggs/minute was at least one, which was on the conservative side. Geographic Information System software (ArcView™, GIS) was used to generate a map for CUFES samples with catch rates of at least 1.0 egg/minute. Complex polygons were drawn around three major areas with this catch rate, and the area of each

polygon was calculated using the GIS software. The three areas were summed to give total spawning area.

The 1997 total spawning area estimate increased 25% from 1996 with a total estimated area of 30,721 square nautical miles (Table 3, Figure 14). Residuals were not serially correlated and predicted values fit the data.

Aerial Spotter Data

Spotter pilots were employed by wetfish fishermen to help locate and capture fish schools. The pilots were also contracted by National Marine Fisheries Service (NMFS) to complete and submit logbooks, creating a record of their observations from each flight. Data recorded include a species identification, school size (metric tons), and geographic location for all observed fish schools, regardless of target species for a particular flight or fishing operation. An index of relative abundance of schooling sardine was obtained from spotter data using a delta-lognormal model developed by Lo et al. (1992). The resulting index shows a decrease during the 1996 fishing year, compared to previous years (Table 3, Figure 15).

Data for 1996-1997 were tabulated using a July through June fishing year, consistent with analyses in previous years. One pilot involved in the program was questioned about possible reasons for the decline in the 1996-97 spotter relative abundance (Tom Wilson, pers. comm.). He expressed surprise in the downward trend, and reported that he and other pilots had seen large volumes of sardine within the Southern California Bight and north of Point Conception during the time period.

Weighting Factors Used for Abundance Index and Catch Data

The relative importance or influence of different input data on biomass estimates from CANSAR-TAM can be controlled by specifying weighting factors (l_i) for each data type (Deriso et al. 1996). In the 1996 sardine assessment (Barnes et al., 1997), there were concerns that problems with fishery selectivity patterns were degrading biomass estimates. Fishery selectivity patterns are estimated primarily from catch-at-age data, so a decision was made to decrease the relative importance of catch-at-age data by increasing the weight of fishery-independent data types to $l_i=4$ (Barnes et al. 1997).

For the 1997 assessment, we chose to equally weight catch-at-age and fishery-independent data types to $l_i=1$, as has been the case for CANSAR assessments prior to 1996. This decision was based primarily on an improvement in weight-at-age data compared to patterns observed in the 1995 and 1996 fisheries (Figure 4). In addition, the CANSAR-TAM model was designed to begin addressing the above mentioned problems with fishery selectivities, further alleviating the need to downweight influence of the catch-at-age data. We set weighting for spawner-recruit estimates to a small value ($l_{SR} = 1 \times 10^{-6}$) because recruitment variability is large for sardine (Jacobson and MacCall 1995) and higher l_{SR} values significantly decrease both the accuracy and precision of the final biomass estimate.

SARDINE ABUNDANCE ESTIMATES

Previous sardine assessments have revealed major uncertainty regarding availability of older sardine (age 3+) to the fishery (e.g., Barnes et al. 1997). Past assessments indicated that the population was composed mostly of new recruits which dominated the fishery age composition data due to their high abundance (Figure 16). An alternative explanation for lack of old fish in fishery samples was that these sardine have moved to northern or offshore areas where fishing does not occur.

The notion that older, larger sardine were unavailable and not selected by the fishery compelled us to address effects of migration on biomass available to the fishery. This biological uncertainty is important because biomass estimates might be higher if older fish exist but were unavailable to the fishery. In an effort to address these uncertainties, we developed a Two-Area Migration Model (CANSAR-TAM) based on the original CANSAR model. CANSAR-TAM provided biomass estimates both within and outside the range of the fishery and survey data without radically changing the data or modeling approach. For comparison, we also estimated sardine biomass using the original CANSAR model used in previous assessments.

CANSAR TWO-AREA MIGRATION MODEL

Fishing mortality rates estimated by the original CANSAR were unreasonably large for the oldest age groups and the problem was pronounced for estimated rates during the first semester (Table 5). The results show that selectivity patterns are implausible with very low selectivities on all but the oldest fish. A biological interpretation of these results is that estimated abundances of old fish are not large enough to account for the observed catch, particularly during the first semester. This problem has become more pronounced over the last two years and indicates serious problems in model structure. The goal in working with our two-area migration (CANSAR-TAM) model was to determine if more reasonable fishing mortality rate and selectivity estimates could be obtained from the fishery as a whole based on assumptions about migration.

Barnes et al. (1997) attempted to solve these problems by re-estimating egg production rates (used to estimate model parameters) for young fish and by applying several types of assessment models. Deriso et al. (1996), in contrast, did not report any difficulties with estimated fishing mortality rates or selectivities. Based on results from several models, data not included in assessment models, and anecdotal information, Barnes et al. (1997) concluded that sardine biomass estimates from CANSAR for later years should be regarded as regional estimates because fish likely existed outside the geographic range of the available data. They suggested that sardine had moved beyond the area utilized by the fishery, data, and model as sardine abundance increased during the 1980's and 1990's.

CANSAR-TAM assumes two habitat areas. Sardine in Area 1 are "inside" and assumed to be adequately sampled by the fishery and abundance indices. Sardine in Area 2 are "outside" and completely unavailable to the fishery or abundance indices. Area 2 includes areas that might be to the north, south or offshore of Area 1. Area 1 is likely centered around the Southern California Bight where most of our fishery and abundance data were collected. In contrast to CANSAR-TAM, the original CANSAR model assumes Area 1 only.

Sardine move from Area 1 to Area 2 in the CANSAR-TAM model but there is no movement back from Area 2 to Area 1. Unidirectional movement may be unrealistic because sardine during the historical fishery were thought to migrate north to feed and south to spawn on an annual basis (Radovich, 1982) and because sardine in the southern stock off Baja California may migrate seasonally (Felix-Uraga et al., 1996). This is an area for future research.

We examined two scenarios in CANSAR-TAM. In Scenario 1 all sardine recruit to Area 1 but migrate to Area 2 over time as they age and grow. In Scenario 2 sardine recruit to both areas and migration from Area 1 to Area 2 occurs as in the first scenario.

CANSAR-TAM Model Calculations

As far as the fishery and abundance indices in Area 1 are concerned, natural mortality and emigration are indistinguishable in the CANSAR-TAM model because both result in permanent losses of fish. This confounding of natural mortality and migration in Area 1 is the central idea behind the CANSAR-TAM model.

The “apparent” rate of natural mortality in Area 1 for sardine age a during year y and semester s was:

$$M_{y,s,a} = m + \mu_{y,s,a} \quad [7]$$

where $m=0.2 \text{ sem}^{-1}$ (equivalent to 0.4 yr^{-1}) is the assumed instantaneous rate for deaths from natural causes and $\mu_{y,s,a}$ is an instantaneous emigration rate parameter that is time and age dependent. In theory, CANSAR would measure sardine abundance and biomass in Area 1 if the apparent rate of natural mortality $M_{y,s,a}$ was used instead of $m=0.2$ in calculations (see below).

In the CANSAR-TAM model, migration rates (Table 6) were calculated:

$$\mu_{y,s,a} = v_{y,s} \phi_a \quad [8]$$

where $v_{y,s}$ was a year and semester specific migration multiplier (constrained to the interval $[0,1]$) and $\phi_a \geq 0$ was an age specific emigration parameter. We assumed that migration was more common in recent years with highest biomass than in early years with low biomass. Based on this *ad-hoc* assumption and trial model runs, we used $v_{y,s}$ values that increased from zero in 1983 to 1.0 in 1992-1997. The change from an increasing trend to constant maximum emigration rates in 1992 coincided with the 1992-1993 El Niño when age zero fish became more common in US fishery and weight-at-age in the US fishery declined dramatically (Figure 4). We also explored scenarios with delayed migration rates that were zero during 1983-1992 and 1.0 afterwards but this scenario gave fishing mortality rate estimates for the population as a whole (see below) that remained that unreasonably large.

We assumed that migration rate multipliers ϕ_a were zero for sardine in the first year of life and increased linearly to 1.0 at age 5+. These choices were *ad-hoc*, but seemed reasonable because sardine (Butler et al. 1996) and other pelagic fish (Parrish et al. 1985) off the west coast

are distributed with the largest individuals to the north and offshore and probably beyond the range of our data.

Abundance and biomass estimates for sardine in Area 1 were obtained by running CANSAR-TAM with the apparent rates of natural mortality ($M_{y,s,a}$) substituted for m . In this mode, CANSAR-TAM and CANSAR are identical except for the assumed rates m and $M_{y,s,a}$. Estimates of sardine abundance and biomass in Area 2 were based on the output for Area 1 and calculations described below.

The number of recruits in Area 2 on 1 July of each year (the beginning of the second semester) was assumed to be either zero (for scenario 1) or an assumed fraction θ_y of total recruitment (for scenario 2). In scenario 2 the number of recruits $R_{y,2}$ in Area 2 was:

$$R_{y,2} = \frac{\theta_y}{1-\theta_y} R_{y,1} \quad [9]$$

where $R_{y,1}$ was the number of recruits (already estimated) for Area 1. Like migration parameters, the recruitment fractions $\theta_y = \gamma \zeta_y$ were the product of a scaling parameter $\gamma=0.2$ and year specific multipliers ζ_y (both constrained to the interval $[0,1]$). For scenario 2 model runs, γ was assumed to increase in proportion to estimated biomass in Area 2. To accomplish this, and for lack of better information, biomass estimates for Area 2 from the Scenario 1 model were scaled to a maximum of one and used as year specific recruitment multipliers for Area 2 in the Scenario 2 model. These ad-hoc assumptions mean that the proportion of total recruitment in Area 2 increased to a maximum of 0.2 at a rate that was roughly in proportion to sardine biomass in Area 2.

After-recruitment abundance of sardine in Area 2 was the sum of surviving migrants from Area 1 during the previous semester and the surviving sardine already in Area 2. The number $n_{y,2,a}$ of sardine that migrated from Area 1 during semester 1, survived, and were counted at the beginning of semester 2 in Area 2 was:

$$n_{y,2,a} = \frac{\mu_{y,1,a-1}}{Z_{y,1,a-1}} (1 - e^{-Z_{y,1,a-1}}) A_{1,y,1,a-1} e^{-m} \quad [10]$$

where $A_{1,y,1,a}$ was the number of sardine in Area 1 at the beginning of semester 1 and $Z_{y,1,a} = m + \mu_{y,1,a}$ was the total "apparent" mortality rate in Area 1. A similar calculation for semester 1 was:

$$n_{y,1,a} = \frac{\mu_{y-1,2,a}}{Z_{y-1,2,a}} (1 - e^{-Z_{y-1,2,a}}) A_{1,y-1,2,a} e^{-m} \quad [11]$$

The subscripts for age and year differ in equations [10] and [11] because the birthday for sardine is assumed to be 1 July (the beginning of the second semester) rather than the beginning of the calendar year.

The number of sardine already in Area 2 at the beginning of semester 1 that survive natural mortality and are counted at the beginning of semester 2 was:

$$k_{y,2,a} = A_{2,y,1,a-1} e^{-m} \quad [12]$$

and the equivalent calculation for semester 1 was:

$$k_{y,1,a} = A_{2,y-1,2,a} e^{-m}. \quad [13]$$

The age and year specific abundance in Area 2 was $N_{2,y,s,a} = n_{y,s,a} + k_{y,s,a}$. We assumed population weights-at-age were the same in both areas so that the “total” biomass in areas 1 and 2 was $B_{y,s,a} = S(A_{1,y,s,a} + A_{2,y,s,a}) w_{y,s,a}$.

To obtain estimates of age and year specific fishing mortality rates $F_{y,s,a}$ for the sardine stock as a whole (Area 1+Area 2), we solved the catch equation:

$$C_{y,s,a} = \frac{F_{y,s,a}}{Z_{y,s,a}} (1 - e^{-Z_{y,s,a}}) (N_{1,y,s,a} + N_{2,y,s,a}) \quad [14]$$

where $C_{y,s,a}$ was the total catch in number for Area 1 and $Z_{y,s,a} = F_{y,s,a} + M_{y,s,a}$. Selectivities at age for the sardine stock as a whole were calculated by scaling year and age specific fishing mortality rates so that the largest was equal to 1.0.

