NOAA Technical Memorandum NMFS

APRIL 1997

STATUS OF THE PACIFIC SARDINE
(Sardinops sagax) RESOURCE IN 1996

J. Thomas Barnes
Marci Yaremko
Larry Jacobson
N.C.H. Lo
Jane Stehly

NOAA-TM-NMFS-SWFSC-237

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

NOAA Technical Memorandum NMFS

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflects sound professional work and may be referenced in the formal scientific and technical literature.

NOAA Technical Memorandum NMFS
This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

APRIL 1997

STATUS OF THE PACIFIC SARDINE (*Sardinops sagax*) RESOURCE IN 1996

J. Thomas Barnes, Marci Yaremko
California Department of Fish and Game
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037

Larry Jacobson, N.C.H. Lo
National Marine Fisheries Service
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, California 92038

and

Jane Stehly
California Department of Fish and Game
330 Golden Shore Drive, Suite 50
Long Beach, California 90802

NOAA-TM-NMFS-SWFSC-237

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service
Rolland A. Schmitten, Assistant Administrator for Fisheries

ABSTRACT

We estimate the biomass of the Pacific sardine (*Sardinops sagax*) population (age one and older) off California and northern Baja California on July 1, 1996 to have been about 510,000 short tons (CV 44% and 95% confidence interval from 287,000 to 1,099,000 tons). Our estimate was based on output from a stock assessment model called CANSAR.

For the first time, biomass estimates from CANSAR were compared to biomass estimates from two other stock assessment models (Virtual Population Analysis or VPA and an age structured model without catch at age data). Results from all three models were similar, although there was considerable uncertainty in biomass estimates for recent years.

Questions about stock structure and distribution were major sources of uncertainty in our sardine assessment. Recent data show increased sardine abundance in the Pacific Northwest off the Columbia River and as far north as British Columbia, but we were unable to determine if those fish were part of the stock available to the California fishery and whether the biomass of sardine in northern areas was included in estimates from our models. Similar questions exist about sardine in Mexican waters south of Ensenada. These problems were confounded by the fact that our survey and fishery data which were mostly collected within the Southern California Bight. We suggest that additional information is needed to resolve these questions because different modeling approaches gave similar results.

INTRODUCTION

This report summarizes data from the 1996 fishery for Pacific sardine (*Sardinops sagax*) and describes our stock assessment models, results and uncertainties. Our report focusses on new developments, new data, and the 1996 fishery because data sources and the stock assessment model are throughly described by Deriso et al. (1996). All biomass and catches are in short tons (2,000 U.S. lbs.). Fishery data for the second half of 1996 are preliminary. Mean weights of individual fish are given in grams (g).

The sardine "stock" harvested by the California fishery has uncertain boundaries, but includes fish off northern Baja California and California. Prior to 1990, the recovery was centered in the Southern California Bight and virtually all commercial fishing occurred to the south of Point Conception. By 1994, spawning habitat had expanded to central California (Lo et al. 1996) and Oregon (Bentley et al. 1996), and a small commercial fishery had developed in Monterey. Although the current recovery began within the geographic area formerly associated with a "northern race" (Radovich 1982) or "northern subpopulation" (Vrooman 1964), a recent study shows low genetic variation throughout the current sardine range (Hedgecock et al. 1992). Hedgecock et al. (1992) found no evidence for genetic isolation within the current population, but they suggest that "geographic populations" based on environmentally determined differences in growth rate and life history may be useful for fisheries models. During the last period of sardine abundance in the northeast Pacific (1920's to 1950's) the California fishery harvested sardine from the "northern subpopulation". It is clear from the old tagging data that sardines which summered (and were tagged) off British Columbia were also harvested in winter/spring fisheries in California (Hart 1943).

The California Department of Fish and Game (CDFG) manages the California fishery based on a regional biomass estimate of sardine age 1+ (at least 12 months old) on July 1 of each year. Biomass estimates used to manage the California fishery include fish off both Mexico and California and use data from both areas. Estimates of total biomass are larger than estimates of spawning biomass because not all one-year-old sardines are sexually mature. Fishing seasons used to manage the California fishery start on 1 January and the birthday for all sardine year classes is assumed to be 1 July. Sardine spawning within the Southern California Bight occurs throughout the year with a broad peak from spring to summer (Deriso et al. 1996).

THE 1996 SARDINE FISHERY

Total statewide landings for the 1996 calendar year are projected to approach the final California quota, which was set after several revisions at 38,350 tons (Figure 1). Sardine landings during both 1995 and 1996 (January-October only) were the largest since the late 1950's (Jacobson et al. 1995).

Section 8150.8 of the Fish and Game Code states that the annual California 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 1996, that formula resulted in an initial southern fishery quota of 23,333 tons, and a northern fishery quota of 11,667 tons. Midyear, the sardine stock assessment was updated and the 1996 fishery quota was increased by 3,350 tons. In October, CDFG re-allocated the uncaught portion of the quota and divided it equally between north and south.

Total landings for the southern California directed sardine fishery reached the quota and the fishery was closed on November 5, 1996. The northern California directed sardine fishery was expected to remain open through the end of the year with November and December landings projected to total approximately 2,000 tons. Once the directed fishery closes, only incidental catch of sardines (35 percent or less by weight) may be taken. Purse seine vessels in the wetfish fleet account for nearly all directed fishing for sardine in California (Jacobson et al. 1995). The majority of statewide 1996 sardine landings were made in southern California (80% through November), by approximately 17 wetfish vessels based in the San Pedro (Los Angeles) area. Twelve wetfish vessels based in Monterey, California accounted for most of sardine landings in northern California.

Other important target species for the southern California wetfish fleet include Pacific mackerel (*Scomber japonicus*), market squid (*Loligo opalescens*), and tunas. In northern California, Pacific herring (*Clupea pallasi*) were also an important target species. During 1996, sardine landings varied by month due to availability, demand, and participation by the wetfish fleet in other fisheries. The ex-vessel price for sardine remained consistently low from 1995 through 1996 at $70-80 per ton. Alternative target species such as market squid (exvessel price $140-300 per ton), tuna ($600-1400 per ton), and Pacific herring were preferred over sardine by the wetfish fleet. Ex-vessel revenue generated by the directed sardine fishery during 1996 is projected to total $2,450,000, a 30% decrease from 1995 (Figure 2) due to the reduced quota allocation and landings in 1996.

During 1996, most California sardine landings (79 percent of the total) were not used for human consumption. Notable uses included: aquaculture food/dead bait (54 percent); live bait (10 percent); and canned pet food (5 percent). No California sardine landings were used for the production of fish meal. About 31 percent of total California landings were used for human consumption, only a small portion of which were canned for human consumption (6 percent of total landings). In May 1996, nine months after closing due to bankruptcy, the only remaining southern California cannery capable of packing fish for human consumption reopened under new management, and began to pack sardine again in October. In northern California there were two canneries producing fish for human consumption, one of which has been in operation since the 1940's.

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 (about

$750/ton) were roughly 10 times greater than for the directed fishery, currently giving an overall value for the bait fishery similar to that of the directed fishery.

In 1996 there was a marked increase in the number of inquiries from foreign and domestic companies about purchase of Pacific sardine and Pacific mackerel. Sardine exports rose from a 1991-1994 average of 1,300 tons to 14,000 tons in 1995. California sardine exports in 1996 will fall short of the 1995 export total due to the decreased quota and landings. The top three importers of frozen blocks of California sardine were the Philippines, Australia, and Japan (Jacobson et al. 1995). The Philippines canned sardine for human consumption, Australia imported them for feed in aquaculture facilities, while Japan supplemented its catch to meet consumer demand following the recent decline and near collapse of their sardine resource.

In all recent years except 1995, sardine landings in Ensenada equaled or exceeded landings in California (Figure 3). Total sardine landings in California and Ensenada are expected to be about 65,000 tons during calendar year 1996.

ASSESSMENT MODEL

Our principal assessment tool was a stock assessment model called CANSAR (Catch-at-age ANalysis for SARdine, Deriso et al. 1996). CANSAR is an extension of methods used in the CAGEAN model for Pacific halibut (*Hippoglossus stenolepis*, Deriso et al. 1985) but is tailored to the information currently available for sardine. The model is an age-structured simulation approach that estimates sardine abundance and biomass, recruitment strength and age specific fishing mortality by year, semester and fishery using data described below. The time frame for our analysis was 1983-1996 but data for the second semester of 1996 were preliminary. Non-linear least-squares were used to find the best fit between model estimates and data. Bootstrap procedures were used to estimate CV's for biomass and recruitment estimates and to calculate bias corrections.

DATA

CANSAR uses both fishery and fishery-independent data (Deriso et al. 1996). Fishery data were aggregate landings (Table 1) or age composition information. Fishery-independent data (Table 2) include abundance indices based on sardine egg and larval data from California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys, spawning area estimates, fish spotter data, and daily egg production method (DEPM) spawning biomass estimates. In addition, average sea surface temperatures at Scripps Pier were used to predict recruitment strengths.

Fishery Data

Catch data were tons landed by semester (January-June or July-December) for the

California and Ensenada fisheries during 1983-1996. Age composition and mean weight-at-age data were available for the U.S. fishery during all semesters when significant landings occurred, but were lacking for the Ensenada fishery after 1992 (Deriso et al. 1996).

During 1996, CDFG aged 3,333 sardines by reading sagittal otoliths for annuli (Yaremko 1996), using specimens from random port samples. For the 14-year period covered by this study, a total of 28,156 sardines were aged from California and Ensenada fishery samples, the oldest of which were age 9. Mean round weight was used to estimate the total number of fish in the catch-at-age data by dividing total tons landed by mean fish weight.

CalCOFI Egg and Larvae Abundance

Like Deriso et al. (1996), we used a generalized additive model (GAM) to standardize CalCOFI survey data for 1983-1996 and measure the abundance of sardine eggs and larvae. All available bongo tow data collected within the current standard CalCOFI grid (essentially the Southern California Bight and excluding tows beyond station 67.5) were for modeling (Figure 4). GAM models were fit by logistic regression to data for individual tows. The dependent variable was zero (if no sardine eggs or larvae were taken in the tow) or one (if either eggs or larvae were taken). Units for the CalCOFI index were the probability of a tow being positive for either a sardine egg or a sardine larvae. Following Deriso et al. (1996), YEAR and MONTH were categorical variables modeled as factors. CalCOFI line (LINE, basically the same as north-south position) was a covariate (continuous variable) modeled using a loess regression line with neighborhood size 0.75.

The major difference between the GAM used for CalCOFI data in this year's sardine assessment and the GAM used in Deriso et al. (1996) was the way location relative to the shore (basically the same as east-west position) was modeled. Deriso et al. (1996) used CalCOFI station number as a covariate that was modeled with a loess regression line. This was probably not the best choice, however, because tows at the same station on different CalCOFI lines might be either close to shore or far offshore due to the irregular coastline of the Southern California Bight (i.e. interactions between along shore and offshore position might be important).

We tried two different approaches to modeling location relative to shore. In the first, the distance in kilometers from shore) along the CalCOFI line at the tow location (a continuous variable) was calculated based on a linear approximation to the coastline (Jacobson et al. 1996). Kilometers from shore was modeled using a loess term with neighborhood size 0.75. In the second approach, we drew a boundary between inshore and offshore stations based on the first CalCOFI station west of the last island or coastline along standard CalCOFI lines (see below and Figure 4). With this approach, a categorical variable called INSHORE was equal to one if a tow was inside the boundary, equal to zero otherwise, and modeled as a factor. SAS code used to calculate INSHORE was:

```
* define inshore/offshore dummies;
* (stdlin is the standard CalCOFI line nearest the tow);
```

```
intlin=round(stdlin);
if (intlin eq 77 and station le 51) then INSHORE=1;
 else if (intlin eq 80 and station le 55) then INSHORE=1;
  else if (intlin eq 83 and station le 55) then INSHORE=1;
   else if (intlin eq 87 and station le 55) then INSHORE=1;
    else if (intlin eq 90 and station le 45) then INSHORE=1;
     else if (intlin eq 93 and station le 40) then INSHORE=1;
       else INSHORE=0;
```

All three approaches gave similar interannual trends in estimated egg and larval abundance for sardine.

To calculate the abundance index used in CANSAR, we chose to use the model with INSHORE as a categorical variable because this approach accounted implicitly for interactions between near shore and offshore position. Another advantage was that we were able to include a statistical interaction between MONTH and OFFSHORE explicitly in the GAM. S-plus code for the final GAM model was:

```
hybridgam1<-gam(possampl ~ factor(YEAR) + factor(MONTH) + factor(INSHORE) +
factor(MONTH) * factor(INSHORE) + lo(LINE, span = 0.75), family = quasi(link =
logit, variance = "mu(1-mu)"))
```

All factors, covariates and interactions were statistically significant, there were no systematic patterns in residual plots and the variance of residuals was approximately as expected under the binomial distribution assumed in fitting the model.

The abundance index (Table 2 and Figure 5) for sardine based on CalCOFI data was calculated for LINE=76.7, INSHORE=1 and MONTH=2 (February) of each year. It shows an increasing trend during 1984-1991. From 1991-1996 the index was quite variable and without trend. Annual changes in oceanic conditions or sardine food supply could account for some of the index variability since 1991.

Spawning Biomass

Spawning biomass for sardine was estimated during 1986, 1987, 1988, 1994 (Lo et al. 1996) using the daily egg production method (DEPM, Lasker 1985). Spawning biomass is estimated by: 1) calculating the standing stock of sardine eggs from icthyoplankton 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. Prior to 1996, sardine egg production was estimated from direct plankton net sampling. Adult fish were sampled in various ways to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average fish weight.

1996 DEPM estimate

Egg production for 1996 was estimated from data collected during an experimental Continuous Underway Fish Egg Sampling (CUFES) cruise carried out by the *R/V David Starr*

Jordan during March and April, 1996 (Figure 6). Sampling gear used on the CUFES cruise included standard CalVET plankton nets, and an experimental sampling device called an "egg pump".

During 1996, daily egg production was estimated using egg pump data from leg 2 (March 21-April 6) of the CUFES cruise. Adult parameters for 1996 DEPM spawning biomass calculations were obtained from adult fish data collected during a 1994 DEPM sardine survey (Lo et al. 1996).

Egg densities from the egg pump were converted to equivalent densities per unit of sea surface area. The conversion was used in 1996 DEPM calculations, and to estimate 1996 spawning area (see below). During leg 1, the CUFES survey area extended from Pt. Loma north to Del Mar and offshore 70 nm. A total of 1437 egg pump samples were collected; samples were taken at intervals of 2-5 minutes. Ninety-one pairs of egg pump/CalVET plankton net samples were collected. Paired samples were collected when there was high numbers of eggs in the egg pump samples. Egg counts from these 91 paired samples were used to derive a conversion factor from the egg pump data (eggs/minute) to CalVET data (eggs/0.05m^2). The conversion was: egg/minute of pump = 0.73 CalVET (Figure 7). Calibration results were very noisy, particularly at higher catch rates.

During leg 2, a total of 905 pump samples were collected. Sampling interval was 30 minutes or shorter (Figure 6). The total survey area was 157,000 km^2 from San Diego to near Monterey bay.

Daily egg production (P_0)

The daily egg production was computed based on the negative exponential mortality curve: $p_t=p_0\exp(-zt)$ where p_t is daily egg production/0.05m^2 at age t and z is the daily instantaneous mortality rate.

Because of the distribution of sardine eggs (Figure 6), the area was post-stratified into two regions to estimate p_0, with region one as the area between CalCOFI lines 73 and 83 and region two as the area north of CalCOFI line 73 and south of CalCOFI line 83. Within each area, daily egg production was computed (units were eggs/minute): 6.3/minute in region one; and 0.48/minute in region two. A value of 2.11/minute for the whole survey was an average of the above two egg production estimates weighted by area size. The egg production per minute divided by 0.73 (Figure 7) was the daily egg production / 0.05m^2 (p_0): 2.89/0.05m^2 (CV=0.75). The daily egg mortality rate was 0.62 /0.05m^2 (CV=0.81).

The high CV of the estimated daily egg production in 1996 was partially due to using the conventional DEPM procedure with the continuous pump samples. Use of CUFES for sardine stock assessments looks promising, but additional calibration work is needed. Application of geostatistics procedures is underway, hopefully to improve the precision of estimate of egg production using egg pump samples.

Sardine spawning biomass (Bs)

The sardine spawning biomass was computed from the daily egg production method:

$$B_s = \frac{P_0 \ A \ C}{R \ S \ F/W_f}$$

where A is the survey area in unit of $0.05m^2$; 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 g to MT. P_0A is the total daily egg production in the survey area, and the denominator in equation (1) is the daily specific fecundity (number of eggs/population weight (gm)/day). Estimates of adult parameters (F, R, W, and S) were not available for 1996, therefore the estimate of the daily specific fecundity from 1994 (23.55 eggs/gm population/day) was used to estimate the spawning biomass of sardine in 1996 (Table 3). Variance of spawning biomass of sardine was not computed.

The estimate of spawning biomass was 425,000 tons for an area of 157,000 km^2 from San Diego to south of Monterey Bay. In a 1994 sardine spawning biomass survey (Lo et al. 1996), the egg production was $0.169/0.05m^2$ (CV=0.22) and the spawning biomass was 122,000 tons for an area of 380,000 km^2 (254,000 km^2 in US water). Therefore, the spawning biomass of sardine has increased three-four fold since 1994.

