Stock Assessment of Pacific Sardine with Management Recommendations for 2001

Executive Summary

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by

Ramon J. Conser[1], Kevin T. Hill[2], Paul R. Crone[1], and Darrin Bergen[2]

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Pacific Fishery Management Council
2130 SW Fifth Avenue, Suite 224
Portland, OR 97201

Addresses for authors:

[1] NOAA/NMFS
Southwest Fisheries Science Center
8604 La Jolla Shores Dr.
La Jolla, CA 92038

[2] California Department of Fish and Game
Southwest Fisheries Science Center
8604 La Jolla Shores Dr.
La Jolla, CA 92038

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Introduction

The following summary presents pertinent results and harvest recommendations from a stock assessment conducted on Pacific sardine (*Sardinops sagax*) in 2000. It is intended that this information will be referred to by the Pacific Fishery Management Council (PFMC) when developing management goals for the upcoming fishing season for sardine beginning January 2001. A complete document that describes details regarding data sources, analyses, and modeling used in this assessment will be prepared later this year and will be distributed prior to the PFMC meeting in March 2001; the complete assessment document, as well as the Executive Summary, will be included in the PFMC series *Stock Assessment and Fishery Evaluation (SAFE)* reports.

The assessment results presented here are applicable to the sardine population off the North America Pacific coast from Baja California, Mexico to British Columbia, Canada. The majority of the fishery-independent and fishery-dependent data were collected off northern Mexico and southern California only (Area 1 or *Inside* Area); however, as was done in past assessments, assumptions regarding sample coverage (e.g., representativeness of survey trends to areas outside Area 1) and sardine biology (e.g., recruit emigration out of Area 1) were used to make scientific inferences about the entire population, e.g., to provide fishery managers coastwide estimates of stock biomass, mortality rates, and harvest guidelines.

Methods

An age-structured stock assessment model (CANSAR-TAM, Catch-at-age **AN**alysis for **SAR**dine - Two Area Model, see Hill et al. (1999) was applied to fishery-dependent and fishery-independent data to derive estimates of population abundance and age-specific fishing mortality rates. In 1998, the original CANSAR model (Deriso et al. 1996) was modified to account for the expansion of the population northward to waters off the Pacific northwest (see above). The models are based on a 'forward-simulation' approach (see Megrey (1989) for a description of the general modeling approach), whereby parameters (e.g., population sizes, recruitments, fishing mortality rates, gear selectivities, and catchability coefficients) are estimated after log transformation using the method of nonlinear least squares. The terms in the objective function (to be minimized) included the sum of squared differences in ($\log_e$) observed and ($\log_e$) predicted estimates from the catch-at-age and various sources of auxiliary data used for 'tuning' the model, e.g., indices of abundance from survey (fishery-independent) data. Bootstrap procedures were used to calculate variance and bias (95% confidence intervals) of sardine biomass and recruitment estimates generated from the assessment model. The CANSAR-TAM model was based on two fisheries (California, U.S. and Ensenada, Mexico) and semesters within a year were used as time steps, with ages being incremented between semesters on July 1 and spawning that was assumed to occur on April 1 (middle of the first semester).

Fishery-dependent data from the California and Ensenada fisheries (1983 to first semester 2000) were used to develop the following time series: (1) catch (in mt)-Table 1 and Figure-1; (2) age distributions (catch-at-age in numbers of fish); and (3) estimates of weight-at-age (fishery- and population-specific). Fishery-independent data (time series) from research surveys included the following indices, which were developed from data collected from Area 1 (*Inside Area*, primarily waters off southern California) and used as relative abundance measures (Table 2): (1) index (proportion-positive stations) of sardine egg

abundance from California Cooperative Oceanic and Fisheries Investigations (CalCOFI) survey data (*CalCOFI Index*)-Figure 2, see Deriso et al. (1996); (2) index of spawning biomass (mt) based on the Daily Egg Production Method (DEPM) survey data (*DEPM Index*)-Figure 3, see Lo et al. (1996); (3) index of spawning area (Nmi^2) from CalCOFI and DEPM survey data (*Spawning Area Index*)-Figure 4, see Barnes et al. (1997); and (4) index of pre-adult biomass (mt) from aerial spotter plane survey data (*Aerial Spotter Index*)-Figure 5, see Lo et al. (1992). Time series of sea-surface temperatures (Figure 6) recorded at Scripps Pier, La Jolla, California were used to determine appropriate harvest guidelines (*Sea-surface Temperature Index*), see Amendment 8 of the Coastal Pelagic Species Fishery Management Plan, Option J, Table 4.2.5-1, PFMC (1998).