CANSAR-TAM Model Abundance Estimates

As expected, the CANSAR-TAM gave higher biomass estimates in Area 1 (within the range of the fishery) than original CANSAR due to the higher assumed value of apparent natural mortality (Table 8, Figure 17). In effect, CANSAR-TAM had to estimate higher recruitments and abundance levels to account for losses (i.e., apparent mortality) due to net emigration. Biomass estimates for the entire stock (Areas 1+2) were substantially larger than for Area 1 and increases due to recruitment in Area 2 were about the same as increases due to migration. Fishing mortality rates (Table 5) and selectivity estimates (Table 7) from CANSAR-TAM for the stock as a whole were more plausible than estimates from CANSAR and had few large values for the oldest age groups.

Complicated models such as CANSAR and CANSAR-TAM can converge to local rather than global minima when estimated with limited data (Deriso et al. 1996). To test for this, we reran CANSAR-TAM 30 times using different initial parameter values to confirm that our final estimates were at the global minima.

Based on CANSAR-TAM, we estimate the July 1, 1997 Area 1 (inside the range of the fishery and survey data) biomass to have been 464,000 tons (95% confidence interval = 250,085 - 958,256 tons, based on 5,000 bootstrap runs). This estimate includes a bias correction based on bootstrap results (Barnes et al. 1997). We currently estimate the July 1, 1996 biomass to have

been 529,095 tons, which is modestly higher than the estimate of 510,000 tons obtained using CANSAR at the end of 1996 (Barnes et al. 1997). Total sardine biomass (Age 1+) increased dramatically from 1983 to 1996 (Table 8, Figure 18). The relatively small downward trend in our 1997 biomass estimate was likely due in part to decreases in three of the four fishery-independent indices used by CANSAR-TAM, as well as an additional year of fishery data.

CANSAR-TAM Model Discussion

Sardine appear to migrate and recruit in areas that are not covered by fishery or survey data. Abundance estimates from CANSAR *for the area covered by the fishery and survey data* (i.e. Area 1) are, therefore, biased low. Estimates of sardine abundance from CANSAR-TAM for Area 1 are more reliable in principle but, as indicated above, assumed migration rates were crude guesses and CANSAR-TAM estimates depend on several assumptions (see below). It is particularly important to remember that CANSAR-TAM estimates for the area not covered by the fishery or survey data (Area 2) are crude guesses that are meant only to indicate the potential importance of sardine outside the area covered by the fishery and survey data.

The use of complicated migration models could be avoided if abundance surveys could be extended over the entire coast. In the absence of coast wide survey data, migration parameters are a key uncertainty. A number of issues need to be resolved if sardine migration models are to be further developed.

We assumed that the area covered by the fishery and our abundance data were the same even though our abundance data likely cover a much broader geographic range. The fishery operates primarily near shore and around islands while CalCOFI data, for example, cover the entire California Bight out to about 200 miles. In a more realistic model, areas covered might differ among surveys and the fishery. Nonlinear relationships between abundance indices and sardine biomass, assumed in both CANSAR and CANSAR-TAM, account for changes that are expected to occur as sardine biomass increases beyond the range of the survey.

The CANSAR-TAM model assumed that migrants were permanently lost from Area 1, even though some seasonal migration in and out of Area 1 is likely. CANSAR-TAM gave higher estimates of fishing mortality for old fish during semester 1 than during semester 2. This may result from differences in abundance of old fish between semesters due to seasonal spawning or feeding migrations. In future models, it might be necessary to include seasonal movement patterns.

The change in migration patterns we assumed during 1992-1993 occurred during a change in selectivities for the US fishery assumed in CANSAR and CANSAR-TAM. Deriso et al. (1996) hypothesized that the apparent change in selectivities was due to a change in the fishery from incidental to directed catches as abundance increased. Our results suggest that changes in selectivity and migration (availability) are likely confounded.

The largest sardine tend to be further north and offshore and outside the range of the current sardine fishery. Thus, weights at age may be larger in Area 2 than in Area 1. A more realistic model might require different weights at age for sardine inside and outside of Area 1. The CANSAR-TAM model assumes two areas and estimates sardine biomass within each, but we

cannot describe the geographic boundaries for either Area.

FISHERY MANAGEMENT

BACKGROUND

Current regulations give considerable latitude to the Department in setting annual sardine harvest quotas. Section 8150.7 of the California Fish and Game Code states that the quota can be set at a level greater than 1,000 tons, providing that the biomass is found to be in excess of 20,000 tons and the added level of take allows for continued increase in the spawning population. The primary goal of management is rehabilitation of the resource, while maximizing sustained harvest. Although biomass has increased dramatically in recent years, the stock remains in a rebuilding stage and is still short of the one million ton level that is associated with recovery (defined during the Department's annual Sardine Biomass Workshops, 1989-1993).

THE RECOMMENDED 1998 QUOTA

To calculate the recommended 1998 fishery quota, we used the same harvest formula as for 1997 (Table 9). The formula was originally selected as the preferred option in the draft Amendment 7 to the Coastal Pelagic Species-Fishery Management Plan (CPS-FMP) (PFMC, 1996). As part of the Pacific Fishery Management Council's (PFMC) CPS-FMP review process the formula underwent extensive scientific and user-group review and received the endorsement of the fishing industry and the scientific community. A decision was made to continue use of this formula until better scientific data on stock distribution are available.

The harvest formula for sardine is:

$$H_{t+1} = (\text{BIOMASS}_t - \text{CUTOFF}) \times \text{FRACTION} \times \text{STOCK DISTRIBUTION}$$

where H_{t+1} is the total California harvest (quota), CUTOFF is the lowest level of estimated biomass at which harvest is allowed, FRACTION is the fraction of biomass above CUTOFF that can be taken by fisheries, and STOCK DISTRIBUTION is the fraction of total BIOMASS_t in U.S. waters. BIOMASS_t is the estimated biomass of fish age 1+ for the whole stock at the beginning of season t.

Formula values for the 1998 California fishery are as follows:

BIOMASS	CUTOFF	FRACTION	CalCOFI/FISH SPOTTER U.S. DISTRIBUTION	QUOTA
464,000	55,000	20%	59%	48,000

Values for FRACTION, STOCK DISTRIBUTION, and CUTOFF were selected using average conditions over time. Since the sardine stock can undergo large fluctuations, the status of

the stock in any given year may not match those average values used in the formula, particularly for STOCK DISTRIBUTION. However, it is not possible to routinely make adjustments to STOCK DISTRIBUTION as part of sardine management. No survey data were available covering the entire range of the stock in recent years. Subjective observations and geographically or temporally limited studies (e.g.: Bentley et al. 1996) were difficult to interpret on a year-by-year basis concerning STOCK DISTRIBUTION. The formula currently apportions 59% of the allowable harvest to the U.S. based on distributional analyses of spotter and CalCOFI data.

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Table 1. - Pacific sardine landings (short tons), 1983-1997.

YEAR	SEMESTER	US	ENSENADA	TOTAL
1983	1	289.8	164.7	454.6
1983	2	98.1	136.8	234.8
1984	1	175.2	0.1	175.3
1984	2	82.7	0.1	82.8
1985	1	354.8	3,498.0	3,852.8
1985	2	298.6	604.0	902.6
1986	1	1,013.8	109.3	1,123.2
1986	2	268.9	158.0	426.9
1987	1	1,437.0	1,074.5	2,511.5
1987	2	871.7	1,605.2	2,476.9
1988	1	3,328.0	683.5	4,011.5
1988	2	844.1	1,559.0	2,403.1
1989	1	2,373.7	508.0	2,881.7
1989	2	1,683.9	6,348.8	8,032.7
1990	1	2,349.5	6,501.8	8,851.3
1990	2	752.7	6,033.8	6,786.4
1991	1	5,700.6	10,216.6	15,917.3
1991	2	2,839.9	24,377.1	27,217.0
1992	1	6,894.1	3,665.8	10,559.9
1992	2	12,188.1	34,428.4	46,616.5
1993	1	13,392.6	20,551.2	33,943.8
1993	2	4,445.5	14,762.4	19,207.9
1994	1	9,365.5	6,288.2	15,653.7
1994	2	4,778.7	16,711.8	21,490.5
1995	1	31,486.0	20,087.3	51,573.3
1995	2	14,247.0	18,919.1	33,166.1
1996	1	18,624.0	17,268.7	35,892.7
1996	2	18,916.4	25,792.8	44,709.2
1997	1	12,843.0	N/A	N/A
1997	2	35,407.7	N/A	N/A

Table 2. Estimated annual sardine revenue (millions of dollars; no inflationary adjustment) as a component of overall wetfish fleet ex-vessel value. 1997 figures reflect revenue reported through September only.

Year	Tuna	Anchovy	Jack mackerel	Pacific mackerel	Sardine	Squid	Total
1983	11.19	0.41	1.76	3.25	0.10	0.74	17.45
1984	11.39	0.49	1.38	5.06	0.17	0.30	18.79
1985	3.20	0.38	1.28	3.33	0.14	3.61	11.94
1986	8.16	0.33	0.82	3.60	0.24	4.81	17.96
1987	9.77	0.26	1.12	4.08	0.30	4.14	19.67
1988	11.48	0.35	0.86	5.03	0.52	7.84	26.07
1989	6.88	0.45	1.52	3.24	0.67	7.16	19.92
1990	4.60	0.60	0.43	4.16	0.30	4.88	14.97
1991	4.85	0.52	0.24	5.30	0.91	6.07	17.91
1992	2.98	0.21	0.25	4.17	1.68	2.49	11.79
1993	1.94	0.50	0.26	1.50	1.61	9.97	15.79
1994	4.27	0.53	0.36	1.29	1.42	15.98	23.85
1995	5.30	0.32	0.22	1.13	3.66	21.38	32.01
1996	6.45	1.02	0.29	1.27	3.11	29.24	41.38
1997	2.90	0.48	0.18	0.59	3.51	21.56	29.21

Table 3. Fishery-independent abundance data for Pacific sardine.

<u>YEAR</u>	<u>CalCOFI Egg and Larvae Index</u>	<u>Spawning Area (N mi²)</u>	<u>Aerial Spotter Index</u>	<u>DEPM Spawning Biomass (Short tons)</u>	<u>3-Season Scripps Pier SST (Deg C)</u>
1983	--	--	--	--	17.80
1984	21.54	--	--	--	17.90
1985	13.13	607	--	--	17.70
1986	19.68	970	62,206	8,443	17.60
1987	43.85	1,850	16,314	17,291	17.20
1988	45.62	2,508	97,919	14,897	17.20
1989	111.42	3,680	59,361	--	17.30
1990	35.84	1,480	33,127	--	17.60
1991	194.94	3,840	63,437	--	17.61
1992	133.49	--	76,604	--	17.84
1993	63.06	--	118,007	--	17.97
1994	143.01	11,361	293,490	122,898	18.04
1995	80.23	--	300,559	--	18.06
1996	109.13	24,480	179,530	424,052	18.11
1997	77.59	30,721	62,125	396,055	18.11

Table 4. Spawning biomass of Pacific sardine and parameter estimates in 1997 based on egg data from CalVET and pump; P_0 , q : ratio of egg density of region 2 to region 1 from pump samples, and R : catch ratio of eggs/minute to eggs/tow from CalVET tows.

Parameter	1997			1996			1994	
	Region 1	Region 2	wted ave.	Region 1	Region 2	wted ave.	US+Mex	US only
p_0 /min				0.48	6.3	2.11		
CV				0.58	0.88	0.75		
p_0 /0.05m ²	4.76	1.004	2.43	(= p_0 /min/0.73)		2.89	0.169	
CV	0.18	0.45	0.21				0.22	
Area (km ²)	66,841	107,255	174,096	112,322	44,395	156,717	380,175	253,850
km ² ;%	38	62	100	72	28	100		
Fish wt(W)						82.5	82.5	
Batch fecundity(F)						24,283	24,283	
Spawning freq(S) ¹						0.149	0.073	
Sex ratio(R)						0.537	0.537	
Eggs/gm biomass(RSF/W)			23.55			23.55	11.53	
Spawn. biomass(mt)			356,280			384,694	111,493	
Daily mortality(Z)	0.35			0.49	0.94	0.62	0.12	
CV	0.14			0.82	0.63	0.81	0.97	
eggs/min	4.16	0.47	² 1.86			² 2.22		
CV	0.42	0.45	0.31			0.24		
q			0.211					
CV			0.43					
R =eggs/min/eggs/tow			0.25			0.73		
CV			0.08			0.16		
	In 1997 reg 1: eggs/min ≥ 2 reg 2: eggs/min < 2			In 1996, Reg 1: Lines < 73 and Lines > 83 Reg 2: Lines between 73 and 83				

¹ Macewicz et al. 1996.

² 1.86 and 2.22 are unweighted averages.