The trend in spawning biomass estimates for sardine indicate increased abundance since 1985 (Figure 8). As described in Deriso et al. (1996), spawning biomass estimates for sardine should be treated as relative, rather than absolute, measures of spawning biomass.

Spawning Area

During each year from 1985-1991, CDFG conducted plankton surveys (usually as part of an DEPM cruise) in the Southern California Bight, using CalVET plankton tows to identify the extent and intensity of sardine spawning. Stations and lines were more closely spaced than for standard CalCOFI cruises, and the area surveyed was adjusted (increased) each year based on the findings of the previous year, other findings from concurrent CalCOFI cruises, and information on the suspected range of the adult population. Spawning area for 1994 was calculated from DEPM survey results in U.S. waters (spawning area in Mexican waters was excluded).

Spawning area for 1996 was calculated from CUFES cruise results. Egg pump catch rates were regressed on CalVET tows for ninety-one paired samples (R^2=0.55) and the regression was used to convert egg pump data to equivalent CalVET catch rates. The slope of the regression line indicated that one egg per tow using a CalVET net was approximately the same as 1.37 eggs/minute using the egg pump (Figure 7). Using these findings, we estimated spawning area for

1996 (an important parameter in the spawning biomass estimate) based on egg pump transects with catch rates of at least 1.37 eggs/minute. Spawning area using these criteria was significantly less than for the entire survey area.

Total spawning area increased during the study period (Table 2 and Figure 9). Smith (1990) found that spawning area was proportional to spawning biomass under conditions when the stock does not occupy its full potential geographic range.

Aerial Spotter Data

Spotter pilots are employed by commercial fishermen to locate schools of fish. Spotters were contracted by NMFS to submit logbooks. We used the logbook data to calculate an index of abundance for sardine (Lo et al. 1992; Deriso et al. 1996). The spotter index showed a large increase during 1993 and 1994, but not in 1995 (Table 2 and Figure 10).

Key Changes to Data and Models for the 1996 Assessment

Weight-at-age data

Weight-at-age for fish taken in the California fishery has declined by about 50% during the past ten years (Figure 11) to such low levels that southern California landings can no longer be used to estimate mean fish size for the whole west coast population. Mean weights-at-age in the southern California fishery were therefore not used directly as weights-at-age for the sardine population during 1993-1996. For the first semester of 1996, we used simple averages of mean weights-at-age from fisheries in southern California and Monterey to estimate population weight-at-age (Figure 12). During 1996, sardine landed in Monterey were larger, resulting in larger fish sizes for the population in CANSAR runs.

Unfortunately, sardine port sampling by CDFG did not begin in Monterey until 1996. We therefore estimated population weight at age by increasing southern California mean weights at age for 1993-1995 (smoothed by linear regression) by an amount proportional to the increases in 1996 (Figure 11).

Fecundity and maturity of young fish

Fecundity-at-age estimates were used in CANSAR to predict spawning area and the CalCOFI egg/larvae index, while maturity-at-age estimates were used to predict DEPM spawning biomass (Deriso et al. 1996). Maturities and fecundities were adjusted downward for age 0 and age 1 fish, to correct for possible bias due to difficulties with catching young sardine with nets used in DEPM surveys. An upward bias in maturity and fecundity estimates probably exists for young fish because nets likely tended to take the largest, and most mature young sardine. Small, immature individuals were probably not taken as efficiently as larger individuals. These sampling problems would have resulted in overestimates of the maturity and fecundity of young sardine.

Downward adjustments to fecundity and maturity of young fish were made on an *ad hoc* basis by comparing an estimate of population age composition to the age composition of DEPM samples, using the estimated and observed age compositions to estimate the degree of under sampling of young fish, and finally making the assumption that young fish not available to the sampling gear were one-half as fecund or mature as large fish sampled by survey gear (Appendix 1). It is likely that overestimates of the maturity and fecundity of young sardine would result in underestimates of biomass but the importance of this potential problem has not been determined.

Saturation in the CalCOFI index

The geographic area of the current CalCOFI grid and data used to estimate our index of egg and larval abundance extends from the U.S./Mexico boundary to Point Conception, and offshore as far as station 67.5. Spawning area in recent years has clearly expanded beyond the area encompassed by our CalCOFI survey data (Lo et al. 1996). Furthermore, the CalCOFI index has not continued to increase to the same extent as other indices of sardine abundance (Figure 5). Thus, it seems likely that the CalCOFI data is beginning to "saturate" (Hillborn and Walters 1994) and that the standard CalCOFI survey area has become almost fully utilized as spawning habitat, causing the index to increase more slowly than sardine abundance. Patchiness of eggs and larvae, and variability in the spawning peak may also be responsible for year to year fluctuations in the index and lack of trend since 1991.

To estimate the degree of saturation in the CalCOFI index, we regressed log CalCOFI index values on log DEPM spawning biomass estimates. The slope of the regression line (β=0.6, R^2=0.84, N= 5) was used in CANSAR as an exponent to adjust predicted CalCOFI index values for saturation (the model was $I_y=qE_y^{\beta}$, where I_y was the predicted CalCOFI index for year y, q was a scaling parameter and E_y was relative egg production, see Deriso 1996).

Weighting factors used for abundance index and catch data types

The relative importance or influence on biomass estimates from CANSAR can be controlled by specifying different weighting factors (λ_t) for each data type (Deriso et al. 1996). As described below, patterns in selectivity parameter estimates from CANSAR were difficult to reconcile with information on recent expansion of the population to Pacific Northwest (selectivity parameters measure the relative vulnerability of each age class to the Mexican or California fishery during either the first of second semester of each year). We were concerned that problems with fishery selectivity patterns were degrading our estimates of sardine biomass. Fishery selectivity patterns are estimated primarily from catch-at-age data so we chose to down weight the relative importance of the catch-at-age data to reduce its importance. There were about four times more parameters associated with fishery data than for fishery-independent data, so we increased the weighting factors for fishery-independent data types (CalCOFI egg and larvae index, spotter pilot observations, spawning area, and DEPM biomass) to 4. This increased the importance of the abundance index data and decreased the importance of the catch and catch-at-age data. The change in biomass estimates was about +30% for 1995 and +45% for 1996.

RESULTS

CANSAR estimates fit abundance index data reasonably well (Figures 5, 8, 9, and 10) and there were no systematic trends in residuals. Predicted values for the DEPM observation in 1996 were much smaller than the observed value, possibly because the observed value was estimated using egg pump data and new procedures.

Two-year-old sardine were an important component of the catch in all years and can be used to explore the fit between observed catch-at-age and model predictions. Catch of two-year-olds during the first semester of each year in the California fishery follows the upward trend in landings (Figure 13). Residuals (observed number of age two sardine minus CANSAR predicted values) were not serially correlated, and the model fit the data adequately. Following Deriso et al. (1996), we used different age-specific fishery selectivities during two periods: 1) 1983-1992, when California sardine catch was largely incidental to other fisheries and the range of the stock was possibly confined to waters south of Point Conception; and 2) 1993-1996, when the directed fisheries became more significant and the stock had probably expanded beyond the Southern California Bight.

Uncertainty About Selectivities and Stock Boundaries

Although CANSAR fit our data reasonably well, a major uncertainty exists about the availability of older sardine (age 3+) to the fishery and geographic range of the "stock" estimated by the model. Catch at age data for the California fishery in recent years were dominated by young fish and old sardine are caught infrequently (Figure 14). Patterns in fishery selectivity parameter estimates from CANSAR for recent years indicate that fisheries in California and Mexico preferentially select older sardine and that fishing mortality rates for old fish are high. In effect, model results indicate that the population is dominated by young fish due to strong recruitments and high mortality of older sardine.

An alternative explanation for the lack of old fish in fishery samples is, however, that old fish have moved to northern or offshore areas where fishing does not take place and no survey data are collected. Pacific hake (*Merluccius productus*), another migratory pelagic species also shows the same propensity for older individuals in the population to migrate progressively further north each summer. The notion that older, larger sardine were not available to surveys and the fishery is compelling and deserves attention given historical data (Radovich 1982) and reports of large sardine off Oregon (Bentley et al. 1996) and British Columbia (Hargreaves et al. 1993).

The two scenarios concerning existence of old sardine can be cast in terms of fisheries selectivity patterns or stock distribution. The scenario corresponding to CANSAR results (old fish eliminated by fishing mortality) implies that fishery selectivities increase with age (are "asymptotic") and that older year classes (ages 2+) are fully available to the southern California fishery. Under this scenario, CANSAR and the available data measures sardine abundance over the entire range and sardine do not distribute themselves along the coast according to size or age.

The alternate scenario, with old fish leaving the area where survey data were collected and the fishery operated seems more likely. This scenario implies that fishery selectivities are "dome-shaped" or decreasing with age and that CANSAR and available data measure sardine abundance over only part of the stocks range.

We attempted to force CANSAR into estimating dome shaped selectivity patterns but results were unsatisfactory because the model's fit to survey and catch data was substantially degraded. The idea that selectivity patterns should be domed was intuitively appealing but there was no basis in the data used by CANSAR for the hypothesis.

This biological uncertainty about selectivity patterns and stock distribution is important because sardine biomass estimates might be higher if older fish exist in the stock but cannot be measured due to lack of northern fishery samples or survey coverage. Analogously, biomass estimates might be smaller if older fish have left the stock for northern habitats and are unavailable to the California fishery. The potential problems with selectivity patterns and uncertainties about distribution likely effect our estimates of sardine biomass but we were unable to determine the likely size or direction of the effect.

Other Modeling Approaches

Uncertainties about fishery selectivity patterns in our current assessment were partially addressed by using two other stock assessment modeling approaches to obtain partially "independent" estimates of selectivity parameters and biomass. The alternative modeling approaches did not make the same fishery assumptions as CANSAR, although they used the same data. Neither of the alternative approaches used all of the available data for sardine and neither was completely explored due to lack of time. Our purpose was not to replace CANSAR, but rather to understand the properties of our data and models for sardine.

VPA

The first alternate approach was a Virtual Population Analysis (VPA) model tuned to abundance index data using the ADEPT procedure (Jacobson 1993). Catch-at-age data were aggregated by July-June annual fishing seasons and mean weights during July-December were used for calculations involving fish weight. The VPA included the 1983 to 1995 fishing seasons (the only fishing seasons for which a full twelve months of data were available). Catch-at-age data for a particular season were scaled up or down until the sum of products of catch and weight-at-age matched total landings in Ensenada and California. Fecundities and maturities-at-age used to "tune" the VPA model to survey data were the same as used in CANSAR. Selectivities-at-age for fish spotter data were the same as in the fishery and were calculated for each year based on fishing mortality rates estimated for the fishery. The VPA contained a spawner-recruit constraint identical to that used in CANSAR (Deriso et al. 1996).

The objective function used in the VPA ADEPT model was basically the same as used in CANSAR and measurement errors in survey indices were assumed to be log-normally distributed.

Parameters estimated in the ADEPT model were a terminal fishing mortality rate multiplier (see below) and scaling parameters for each abundance index. The same exponent parameter (β, see above) was used for the CalCOFI index.

As in most VPA models tuned to aggregate (ages combined) abundance index data, it was impossible to estimate the fishing mortality rates for each age group in the last year directly (Jacobson et al. 1994a). Instead, we set fishery selectivities (scaled to 1.0 at the terminal age) in the terminal season (1995) equal to average values for 1993-1992 and estimated a fishing mortality rate multiplier that scaled the average selectivities in the terminal season to fishing mortality rates for each age. Subroutines used to set selectivities for abundance indices and calculate objective function values in the ADEPT VPA model, as well as a parameter file, are given in Appendices 2-4.

Age structured model with no catch or catch-at-age data

Catch-at-age data for pelagic fish are often difficult to model and problems with models complicated by selectivity parameters can lead to erroneous biomass estimates (Jacobson et al. 1994b). We experimented with a model that did not use catch-at-age or catch data for sardine that was similar to an approach used for northern anchovy, *Engraulis mordax* (Jacobson et al. 1994b). The alternate model was implemented starting with our "base run" CANSAR model, by progressively reducing the weights (λ_i) used in the objective function for California and Mexican fishery data to almost zero (1 x 10^{-6}). This approach enabled us to effectively remove the fishery data from the model, so that it simulated a production model. An important advantage was that the model continued to estimate fishery selectivities although these parameters had almost no effect on biomass estimates or fit to the abundance index data.

Results using alternate models

Biomass estimates for early years from alternate models were similar to CANSAR estimates (Figure 15). There were substantial differences in the sardine biomass estimates for recent years but the estimates from alternate models fell within the 95% confidence intervals from CANSAR. Thus, biomass estimates for recent years from the three models for sardine reflect the intrinsic uncertainty in our data but gave reasonably similar results.

VPA results indicated that fishery selectivities for sardine were highly variable from year to year. This result reinforces the idea that sardine selectivities are likely hard to estimate. Fishery selectivities for recent years from the alternative models were asymptotic and similar to those from CANSAR. We concluded that additional data, rather than different modeling approaches, will be required to answer our questions about selectivities and distribution of the stock.

Sensitivity Analysis

We evaluated the sensitivity of recent biomass estimates from CANSAR to differences in data sources by estimating sardine biomass during 1996 and average sardine biomass during 1992-1996 while systematically changing the weights on each data type (Table 4). Biomass estimates for 1996 were sensitive (change > 10%) to halving or doubling weights on all data types other than fish spotter data. Trends in direction of change with increasing or decreasing weight were the same as in Deriso et al. (1996, Table 6) for all data types except the California fishery data although the sensitivity of the new sardine biomass estimates was stronger (particularly for DEPM and spawning area data).

Patterns in sensitivity of sardine biomass to the weight on California fishery data were anomalous. Sensitivity results indicate that mean 1992-96 sardine biomass estimates would increase if the weights on California fishery data were either increased or decreased (Figure 16). These results support the idea that relationships between fishery catch-at-age data and sardine abundance are complex.

Addressing Data Needs

For several years, priority has been given to acquiring data from north of the Southern California Bight, and much of those data were used in our assessment. Since 1990, four sardine icthyoplankton surveys (Lo et al.,1996; Bentley et al., 1996; Barnes and Yaremko, 1996; and 1996 CUFES cruise-see above) were conducted in waters north of Point Conception. Unfortunately, we were not able to incorporate data from the two northernmost surveys (Bentley et al. 1996; Barnes and Yaremko, 1996) in our assessment. The 1995 CDFG survey was conducted during August (Barnes and Yaremko, 1996), which proved to be too late in the season to detect sardine spawning that year. One of the 1994 surveys (Bentley et al. 1996) found sardine spawning off Oregon, but we were unable to determine whether those fish were part of the stock available to California fishermen, and so the findings were not used in our assessment. Another sardine survey (including standard icthyoplankton sampling, CUFES, trawl sampling for adults, and a test of airborne LIDAR for school detection) is scheduled by NMFS during the spring of 1997.

Fishery sampling was also extended to the north in recent years, in response to increased abundance of sardine. Sampling of the directed fishery in Monterey was instituted by CDFG in 1996, and the size-at-age data used in our analysis. Two other promising sources of fishery data became available during 1996. The Pacific States Marine Fisheries Commission began funding a multi-year study to collect and analyze sardine and mackerel (*Scomber japonicus*) data from Pacific northwest whiting bycatch during 1996; and the Canadian Department of Fisheries and Oceans collected samples from an experimental sardine fishery in British Columbia during 1996 (D. Ware, Pacific Biological Station, Nanaimo, B.C., pers. comm.). Geographic stratification in CANSAR is presently limited to separate selectivity parameters for Mexican and California fisheries. When sufficient data become available from the new northern sources (including the Monterey fishery), further geographic stratification will be investigated.

Uncertainties in our assessment emphasize the importance of recent efforts to obtain new data as sardine range has extended to the north. As additional data are obtained from these and other sources, uncertainties in our assessment will be reduced.

Abundance Estimates

Results from our base case CANSAR run indicate that sardine biomass (age 1+) increased dramatically from 1983 to 1996 (Table 5 and Figure 17). After correction for bias (Deriso et al. 1996), we estimate sardine biomass on July 1, 1996 biomass to have been about 510,000 tons with a CV of 44% and nonparametric 95% confidence interval of 287,000 to 1,099,000 tons (bias corrections, CV and confidence intervals based on 1,000 bootstrap iterations). Recent recruitments appear strong (Table 5 and Figure 18). Our new estimates indicate that sardine biomass on July 1, 1995 was about 394,000 tons, which is about 12% larger than our initial 1995 biomass estimate (353,000 tons) made using CANSAR and data available at the end of 1995 (Barnes et al. 1996). The relatively small upward revision to our 1995 biomass estimate was due to the changes in our assessment as noted above, including an additional year of input data. Retrospective bias is not a problem in biomass estimates from CANSAR (Deriso et al. 1996).

CANSAR results are clearly regional estimates of biomass. During the early stages of recovery, it is likely that CANSAR estimates included the northern limit of the stock. In recent years, sardine range has expanded beyond California fisheries and most survey data. Managers need to decide whether to base quotas for the California fishery on estimated biomass of the entire population, or on estimated biomass available to the fishery.

