STATUS OF THE PACIFIC SARDINE (*Sardinops sagax*) RESOURCE AND FISHERY

by **J. Thomas Barnes, Marci Yaremko** and **Doyle Hanan**

MARINE RESOURCES DIVISION
ADMINISTRATIVE REPORT 96-1
1996

Marine Resources Division Administrative Report Series

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ABSTRACT

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

We estimate the sardine population size to have been 353,000 short tons on July 1, 1995. Our estimate was based on output from an integrated stock assessment model called CANSAR (Deriso 1993). 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 1995. CANSAR couples a simulation model with sardine population dynamics. Non-linear least-squares criteria are used to tune the model to match catch-at-age data and other indices of sardine abundance.

To calculate the 1996 fishery quota, we used the harvest formula selected as the preferred option in the draft Coastal Pelagic Species-Fishery Management Plan (CPS-FMP). That formula has undergone extensive scientific and user-group review as part of the Pacific Fishery Management Council's (PFMC) CPS-FMP adoption process and has the endorsement of the fishing industry and the scientific community. Use of this formula will result in a reduced fishing mortality rate compared to the formula used to calculate the quota in 1995. We conclude that it is particularly important to reduce fishing mortality for 1996 because the rates may have been excessive in recent years, especially for older aged sardines.

Accordingly, we recommend a 1996 sardine harvest quota of 35,000 short tons.

INTRODUCTION

Our evaluation of the sardine resource is based on results from the CANSAR stock assessment model that was first used by the California Department of Fish and Game (Department) for sardine management in 1993. The CANSAR model uses the 1986 and 1994 Daily Egg Production Method (DEPM) (Lasker 1985) spawning biomass estimates as a source of fishery independent data, in addition to other indices of relative abundance, and catch and age data from historical and current fisheries during 1983-1995.

The Department manages the sardine fishery based upon an estimate of total biomass, which includes all fish in the population that are 12 months of age and older. Because some fish in the youngest year class are not yet spawning, estimates of total biomass are larger than spawning biomass.

The following report summarizes the 1995 fishery, describes the recently completed stock assessment work, and recommends 1996 sardine fishing quotas. All weight references are presented in short tons.

THE 1995 SARDINE FISHERY

The rebuilding of a California sardine fishery continued in 1995. Total statewide landings for the 1995 calendar year are projected to approach the quota, which was set at 54,645 short tons for 1995 (Figure 1). Landings from January through the beginning of November totaled 41,990 tons, the highest since the late 1950's.

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 1995, that formula resulted in an initial southern fishery quota of 34,764 tons, and a northern fishery quota of 17,381 tons. In October, the Department re-allocated an uncaught portion of the northern fishery quota and divided it in half between north and south.

The majority of sardine landings were caught in southern California (89% to date for 1995), where approximately 15 purse seine vessels account for most landings of sardine and other coastal pelagic species such as Pacific mackerel and market squid. A few additional vessels also targeted sardine in the Monterey area. Ex-vessel revenues from sardine throughout California during July 1994-June 1995 totaled $1,880,000, an increase over the previous 12 month period. The ex-vessel price remained steady around $70 per ton. A total of 38 vessels each recorded landing at least 55 tons of coastal pelagic species during the 1994 fishing year.

Currently, over 80 percent of sardine landed in southern California are being sold at the fresh fish market, while about 20 percent of the southern landings are being packed as pet food. This ratio has changed dramatically since 1991, when canners for both human and pet consumption were purchasing about 75 percent of the ex-vessel landings. In August 1995 the last mainland tuna cannery in the United States ended production when they were forced into Chapter 11 bankruptcy. Although the closed cannery primarily produced canned tuna, it was also the only remaining packer of canned sardine for human consumption in southern California. Fishermen are hopeful that the cannery will reopen under new ownership following a court decision scheduled for December 12, 1995. However, a northern California cannery continues to pack sardine for human consumption.

Industry representatives report that foreign interest in sardine is continuing to increase, particularly from China and Japan, and that they are looking to import more of the product from either the U.S. or Mexico. Frozen blocks of sardine are increasingly exported for use as food for fish reared in aquaculture facilities. The frozen exports are also canned abroad for human consumption.

For the remainder of the year, we project California sardine landings to total about 4,400 tons. When combined with landings from previous months, the 1995 total may approach the quota allocation for the year. However, we do not

anticipate that the quota will be filled as in previous years. Market squid availability to the fleet has been high this year. During periods of good market squid fishing, the fleet routinely diverts fishing effort from sardine and targets squid instead. Squid are one of the preferred target species for the wetfish fleet because they receive an ex-vessel price of approximately $140-300 per ton.

During 1991 through 1994, California fishermen landed most of the southern quota early in the year, usually resulting in a mid-season southern fishery closure, which remained in effect until reallocation of a portion of the unused northern quota each October. Conversely, Mexican fishermen tended to land the majority of their total landings in the latter half of the year, and are likely to do so again in 1995. Landings from Mexico (Ensenada) have equaled or exceeded those of California in recent years (Figure 2). During January through September 1995, the Ensenada fleet landed over 28,000 tons of sardine. Since 1994, landings at Ensenada have usually exceeded 2,000 tons per month and in California landings have exceeded 2,000 tons per month for most of 1995 (Figure 3). Total sardine landings from all sources (California and Mexico) are expected to be about 88,000 tons for calendar year 1995.

SARDINE BIOMASS ESTIMATES

BACKGROUND

We estimated sardine biomass and recruitment during 1983-1995 using an integrated stock assessment model called CANSAR (Catch-at-age analysis for sardine). 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 DEPM spawning biomass estimates for 1986 and 1994. CANSAR provides confidence intervals for annual abundance estimates, which improves the usefulness of the estimates for fishery managers.

THE MODEL

CANSAR is a forward-projecting age-structured analysis that uses 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 1995. CANSAR couples a simulation model with population dynamics of the sardine population. Non-linear least-squares criteria are used to tune the catch-at-age data to the various indices of sardine abundance.

THE DATA

Fishery-based data include tons landed by semester for the California and Ensenada fisheries. Size and age composition data are available for the U.S. fishery for each semester, but are lacking for the Ensenada fishery beyond 1992.

Fishery-independent data include an index of sardine egg abundance in the southern California Bight; an annual estimate of spawning area; an index of adult abundance from aerial spotter logbooks; and daily egg production method estimates of spawning biomass for 1986 and 1994.

Catch-at-age Data

Age composition data were available during the study period from all but two semesters for the California fishery, but were lacking prior to the second semester of 1990 for the Ensenada fishery. A combined sample of 24,823 sardine were aged, the oldest of which were assigned to age 9. Mean round weight was used to estimate the number of fish in the landings by dividing total tons landed by mean fish weight.