Survey indices of relative abundance were re-estimated using generally similar techniques as was done in previous assessments (e.g., see Hill et al. 1999). The final model configuration was based on equally 'weighted' indices except for the CalCOFI index, which was downweighted to 0.7 (relative to 1.0 for the other indices). The relative weight used for the CalCOFI index (0.7) was consistent with previous assessments in which the proportion of the total spawning area covered by the CalCOFI surveys (~70%) was used to determine its relative weighting in the model. Further the CalCOFI Index has undergone considerable saturation in recent years due to the higher frequency of positive stations as the sardine stock expanded throughout and beyond the southern California Bight. As in the previous assessment, the CalCOFI index was fit with a non-unity exponent (0.3547) to allow for a nonlinear relationship between the index and sardine spawning biomass. This procedure produced a better fit to these data and a more acceptable residual pattern than assuming the classical linear relationship between the index of abundance and population size. Finally, in past assessments the Aerial Spotter Index was assumed to primarily track adult spawning biomass. However, further examination of the sampling design used to collect these data (i.e., sampling space is inshore waters only) indicated this index more likely observed pre-adult fish (mostly age 0-2 fish) than strictly adult spawners and thus, the 'selectivity' ogive was adjusted to reflect this sampling attribute.

It is important to note that survey indices used in fishery assessments are often based on variable and biased data; however, we assumed that biases were generally consistent from year to year, which in effect, allows the trend indicated in an index to be interpreted in relative terms and ultimately, useful in statistical modeling. Additionally, sensitivity analysis included alternative model configurations that were based on differentially weighted indices, which produced generally similar results from the modeling. For example, reduced weighting of the Aerial Spotter Index and CalCOFI Index (see Hill et al. 1999) resulted in similar model predicted fits to these survey data, as well as similar trends in estimated spawning biomass ($\geq$1-year old fish).

Results

Pacific sardine landings for the directed fisheries off California, U.S. and Ensenada, Mexico remained at the high levels that were reached last year (115,000 mt), with a total harvest of roughly 114,000 mt (Table 1, Figure 1); note that semester 2 landings in 2000 reflect projected estimates based on landing patterns observed in the fisheries during the mid to late 1990s (Table 1). California landings in 2000 (59,925 mt) are expected to increase slightly (6% or 3,200 mt) from the 1999 estimated landings (56,747), while Ensenada landings in 2000 (53,579 mt) are forecasted to decrease slightly (9% or 5,000 mt) from landings made in 1999 (58,569 mt). Currently, the U.S. fishery (California landings) is regulated using a quota (harvest guideline) management scheme and the Mexico fishery (Ensenada

landings) is essentially unregulated. Since the mid 1990s, actual landings from the California fishery have been less than the recommended quotas.

As was the case in recent years, landings from the U.S. Pacific sardine fishery (California, Oregon, and Washington) are well below the harvest guideline recommended for 2000 (186,791 mt), with roughly 55,543 mt (30% of harvest guideline) landed through September 2000 and over 131,000 mt of the quota remaining (the fishing year ends on December 31, 2000).

Estimated stock biomass (≥1-year old fish on July 1, 2000) from the assessment conducted this year indicated the sardine population has remained at a relatively high abundance level, with a bias-corrected estimate of nearly 1.2 million mt (Table 3 and Figure 7). Estimated recruitment (age-0 fish on July 1, 2000), albeit more variable than stock biomass statistics, also remained at relatively high abundance, with number of recruits increasing slightly from last year to nearly 14 billion (Table 3 and Figure 8).