ACKNOWLEDGMENTS

Dan Ware (DFO, Pacific Biological Station, Nanaimo, B.C., Canada) and Richard Parrish (NMFS, Pacific Environmental Group, Monterey) reviewed the manuscript and made helpful suggestions. Walterio Garcia Franco (INP-CRIP, Ensenada) provided data from the Ensenada fishery. John Hunter (NMFS, SWFSC) suggested ways to estimate the exponent parameters for CalCOFI data. Richard Charter (NMFS, SWFSC) provided CalCOFI and spotter pilot data. Port sample data were provided by CDFG Monitoring and Management Units in Long Beach and Monterey, pursuant to National Oceanic and Atmospheric Administration Award No. NA66FI0220-01. Doyle Hanan (CDFG) gave support and advice throughout the assessment.

LITERATURE CITED

Barnes, J.T., M. Yaremko and D. Hanan. 1996. Status of the Pacific sardine resource and fishery, 1994 and 1995. Calif. Dept. of Fish and Game, MRD Admin. Rep. 96-1. 19p.

Barnes, J.T. and M. Yaremko. 1996. Pelagic Fisheries Research and Assessment. Calif. Dept. Fish and Game, MRD Cruise Report 95-M-9. 3p.

Bentley, P.J., R.L. Emmett, N.C.H. Lo and G. Moser. 1996. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. Calif. Coop. Oceanic Fish. Invest. Rep. 37:193-200.

Deriso, R.B., J.T. Barnes, L.D. Jacobson, and P.J. Arenas. 1996. Catch-at-age analysis for Pacific sardine (*Sardinops sagax*), 1983-1995. Calif. Coop. Oceanic Fish. Invest. Rep. 37:175-187.

Deriso, R., T.J. Quinn and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42:4.

Hargreaves, N. B., D. M. Ware, G. A. McFarlane. 1993. Return of Pacific sardine *(Sardinops sagax*) to the British Columbia coast in 1992. Can. J. Fish. Aquat. Sci. 51: 460-463.

Hart, J.L. 1943. Tagging experiments on British Columbia pilchards. J. Fish. Res. Board Can. 6:164-182.

Hedgecock, D., E. S. Hutchinson, G. Li, F. L. Sly, and K. Nelson. 1989. Genetic and morphometric variation in the Pacific sardine, *Sardinops sagax caerulea*: comparisons and contrasts with historical data and with variability in the northern anchovy, *Engraulis mordax.* Fish. Bull., U.S. 87:653-671.

Hilborn, R. and C. J. Walters. 1992. Quantitative fisheries stock assessment. Routledge, Chapman and Hall. 570 p.

Jacobson, L.D. 1993. ADEPT: Software for VPA analysis using Gavaris's procedure. NMFS, SWFSC Admin. Rep. LJ-93-02. 71p.

Jacobson, L.D., E.S. Konno, and J.P. Pertierra. 1994a. Status of Pacific mackerel and trends in biomass. Calif. Coop. Oceanic Fish. Invest. Rep. 35: 36-39.

Jacobson, L. D., N. C. H. Lo, and J. T. Barnes. 1994b. A biomass-based assessment model for northern anchovy, *Engraulis mordax.* Fish. Bull., U.S. 92: 711-724.

Jacobson, L.D, N.C.H. Lo, S.F. Herrick, and T. Bishop. 1995. Spawning biomass of the northern anchovy in 1995 and status of the coastal pelagic fishery during 1994. NMFS, SWFSC Admin. Rep. LJ-95-11. 49p.

Jacobson, L.D., S. Ralston, and A.D. MacCall. 1996. Historical larval abundance indices for bocaccio rockfish (*Sebastes paucispinis*) from CalCOFI data. NMFS, SWFSC Admin. Rep. LJ-96-06. 30p.

Lasker, R. 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy (*Engraulis mordax*). NOAA Technical Report NMFS 36. 99p.

Lo, N.C.H., Y.G. Ruiz, M. Jacob C., H.G. Moser and R.J. Lynn. 1996. Egg production and spawning biomass of sardine (*Sardinops sagax*) in 1994, determined by the daily egg production method. Calif. Coop. Oceanic Fish. Invest. Rep. 37:160-174.

Lo, N.C.H., L.D. Jacobson and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526.

MacCall, A.D. 1990. Dynamic geography of marine fish populations. University of Washington Press. 153 pp.

PFMC 1996. Amendment 7 to the northern anchovy fishery management plan. Pacific Fishery Management Council, Portland, OR.

Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned? Calif. Coop. Ocean. Fish. Invest. Rep. 23: 56-78.

Smith, P.E. 1990. Monitoring interannual changes in spawning area of Pacific sardine (*Sardinops sagax*). Calif. Coop. Oceanic Fish. Invest. Rep. 31:145-151.

Vrooman, A.M. 1964. Serologically differentiated subpopulations of the Pacific sardine, *Sardinops caerulea.* J. Fish. Res. Board Can. 21:691-701.

Yaremko, M.L. 1996. Age determination in Pacific sardine, *Sardinops sagax.* NOAA Tech. Mem. NOAA-TM-NMFS-SWFSC-223. 32 p.

Table 1

Pacific Sardine Landings, 1983-1996

Short Tons

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	3498.0	3852.8
1985	2	298.6	604.0	902.6
1986	1	1013.8	109.3	1123.2
1986	2	268.9	158.0	426.9
1987	1	1437.0	1074.5	2511.5
1987	2	871.7	1605.2	2476.9
1988	1	3328.0	683.5	4011.5
1988	2	844.1	1559.0	2403.1
1989	1	2373.7	508.0	2881.7
1989	2	1683.9	6348.8	8032.7
1990	1	2349.5	6501.8	8851.3
1990	2	752.7	6033.8	6786.4
1991	1	5700.6	10216.6	15917.3
1991	2	2839.9	24377.1	27217.0
1992	1	6894.1	3665.8	10559.9
1992	2	12188.1	34428.4	46616.5
1993	1	13392.6	20551.2	33943.8
1993	2	4445.5	14762.4	19207.9
1994	1	9365.5	6288.2	15653.7
1994	2	4778.7	16711.8	21490.5
1995	1	31365.8	20119.2	51485.0
1995	2	16626.3	18919.1	35545.5
1996	1	20801.6	17262.8	38064.4

Table 2

Fishery-independent data types used in CANSAR

YEAR	CalCOFI EGG and LARVAE INDEX	DEPM SPAWNING BIOMASS (Short tons)	SPAWNING AREA (N mi^2)	AERIAL SPOTTER INDEX	3-SEASON SCRIPPS PIER SST (Deg C)
1983	--	--	--	--	17.80
1984	26.60	--	--	--	17.90
1985	13.10	--	607	--	17.70
1986	17.30	8,440	970	51,775	17.60
1987	34.20	17,285	1,850	13,454	17.20
1988	65.90	14,892	2,508	77,886	17.20
1989	82.40	--	3,680	48,054	17.30
1990	54.10	--	1,480	26,914	17.60
1991	216.90	--	3,840	52,093	17.61
1992	131.40	--	--	61,072	17.84
1993	82.90	--	--	95,822	17.97
1994	169.00	122,865	11,360	237,065	18.04
1995	56.20	--	--	234,995	18.06
1996	199.00	423,933	24,480	125,668	18.06

Table 3

Estimates of egg production rates and adult reproductive parameters for 1996 and 1994 daily egg production method surveys.

Sardine biomass		1996			1994	
Paramter	region 1	region2	wted average		US+MEX	US only
p0/min	0.48	6.3	2.11			
(CV)	0.58	0.88	0.75		0.22	
p0/0.05m2(=p0/min/0.73)			2.89		0.169	
area(km2)	112322	44395	156717		380175	253850
(%)	72	28	100			
f weight(W)			82.5		82.5	
b.fecundity (F)			24282.52		24282.52	
s.frequency(S) (Macewiz 1996)			0.149		0.0729	
s.ratio(R)			0.537		0.537	
# eggs/gm biomass=RSF/W			23.55		11.53	
s. biomass(mt)			384694		111493	
daily mortality(Z)						
	0.49	0.94	0.62		0.12	
(CV)	0.82	0.63	0.81		0.97	
Reg 1: Lines < 73 and Lines >83						
Reg 2: Lines between 73 and 83						

Table 4. Sensitivity of biomass estimates for Pacific sardine to weights (λ_t) used in CANSAR. Discrepancies between best fit estimates and estimates with different weights are given in the table as percentages of best fit estimates. For each run, base case weights (λ_t=0.1 for spawner-recruit calculations, 1.0 for California and Mexican fishery data and 4.0 for other data types) were scaled by the multiplier in the first column. Bias corrections were not used.

Multiplier	Calif. Fishery	Mexican Fishery	CalCOFI	Spawning Area	Fish Spotter	Daily Egg Production	Spawner-Recruit
Mean 1992-1996 Biomass							
0.0	86%	84%	12%	-16%	7%	-26%	9%
0.5	8%	4%	4%	-9%	-1%	-13%	1%
2.0	1%	-15%	-8%	3%	-7%	8%	-6%
10.0	44%	-14%	-21%	52%	-9%	75%	-9%
1996 Biomass							
0.0	90%	74%	24%	-22%	-2%	-36%	39%
0.5	17%	4%	13%	-11%	-4%	-17%	11%
2.0	-2%	-12%	-11%	4%	-2%	14%	-10%
10.0	15%	-14%	-18%	66%	0%	125%	-23%

TABLE 5

CANSAR ESTIMATES OF BIOMASS (Short Tons) AND RECRUITMENT (Age 0, X10 ^ 3)

(Corrected for bias based on 1,000 bootstrap iterations)

YEAR (July 1)	AGE 1+ BIOMASS	BIOMASS STD. ERROR	NUMBER RECRUITS	RECRUITS STD. ERROR
1983	6768	4528	136859	55371
1984	16397	6625	161411	45367
1985	20274	5030	121743	35228
1986	30209	6939	411165	102861
1987	51433	11010	357021	85650
1988	67980	13011	561745	115128
1989	86273	14270	466690	109722
1990	98993	15146	1819511	553101
1991	201018	49450	2098867	661125
1992	206647	52095	1412891	531664
1993	229327	64655	4194797	1526370
1994	397256	114779	4848384	1909534
1995	393975	132763	6847677	3340238
1996	509956	223994	6319333	4674630

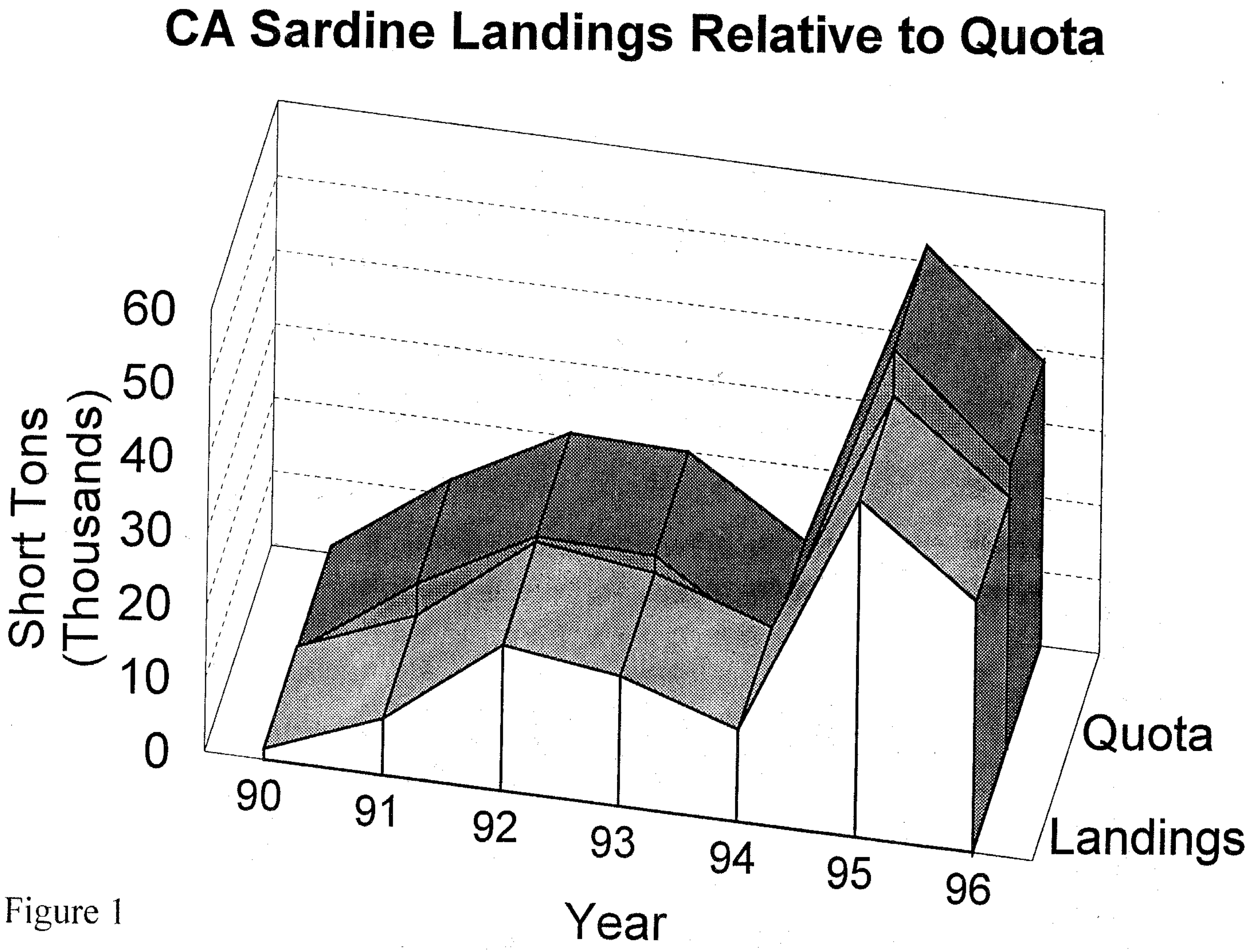

CA Sardine Landings Relative to Quota
Short Tons (Thousands)
60
50
40
30
20
10
0
90
91
92
93
94
95
96
Year
Quota
Landings

Figure 1

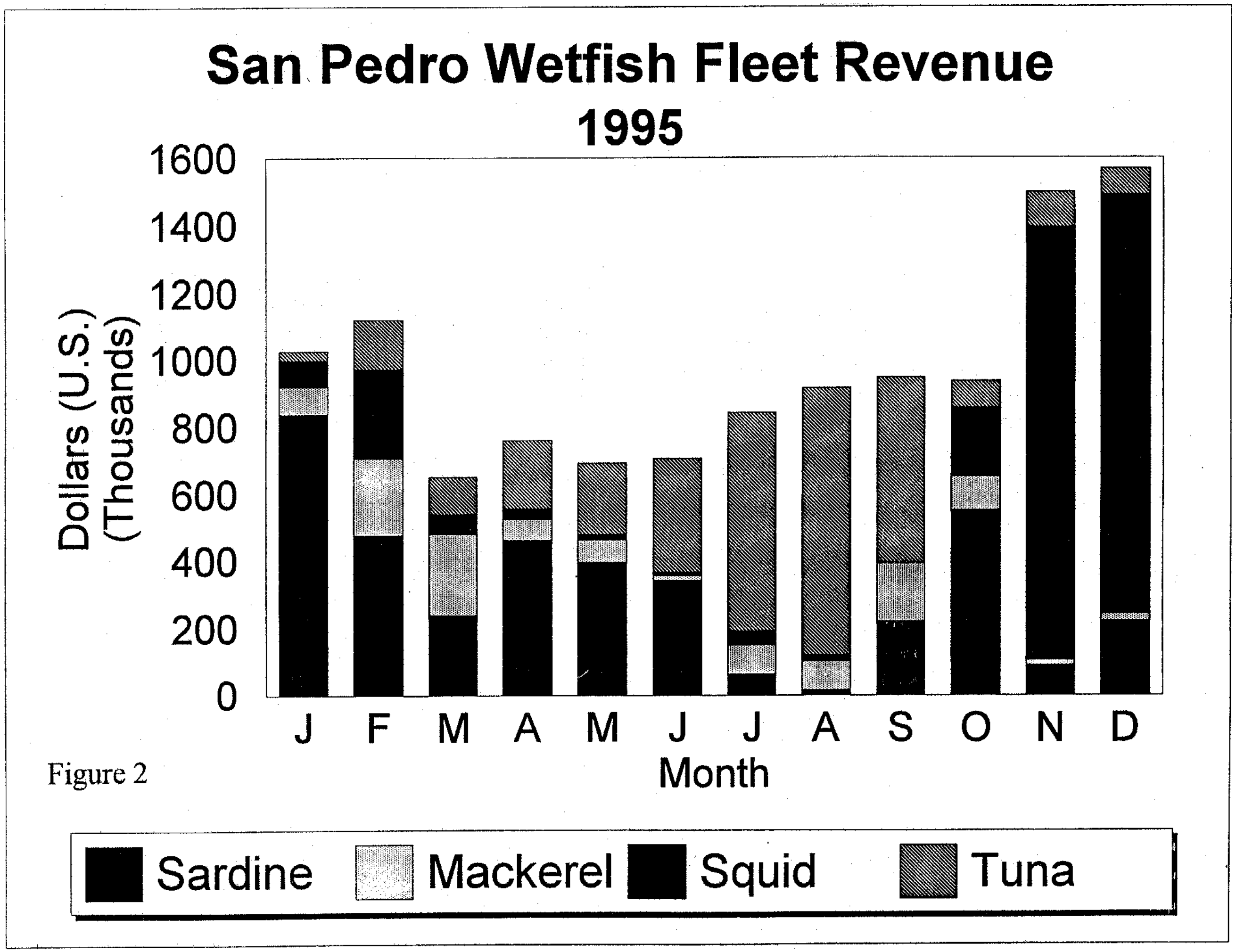
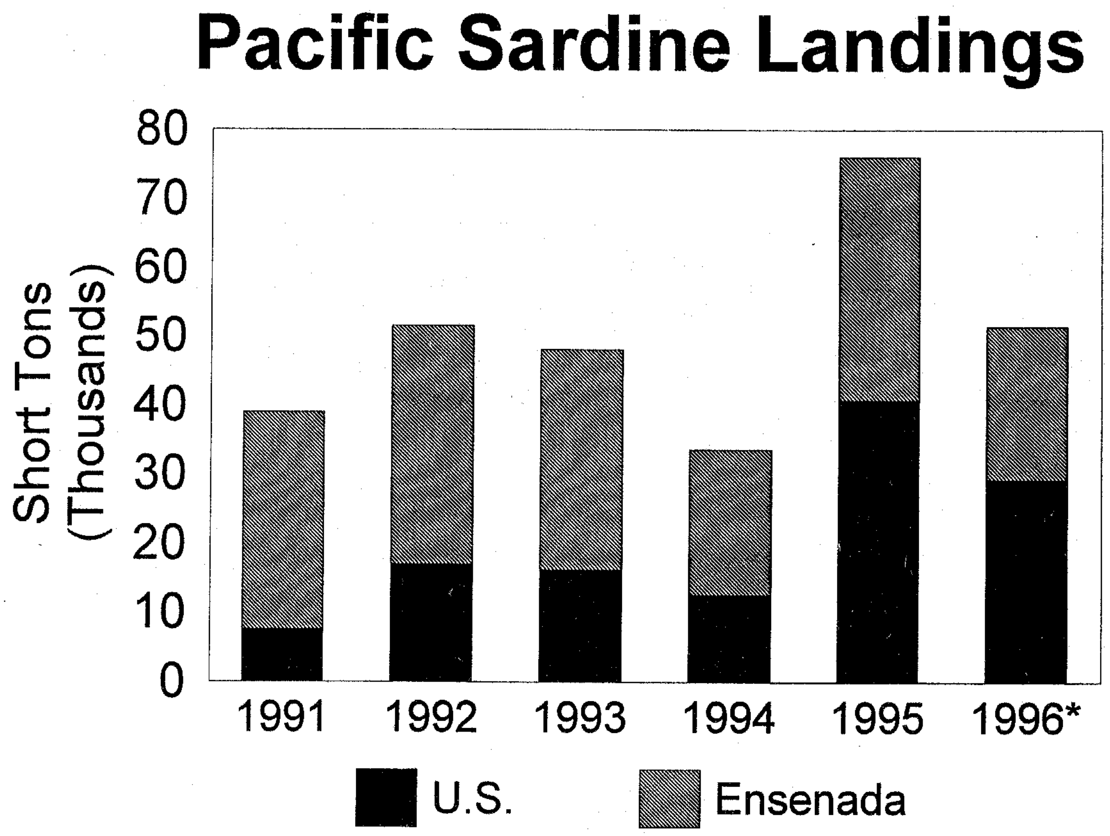