Catch of age 2 fish during the first semester of each year is depicted to illustrate the trend in landings and fit between observed age composition and model predictions (Figure 4). Residuals are not serially correlated, and the model fits the data. We used different age-specific fishery selectivities during two separate periods in the time series: 1)

during 1983-1990, when most sardine landings were due to by-catch in the Pacific mackerel fishery; and 2) during 1991-1995, when the directed fishery dominated the landings.

Egg Abundance

We used a generalized additive model (GAM) to standardize California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey data during 1984-1995. Bongo 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 CalCOFI station effects, and was fit to the proportion of CalCOFI stations positive for eggs, assuming binomial sampling error.

The index shows an increasing trend during the study period. No trend is apparent in residuals, and the model adequately fits the data (Figure 5).

Spawning Area

During each year from 1985-1991, the Department conducted plankton surveys 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.

Total spawning area increased during the study period (Figure 6). Residuals are not serially correlated and predicted values fit the data. Spawning area is proportional to spawning biomass under conditions when the stock does not occupy its full potential geographic range (Smith, 1990). The data suggest a steady increase in biomass, with the exception of 1990. Expanding spawning area during recent years conforms with MacCall's (1990) basin model.

Aerial Spotter Data

Spotter pilots are employed by wetfish fishermen to help locate and capture fish schools. The pilots are also contracted by National Marine Fisheries Service (NMFS) to complete and submit logbooks, creating a record of their observations from each flight. Logbook records include species identification, school size (tons), and geographic location for all observed fish schools, regardless of the target species for a particular fishing operation. An index of abundance was obtained from the spotter data using a delta-lognormal model developed by Lo et al. (1992). The resulting index shows a large increase during 1994 and 1995, compared to previous years (Figure 7). There is no trend in residuals for the spotter index, although predicted values from CANSAR do not show as great an increase during 1994 and 1995 as occurs in the observed data.

ABUNDANCE ESTIMATES

Total sardine biomass (Age 1+) has increased dramatically from 1983 to 1994 (Figure 8) and continuing that trend, we estimate the July 1, 1995 biomass to be 353,000 tons (CV = 0.45, based on 1,000 bootstrap runs). We currently estimate the July 1, 1994 biomass to have been 238,000 tons, which is considerably less than the biomass estimate for that date (364,303 tons) that was obtained at the end of 1994 (Barnes and Hanan, 1994). The change in 1994 biomass estimate is due to several factors, all of which improve the fit of the model predictions to the data. The most important changes in this year's assessment were: 1) an additional year of input data; 2) refined estimates of maturity-at-age and fecundity-at-age now available from the 1994 DEPM histology work, and 3) fishery selectivities that were estimated separately for two periods in the 1983-1995 time series (as noted above).

FISHERY MANAGEMENT

BACKGROUND

Current regulations give considerable latitude to the Department in setting annual sardine quotas.

Section 8150.7 of the 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 well short of the one million ton level that is associated with recovery (defined during the Department's annual Sardine Biomass Workshops, 1989-1993).

The 1995 harvest quota was based on a harvest formula arrived at through consensus of the fishing industry and the Department. That formula set the quota at 15 percent of the total biomass, when the biomass was greater than 50,000 tons. The same harvest formula was initially included in Assembly Bill 76, which was passed by the legislature in September 1995. However, harvest formula language was removed from the bill prior to its adoption by the Assembly.

During 1995, the PFMC proceeded with development CPS-FMP. With full support of the fishing industry, the Department, and the scientific community, the PFMC voted to submit the CPS-FMP to the Secretary of Commerce, for final approval and implementation. If approved, the CPS-FMP will streamline wetfish management by making it subject to the Council process, and remove management authority for sardine from the California state legislature.

THE 1996 QUOTA

Because of consensus within the wetfish industry and the scientific community in support of the CPS-FMP, we are using the preferred harvest formula presented in the CPS-FMP to set the 1996 sardine quota for California. Use of this formula results in a lower fishing mortality than was allowed in 1995, as explained below.

The rationale for adopting the CPS-FMP formula is based on many factors, including: 1) the Department's management directive as stated in Fish & Game Code; 2) interdecadal changes in the California Current system and their relationship to the current favorable oceanographic regime for sardine; 3) recent performance of the fishery; 4) current biomass and age composition of the stock; 5) current fishing mortality from all sources; and 6) observed stock productivity in recent years. Following is a list of key facts that should be considered in examining the appropriate level for the 1996 quota, and a limited discussion of some associated implications for management:

- Section 8150.7 of the Fish and Game Code states that the primary goal of management is rehabilitation of the resource. An added management objective is to maximize the sustained harvest, and therefore a quota can be set at a level greater than 1,000 tons, providing that the higher level of take allows for continued increase in the spawning population. Although the biomass has increased dramatically in recent years, it remains in a rebuilding stage and is well short of the one million ton level associated with recovery.

- There have been clear changes in oceanographic conditions of the California Current since the 1970's, and the effect has been favorable for sardine. In a historical context, these oceanographic changes form patterns or regimes that ebb and flow on a time scale of roughly three decades (or about 60 years for one complete cycle). Based on the geological record of past sardine regimes as observed in fish scales retrieved from bottom cores of anaerobic ocean sediments (Baumgartner et al., 1992), it is highly likely that the current favorable regime is more than half over.

- Sardine quotas have increased sharply in recent years, from 12,000 tons in 1994 to 55,000 tons in 1995. Landings have also increased, but in 1995 part of the quota will probably not be filled. At no time during 1995 was sardine fishing curtailed due to quota restrictions. Market demand, sardine availability on the fishing grounds, and redirected fishing effort to other high-value species such as squid and tuna were the limiting factors for the 1995 sardine harvest, rather than the quota. Considering the incomplete

nature of the recovery, and interest in discouraging over-capitalization, it is prudent for the quota not to greatly exceed current demand. The overall take from the sardine stock in 1995 is projected to total over 80,000 tons, including landings in California and in Ensenada, Mexico.

● Sardine biomass has increased dramatically in recent years, and was estimated to be 353,000 tons on July 1, 1995. Much of this biomass estimate is comprised of young-of-the-year fish which are primarily estimated using a spawner-recruit model which has quite low resolution. Use of the model is further complicated by the reduction in age at maturity which has occurred in recent years and insufficient information is available to determine what weighting should be used when including young fish in the spawning biomass (used to calculate recruitment). In addition, the coefficient of variation in the sardine biomass is quite large, and the age composition of the population is highly skewed toward young fish. A fully recovered population will exhibit an age composition with a much more significant component of older fish. Despite the continued growth in biomass, the recovery remains incomplete because much of the biomass is comprised of young-of-the-year fish. Also, the estimated spawning biomass is considerably lower than total biomass, because not all of the youngest fish spawn (Figure 9). A fully recovered population will exhibit an age composition less skewed to the young fish, with older fish (up to age 10+) (Mosher and Eckles 1954) comprising part of the population.