Harvest Guideline for 2001

The harvest guideline recommended for the U.S. (California, Oregon, and Washington) Pacific sardine fishery for 2001 is 134,737 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 4. To calculate the proposed harvest guideline for 2001, we used the maximum sustainable yield (MSY) control rule defined in Amendment 8 of the Coastal Pelagic Species-Fishery Management Plan, Option J, Table 4.2.5-1, PFMC (1998). This formula is intended to prevent Pacific sardine from being overfished and maintain relatively high and consistent catch levels over a long-term horizon. The Amendment 8 harvest formula for sardine is:

$$HG_{2001} = (\text{TOTAL STOCK BIOMASS}_{2000} - \text{CUTOFF}) \bullet \text{FRACTION} \bullet \text{U.S. DISTRIBUTION},$$

where HG_{2001} is the total U.S. (California, Oregon, and Washington) harvest guideline recommended for 2001, TOTAL STOCK BIOMASS_{2000} is the estimated stock biomass (ages 1+) from the current assessment conducted in 2000 (see above), CUTOFF is the lowest level of estimated biomass at which harvest is allowed, FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries (see below), and U.S. DISTRIBUTION is the percentage of TOTAL STOCK BIOMASS_{2000} in U.S. waters.

The value for FRACTION in the MSY control rule for Pacific sardine is a proxy for F_{msy} (i.e., the fishing mortality rate that achieves equilibrium MSY). Given F_{msy} and the productivity of the sardine stock have been shown to increase when relatively warm-water ocean conditions persist, the following formula has been used to determine an appropriate (sustainable) FRACTION value:

$$\text{FRACTION or } F_{msy} = 0.248649805(T^2) - 8.190043975(T) + 67.4558326,$$

where T is the running average sea-surface temperature at Scripps Pier, La Jolla, California during the three preceding years. Ultimately, under Option J (PFMC 1998), F_{msy} is constrained and ranges between 5% and 15%. The F_{msy} is equal to 15% under current oceanic conditions (T_{2000} = 17.73 °C; Figure 6).

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Table 1. Pacific sardine time series of landings (mt) by semester (1 is January-June and 2 is July-December) in California and Baja California (Ensenada), 1983-2000. Semester 2 (2000) estimates are projections.

	CALIFORNIA			ENSENADA			
Year	Semester 1	Semester 2	Total	Semester 1	Semester 2	Total	Grand Total
83	245	244	489	150	124	274	762
84	188	187	375	<1	<1	0	375
85	330	335	665	3,174	548	3,722	4,388
86	804	483	1,287	99	143	243	1,529
87	1,625	1,296	2,921	975	1,457	2,432	5,352
88	2,516	1,611	4,128	620	1,415	2,035	6,163
89	2,161	1,561	3,722	461	5,763	6,224	9,947
90	2,272	1,033	3,305	5,900	5,475	11,375	14,681
91	5,680	3,354	9,034	9,271	22,121	31,392	40,426
92	8,021	13,216	21,238	3,327	31,242	34,568	55,806
93	12,953	4,889	17,842	18,649	13,396	32,045	49,887
94	9,040	5,010	14,050	5,712	15,165	20,877	34,927
95	29,565	13,925	43,490	18,227	17,169	35,396	78,886
96	17,896	18,161	36,057	15,666	23,399	39,065	75,121
97	11,865	34,331	46,196	13,499	54,941	68,439	114,636
98	21,841	19,215	41,055	20,239	27,573	47,812	88,868
99	31,791	24,956	56,747	34,760	23,810	58,569	115,316
00	34,518	25,407	59,925	25,800	27,779	53,579	113,504

Table 2. Pacific sardine time series of survey indices of relative abundance and sea-surface temperature, 1983-00.

Year	CalCOFI (% positive)	DEPM (mt)	Spawning area (Nmi^2)	Spotter plane (mt)	Sea-surface temperature (C)
83	na	na	40	na	17.25
84	4.362	na	480	na	17.58
85	2.715	na	760	na	17.80
86	1.316	7,659	1,260	43,478	17.87
87	4.286	15,705	2,120	15,430	17.71
88	6.716	13,526	3,120	85,266	17.55
89	9.140	na	3,720	47,847	17.24
90	3.623	na	1,760	29,723	17.19
91	12.805	na	5,550	54,242	17.35
92	10.825	na	9,697	60,442	17.61
93	6.061	na	7,685	104,223	17.84
94	17.010	111,493	24,539	253,270	17.97
95	10.811	na	23,816	249,428	18.04
96	28.000	83,176	25,889	151,646	18.06
97	17.949	356,300	40,592	86,121	18.06
98	17.447	313,986	33,447	150,258	18.44
99	16.667	282,248	55,173	52,652	18.04
00	5.556	1,063,837	32,785	74,410	17.73

Table 3. Pacific sardine time series of stock biomass (≥age-1 fish in mt) and recruitment (age-0 fish in 1,000s) estimated at the beginning of semester 2 of each year. Stock biomass estimates are presented for Area 1 (*Inside*) and the Total Area of the stock. The 95% Cis for Total Area biomass and recruitment estimates are also presented.