Table 5. Fishing mortality rates estimated using original CANSAR (no migration) and the CANSAR-TAM Model.

F AT AGE FOR SEASON 1 - CANSAR NO MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.021	0.001	0.069	0.001	0.007	0.002	0.001	0.004	0.007	0.003	0.052	0.023	0.138	0.030	0.023
1	0.238	0.040	0.338	0.018	0.051	0.026	0.024	0.027	0.062	0.040	0.154	0.063	0.494	0.086	0.065
2	0.830	0.144	1.076	0.064	0.170	0.093	0.085	0.091	0.213	0.140	0.313	0.105	1.266	0.164	0.122
3	1.134	0.164	1.999	0.082	0.269	0.122	0.102	0.143	0.315	0.180	0.522	0.161	2.294	0.266	0.197
4	1.920	0.155	5.373	0.118	0.595	0.188	0.124	0.309	0.629	0.262	1.272	0.355	6.057	0.630	0.463
5	>9.999	1.295	>9.999	0.860	3.913	1.343	0.948	2.040	4.228	1.903	>9.999	>9.999	>9.999	>9.999	>9.999

F AT AGE FOR SEASON 2 - CANSAR NO MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.002	0.000	0.002	0.000	0.001	0.001	0.002	0.001	0.003	0.005	0.002	0.003	0.002	0.003	0.002
1	0.026	0.003	0.026	0.004	0.020	0.010	0.023	0.013	0.041	0.081	0.038	0.045	0.057	0.064	0.037
2	0.109	0.012	0.107	0.017	0.083	0.042	0.098	0.052	0.172	0.342	0.131	0.167	0.164	0.204	0.107
3	0.211	0.015	0.211	0.029	0.170	0.086	0.206	0.111	0.375	0.694	0.271	0.367	0.282	0.391	0.184
4	0.233	0.013	0.235	0.031	0.192	0.097	0.235	0.127	0.433	0.782	0.303	0.423	0.287	0.424	0.186
5	0.680	0.029	0.688	0.087	0.569	0.288	0.701	0.380	1.302	2.309	0.875	1.254	0.727	1.170	0.471

F AT AGE (WHOLE POPULATION) FOR SEASON 1 - CANSAR TWO-AREA MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.020	0.001	0.059	0.001	0.005	0.001	0.001	0.003	0.005	0.002	0.035	0.016	0.097	0.020	0.014
1	0.232	0.037	0.298	0.014	0.036	0.019	0.017	0.019	0.044	0.028	0.106	0.044	0.345	0.056	0.042
2	0.843	0.142	0.977	0.052	0.124	0.068	0.060	0.065	0.147	0.096	0.193	0.068	0.777	0.095	0.073
3	1.220	0.169	1.894	0.068	0.201	0.090	0.073	0.100	0.208	0.110	0.252	0.085	0.918	0.101	0.092
4	2.209	0.175	4.414	0.093	0.430	0.139	0.088	0.205	0.366	0.135	0.364	0.119	0.695	0.067	0.110
5	15.785	1.476	8.276	0.051	1.466	0.658	0.520	0.686	0.648	0.223	0.084	0.092	0.099	0.001	0.028

F AT AGE (WHOLE POPULATION) FOR SEASON 2 - CANSAR TWO-AREA MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.002	0.004	0.001	0.002	0.002	0.002	0.001
1	0.024	0.002	0.021	0.003	0.014	0.007	0.016	0.009	0.029	0.059	0.025	0.029	0.037	0.040	0.025
2	0.106	0.011	0.089	0.013	0.061	0.030	0.069	0.037	0.120	0.237	0.084	0.107	0.100	0.121	0.071
3	0.215	0.014	0.180	0.024	0.128	0.062	0.144	0.078	0.245	0.431	0.147	0.210	0.121	0.190	0.108
4	0.259	0.013	0.198	0.026	0.149	0.072	0.166	0.087	0.260	0.405	0.118	0.188	0.043	0.123	0.083
5	0.783	0.033	0.083	0.066	0.386	0.192	0.412	0.177	0.440	0.440	0.082	0.144	0.001	0.038	0.042

Table 7. Age- and year-specific fishing selectivities (sem⁻¹) from CANSAR-TAM model for sardine in semesters 1 and 2.

SELECTIVITES AT AGE FOR SEASON 1 (U.S. Fishery) - CANSAR NO MIGRATION MODEL

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002
1	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.004	0.004	0.004	0.004	0.004
2	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.004	0.004	0.004	0.004	0.004
3	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.005	0.005	0.005	0.005	0.005
4	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.007	0.007	0.007	0.007	0.007
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

SELECTIVITES AT AGE FOR SEASON 2 (U.S. Fishery) - CANSAR NO MIGRATION MODEL

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.011	0.011	0.011	0.011	0.011
1	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.406	0.406	0.406	0.406	0.406
2	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.908	0.908	0.908	0.908	0.908
3	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	1.000	1.000	1.000	1.000	1.000
4	0.437	0.437	0.437	0.437	0.437	0.437	0.437	0.437	0.437	0.437	0.671	0.671	0.671	0.671	0.671
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.424	0.424	0.424	0.424	0.424

SELECTIVITIES AT AGE FOR WHOLE POPULATION IN SEASON 1 -- CANSAR TWO-AREA MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.001	0.001	0.007	0.010	0.003	0.002	0.001	0.004	0.008	0.008	0.097	0.135	0.106	0.194	0.131
1	0.015	0.025	0.036	0.153	0.025	0.029	0.032	0.028	0.068	0.127	0.291	0.366	0.376	0.557	0.383
2	0.053	0.096	0.118	0.557	0.085	0.104	0.116	0.095	0.228	0.432	0.529	0.575	0.846	0.940	0.663
3	0.077	0.115	0.229	0.725	0.137	0.137	0.140	0.146	0.322	0.493	0.692	0.717	1.000	1.000	0.838
4	0.140	0.119	0.533	1.000	0.294	0.211	0.170	0.299	0.565	0.604	1.000	1.000	0.758	0.665	1.000
5	1.000	1.000	1.000	0.542	1.000	1.000	1.000	1.000	1.000	1.000	0.232	0.777	0.107	0.013	0.251

SELECTIVITIES AT AGE FOR WHOLE POPULATION IN SEASON 2 -- CANSAR TWO-AREA MIGRATION MODEL

AGE	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0	0.002	0.003	0.006	0.002	0.002	0.002	0.003	0.003	0.005	0.008	0.009	0.009	0.013	0.010	0.009
1	0.031	0.074	0.104	0.046	0.037	0.036	0.039	0.050	0.065	0.134	0.169	0.139	0.307	0.209	0.228
2	0.135	0.323	0.449	0.199	0.158	0.154	0.166	0.210	0.272	0.539	0.572	0.508	0.828	0.637	0.657
3	0.275	0.429	0.906	0.358	0.330	0.321	0.349	0.437	0.557	0.977	1.000	1.000	1.000	1.000	1.000
4	0.331	0.400	1.000	0.393	0.386	0.372	0.402	0.489	0.590	0.919	0.801	0.895	0.356	0.649	0.771
5	1.000	1.000	0.418	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.553	0.687	0.009	0.201	0.392

Table 8. Estimates of Pacific sardine Age 1+ biomass (short tons, semester 2) and recruitment (Age 0, 1x10³) estimated using original CANSAR (no migration) and CANSAR-TAM Models.

YEAR (July 1)	CANSAR - NO MIGRATION				CANSAR-TAM MODEL				
	Age 1+ Biomass	Biomass Std. Error	Number Recruits	Recruits Std. Error	Age 1+ Biomass Inside	Biomass Total	Inside Biomass Std. Error	Number Recruits	Recruits Std. Error
1983	5,261	3,126	108,156	38,165	5,548	5,548	3,294	124,792	46,220
1984	12,554	4,438	140,799	39,593	14,063	14,076	5,089	171,998	51,767
1985	16,364	4,059	116,091	28,966	19,904	20,007	5,464	150,979	40,640
1986	21,965	4,867	408,879	88,555	27,475	27,805	6,672	560,504	127,745
1987	46,304	8,568	375,278	75,588	61,914	62,780	12,617	536,315	110,399
1988	65,520	10,533	657,105	131,973	90,220	92,390	15,551	910,451	202,176
1989	99,711	14,916	507,462	123,455	136,367	141,675	22,463	708,074	181,449
1990	111,477	17,226	1,990,249	537,127	150,485	161,366	26,009	2,754,470	794,893
1991	131,401	27,642	2,372,635	709,733	177,327	192,841	41,099	3,235,490	1,004,289
1992	203,615	47,225	1,501,635	553,768	269,912	297,112	67,529	1,983,927	719,053
1993	180,221	50,982	3,612,789	1,172,300	240,918	283,610	68,840	4,732,461	1,571,951
1994	281,158	71,303	5,228,857	1,607,538	358,937	428,684	92,988	6,818,239	2,233,333
1995	293,955	75,640	4,103,719	1,873,824	397,155	503,959	110,281	5,511,022	2,573,323
1996	405,299	124,507	1,844,218	1,720,460	529,095	671,305	170,674	2,378,929	2,274,789
1997	372,623	161,944	*****	*****	463,999	630,584	209,469	*****	*****

Table 9. Pacific sardine quotas (short tons) for 1998. The statewide quota is based on the following formula and a total biomass estimate of 464,000 short tons.

$$QUOTA = (BIOMASS_{total} - 55,000) \times 20\% \times 59\%$$

Directed Fishery Quota (available 1/1/98)	48,000 tons
Southern California Allocation	32,000 tons
Northern California Allocation	16,000 tons

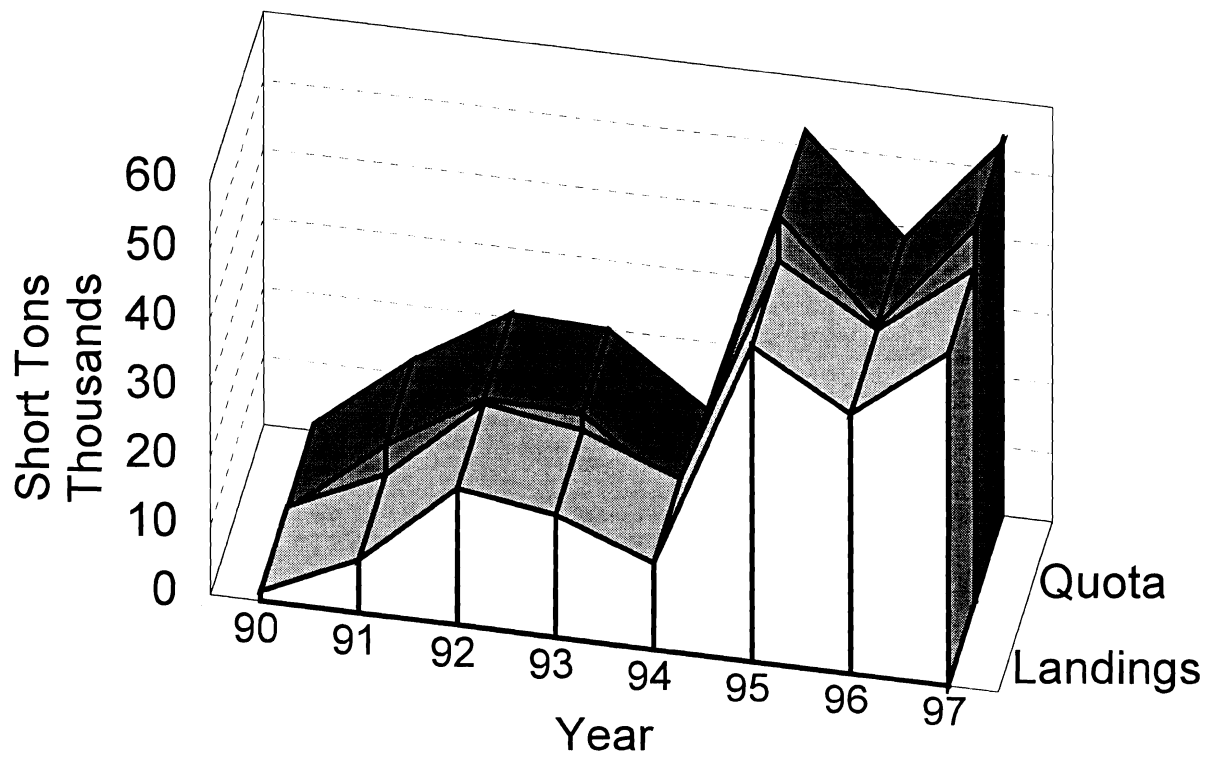


Figure 1. California sardine landings relative to quota, 1990-1997.