● Instantaneous fishing mortality from all sources increased from about 0.14 in 1991 to about 0.36 in more recent years. A level of 0.36 is excessive for a partially recovered stock that remains in a rebuilding phase. The current level of fishing mortality is also in excess of the preferred target (20%) in the draft CPS-FMP. Fishing mortality is not constant among ages, but rather increases for the older fish, thus exacerbating effects of high mortality on older fish. During the past four years, annual instantaneous F for age 3 fish has averaged 0.903 (59% fishing mortality), which is much too high. Older fish are more fecund than younger ones, and make proportionally greater contributions to the reproductive output of the stock. High mortality on the older ages greatly reduces the stock's reproductive cushion against year-class failure. A hypothetical scenario of three successive year-class failures, combined with the current level of fishing mortality, would reverse the recovery and drive the stock down to depressed levels. Since it is not possible to regulate age-specific fishing mortality, the only way to reduce it for the older ages is by the overall quota.

● Stock productivity has been remarkably high during the current recovery. Despite a significant fishery, there is a linear increase in the natural logarithm of biomass since 1983 ($r^2 = 0.95$, slope = 0.255). Based on the log-scale slope, the observed rate of increase in biomass is 29 percent per year, not including removals due to fishing. Overall productivity has been on the order of 50% per year. Should the observed rate of increase continue, the biomass could reach the one million ton level in only a few years. Once the population approaches full recovery, a higher level of fishing mortality could be allowed with less concern that it would have a significant adverse affect on the recovery.

Rehabilitation of the resource is incomplete, and the use of a 15% harvest rate for the 1995 fishery resulted in excessively high fishing mortality for the older ages. To reduce fishing pressure on older ages and provide a reserve against year class failure, the 1996 quota is based on preferred option in the draft CPS-FMP. That formula provides for a lower California fishing mortality rate compared to the 15% used last year, and results in a 1996 directed fishing quota of 35,000 tons (Table 2):

BIOMASS	FRACTION	CalCOFI US DISTRIBUTION	CUTOFF	QUOTA
353,000	20%	59%	55,000	35,000

ACKNOWLEDGMENTS

We thank Walterio Garcia Franco (INP, Ensenada) for providing the landing data from the Ensenada fishery. Beverly Macewicz [NMFS, Southwest Fisheries Science Center (SWFSC)] and John Butler (NMFS, SWFSC) provided data on age-specific maturity, fecundity, and spawning fraction. Larry Jacobson (NMFS, SWFSC) modified the CANSAR code and gave technical advice.

LITERATURE CITED

Barnes, J.T. and D. Hanan. 1994. Status of the Pacific sardine resource and fishery, 1994 and 1995. Calif. Dept. of Fish and Game, Marine Resources Div. Report. 7p.

Baumgartner, T.R., A. Soutar and V. Ferreira-Bartrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. Calif. Coop. Oceanic Fish. Invest. Rep. 33:24-40.

Deriso, R. 1993. A report on integrated stock assessment of Pacific sardine. Appendix 2. *In* Project report on Pacific sardine (*Sardinops sagax*) resource research, 1991/1992 phase III. *Edited by* F.J. Hester. California Seafood Council, Santa Barbara, Calif.

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

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., 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.

Mosher, K.H. and H.H. Eckles. 1954. Age determination of Pacific sardines from otoliths. U.S. Fish and Wild. Ser. Research Report 37. 63 p.

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

Table 1 **CANSAR ESTIMATES OF BIOMASS (Short Tons) AND RECRUITMENT (Age 0, x10^3)**

YEAR (July 1)	AGE 1+ BIOMASS	BIOMASS STD. ERROR	NUMBER RECRUITS	RECRUITS STD. ERROR
1983	10983	5167	191333	66395
1984	24463	7623	202430	50251
1985	26603	6123	144331	38277
1986	38590	7946	509403	106700
1987	65754	11704	394432	78769
1988	83517	13428	639083	125471
1989	102045	15194	449140	95533
1990	109339	15415	1395270	317149
1991	174879	30599	1604287	418454
1992	162147	31979	1677229	553193
1993	166909	44349	3066867	1146126
1994	238127	74945	3845750	1790862
1995	352608	157430	4271465	2807219

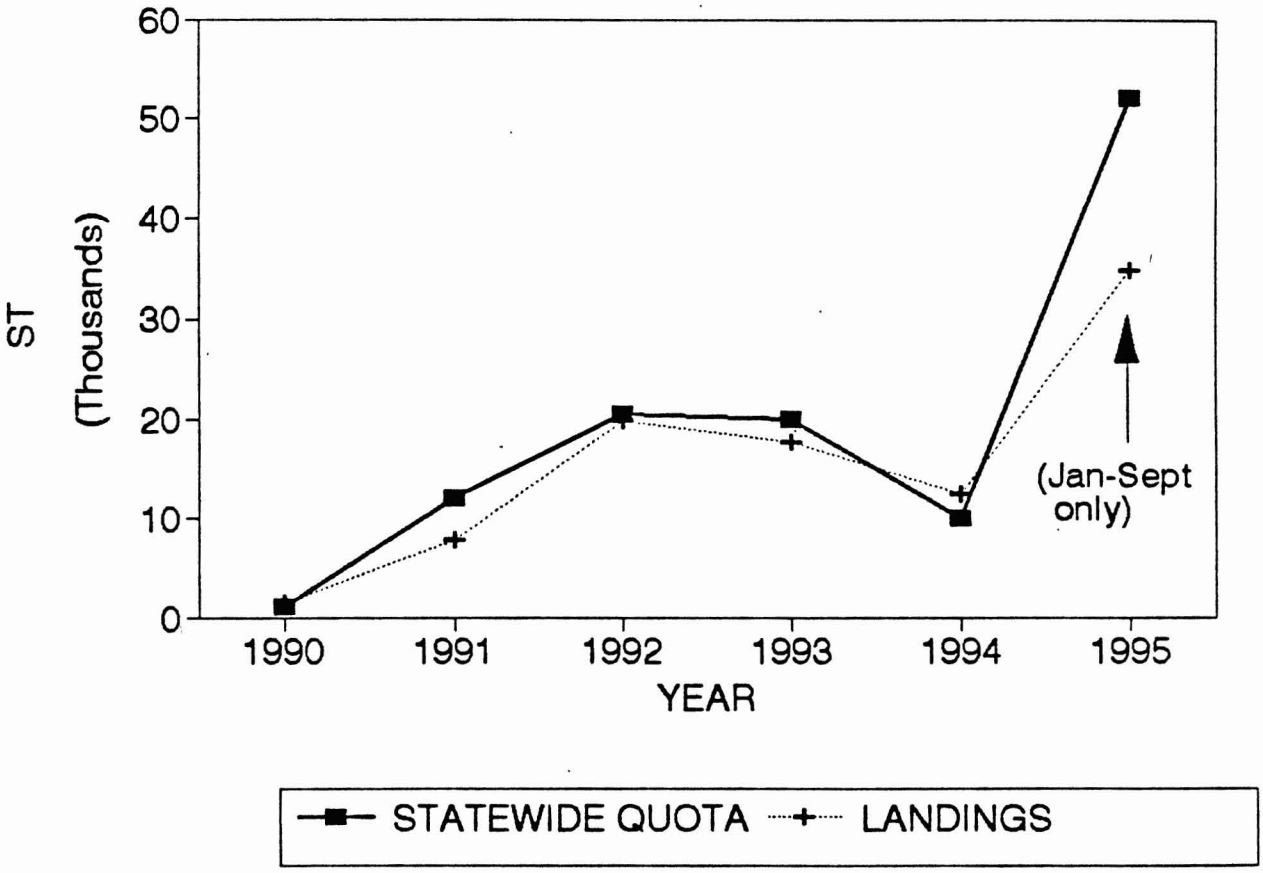
Table 2. 1996 Pacific Sardine Quotas (in short tons). The quota is based on the following formula and a total biomass estimate of 353,000 short tons.