San Pedro Wetfish Fleet Revenue
1995
Dollars (U.S.) (Thousands)
1600
1400
1200
1000
800
600
400
200
0
J
F
M
A
M
J
J
A
S
O
N
D
Month
Sardine
Mackerel
Squid
Tuna

Figure 2



Pacific Sardine Landings

*incomplete; 1996 landings depict catch Jan-Aug for Ensenada and Jan-Oct for the U.S.

Figure 3

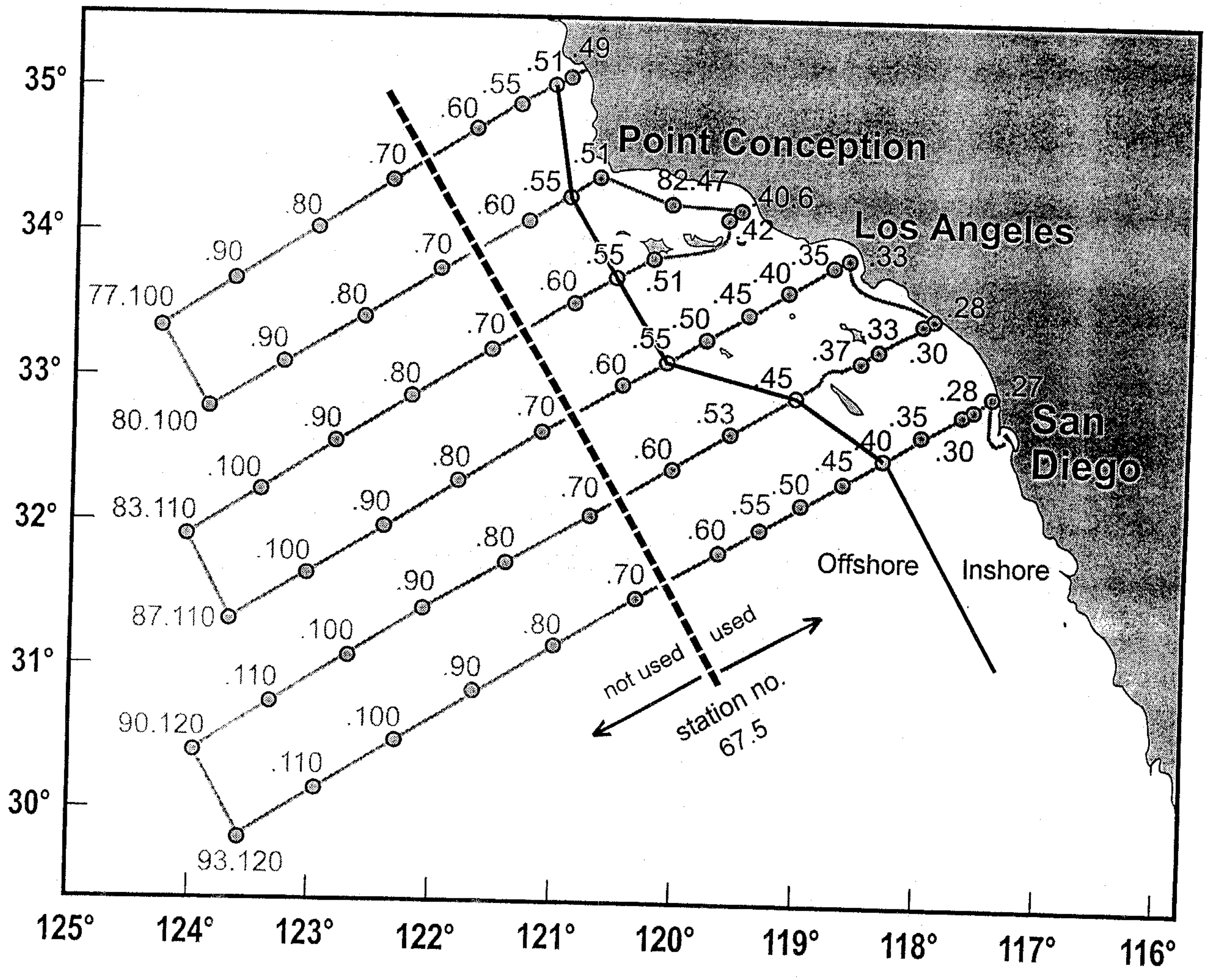

Point Conception
Los Angeles
San Diego
Offshore
Inshore
not used
used
station no. 67.5
77.100
80.100
83.110
87.110
90.120
93.120
82.47
40.6
35°
34°
33°
32°
31°
30°
125°
124°
123°
122°
121°
120°
119°
118°
117°
116°

Figure 4

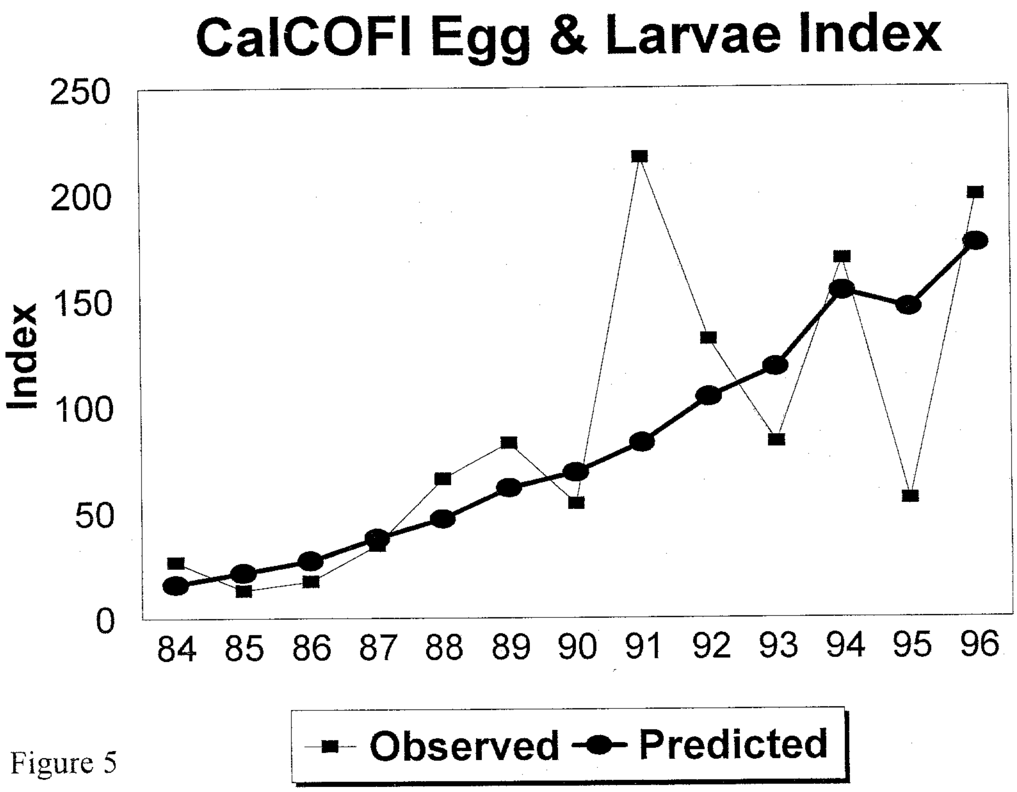

CalCOFI Egg & Larvae Index
Index
250
200
150
100
50
0
84
85
86
87
88
89
90
91
92
93
94
95
96
Observed
Predicted

Figure 5

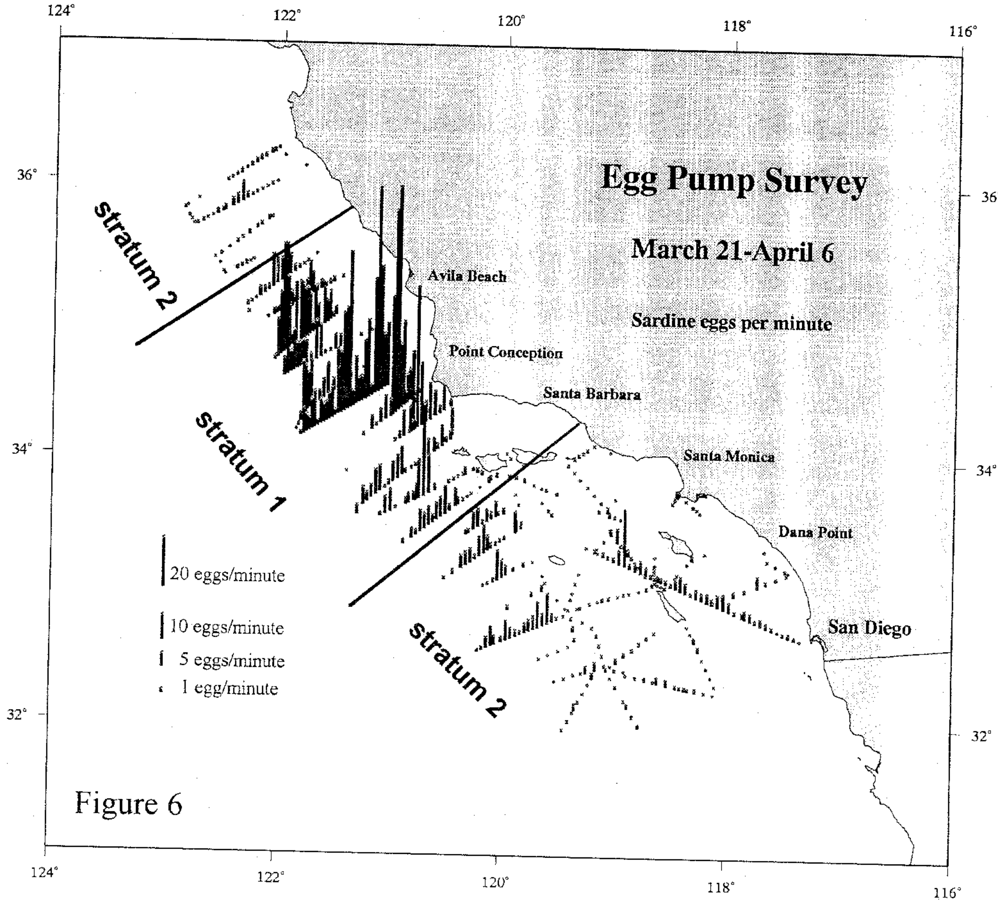

Egg Pump Survey
March 21-April 6
Sardine eggs per minute
Avila Beach
Point Conception
Santa Barbara
Santa Monica
Dana Point
San Diego
stratum 2
stratum 1
stratum 2
20 eggs/minute
10 eggs/minute
5 eggs/minute
1 egg/minute
124°
122°
120°
118°
116°
36°
34°
32°

Figure 6

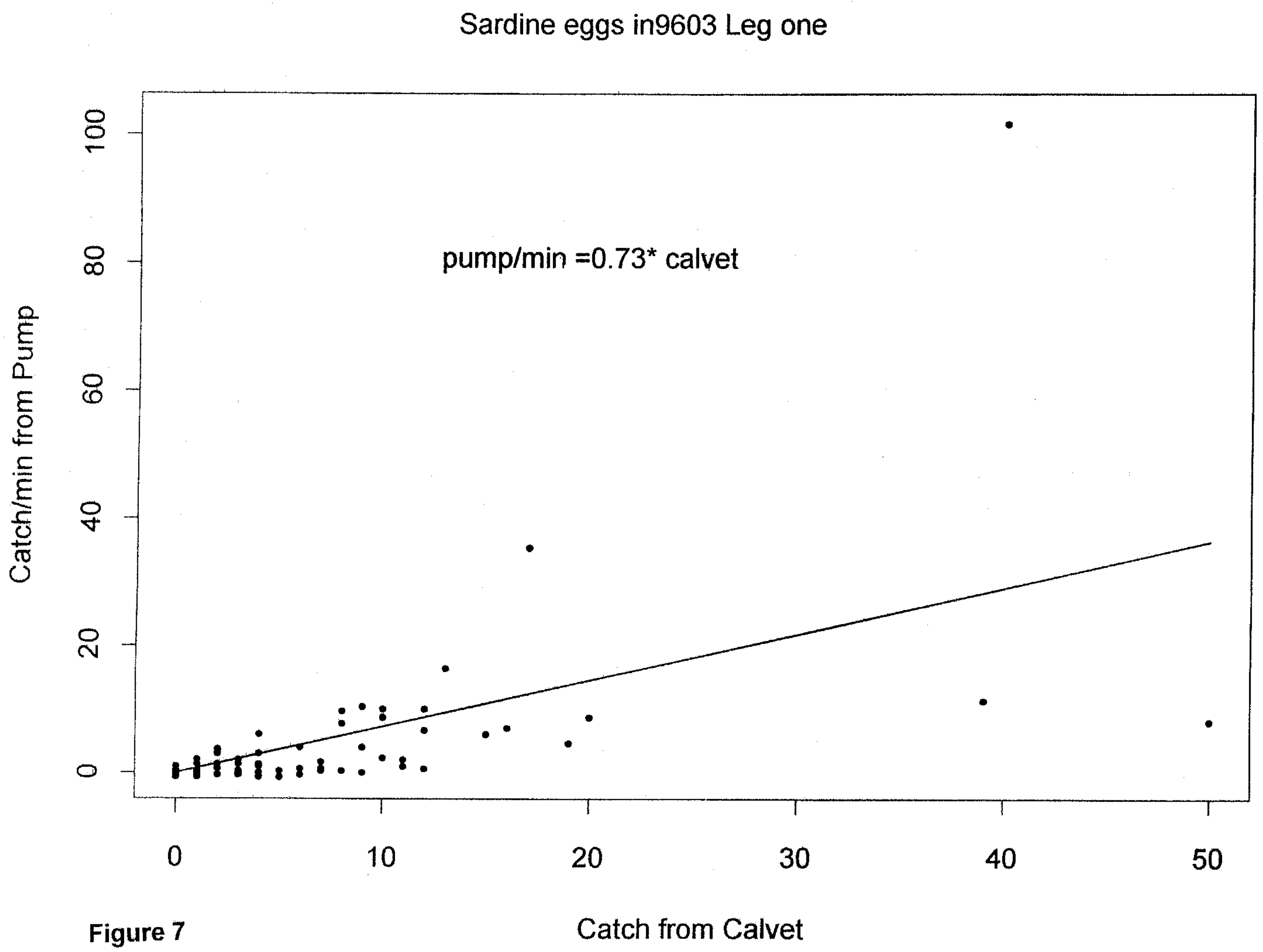

Sardine eggs in9603 Leg one
pump/min =0.73* calvet
Catch/min from Pump
0
20
40
60
80
100
0
10
20
30
40
50
Catch from Calvet