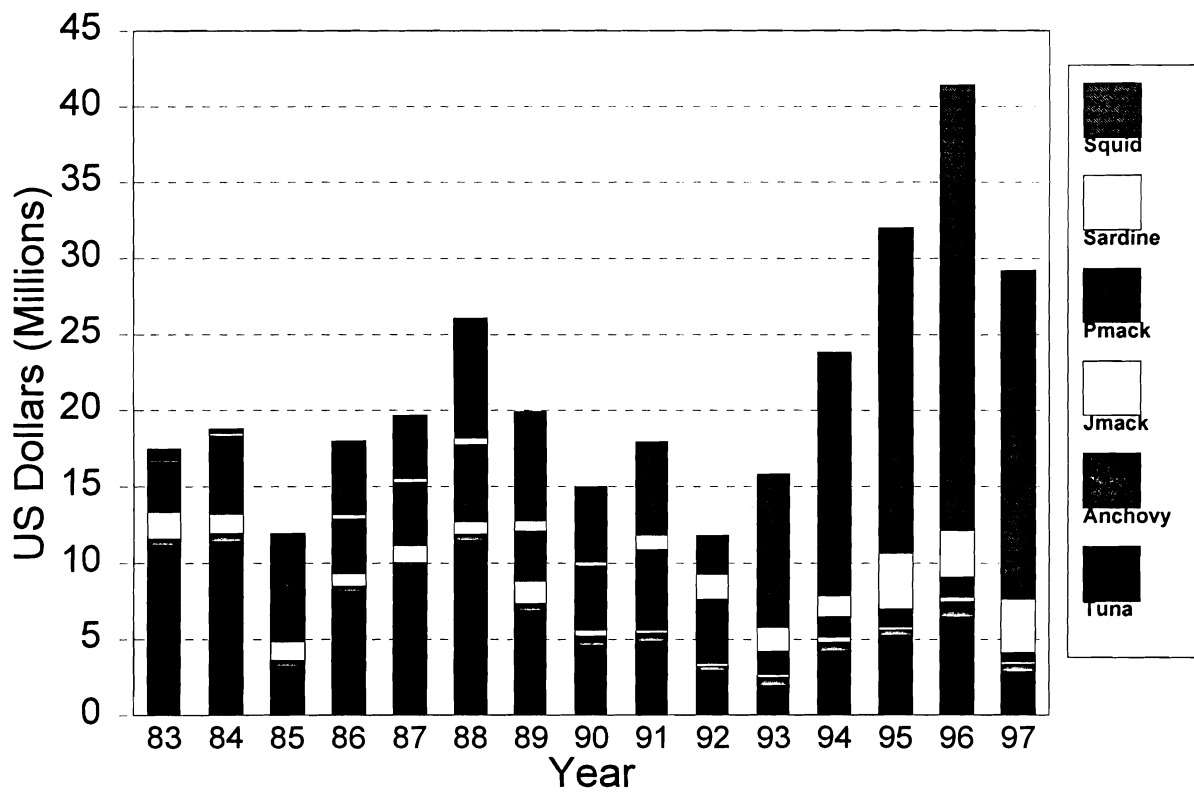


Figure 2. Estimated annual sardine revenue (millions of dollars; no inflationary adjustment) as a component of overall wetfish fleet ex-vessel value. 1997 figures reflect revenue reported through September only.

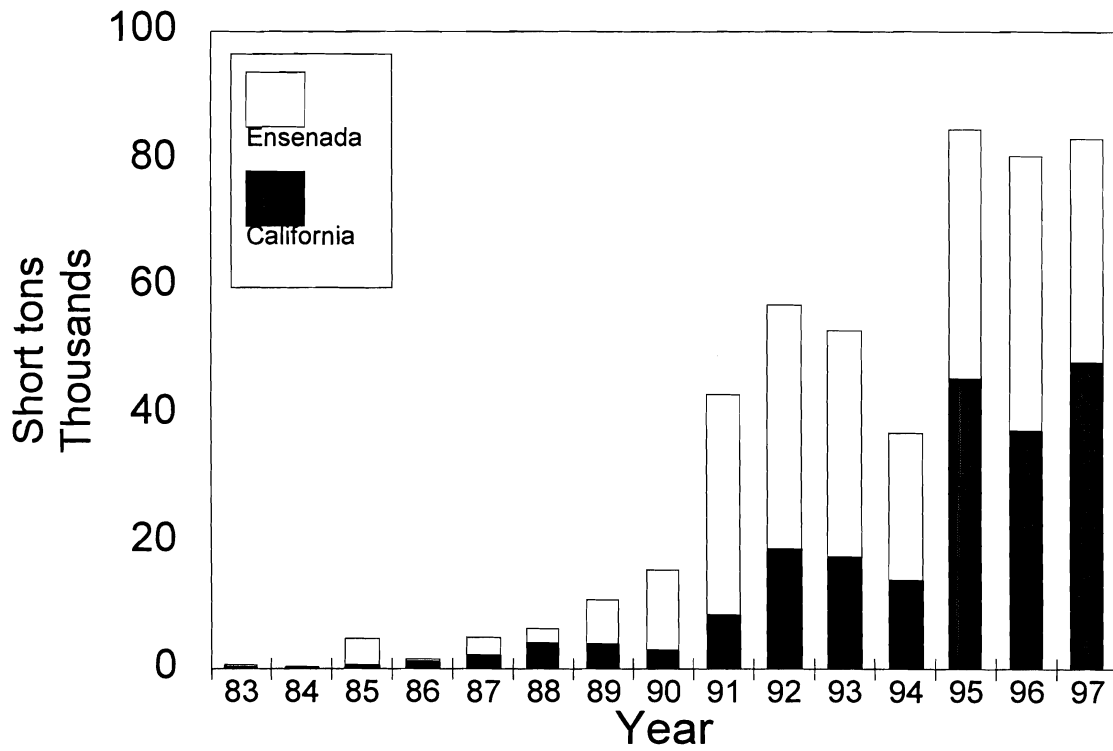


Figure 3. Annual sardine landings by directed fisheries in California and Ensenada, 1983 through 1997. Projected values were substituted for the remainder of 1997.

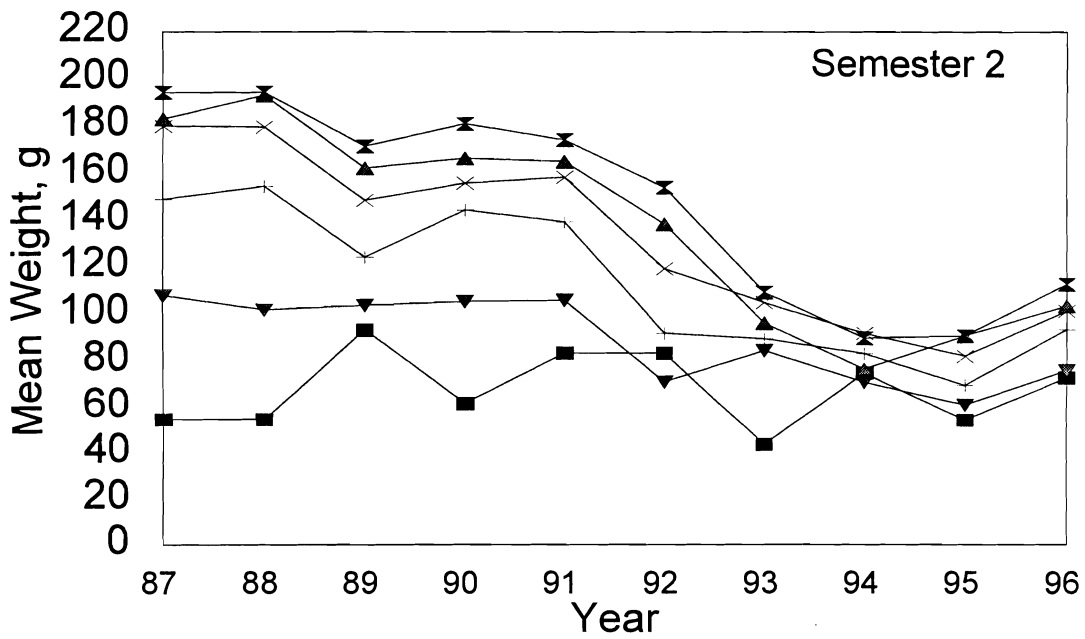
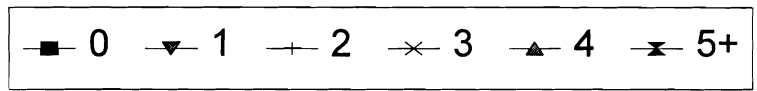
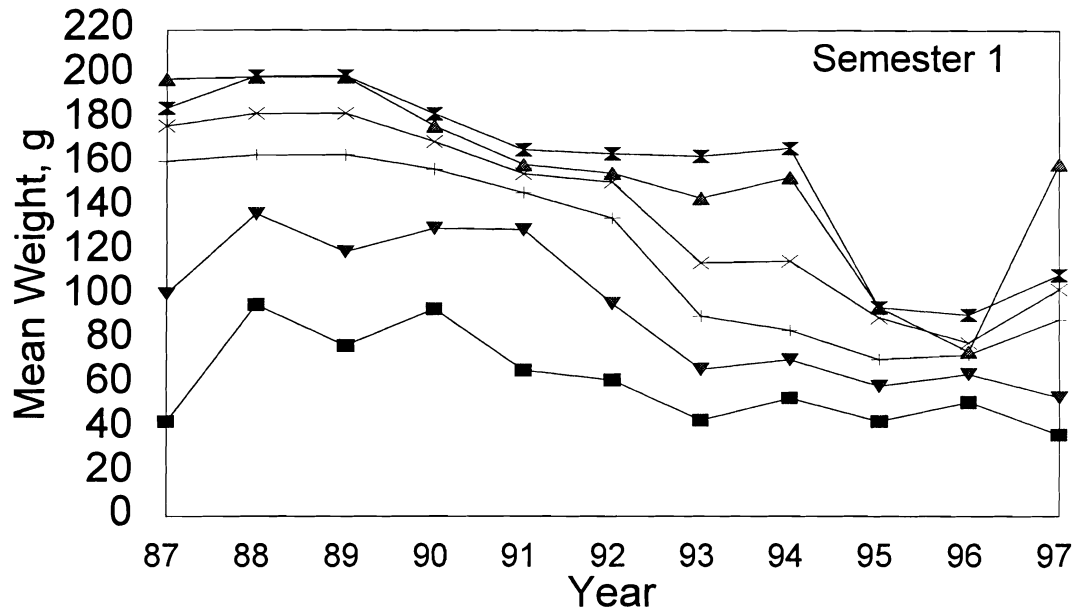


Figure 4. Pacific sardine weights-at-age for the California fishery, 1987-1997.