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

Directed Fishery Quota (available 1/1/96)	**35,000 tons**
Northern California Allocation	11,667 tons
Southern California Allocation	23,333 tons

CALIFORNIA LANDINGS RELATIVE TO QUOTA
1990-1995

Figure 1



CALIFORNIA/ENSENADA LANDINGS
1985-1995

Figure 2

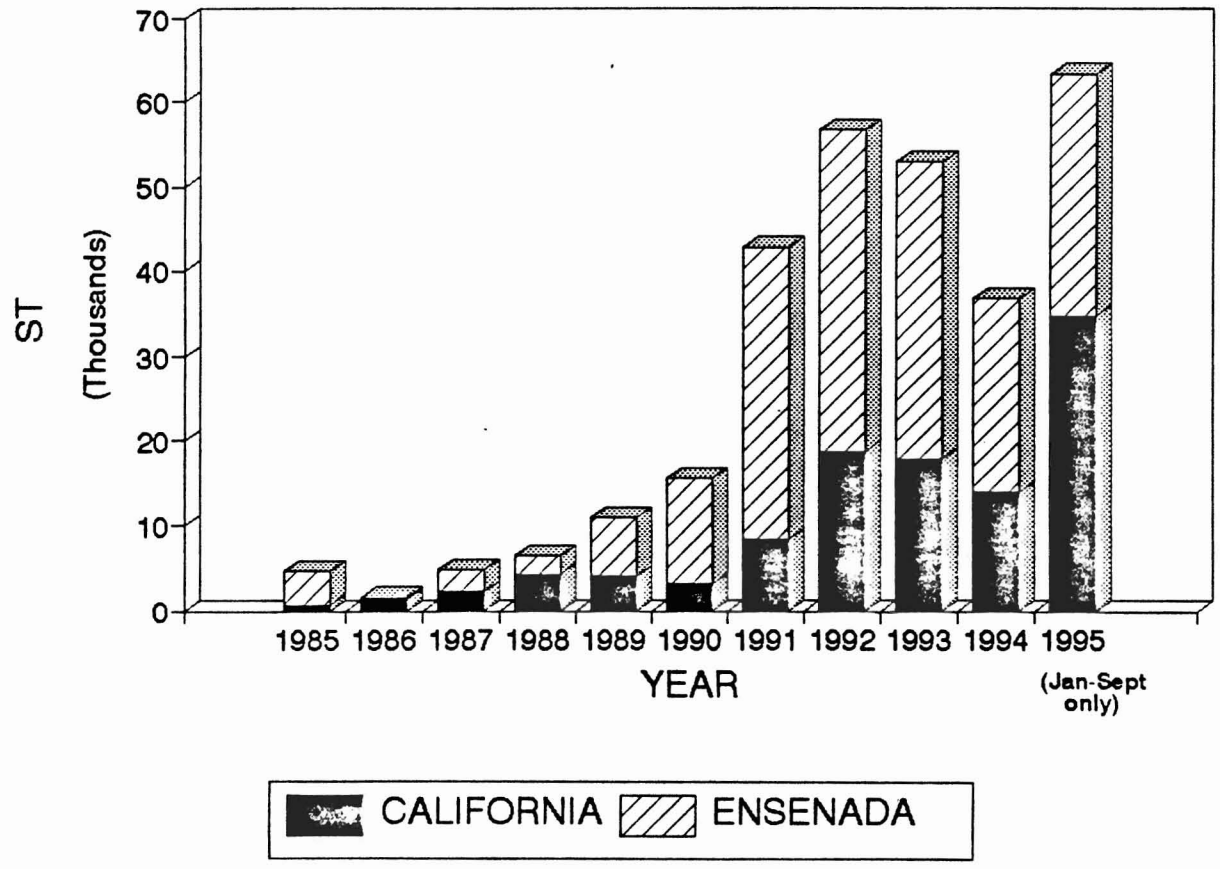


Figure 3

MONTHLY SARDINE LANDINGS

1994-1995

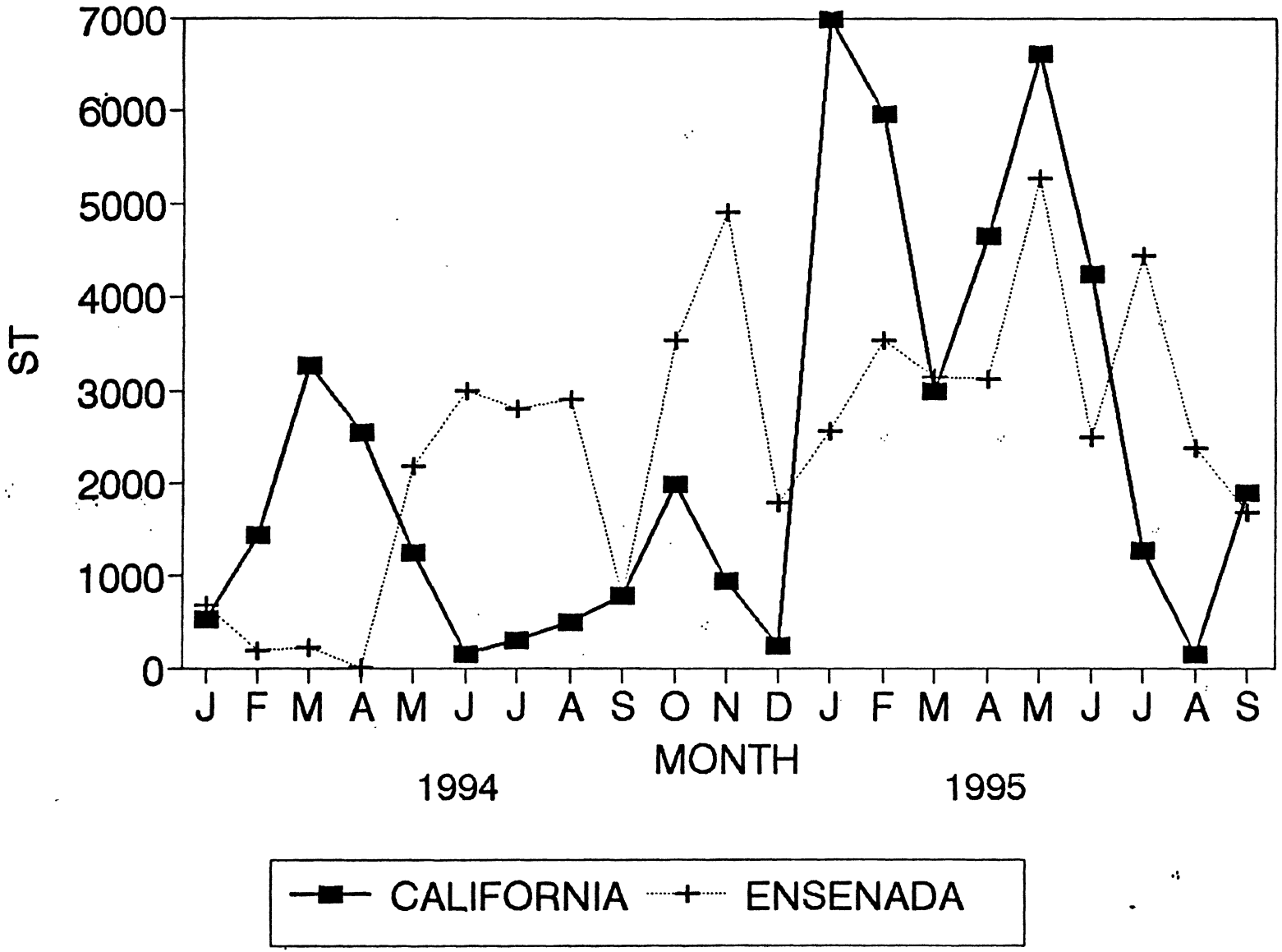


Figure 4

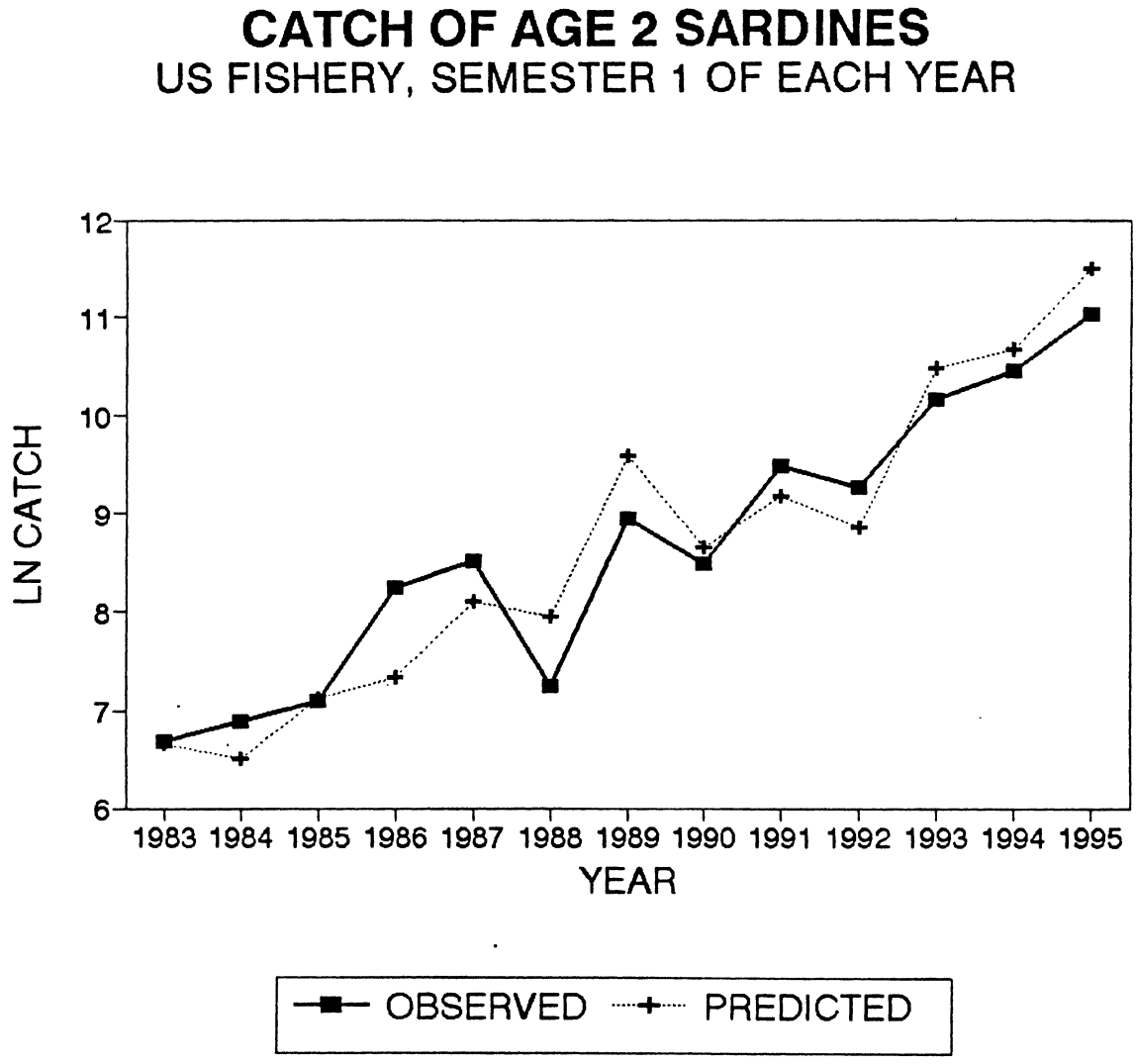

CATCH OF AGE 2 SARDINES
US FISHERY, SEMESTER 1 OF EACH YEAR
LN CATCH
12
11
10
9
8
7
6
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
YEAR
OBSERVED
PREDICTED