	Stock biomass				Recruitment		
Year	Area 1	Total Area	Lower CI	Upper CI	Total Area	Lower CI	Upper CI
83	5,056	5,056	2,957	10,099	141,403	88,847	246,958
84	12,816	12,878	9,063	21,581	226,169	147,229	371,294
85	20,961	21,439	15,673	33,385	219,856	155,365	352,332
86	29,917	31,484	24,446	46,926	846,294	615,775	1,287,227
87	72,083	75,573	59,772	108,304	832,040	617,653	1,190,540
88	105,088	114,408	94,477	152,212	1,461,068	1,063,523	2,219,947
89	160,457	178,912	148,464	239,814	1,158,867	810,564	1,894,887
90	175,762	208,108	173,068	282,917	4,709,570	3,090,489	8,018,753
91	222,968	258,856	198,733	394,671	5,902,130	3,685,261	10,226,905
92	350,673	416,435	308,879	643,578	4,105,231	2,593,962	7,299,626
93	331,202	438,385	336,054	655,658	8,927,805	6,324,826	14,328,381
94	482,639	635,350	511,046	912,435	10,906,645	7,633,095	16,934,560
95	511,541	720,733	580,872	1,013,478	6,785,885	4,781,041	10,792,603
96	537,008	789,746	654,219	1,076,120	5,565,890	3,820,403	9,088,025
97	483,698	765,450	644,562	1,032,142	8,135,807	5,105,778	13,574,897
98	435,700	738,098	601,127	1,030,048	19,021,736	12,389,294	33,111,696
99	693,865	1,084,814	818,716	1,654,253	11,581,850	6,958,572	22,728,400
00	718,662	1,182,465	834,879	1,896,204	13,584,794	6,940,772	28,942,209

Table 4. Proposed harvest guideline for Pacific sardine for the 2001 fishing season. See the **Harvest Guideline for 2001** section for methods used to derive harvest guideline.

Total stock biomass (mt)	Cutoff (mt)	Fraction (%)	U.S. Distribution (%)	Harvest guideline (mt)
1,182,465	150,000	15%	87%	**134,737**

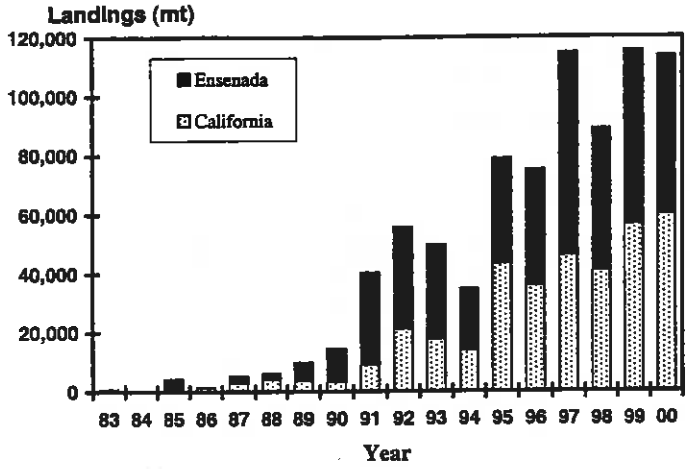

Figure 1. Pacific sardine landings (mt) in California and Baja California (Ensenada), 1983-00.

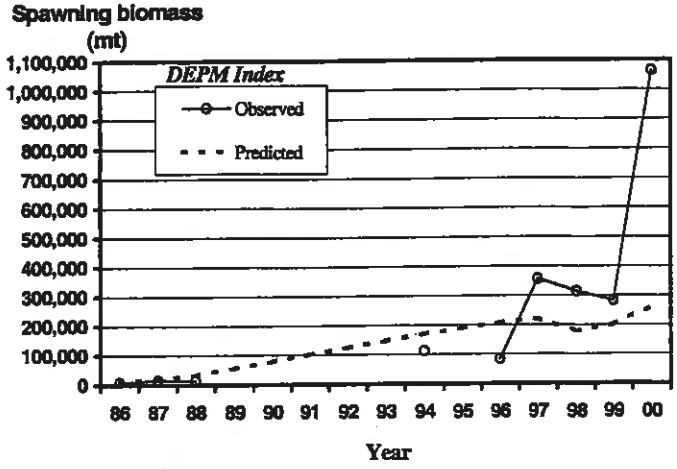

Figure 3. Index of relative abundance of Pacific sardine spawning biomass (mt) off California based on daily egg production method (DEPM) estimates from ichthyoplankton survey data (1986-00). Note no sample data (Observed estimates) were available for years 1989-93 and 1995.