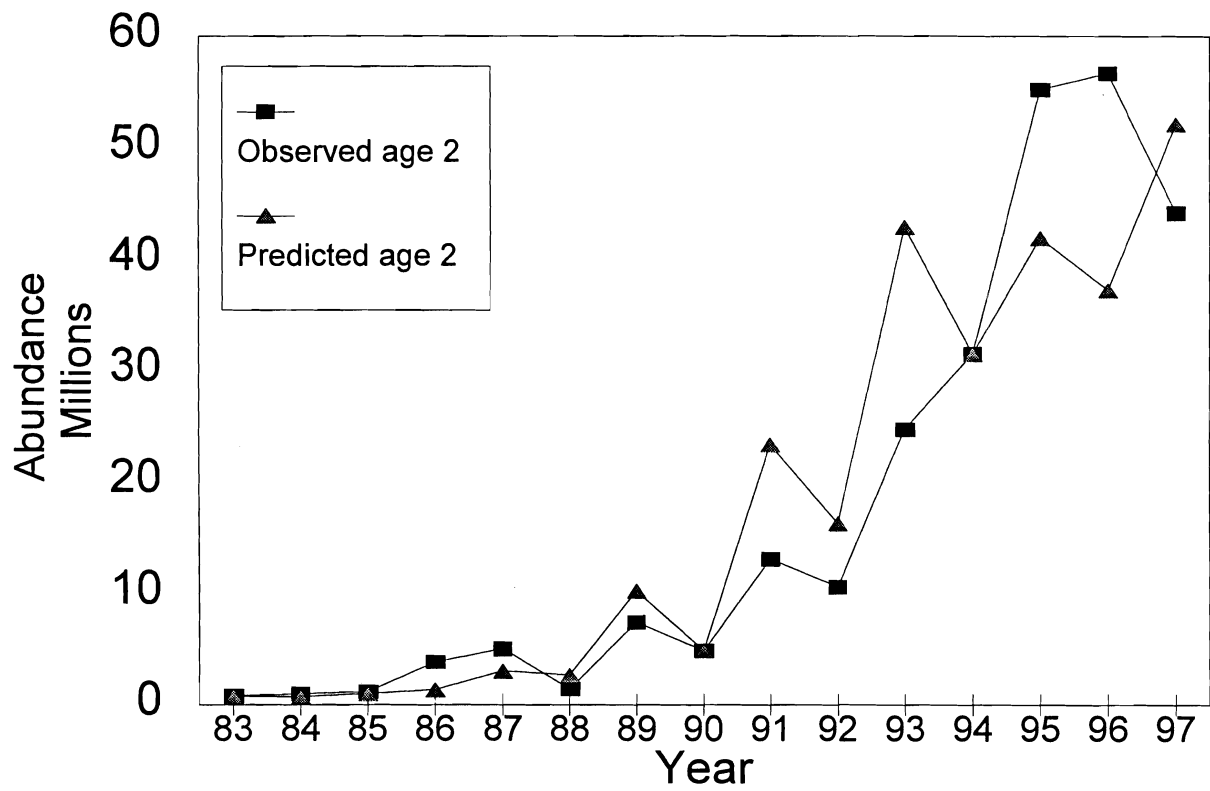


Figure 5. Observed and predicted catch (abundance) of age-2 sardine from CANSAR-TAM, 1997.

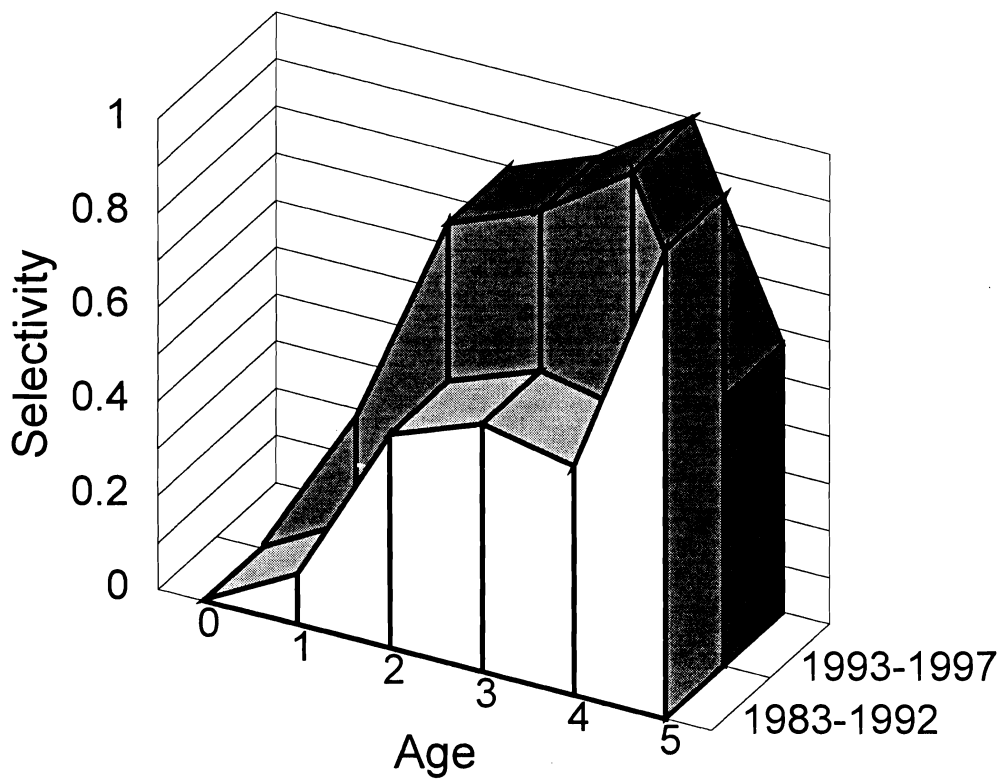


Figure 6. Fishery selectivity patterns (semester 2) used in 1997 CANSAR-TAM model.

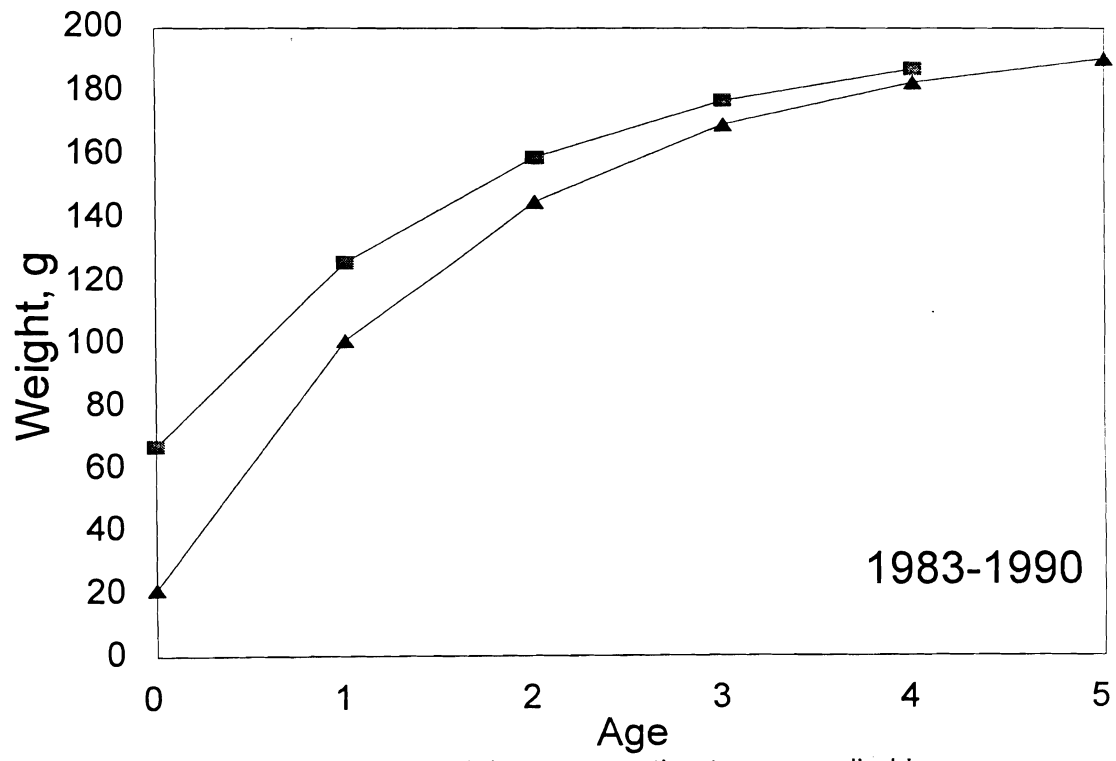
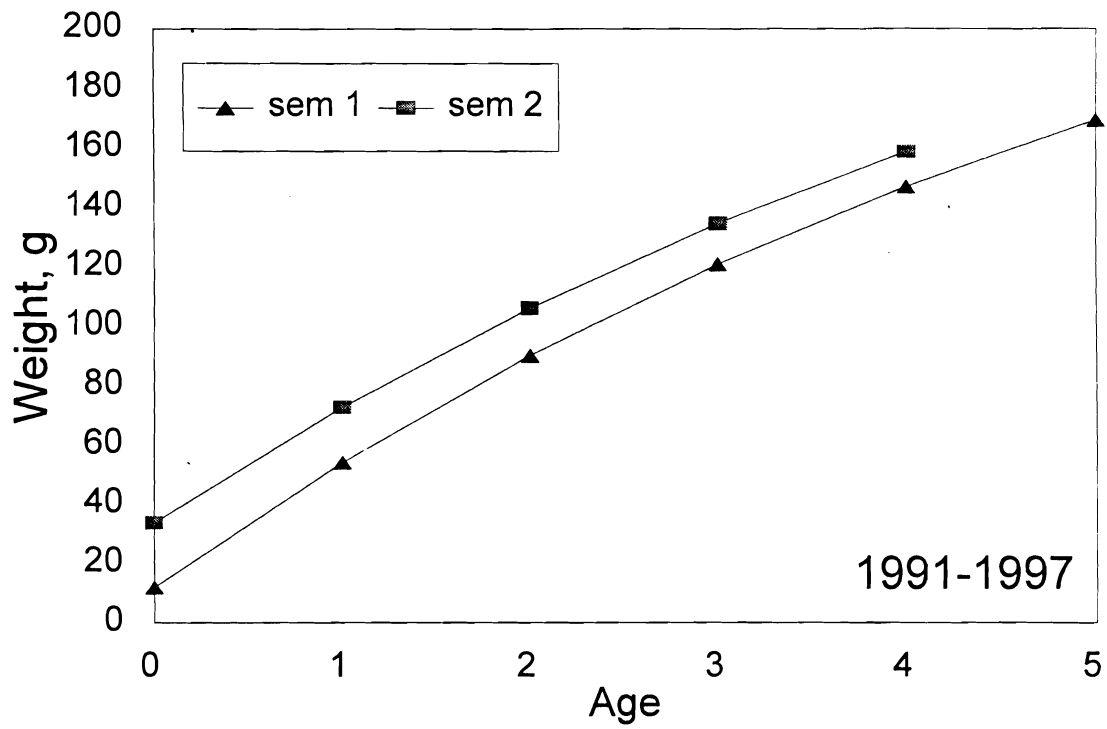


Figure 7. Sardine population weight-at-age estimates as applied in CANSAR-TAM.

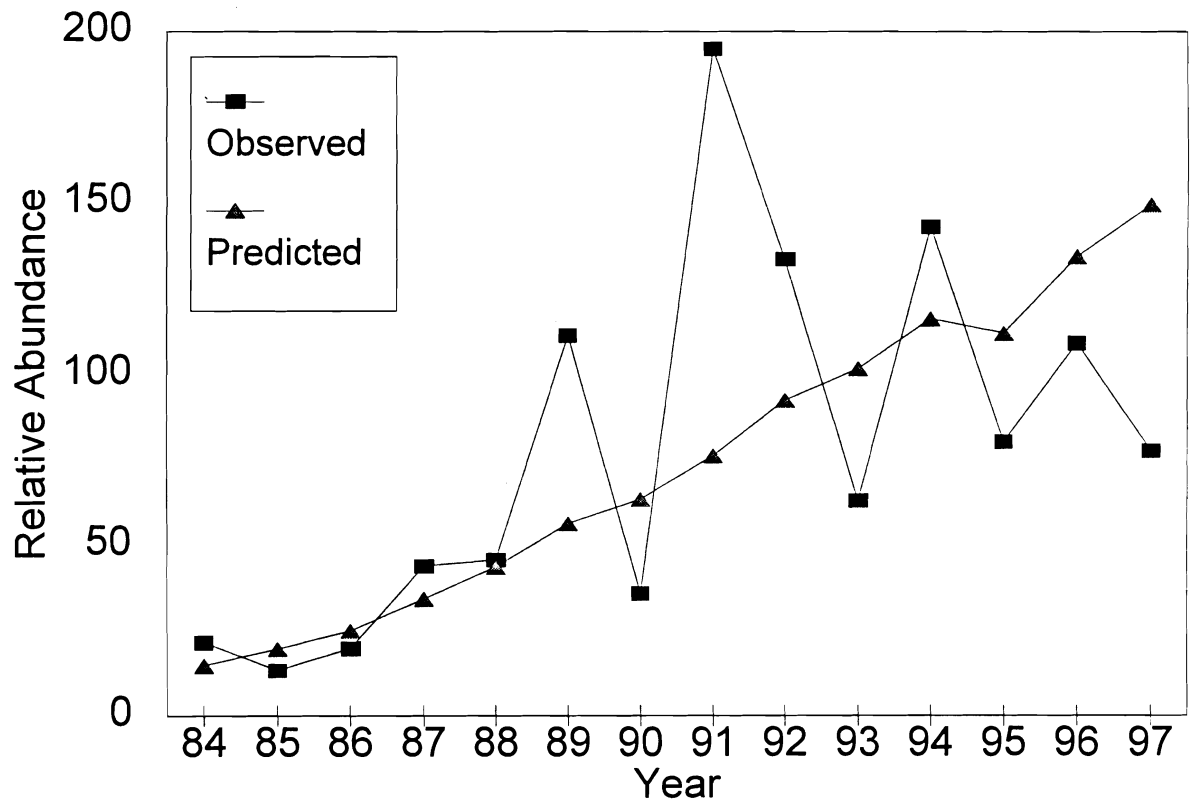


Figure 8. Observed and predicted CalCOFI egg and larvae index, 1984-97, Sept.-Oct. season, from CANSAR-TAM, 1997.