Figure 5

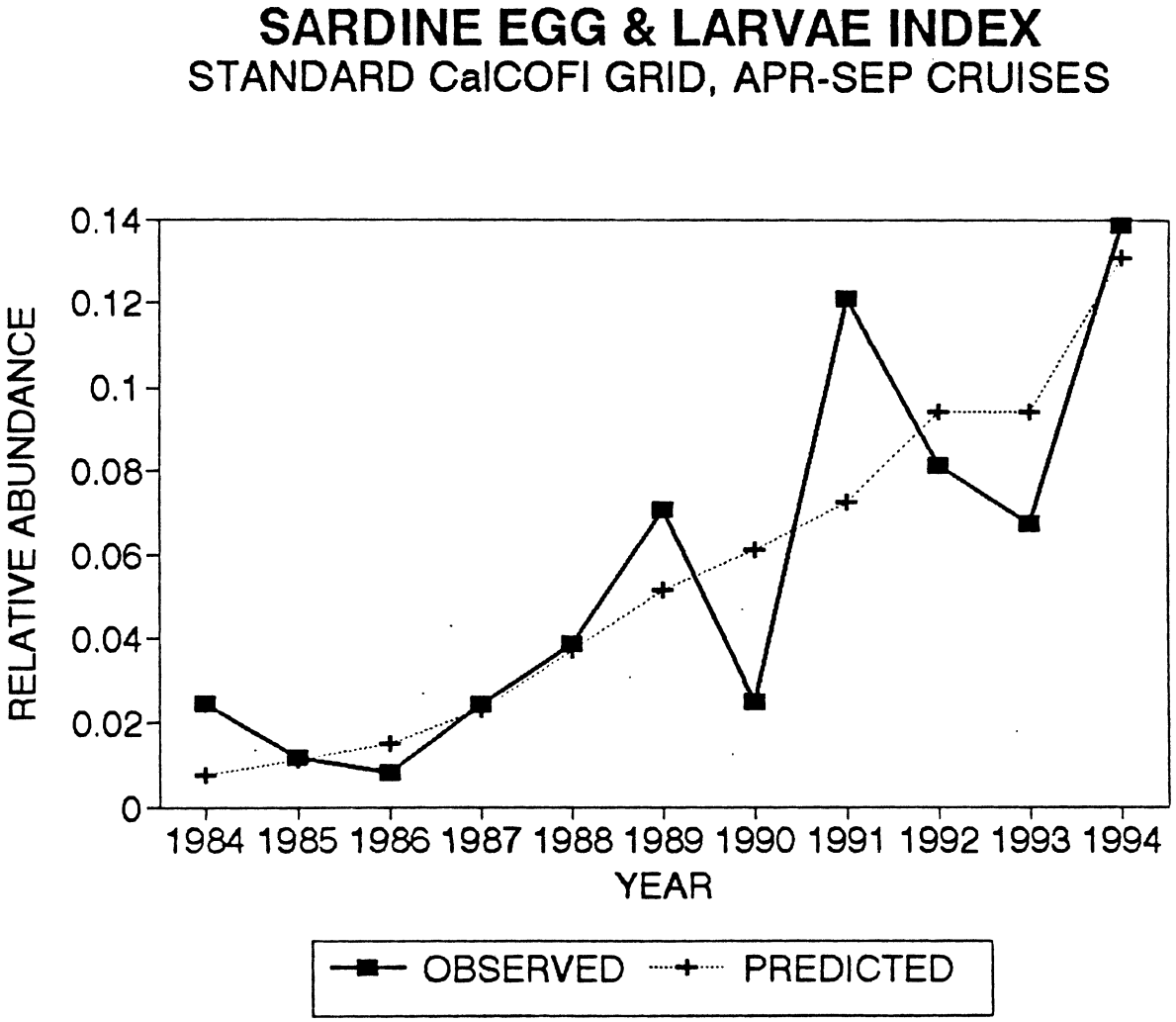

SARDINE EGG & LARVAE INDEX
STANDARD CalCOFI GRID, APR-SEP CRUISES
RELATIVE ABUNDANCE
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994
YEAR
OBSERVED
PREDICTED