Figure 7

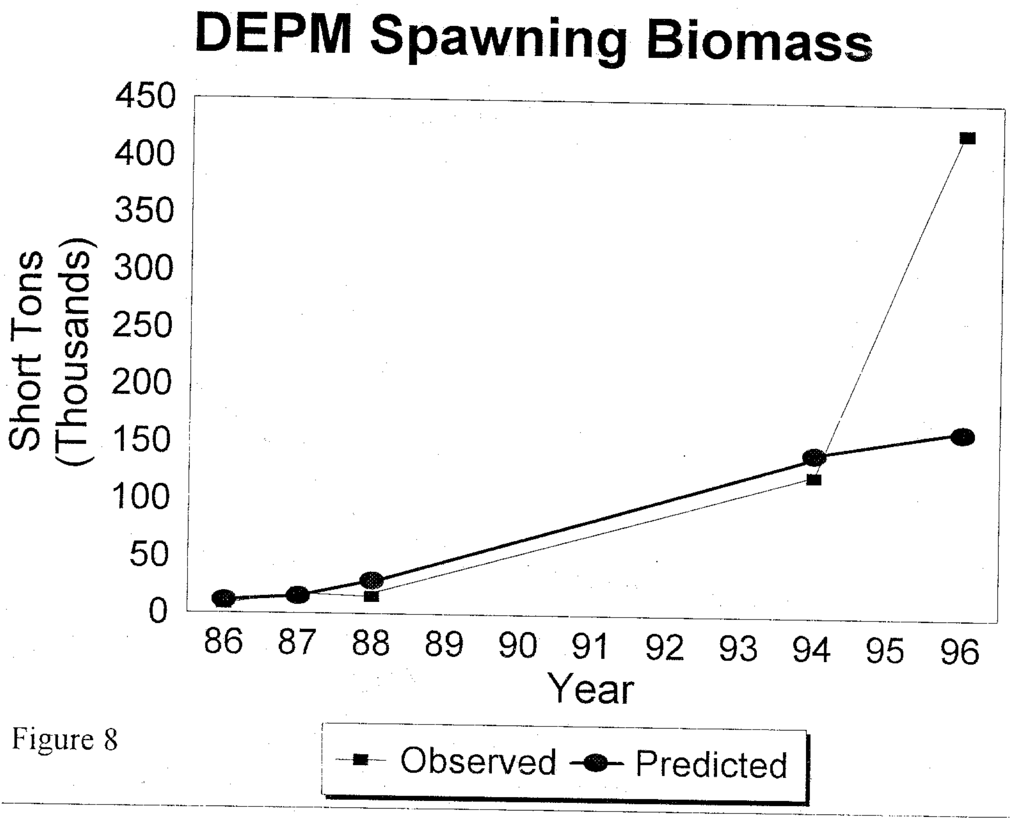

DEPM Spawning Biomass
Short Tons (Thousands)
450
400
350
300
250
200
150
100
50
0
86
87
88
89
90
91
92
93
94
95
96
Year
Observed
Predicted

Figure 8

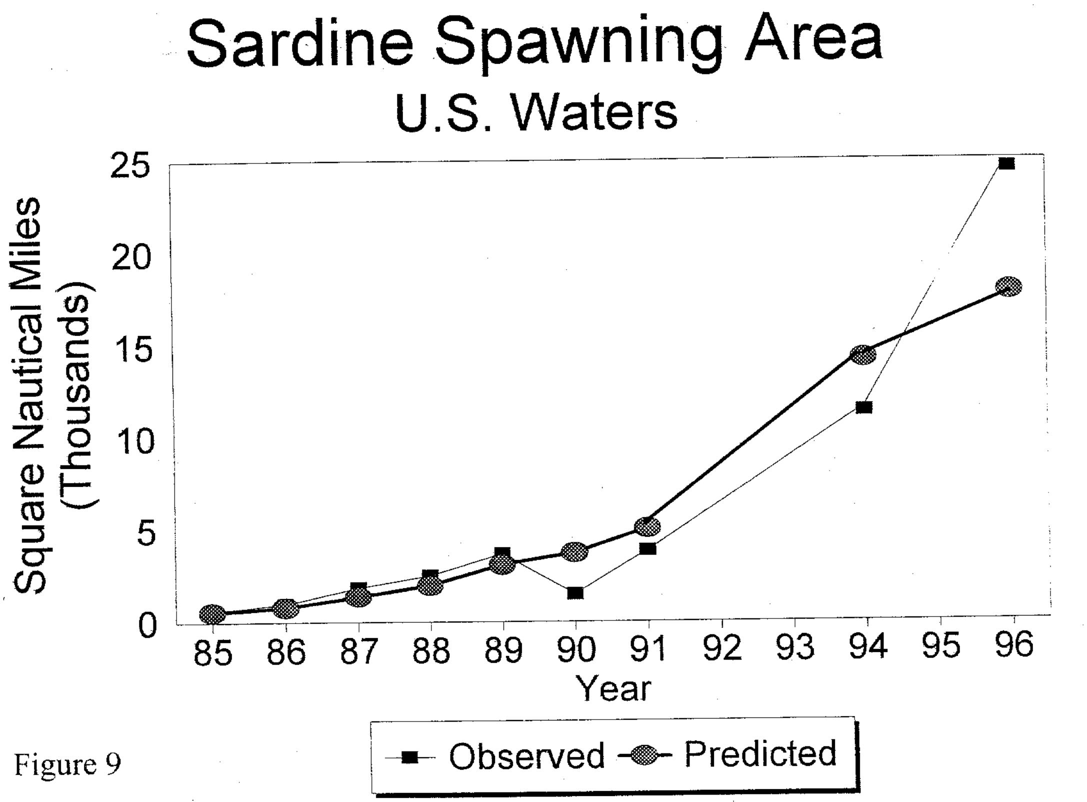

Sardine Spawning Area
U.S. Waters

Figure 9

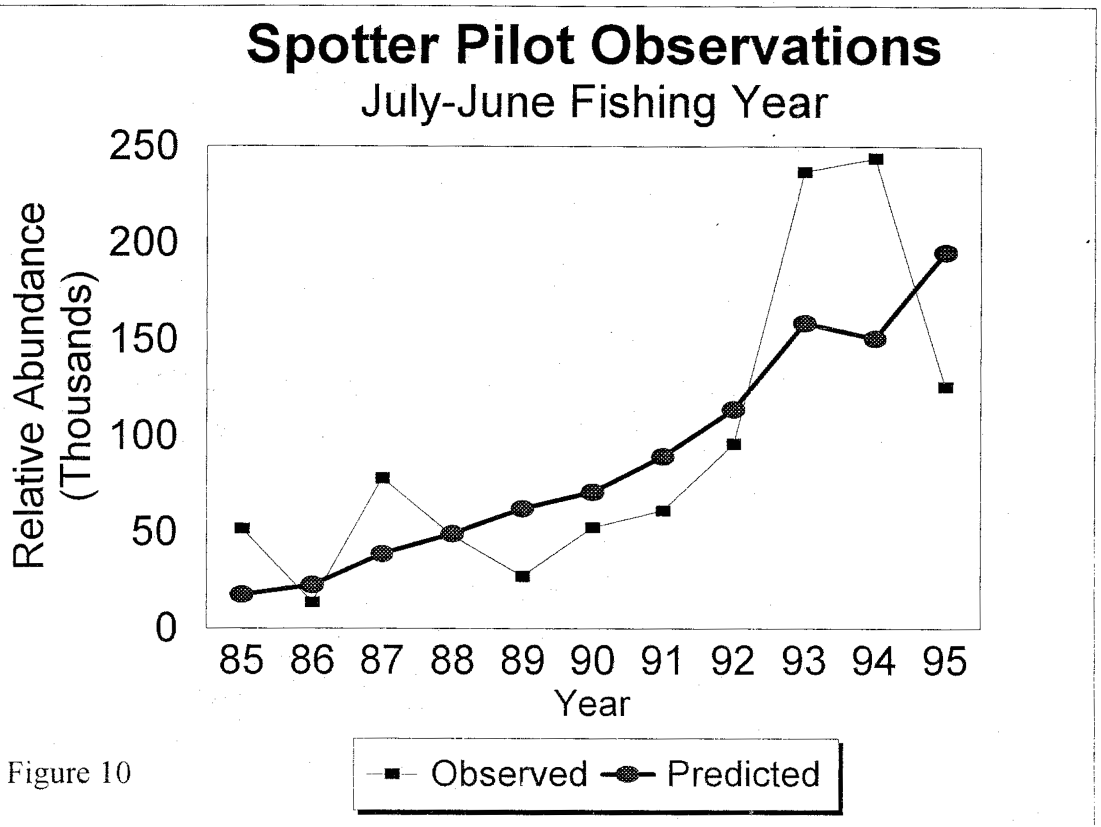
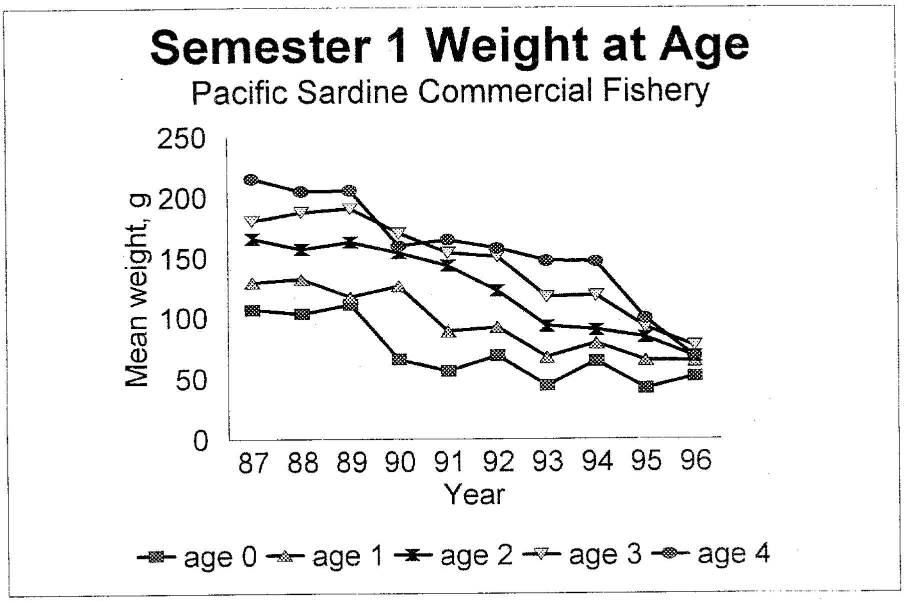

Spotter Pilot Observations
July-June Fishing Year
Relative Abundance (Thousands)
250
200
150
100
50
0
85
86
87
88
89
90
91
92
93
94
95
Year
Observed
Predicted

Figure 10


Semester 1 Weight at Age
Pacific Sardine Commercial Fishery
Mean weight, g
0
50
100
150
200
250
87
88
89
90
91
92
93
94
95
96
Year
age 0
age 1
age 2
age 3
age 4

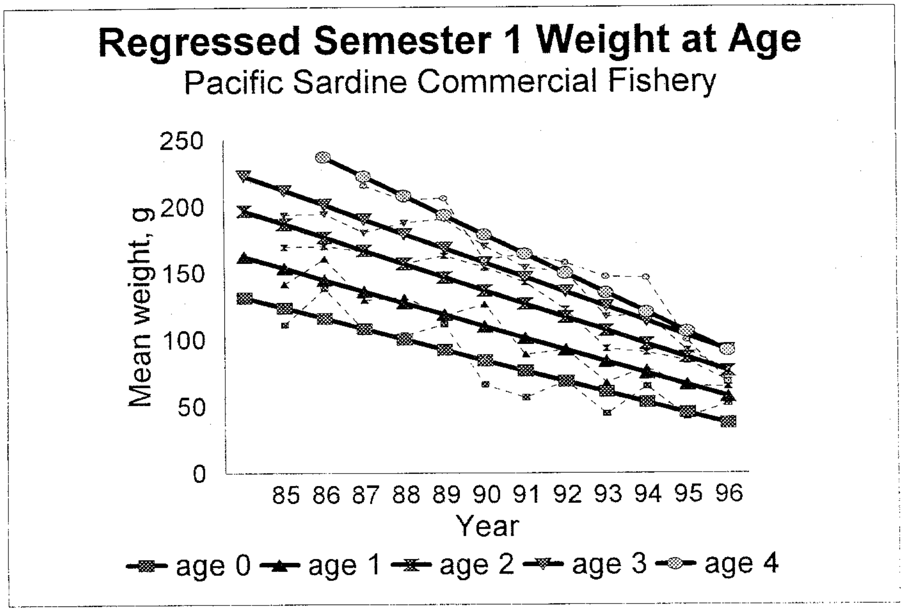

Regressed Semester 1 Weight at Age
Pacific Sardine Commercial Fishery
Mean weight, g
0
50
100
150
200
250
85
86
87
88
89
90
91
92
93
94
95
96
Year
age 0
age 1
age 2
age 3
age 4

Figure 11

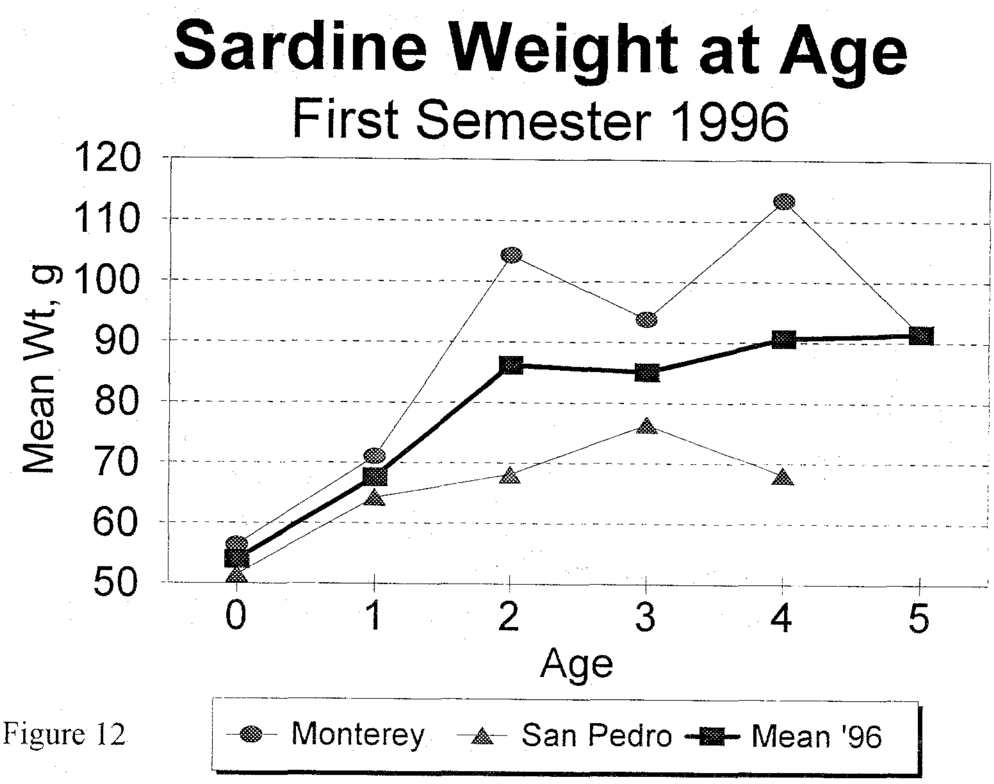

Sardine Weight at Age
First Semester 1996
Mean Wt, g
120
110
100
90
80
70
60
50
0
1
2
3
4
5
Age
Monterey
San Pedro
Mean '96