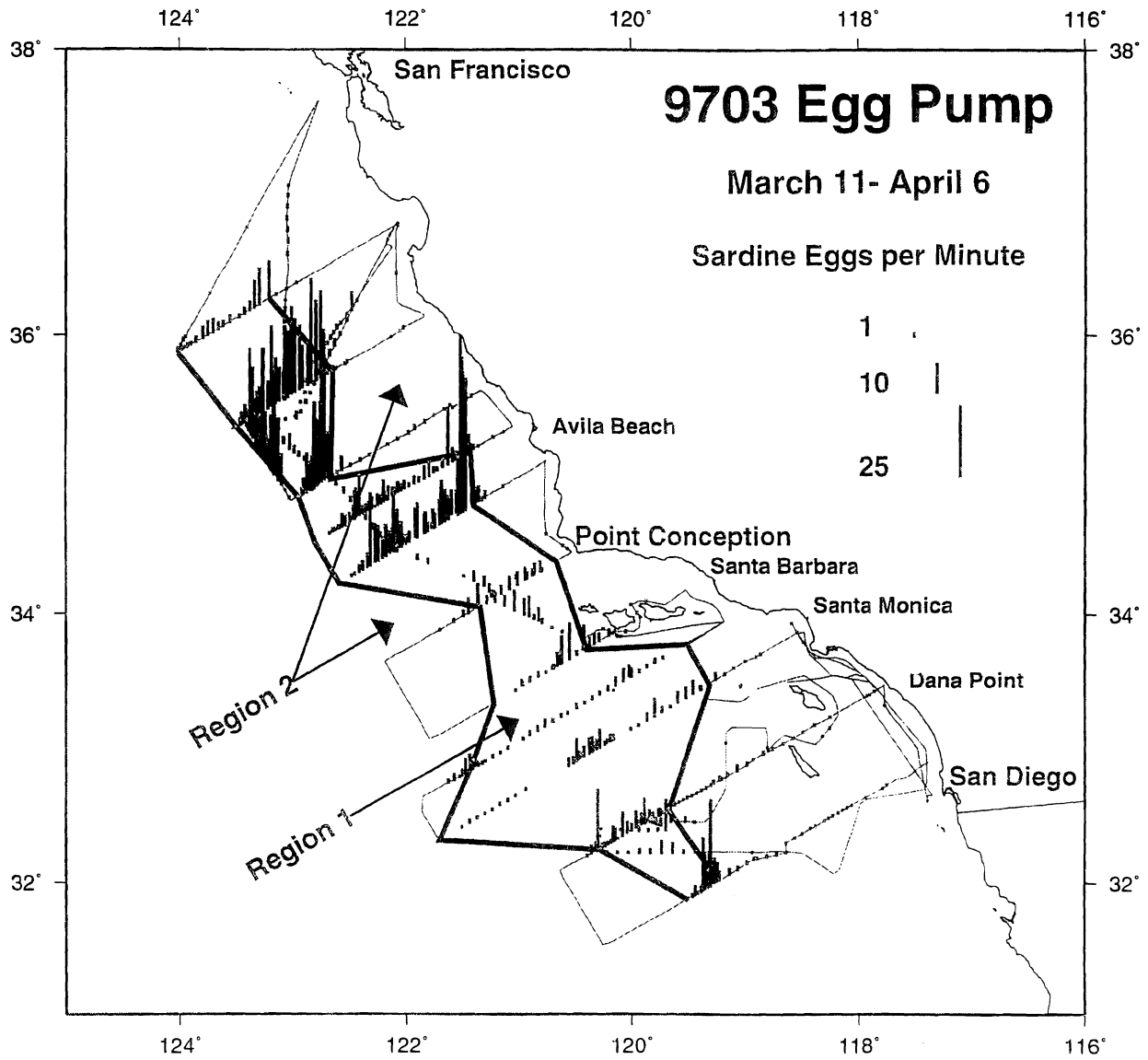


Figure 9. 1997 CUFES survey area with pump samples and the two regions.

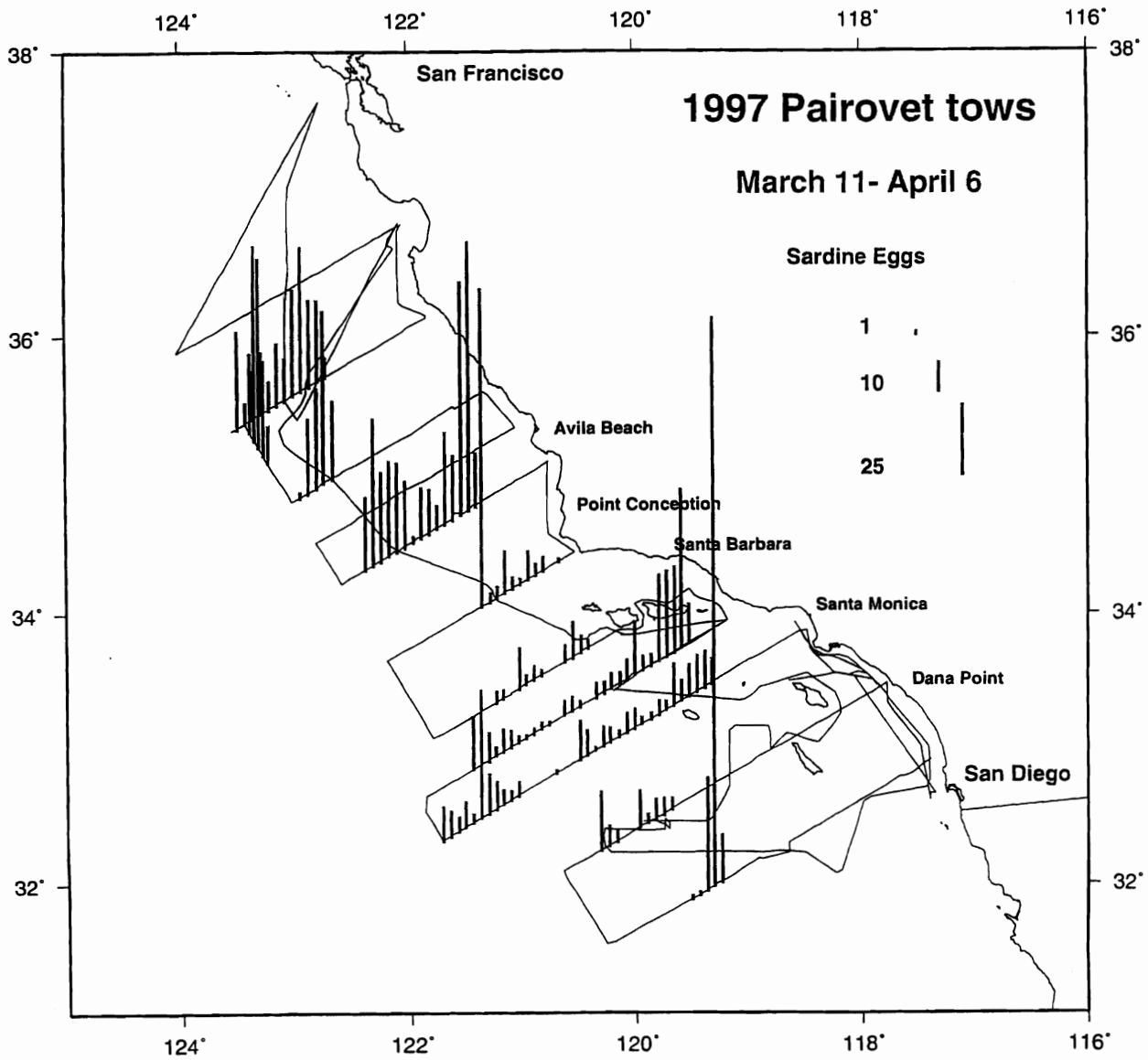


Figure 10. CalVET samples with track line in 1997 sardine egg survey.

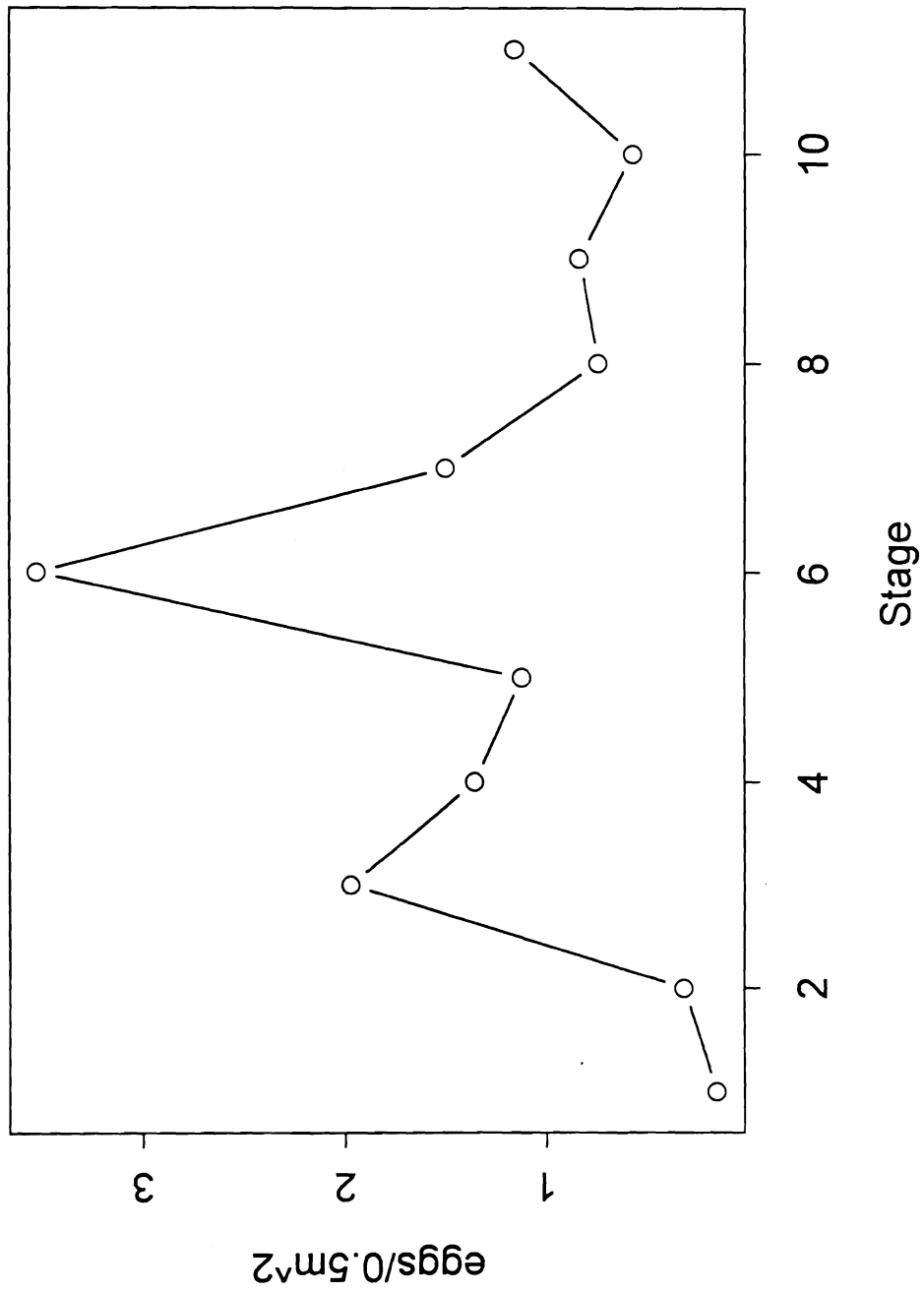


Figure 11. Eggs/0.05m² for each sardine egg stage from CalVET samples in region 1, 1997