Figure 6

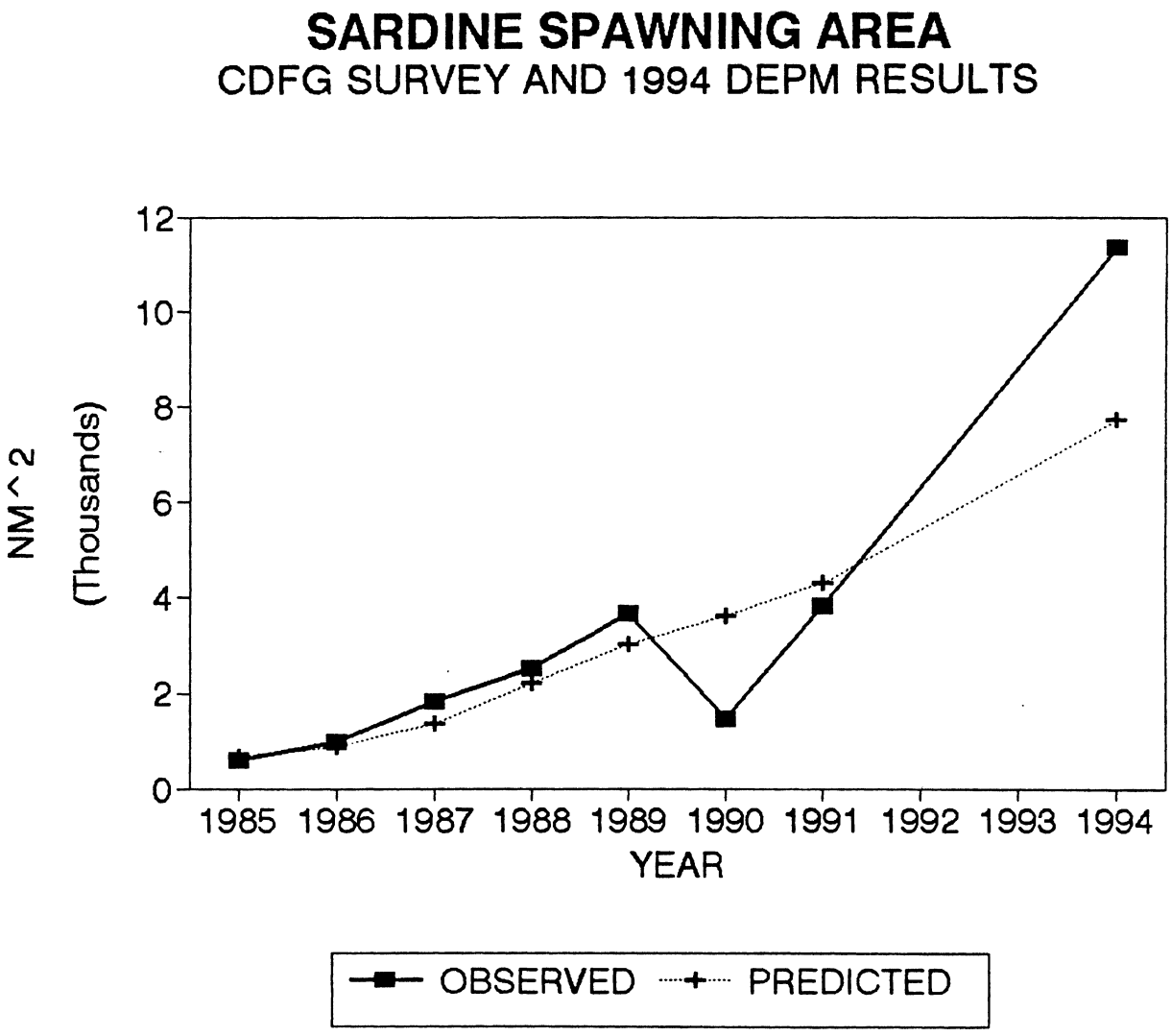

SARDINE SPAWNING AREA
CDFG SURVEY AND 1994 DEPM RESULTS
NM^2
(Thousands)
12
10
8
6
4
2
0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994
YEAR
OBSERVED
PREDICTED

Figure 7

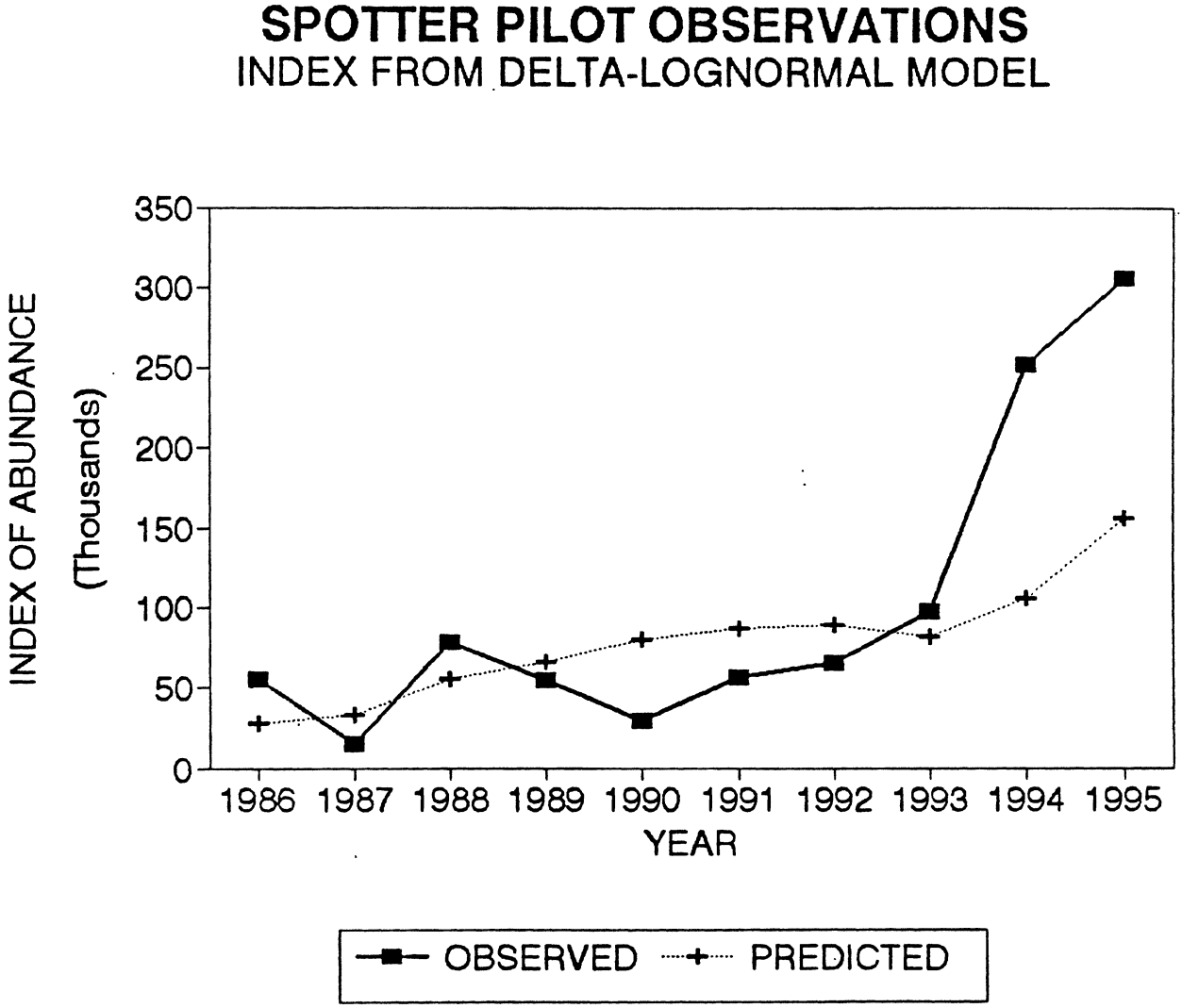

SPOTTER PILOT OBSERVATIONS
INDEX FROM DELTA-LOGNORMAL MODEL
INDEX OF ABUNDANCE
(Thousands)
350
300
250
200
150
100
50
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
YEAR
OBSERVED
PREDICTED