Figure 12

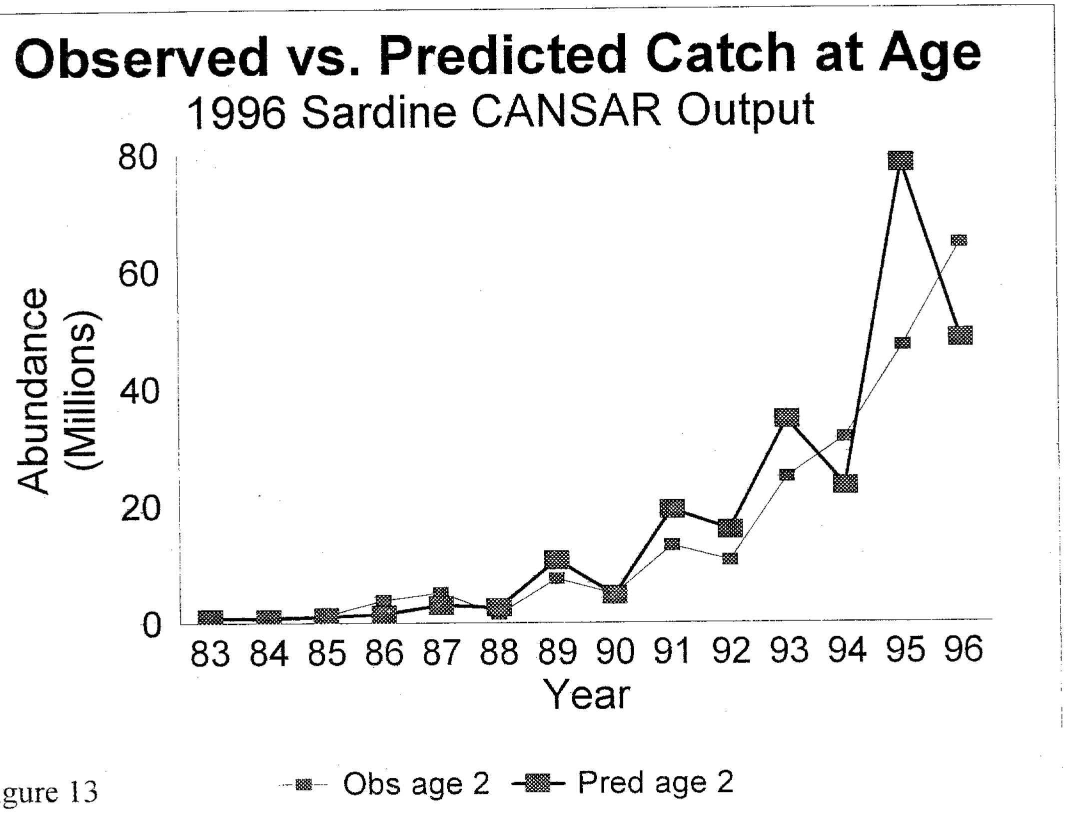

Observed vs. Predicted Catch at Age
1996 Sardine CANSAR Output
Abundance (Millions)
80
60
40
20
0
83
84
85
86
87
88
89
90
91
92
93
94
95
96
Year
Obs age 2
Pred age 2

Figure 13

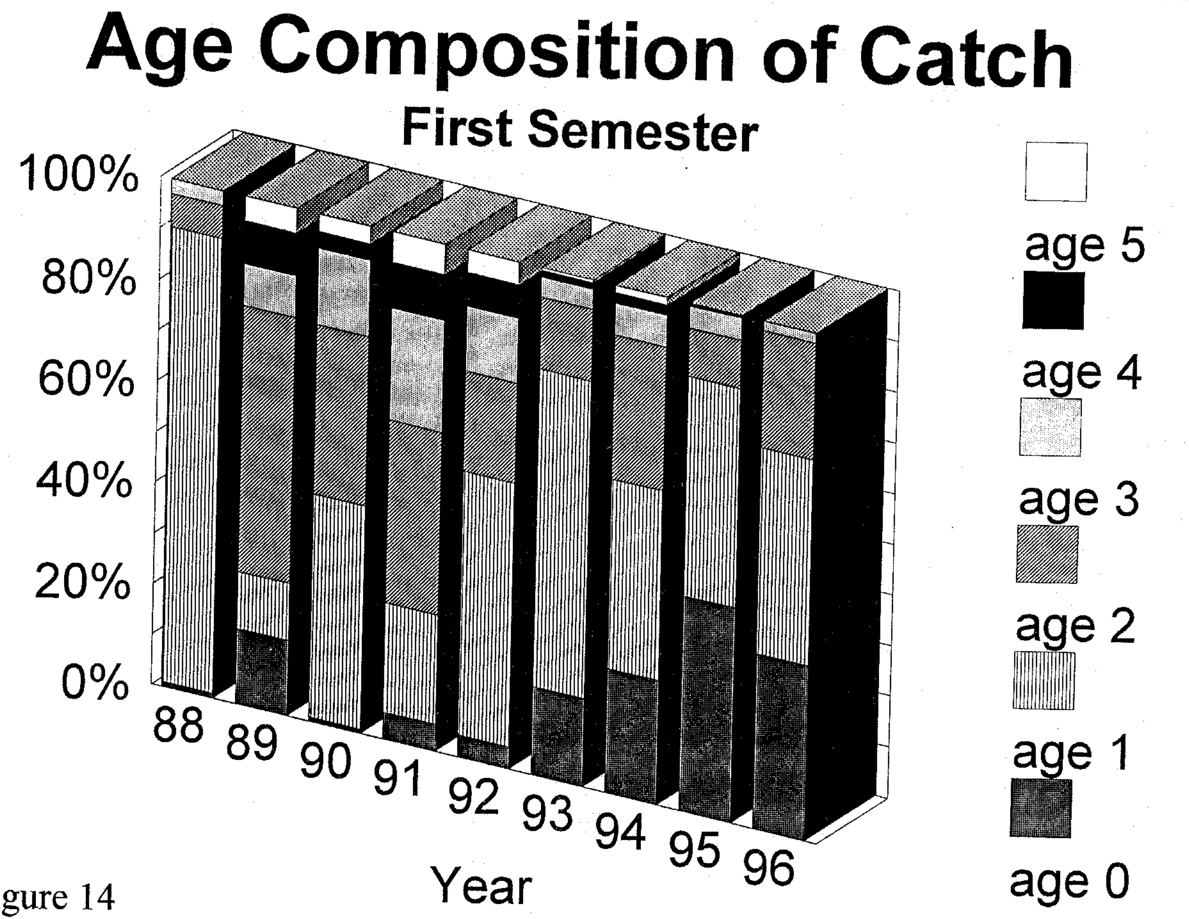

Age Composition of Catch
First Semester
100%
80%
60%
40%
20%
0%
88
89
90
91
92
93
94
95
96
Year
age 5
age 4
age 3
age 2
age 1
age 0

Figure 14

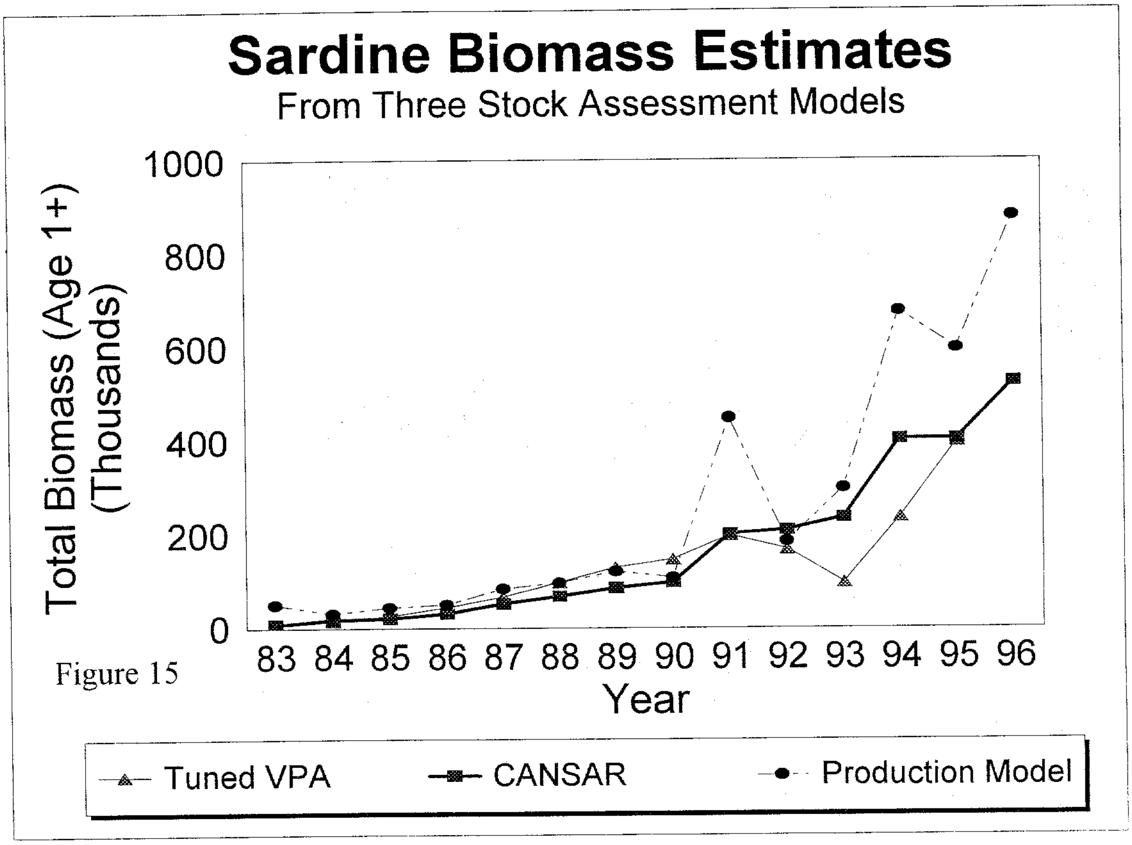
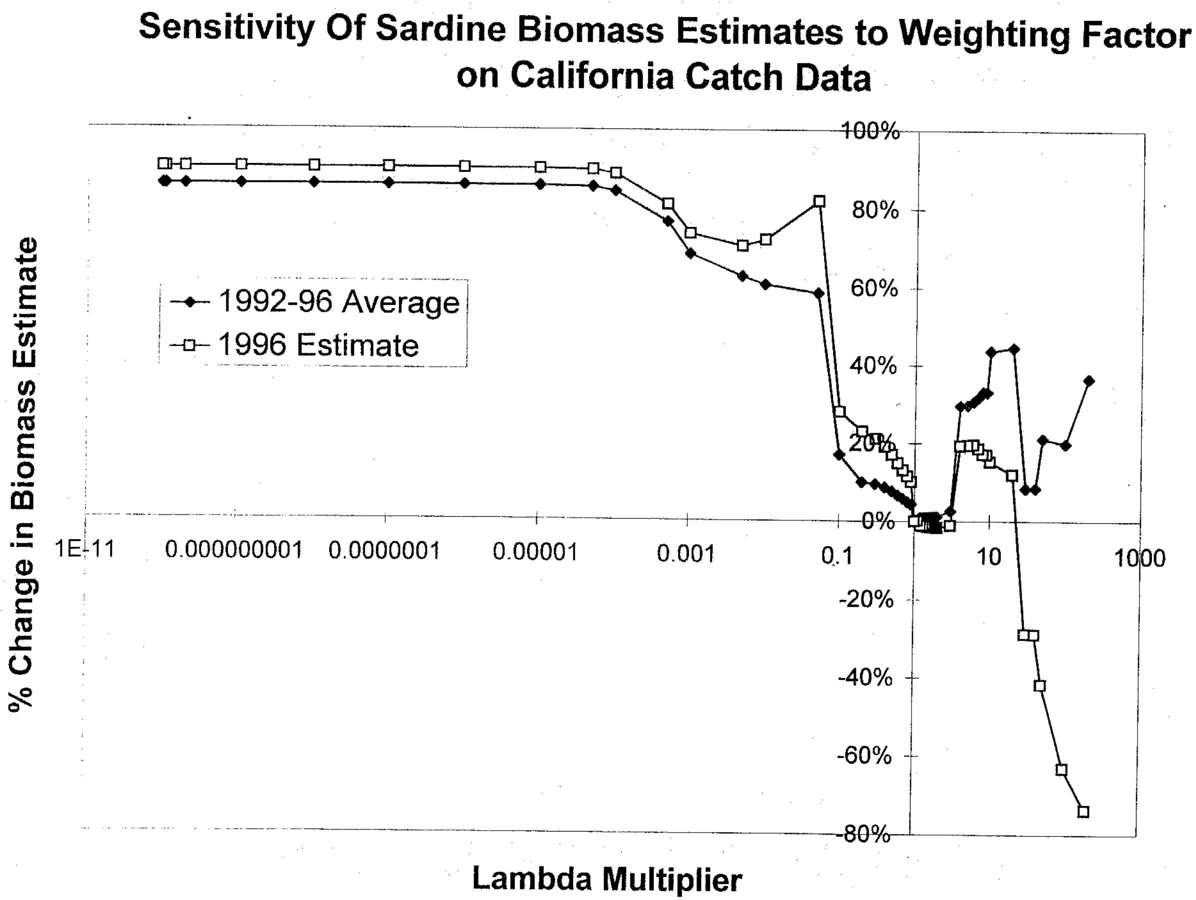

Sardine Biomass Estimates
From Three Stock Assessment Models
Total Biomass (Age 1+) (Thousands)
1000
800
600
400
200
0
83
84
85
86
87
88
89
90
91
92
93
94
95
96
Year
Tuned VPA
CANSAR
Production Model

Figure 15



Sensitivity Of Sardine Biomass Estimates to Weighting Factor on California Catch Data

Figure 16

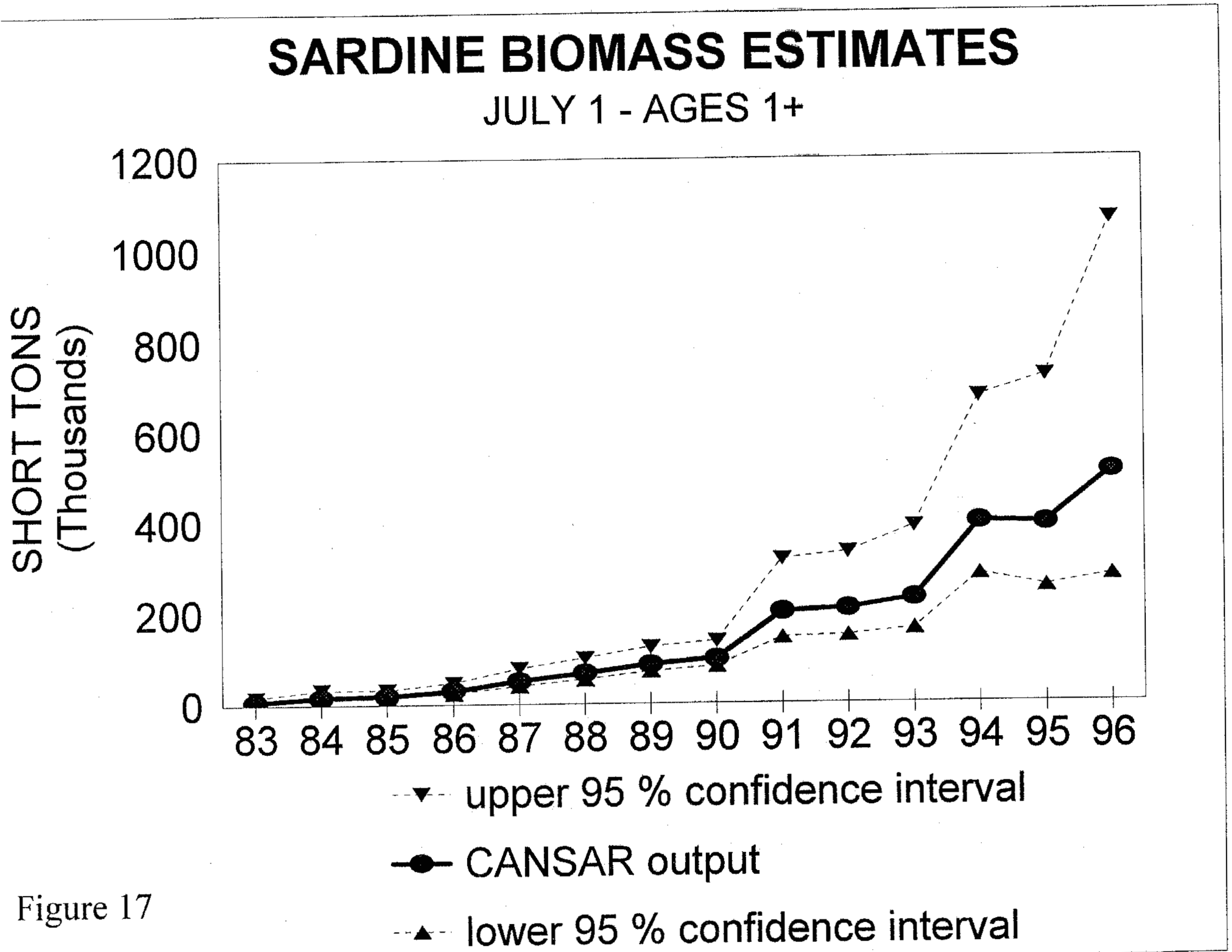

SARDINE BIOMASS ESTIMATES
JULY 1 - AGES 1+
SHORT TONS (Thousands)
1200
1000
800
600
400
200
0
83
84
85
86
87
88
89
90
91
92
93
94
95
96
upper 95 % confidence interval
CANSAR output
lower 95 % confidence interval

Figure 17

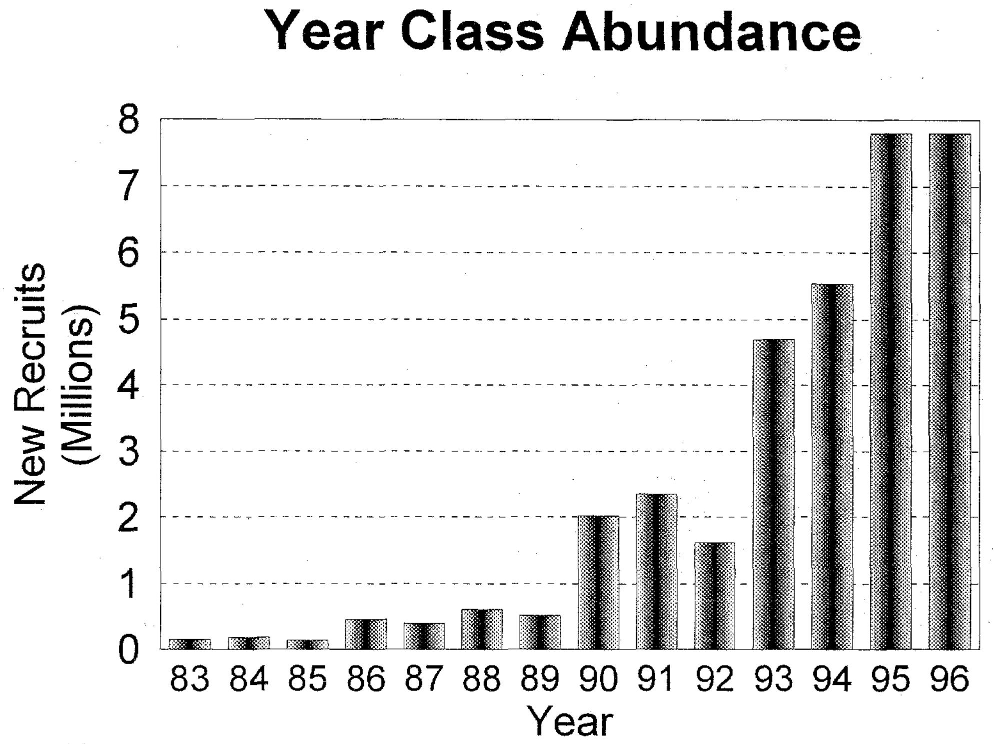

Year Class Abundance
New Recruits (Millions)
8
7
6
5
4
3
2
1
0
83
84
85
86
87
88
89
90
91
92
93
94
95
96
Year

Figure 18

Appendix 1

Worksheet MATCALC1.XLS

This spreadsheet calculates the maturity of age 0 and age 1 sardine in the population based on observed maturities at age in 1994 DEPM samples and observed DEPM sample age composition data. The calculations assume population age composition from an exponential mortality model and that the maturity of age 0 and age 1 sardine not sampled by DEPM gear is a fraction (Maturity Multiplier) of the maturity of age 0 and age 1 sardine that were sampled by DEPM gear.