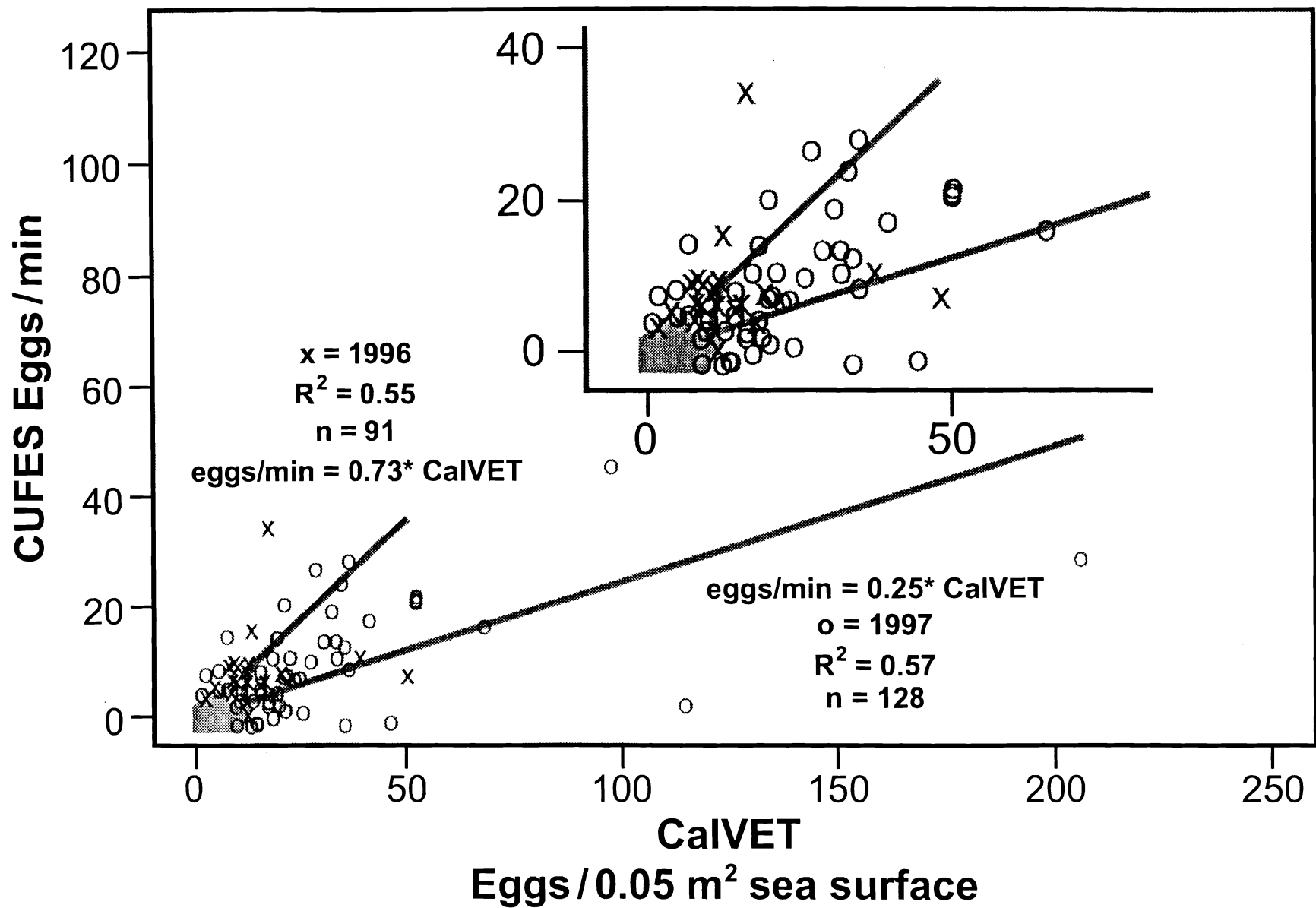


Figure 12. Sardine eggs/min from pump and eggs/tow from CalVET for 1996 and 1997.

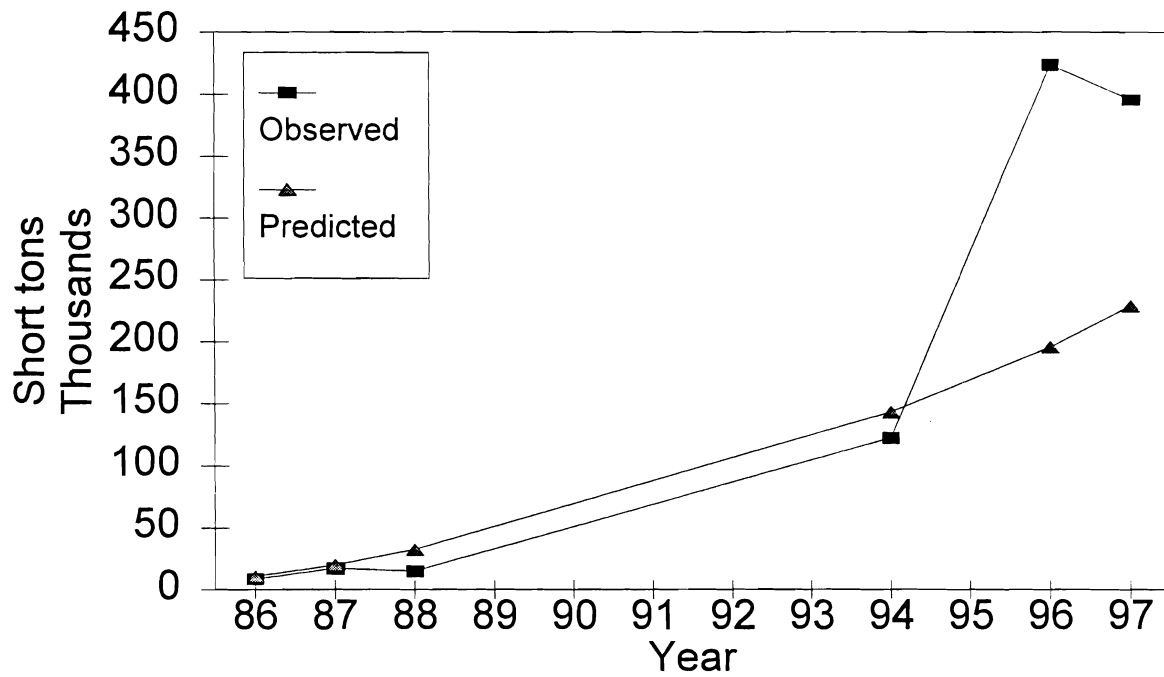


Figure 13. Observed and predicted Daily Egg Production Method sardine spawning biomass from CANSAR-TAM, 1997.

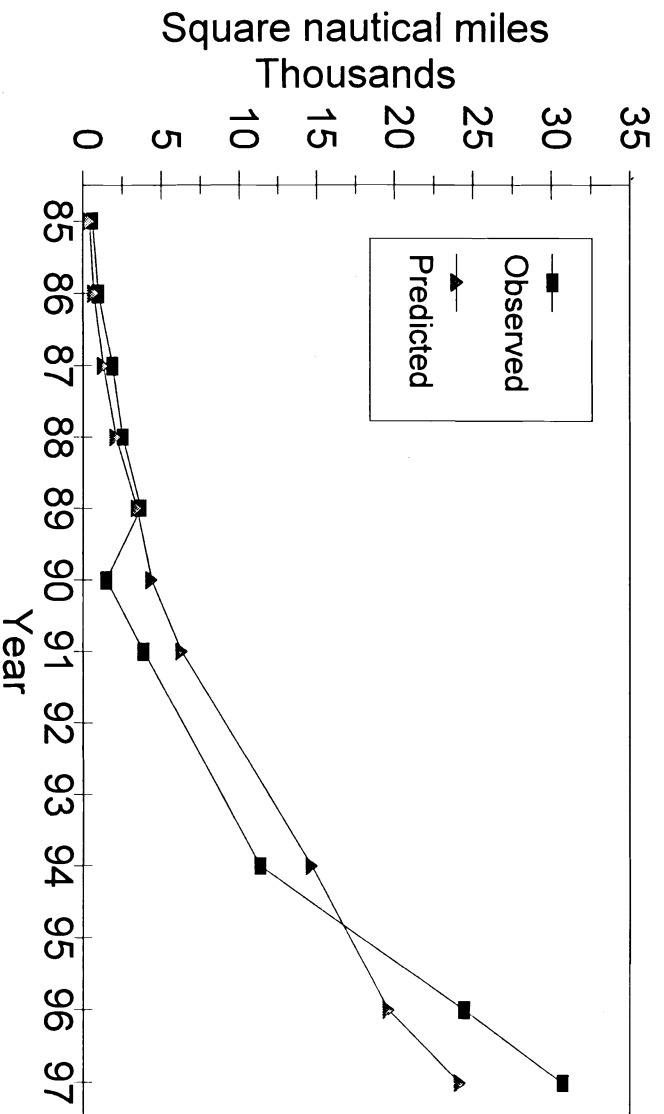


Figure 14. Observed and predicted sardine spawning area (Nm²) from CANSAR-TAM, 1997.

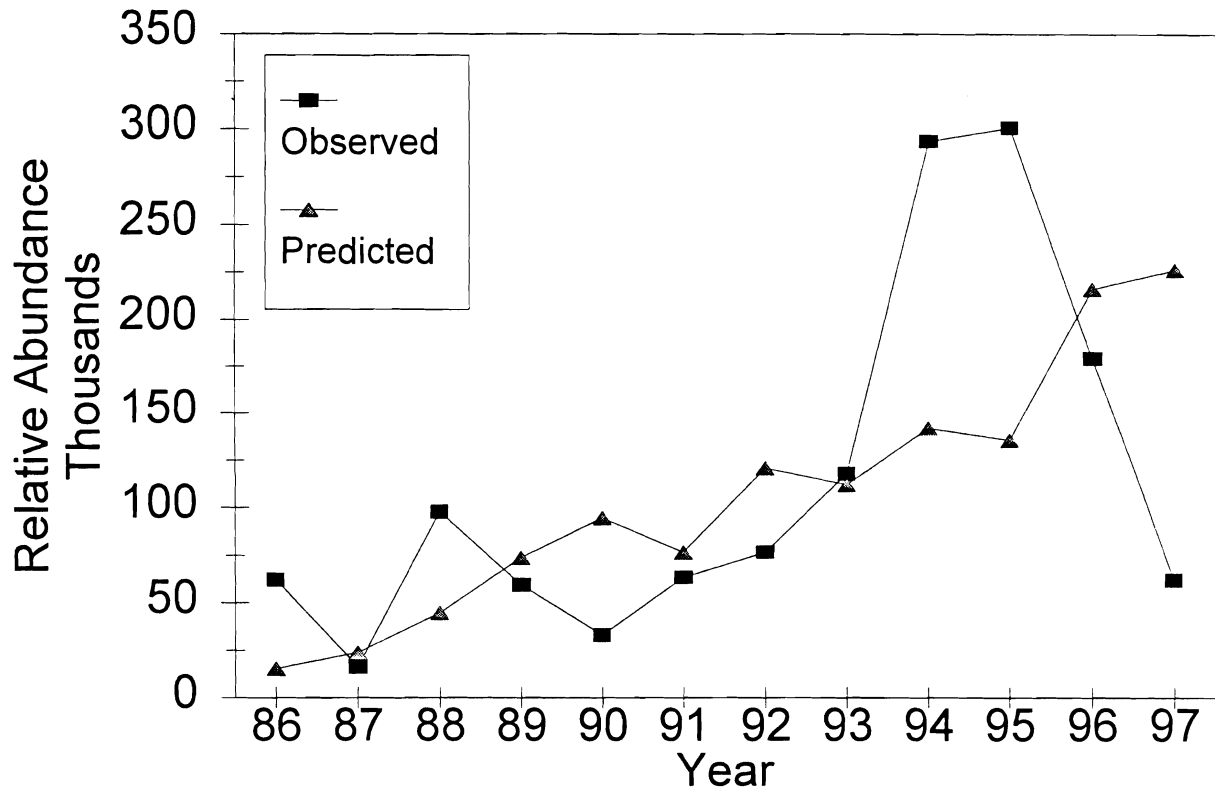


Figure 15. Observed and predicted spotter pilot observations of sardine abundance, 1986-1997 July-June fishing years, from CANSAR-TAM, 1997.