Figure 8

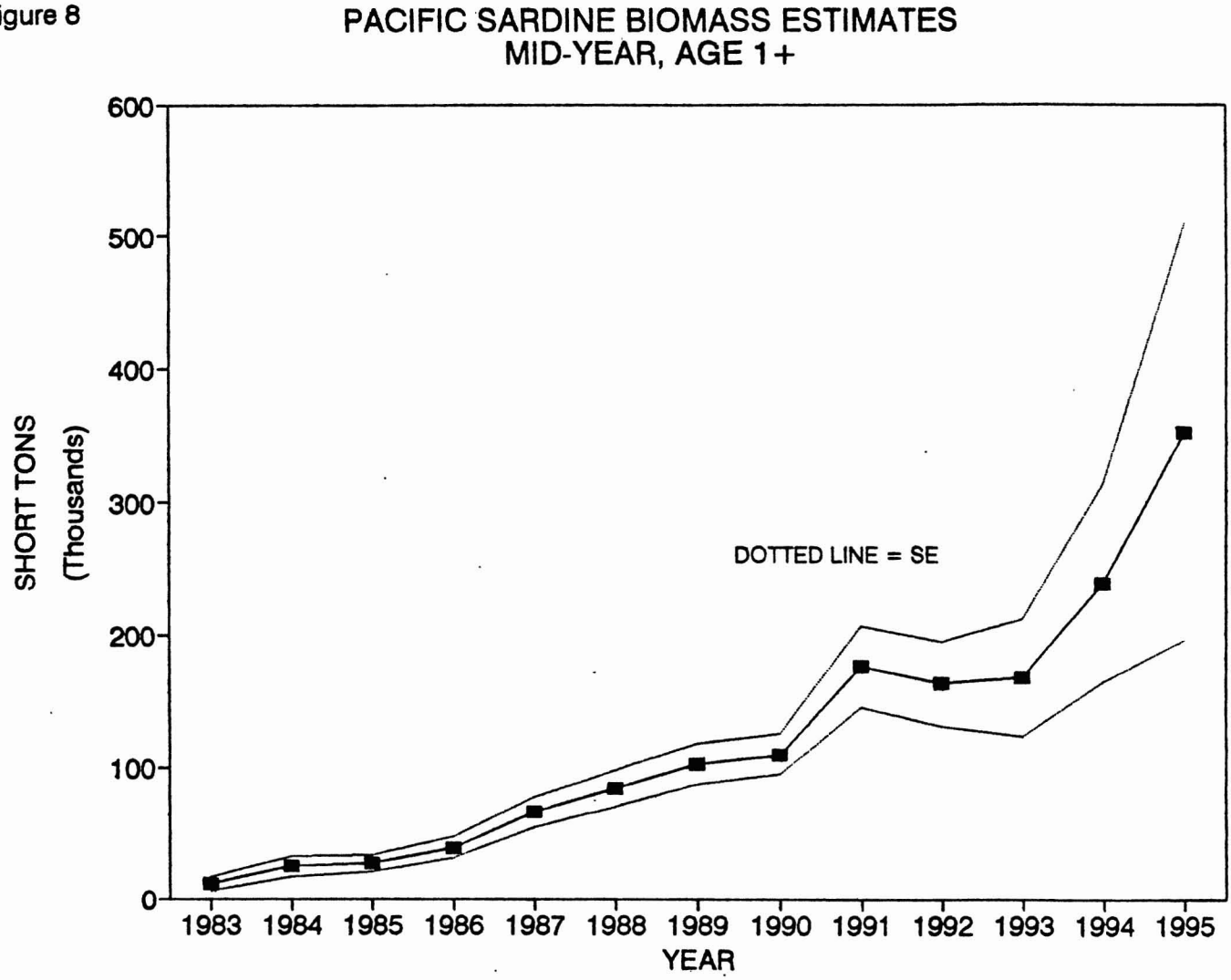
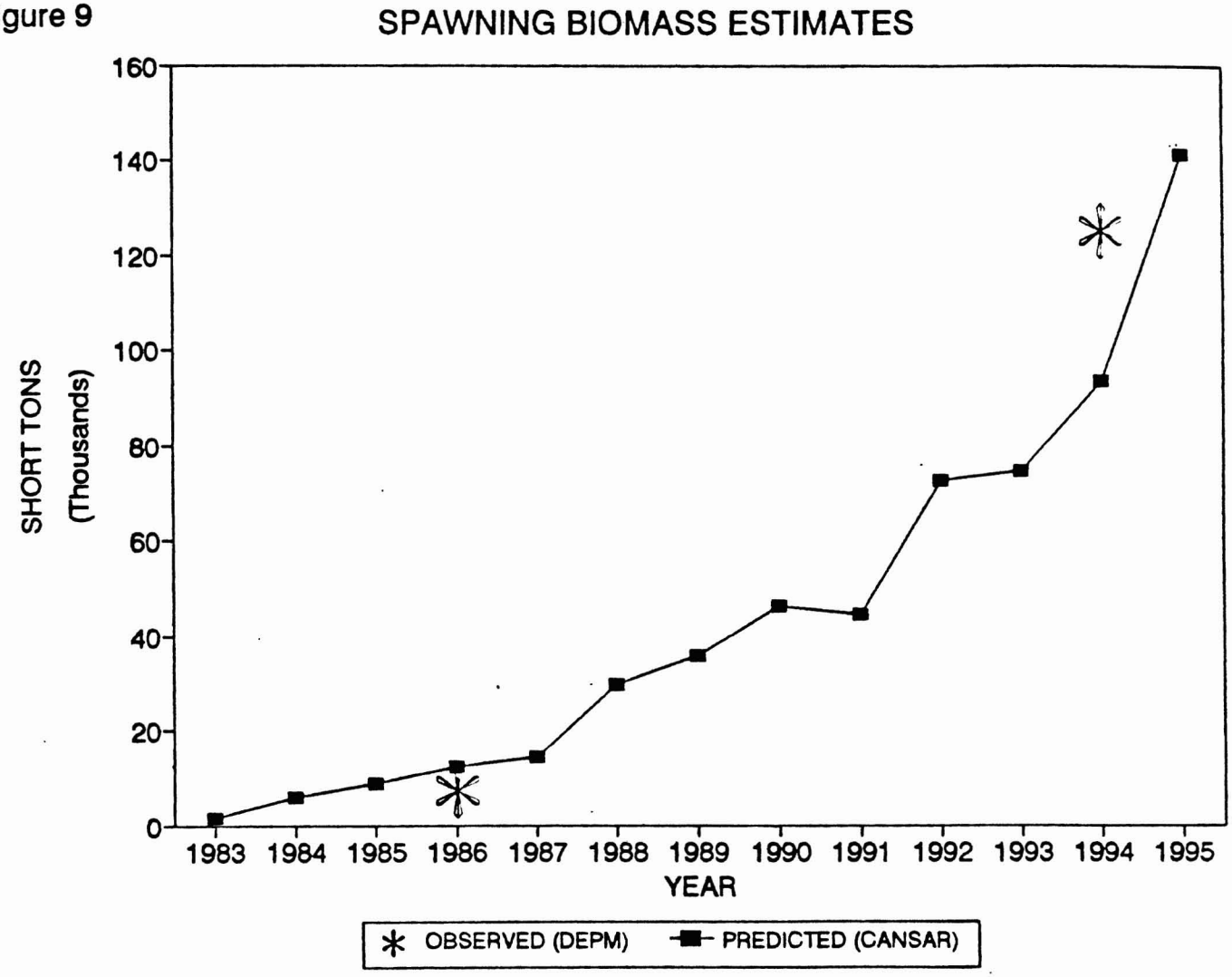

PACIFIC SARDINE BIOMASS ESTIMATES
MID-YEAR, AGE 1+
SHORT TONS
(Thousands)
600
500
400
300
200
100
0
DOTTED LINE = SE
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
YEAR

Figure 9


SPAWNING BIOMASS ESTIMATES
SHORT TONS
(Thousands)
160
140
120
100
80
60
40
20
0
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
YEAR
OBSERVED (DEPM)
PREDICTED (CANSAR)