Steps are as follows: First, a catch curve is used to estimate Z from the population age composition estimate for 1994 on p. 185 of Deriso et al (1996). The estimate of Z is then used in a exponential mortality model to calculate expected numbers of sardine at ages 0, 1 and 2+. Next, EXCEL's solver function is used to estimate DEPM selectivities on the basis of the age composition calculated from the exponential mortality model and the observed DEPM age composition. Finally, the assumptions about selectivity, maturity of sardine in DEPM samples and maturity of sardine not sampled by DEPM are combined to infer the population maturity at age.

The logic this approach is that DEPM gear likely take just the largest and most mature female sardine age 0 and 1. Thus, estimates of maturity at age for the youngest age groups are likely biased high. The calculations in this spreadsheet adjust the estimates of maturity for young fish to account for the sampling bias. Note-it is easy to do sensitivity analyses on maturities and Z.

Assumed population Z in exponential mortality model =	1.40
Assumed Maturity Multiplier for Unsampled Age 0 and Age 1 Sardine =	0.50

Data:

Age	Observed 1994 DEPM Age Composition (p. 185 in Deriso et al. 1996)	Observed Maturity in 1994 DEPM Samples
0	0.21	0.58
1	0.41	0.79
2+	0.38	not needed
Total	1	

Exponential Mortality Model:

Assumed Population Abundance/Age Composition With Plus Group (From Exponential Mortality Model Assuming Z)
0.75
0.19
0.06
1

Solver Selectivity Estimates:

DEPM Selectivity Estimates from Solver	Solver Calcs: Unscaled DEPM Age Composition	Solver Calcs: Scaled DEPM Age Composition
0.04	0.03	0.21
0.35	0.07	0.41
1.00	0.06	0.38
	0.16	1
	Obj. Function	3.88015E-05

Population Maturity:

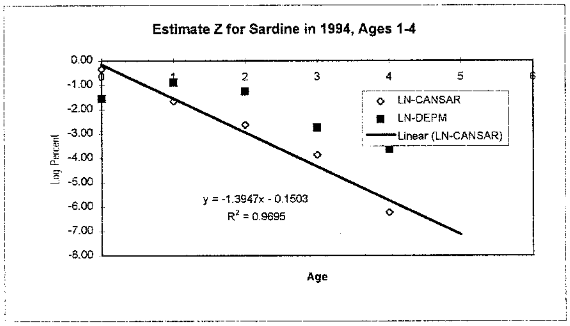
Implied Population Maturity
30%
53%

Exponential mortality model (Intermediate Calculations):

Age	Population Abundance/Age Composition With NO Plus Group
0	1000.00
1	246.60
2	60.81
3	15.00
4	3.70
5	0.91
6	0.22
7	0.06
8	0.01
9	0.00
10	0.00
11	0.00
12	0.00
13	0.00
14	0.00
15	0.00
Total	1327.31

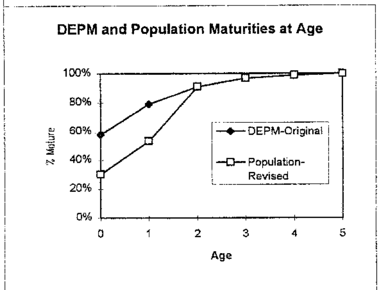
Estimate Z for Sardine Population From Data in Text Table on p. 185 of Deriso et al. (1996) and Catch Curve (Use Ages 1-4 only because Age 5 is a plus group):

Age	CANSAR	DEPM	LN-CANSAR	LN-DEPM
0	0.710	0.212	-0.34	-1.55
1	0.190	0.413	-1.66	-0.88
2	0.073	0.282	-2.62	-1.26
3	0.021	0.064	-3.86	-2.76
4	0.002	0.026	-6.21	-3.64
5	0.004	0.003		
total	1	1		



DEPM and Population Maturities for Comparison:

Age	DEPM-Original	Population-Revised
0	58%	30%
1	79%	53%
2	91%	91%
3	97%	97%
4	99%	99%
5	100%	100%



Appendix 2. Subroutine FETCHQ calculates age specific selectivites for the sardine VPA model.

```
C       SpeedEdit 64,69,21,0,0,3,0,3 Updated 12/15/93 12:54:14
C       double precision for adept   S. Bell

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      SUBROUTINE FETCHQ(year,season,SURVEY,PARS,QVECT)
      IMPLICIT NONE
C
C     THIS SUBROUTINE CALCULATES AGE SPECIFIC AVAILABILITIES FOR A
C     A SPECIFIED season and SURVEY IN THE pacific mackerel adapt model.
C     THE VALUES RETURNED ARE SCALED TO LIE BETWEEN ZERO AND ONE.
C                                   LARRY JACOBSON
C                                   MAY 27, 1992
c
c     a specified year and season too.
c                                   Larry Jacobson
c                                   April 24, 1996
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     INCLUDE SIMINC1.INC WHICH HOLDS GLOBAL PARAMETERS AND VARS
C       USED BY SIMPLEX SKELETON PROGRAM
      include'SIMINC1.INC'

C     INCLUDE MYDAT1.INC WHICH HOLDS USER DEFINED PARAMETERS AND
C       VARIABLES
      include'MYDAT1.INC'

c     include file that specifies indices for survey types
      include 'survptr.inc'

C------------------------- VARS PASSED ---------------------------------

C     P HOLDS THE CURRENT PARAMETER ESTIMATES--DO NOT CHANGE VALUES!
      double precision PARS(MAXPAR)

C     SURVEY IS THE SURVEY TYPE
      INTEGER SURVEY,year,season

C     QVECT IS THE PARAMETER OF AGE SPECIFIC AVAILABILITIES TO BE CALCULATED
      double precision QVECT(maxage)

C------------------------ LOCAL VARIABLES ------------------------------

C     COUNTER FOR AGES
      INTEGER AGE

C     TEMPORARY VARIABLE
      double precision TEMP1

C-------------------------- EXECUTABLE ---------------------------------
c     intialize
      do 10 age=1,maxage
        qvect(age)=badr
10    continue

      if (survey.eq.calcof.or.survey.eq.cdfg) then
c     use net fecundities at age
        qvect(1)= 0.0350
        qvect(2)= 0.153
        qvect(3)= 0.434
        qvect(4)= 0.632
        qvect(5)= 0.817
        qvect(6)= 1.000
      else if (survey.eq.spottr) then
c     use the fishery selectivity
cc     use geometric mean of selectivities during first and second semesters
        do 1000 age=1,nages
     temp1=max(smallr,fmatrx(year,1,age))
```

```
c          temp1=max(smallr,fmatrx(year,1,age))
c          temp2=max(smallr,fmatrx(year,2,age))
c          temp1=log(temp1*temp2)/2.0d0
          qvect(age)=exp(temp1)
1000    continue
      else if (survey.eq.depm) then
c     use maturities at age
        qvect(1)=0.27
        qvect(2)=0.51
        qvect(3)=0.91
        qvect(4)=0.97
        qvect(5)=0.99
        qvect(6)=1.00
      else if (survey.eq.srcurv) then
c     use ones except for age 0 (as in Jacobson and MacCall 1995)
        qvect(1)=dzero
        do 15 age=2,nages
          qvect(age)=1.0d0
15      continue
      else
        CALL FATAL(SCREEN,'SUBROUTINE FETCHQ',
     +    'SURVEY TYPE NOT DEFINED, PROBLEM WITH INDEX?')
      endif

C
CVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV

C     SCALE ALL VALUES TO A MAXIMUM OF 1.0
      TEMP1=dZERO
      DO 4000 AGE=1,NAGES
        IF (QVECT(AGE).GT.TEMP1) TEMP1=QVECT(AGE)
4000  CONTINUE
      DO 5000 AGE=1,NAGES
        QVECT(AGE)=QVECT(AGE)/(TEMP1+smallr)
5000  CONTINUE

c      print *,year,season,SURVEY,PARS,QVECT
c      pause
      RETURN
      END
```