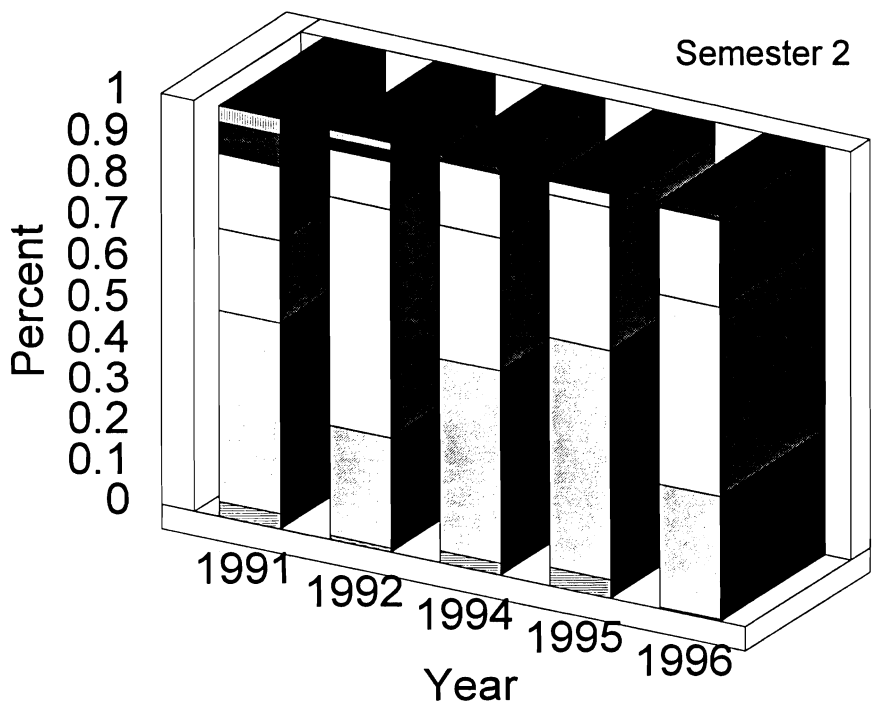
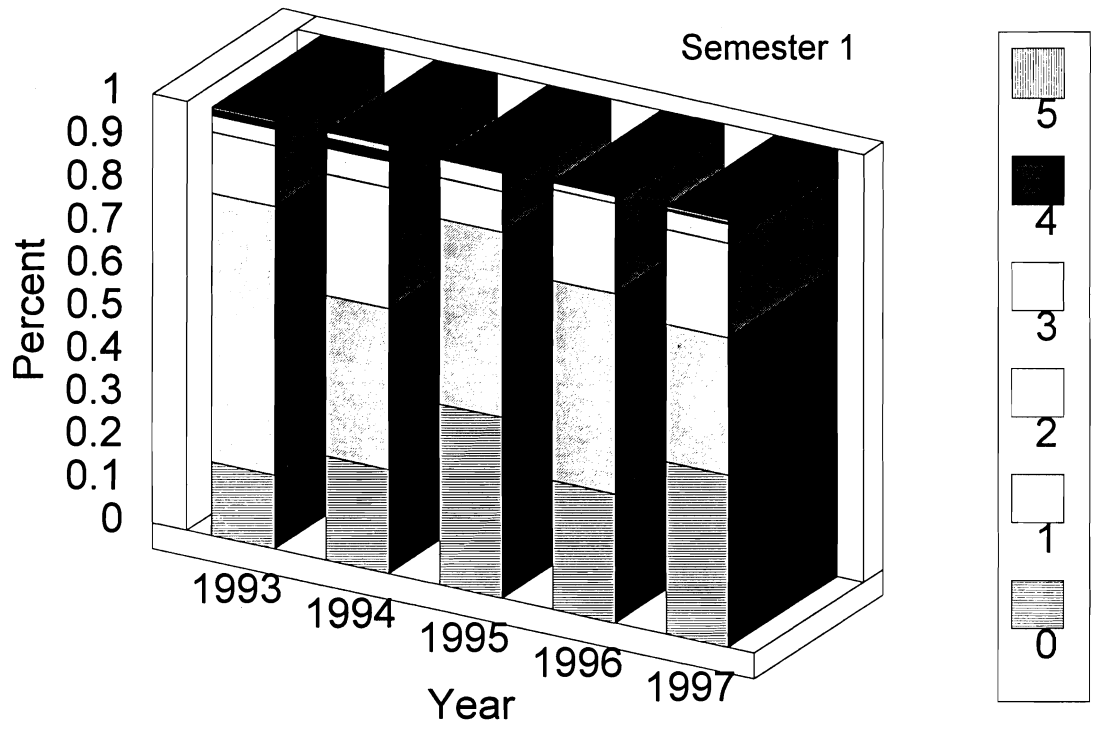


Figure 16. Proportional catch-at-age for the southern California fishery. No semester 2 age composition was available in 1993.

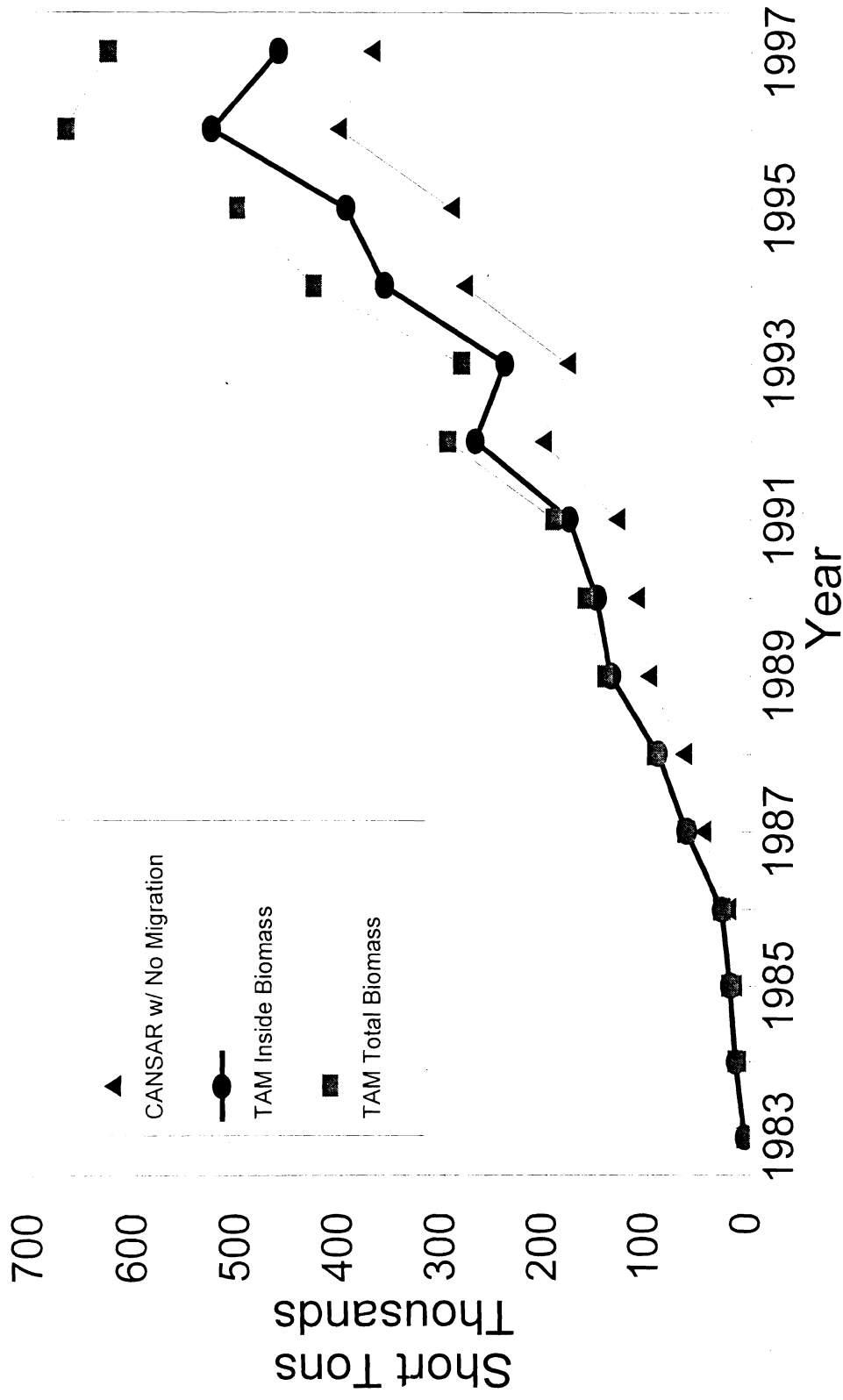


Figure 17. Pacific sardine July 1, age 1+ biomass estimates based on original CANSAR (no migration), CANSAR-TAM Area 1 (inside range of the fishery and survey data), and CANSAR-TAM Areas 1 and 2 (total biomass). Estimates are bias corrected based on 5,000 bootstrap runs.

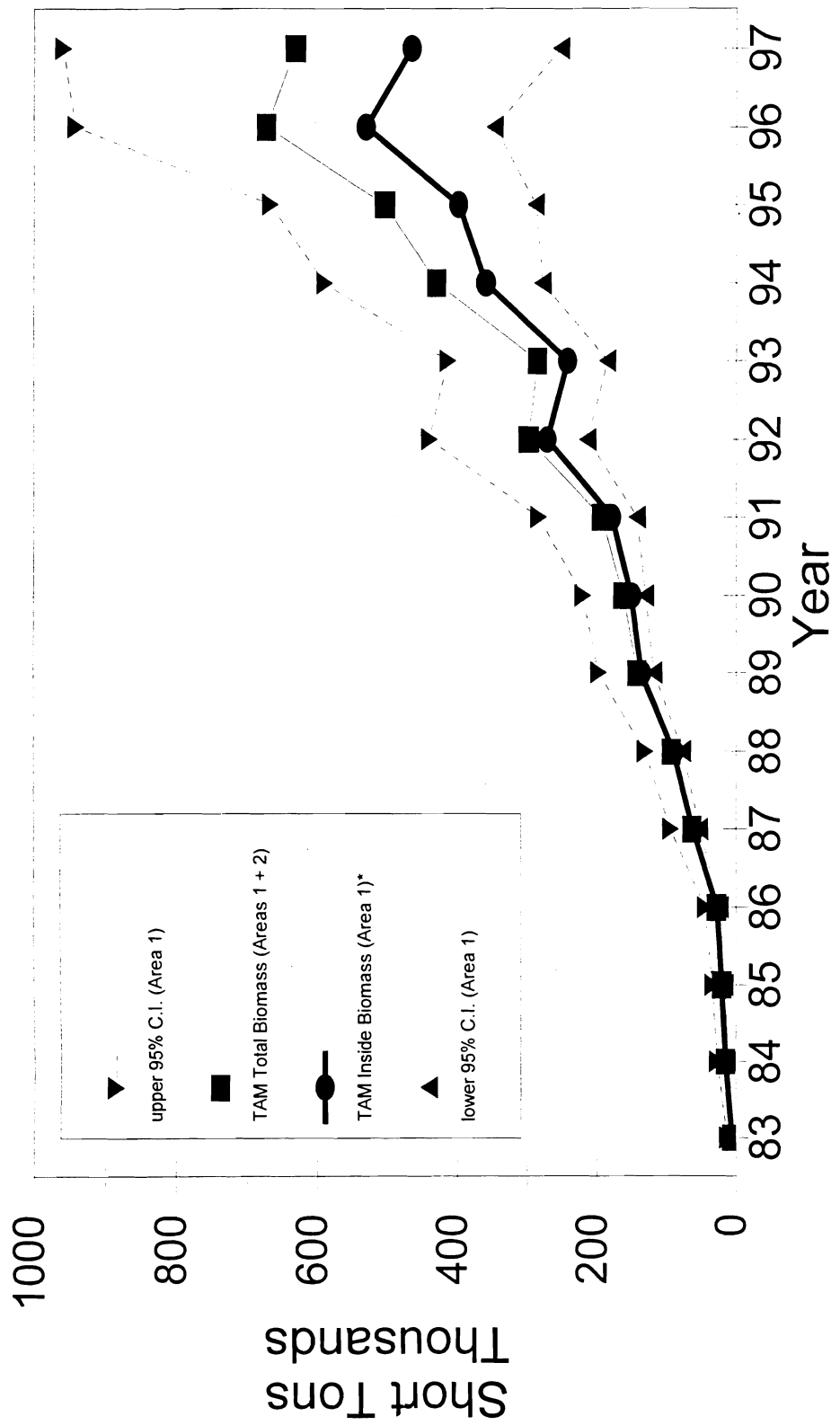


Figure 18. Pacific sardine July 1, age 1+ biomass estimates based on CANSAR-TAM. Estimates include Area 1 (inside ran of fishery and survey data), and Area 1+2 (total biomass). Estimates and 95% confidence limits are bias corrected based 5,000 bootstrap runs.