Appendix 3. Function GETOBJ calculates objective function values used to estimate parameters in the sardine VPA model.

```
C       SpeedEdit 257,263,18,0,0,3,0,3 Updated 12/15/93 13:03:36
C       double precision for adept   S. Bell
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      double precision FUNCTION GETOBJ(P)
      IMPLICIT NONE
C
C     FILE SCHNUTE.FOR
C
C     TEMPLATE GETOBJ.FOR FOR USE WITH SIMPLEX PROGRAM.
C
C     THE REAL VECTOR ARGUMENT P HOLDS THE PARAMETER ESTIMATES.
C
C     THE INTEGER VARIABLE CALLS, WHICH IS DECLARED IN THE INCLUDE FILE,
C     SHOULD BE INCREMENTED EACH TIME THIS FUNCTION IS CALLED.
C
C     DOCUMENTATION:
C     -------------------------
c     This subroutine set up for Pacific mackerel.
C
c     There are two choices for Pacific mackerel in this implementation.
c
c     Choice 1:
c
c     If p(2) < 0, then specify the selectivity for each true age separately
c     (6 parameters for ages 0 to 5; age 6 is a plus group)  The parameters
c     for selectivities are logs and scaled so that the arithmetic
c     value for the oldest true age is equal to one (all other selectivity
c     and terminal f parameters are estimated relative to the value for the
c     oldest true age).  Selectivity for the oldest true age must be held
c     constant (i.e. not estimated, this is specified in the parameter file).
c     The code checks for this.  The FORTRAN parameter PTTOSS (set in the
c     rundefin.csv input data file) is the position of the first age specific
c     selectivity parameter.  The selectivity parameters are estimated in
c     log scale to assure positivity.  Make sure that you do not try to
c     estimate either the parameter used as  the switch for choosing a
c     selectivity option or the selectivity of the last true age.
c
c     For this option, the fishing mortality rate multiplier (same as the
c     terminal fishing mortality rate for the last true age) is modelled
c     as a separate parameter that can be either estimated or set manually.
c     The fishing mortality rate parameter is log scale so that it can never
c     become less than zero when converted to an arithmetic value.  The
c     fishing mortality rate is the first parameter in the initial value
c     file.
c
c     Choice 2:
c
c     If p(1) >= 0, then use a function to estimate fishing mortality
c     selectivities or rates for each true age in the last year.  The FORTRAN
c     parameter PTTOLG is the position of the first model parameter used
c     for calculations.  Any function may be programmed and used; in this
c     implementation there is room for 3 parameters.  The function is for
c     selectivities (the terminal f multiplier is used to calculate terminal
c     f's and should be estimated).
c
c     Position/description of parameters in initial parameter file (assuming
c     a two parameter function such as the logistic with mortality
c     multiplier):
c
c       Order    Description
c         1   Log scale F for fully recruited ages-ESTIMABLE
c         2   Switch (< 0: set selectivities manually, >=0: use
c             logistic function)-DON'T ESTIMATE
c         3   Slope of logistic function (ignored if switch <0)-ESTIMABLE
c         4   Space for another selectivity parameter-MAY BE ESTIMABLE
c         5   Intercept of logistic function (ignored if switch <0)-ESTIMABLE
c         6   Log selectivity age 0 (ignored if switch >=0)-ESTIMABLE
c         7    ""                 1    ""
c         8    ""                 2    ""
```

```
c          9     ""              3     ""
c         10     ""              4     ""
c         11     ""              5     "" (last true age-NEVER ESTIMATE,
c                                          should be set to log(1)=0)
c                -- other parameters --

c
c-----More notes
c
c     4/19/94 / Larry Jacobson
c     This version of getobj.for set up for use with Pacific mackerel
c     and analysis done for Admin. Rept. LJ-94-08 and CalCOFI paper for
c     1994 with Eddy Konno and Juan Pablo Pertiera.  There are three
c     indices of abundance.  SPOTTER data are type 1; CalCOFI DENSITY
c     data are type 3; and CALCOFI proportion positive (PROP+) data are
c     type 4.  There is room for one other data type (type 2) but no
c     calculations are performed.  Likelihood calcs for PROP+ are based
c     on the binomial distribution with the parameter N equal to number
c     of tows.  Likelihood calcs for DENSITY and SPOTTER assume lognormal
c     variability with log scale standard errors based on survey CV values.
c     PROP+ is confined to the interval (0,1) and code is included for
c     three types of "detection functions" that are confined to the
c     appropriate interval: logistic linear function, Von Bertalanffy
c     function, and Michaelis Menton function.  This version includes a
c     constraint that calculates a sums of squares penalty for selectivities
c     in the terminal years and quarters that differ from the average
c     selectivities during the same period.  The sum of squares is log
c     scale to the penalty for a given selectivity is ln(s/mean).  I'm
c     not sure how well this option works so am leaving it in for now.
c
c     7 october 1995 / larry jacobson
c     -contraint on terminal selectivities removed, random number routines
c     replaced with routines based on imsl routines.
c
c     24 April 1996 / larry jacobson
c     -code designed to keep logistic selex for terminal year at
c      reasonable levels (originally from model for Japanese sardine)
c      included.
c     -also a cpue index for commercial partyboat fishing vessels and an
c      index of abundance based on southern calif. edison impingement data
c      included.
c
c     14 November 1996 / Larry Jacobson
c      now I'm using it with Pacific sardine.
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C
C     INCLUDE SIMINC1.INC WHICH HOLDS GLOBAL PARAMETERS AND VARS
C       USED BY SIMPLEX SKELETON PROGRAM
      INCLUDE 'SIMINC1.INC'

C     INCLUDE MYDAT1.INC WHICH HOLDS USER DEFINED PARAMETERS AND
C       VARIABLES
      INCLUDE 'MYDAT1.INC'

c     include file that specifies indices for survey types
      include 'survptr.inc'

C------------------------- VARS PASSED --------------------------------

C     P HOLDS THE CURRENT PARAMETER ESTIMATES--DO NOT CHANGE VALUES!
      double precision P(MAXPAR)
C
C---------------------- REAL PARAMETERS -------------------------------
C
C     NONO HOLDS THE PENALTY FOR EXCEEDING THE BOUNDS FOR A PARAMETER
      double precision NONO
      PARAMETER(NONO=1.0D+30)

c     minlg is the smallest allowable logistic slope or exp(intercept)
      double precision minlg
      parameter(minlg=1.0d-6)

c     maxslp is the largest allowable value for the logistic slope x n of ages
      double precision maxslp
```

```
      parameter(maxslp=30.0d0)

c     maxf is the largest possible terminal f value, in badly constrained problems
c      the estimator will sometimes try absurdly large values
      double precision maxf
      parameter(maxf=5.0d0)

c     minf is the smallest possible terminal f value, in badly constrained problems
c      the estimator will sometimes try absurdly small values
      double precision minf
      parameter(minf=0.001)


c;;;;;;;;;;;;;;;; Integer parameters used for Pacific mackerel model
c
c     pttolg is the position of the first logistic function parameter
      integer pttolg
      parameter (pttolg=3)
c
c     pttoss is the positition of the first age specific selex parameter
      integer pttoss
      parameter (pttoss=5)
c
c     go2sea is the season at which recruitment occurs for spawner-recruit
c     constraint
      integer go2sea
      parameter (go2sea=1)
C------------------------- LOCAL VARIABLES -----------------------------

C     DBTEMP IS THE SUM OF SQUARES
      DOUBLE PRECISION DBTEMP

c     logistic slope and intercept
      double precision intrcp,slope

c     tosmal is the smallest allowed value for exp(intrcp+slope)-used to avoid
c      underflows
      double precision tosmal

c     ricker parameters-biomass slope, intercept and temperature slope
      double precision zlope,intcpt,tslope

c-----integers---------------------------------------------------------

c     counters
      integer i,year,season,survey,age

c     pnttoy points to the year used to compute spawning biomass/egg production
c      in s-r calcs (with the spawner-recruit constraint treated as a survey)
      integer pnttoy

c
c-----reals------------------------------------------------------------
c
c     z is a mortality rate
      double precision z

c     f is the arithmetic scale terminal f
      double precision f
c
c     temp and max are temporary variables
      double precision temp,max

c
c     ques holds age specific availabilities
      double precision ques(maxage)
c
c     temporary variables used for debugging
      double precision temp1,temp2
c
C************************* EXECUTABLE CODE ****************************

C     IMPORTANT TO INCREMENT CALLS IN GETOBJ REGARDLESS OF APPLICATION
      CALLS=CALLS+1
```

```
C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
C-- START USERS CODE
C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^


C     ZERO LIKELIHOOD and variances FOR EACH SURVEY TYPE
      DO 857 SURVey=1,MAXSUR
        LIKE(SURVey)=dZERO
        sdsurv(survey)=dzero
857   CONTINUE

c;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
c     set the terminal f values

c     first calculate the arithmetic terminal f for fully recruited ages
      f=dexp(p(1))

      if (f.gt.maxf) then
        print *,
     +'terminal f too large - original value ',f,' reset to ',maxf
        f=maxf
      endif

      if (f.lt.minf) then
        print *,
     +'terminal f too small - original value ',f,' reset to ',minf
        f=minf
      endif

      if (p(2).lt.dzero) then

c     use a parameter for selectivity of each true age, first check that
c       last true age has selex equal to 1
        if (p(ltrua-fage+pttoss).ne.dzero)
     +        call fatal(screen,'subroutine getobj',
     +'selx oldest true age used as reference, fix par @ log(1)=0')
c
c       calculate and store f's
        do 1000 i=1,ltrua-fage+1
          termf(i)=dexp(p(i+pttoss-1))*f
1000    continue

      else

c     check to see if logistic function parameters are getting outrageous
        intrcp=p(pttolg)
        slope=dexp(p(pttolg+1))

387   format(/,1x,a)
388   format(1x,a)
928   format(
     +1x,'Slope parameter     = ',1pe14.6,' Slope         = ',1pe14.6,/,
     +1x,'Intercept parameter = ',1pe14.6,' e^(Intercept) = ',1pe14.6,/)

c     check slope - it should be positive for ascending function
        if (slope.le.minlg) then
          write(screen,387)
     +       'logistic slope too small in getobj.for - selectivites'
          write(screen,388)
     +       'flat or tending to decline with age - suggest using lower'
          write(screen,388)
     +       'bound or other function'
          write(screen,928)  p(pttolg+1),slope,intrcp,dexp(intrcp)
        endif

c     make sure combination of slope and intercept doesn't cause overflow for oldest
c       ages
        if (intrcp+slope*dble(ltrua-fage+1).ge.maxslp) then
          write(screen,387)
     +'maximum age * logistic slope or intercept parameter'
          write(screen,388)
     +'too large - selectivites may be flat or tending to decline '
          write(screen,388)
     +'with age - suggest using upper bounds or other function'
          write(screen,928)  p(pttolg+1),slope,intrcp,dexp(intrcp)
```

```
        endif

c     look out for underflow at youngest ages due to intercept getting too small
        tosmal=dlog(minlg)
        if (intrcp+slope.le.tosmal) then
          write(screen,387)
     +'intercept parameter too small - selectivitity of youngest or all'
          write(screen,388)
     +'ages tending towards zero - use a lower bound on intercept'
          write(screen,928) p(pttolg+1),slope,intrcp,dexp(intrcp)
        endif

c     use scaled logistic function for terminal selectivities, first calculate unscaled
c      values and maximum
        max=dzero
        do 1010 i=1,ltrua-fage+1
c     watch out for overflow drom exponents that are too large
          temp=dmin1(intrcp+slope*dble(i),maxslp*10.0d0)
c     watch out for underflow from intercept parametes that are too small
          temp=dmax1(temp,tosmal/0.1d0)
          temp=dexp(temp)
          termf(i)=temp/(1.0d0+temp)
          if (termf(i).gt.max) max=termf(i)
1010    continue

c     selectivity and fishing rate parameters are defined using an ascending
c      logistic curve withthe last true age as a reference - maximum selectivity
c      should occur at the last true age
       if (max.ne.termf(ltrua-fage+1)) then
            do 93 i=1,ltrua-fage+1
               print *,'age = ',i,' selex@age = ',termf(i)
93          continue
            print *,'maximum = ',max,' slope = ',slope,
     +   ' intercept = ',intrcp
          call fatal(screen,'subroutine getobj',
     +      'maximum selectivity does not occur at last true age')
       endif

c     now scale selectivities to that for oldest true age and multiply by
c       fishing mortality
        do 1015 i=1,ltrua-fage+1
          termf(i)=termf(i)/max*f
1015    continue

      endif

C     DO THE VPA
      CALL VPA(maxyr,maxage,maxsea,
     +               nyears,nages,nsea,lsly,fage,
     +               termf,adfl,adfn,adfdat,seasm,
     +               plusl,domurp,avone,skipnc,
     +               catch,fmatrx,nmatrx,screen,doout)

c     calculate population biomass at age for begining of each year
c       and season, this will be used in goodness of fit calcs
      do 1530 year=1,nyears
        do 1520 season=1,nsea
          do 1510 age=1,nages
c     weights at age already in correct units for output so don't correct
            bmatrx(year,season,age)=nmatrx(year,season,age)*
     +               wmatrx(year,season,age)
1510      continue
1520    continue
1530  continue

c++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
c
c     now biomass and abundance of at the beginning of all years/seasons
c      have been computed and stored, we can loop over years and surveys
c      to do likelihood calculations

c     loop over years
      do 3000 year=1,nyears

c
C     loop over SURVEYS IN CURRENT YEAR
```

```
        DO 4000 survey=1,NSURV

C     FIND OUT IF THERE IS ANY DATA FOR CURRENT SURVEY AND THIS YEAR
          IF (SURDAT(year,survey,3).gt.dzero) THEN

c!!!!! spawner-recruit hack for mackerel!!!!
          if (survey.eq.srcurv) then
            if(year.le.1) call fatal(screen,'function getobj',
     +        'spawner-recruit datum not valid for first year!')
            pnttoy=year-1
          else
            pnttoy=year
          endif

c     fetch season for current survey datum (if it exists)
            season=surdat(year,survey,1)

C     FETCH AGE SPECIFIC Q'S FOR SURVEY TYPE
            CALL FETCHQ(pnttoy,season,survey,P,QUES)

C     CALCULATE PREDICTED SURVEY VALUE FROM BIOMASS AT TIME OF SURVEY
            IHAT(year,survey)=dZERO
            DO 3998 AGE=1,nages
c     avoid ages for cohorts that were omitted from the analysis
              if (nmatrx(pnttoy,season,age).ge.dzero) then
C     CALCULATE BIOMASS AT AGE AT IME OF SURVEY
                z=seasm+fmatrx(pnttoy,season,age)
c     retrieve biomass at age in current year/season
                temp=bmatrx(pnttoy,season,age)
c     warn user if no weight at age data for this age group, this is
c      a bit tricky.  if fish exist then the biomass should be greater
c      than zero so goodness of fit calcs (which depend on biomass)
c      will be right.  however, it doesn't matter if the q for the
c      age group is zero.

                if (nmatrx(pnttoy,season,age).gt.dzero.and.
     +            temp.le.dzero.and.ques(age).ne.dzero)
     +                 write(screen,5483) survnm(survey),
     +                 age+fage-1,season,pnttoy+fyear-1
                TEMP=temp*DEXP(-z*SURDAT(year,survey,2))
C     CALCULATE CONTRIBUTION OF AGE CLASS TO PREDICTED SURVEY DATA
                IHAT(year,survey)=IHAT(year,survey)+TEMP*QUES(AGE)
               endif
3998        CONTINUE

5483  format(/,1x,'Warning...goodness of fit calculations for ',a12,
     +    ' index',/,
     +1x,'wrong becuase no weight data for age ',i2,' in season ',i2,
     + ' of year ',i4)

C     SCALE INDICES TO SAME UNITS AS BIOMASS

            IF (survey.EQ.calcof) THEN
c     calcofi data comes first
              temp1=dexp(p(pttosq))
              temp2=dexp(p(pttosq+1))
              ihat(year,survey)=temp1*ihat(year,survey)**temp2

            ELSE IF (survey.EQ.cdfg) THEN
c     spawning area comes second
              temp1=dexp(p(pttosq+2))
              temp2=dexp(p(pttosq+3))
              ihat(year,survey)=temp1*ihat(year,survey)**temp2


            else if (survey.eq.spottr) then
c     spotter data third
              temp1=dexp(p(pttosq+4))
              temp2=dexp(p(pttosq+5))
              ihat(year,survey)=temp1*ihat(year,survey)**temp2
c
            else if (survey.eq.depm) then
c       depm data fourth
              temp1=dexp(p(pttosq+6))
```

```
              temp2=dexp(p(pttosq+7))
              ihat(year,survey)=temp1*ihat(year,survey)**temp2

           ELSE IF (survey.EQ.srcurv) THEN
c     Spawner-recruit constraint-ricker curve with density dependent term
c      forced to be negative and an environmental term
c
c     save ricker parameters stuff for use in outsur.for
              intcpt=p(pttosq+8)
              zlope=-dexp(p(pttosq+9))
              tslope=dexp(p(pttosq+10))
c     save egg deposition/spawning biomass
              ihat(year,survey)=ihat(year,survey)*
     + exp(intcpt+zlope*ihat(year,survey)+tslope*envdat(year,1))
            else
              call fatal(SCREEN,'SUBROUTINE GETOBJ',
     +                'survey index out of bounds')
            endif

C     CALCULATE LOG SCALE DEVIATION, used to calculate standard
c       deviations and in likelihood calcs for lognormal surveys
c!!!!!! spawner-recruit hack, set dependent variable to vpa recruits
            if (survey.eq.srcurv) then
               temp=nmatrx(year,go2sea,1)
               surdat(year,survey,3)=temp
            endif
            temp=surdat(year,survey,3)/ihat(year,survey)
            if (temp.le.dzero) then
              write(screen,8402) year+fyear-1,season,survey
              call fatal(screen,'subroutine getobj',
     +'error in calculations-observed or predicted survey value <= 0.0')
            endif
            temp=dlog(temp)
c     increment sum of squares for approximate residual variance
            sdsurv(survey)=sdsurv(survey)+temp**2

c     now do actual likelihood calcs which depend on the error structure
c       (all surveys have a log normal error structure)

c     standardize the log scale deviation for likelihood calculations
             temp=temp/SURDAT(year,survey,6)
             SURDEV(year,survey)=temp
C     INCREMENT SUM OF LOG LIKELIHOODS
              LIKE(survey)=LIKE(survey)+temp**2

            endif

cccc          ENDIF

8402  forma t(/,1x,'Problem with likelihood calcs for year ',i4,
     +      ', season ',i2,' and survey ',i2)
4000    CONTINUE

3000  continue


C     TIDY UP OBJECTIVE FUNCTION CALCULATIONS

      DBTEMP=DZERO
      DO 5952 survey=1,NSURV
         IF (SURNCT(survey).GT.IZERO) THEN
           LIKE(survey)=LIKE(survey)/2.
           DBTEMP=DBTEMP+SLWTS(survey)*LIKE(survey)
         ENDIF
5952  CONTINUE

c     finish calculating approximate sd for surveys, note this is
c      approximated from the average squared residual since no one
c      knows what the correct degrees of freedom is
      do 5959 survey=1,nsurv
        if (surnct(survey).gt.izero)
     +     sdsurv(survey)=Dsqrt(sdsurv(survey)/surnct(survey))
5959  continue

C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
```

```
C-- END USERS CODE
C^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^

C     CHECK FOR BOUNDS ON PARAMETER ESTIMATES
      IF (BND) THEN
        DO 500 I=1,NPAR
C     CHECK FOR LOWER BOUND
          IF (BOUNDL(I,LO).AND.P(I).LT.BOUNDV(I,LO)) THEN
            DBTEMP=DBTEMP+NONO*(P(I)-BOUNDV(I,LO))**2
C            IF (TALK) WRITE(PUTOUT,503) I,PARLBL(I),P(I),BOUNDV(I,LO)
          ENDIF
C     CHECK FOR UPPER BOUND
          IF (BOUNDL(I,HI).AND.P(I).GT.BOUNDV(I,HI)) THEN
            DBTEMP=DBTEMP+NONO*(P(I)-BOUNDV(I,HI))**2
C            IF (TALK) WRITE(PUTOUT,504) I,PARLBL(I),P(I),BOUNDV(I,HI)
          ENDIF
500     CONTINUE
      ENDIF

503   FORMAT(/,1X,
     +'PARAMETER ',I3,1X,'(',A,') < LOWER BOUND,',/,1X,
     +'CURRENT VALUE = ',1PE14.6,1X,'LOWER BOUND = ',1PE14.6)

504   FORMAT(/,1X,
     +'PARAMETER ',I3,1X,'(',A,') > UPPER BOUND,',/,1X,
     +'CURRENT VALUE = ',1PE14.6,1X,'LOWER BOUND = ',1PE14.6)

C     CONVERT VALUE TO REAL
      GETOBJ=dble(DBTEMP)

      RETURN

      END
```

Appendix 4. A parameter file used with the sardine VPA model.

```
best parameter estimates
         20   !NUMBER PARAMETERS
'log full f  ',7.77E-01,1.00E+00,
'SWITCH!!!!!!',-1.00E+11,0.00E+00
'LogistcSlope',0.00E+00,0.00E+00
'LogistcIntcp',0.00E+00,0.00E+00
'log_SelxAge0',-3.55E+00,0.00E+00  <- average selx during 1983-1992 seasons
'log_SelxAge1',-1.12E+00,0.00E+00  <- average selx during 1983-1992 seasons
'log_SelxAge2',-4.73E-01,0.00E+00  <- average selx during 1983-1992 seasons
'log_SelxAge3',-2.24E-02,0.00E+00  <- average selx during 1983-1992 seasons
'log_SelxAge4',0.00E+00,0.00E+00   <- average selx during 1983-1992 seasons
'LnCalCofi_Q ',2.55E+00,1.00E+00
'LnCalCofiExp',-5.11E-01,0.00E+00
'LnCalCDFG_Q ',5.20E+00,1.00E+00
'LnCalCDFGExp',0.00E+00,0.00E+00
'LnCalSpot_Q ',7.00E+00,1.00E+00
'LnCalSpotExp',0.00E+00,0.00E+00
'LnCalDEPM_Q ',6.51E+00,1.00E+00
'LnCalDEPMExp',0.00E+00,0.00E+00
'RickerInterc',-7.11E+00,0.00E+00
'LogRickerBio',-8.06E+00,0.00E+00
'LogRickerTem',-3.98E-02,0.00E+00
  0     !NUMBER OF LOWER BOUNDS SPECIFIED
  0     !NUMBER OF UPPER BOUNDS SPECIFIED
```

RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167. Paper copies vary in price. Microfiche copies cost $9.00. Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC- 227 The Hawaiian monk seal in the Northwestern Hawaiian Islands, 1993.
T.C. JOHANOS, and T.J. RAGEN
(February 1996)

228 Comprehensive Ocean Data Extraction - User's Guide
R. MENDELSSOHN, and C. ROY
(April 1996)

229 The Hawaiian monk seal in the Northwestern Hawaiian Islands, 1994.
T.C. JOHANOS, and T.J. RAGEN
(May 1996)

230 Status of marine turtles in the Pacific Ocean relevant to incidental take in the Hawaii-based pelagic longline fishery.
A.B. BOLTEN,J.A. WEATHERALL, G.H. BALAZS, and S.G. POOLEY
(August 1996)

231 Coastal upwelling indices, west coast of America 1946-1995.
F.B. SCHWING, M. O'FARRELL, J. STEGER, and K. BLATZ
(September 1996)

232 The physical oceanography off the central California coast during May-June 1995: A summary of CTD data from pelagic juvenile rockfish surveys.
K.M. SAKUMA, F.B. SCHWING, K. BALTZ, D. ROBERTS,K
H.A. PARKER, and S. RALSTON
(September 1996)

233 Abundance of cetaceans in California waters based on 1991 and 1993 ship surveys.
J. BARLOW and T. GERRODETTE
(September 1996)

234 Fixed costs and joint cost allocation in the management of Pacific whiting - A Workshop Report -.
J. TERRY, G. SYLVIA, D. SQUIRES, W. SILVERTHORNE, J. SEGER, G. MUNRO, R. MARASCO, D. LARSON, J. KIRKLEY, L.. JACOBSON, S. HERRICK, J. GAUVIN, AB. GAUTAM, S. FREESE, and R. BALDWIN
(September 1996)

235 Ichthyoplankton vertical distributions near Oahu, Hawai'i, 1985-1986: Data report.
G.W. BOEHLERT and B.C. MUNDY
(December 1996)

236 Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids.
G.W. BOEHLERT
(March 1997)