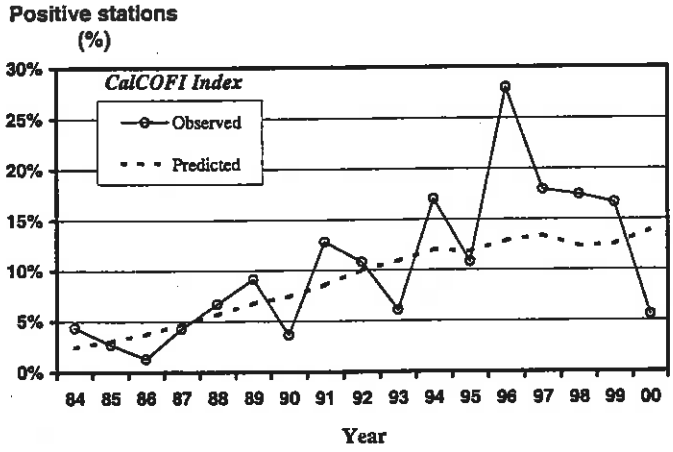

Figure 2. Index of relative abundance of Pacific sardine eggs (proportion-positive stations) off southern California based on CalCOFI bongo-net survey (1984-00).

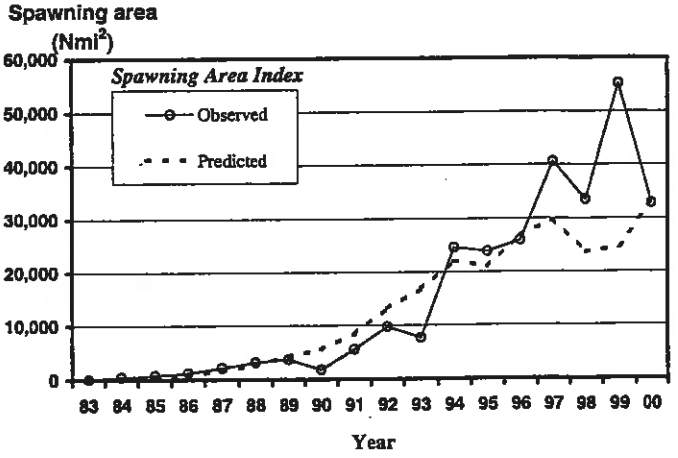

Figure 4. Index of relative abundance of Pacific sardine spawning stock size based on estimates of spawning area (Nmi^2) calculated from CalCOFI and DEPM survey data (1983-00).

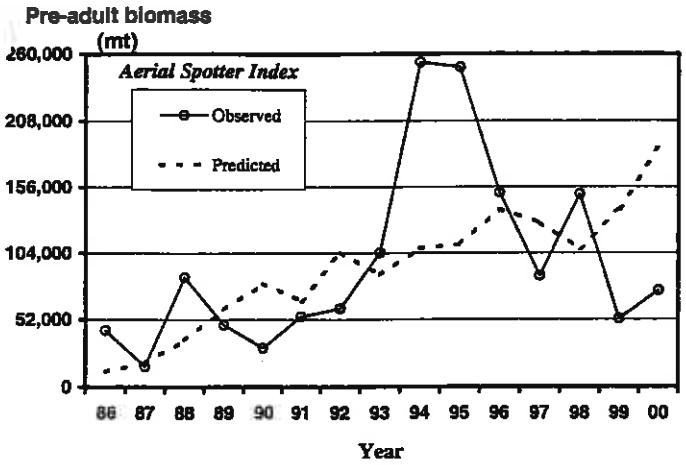

Figure 5. Index of relative abundance of Pacific sardine pre-adult biomass (mt) off California based on aerial spotter plane survey data (1986-00).

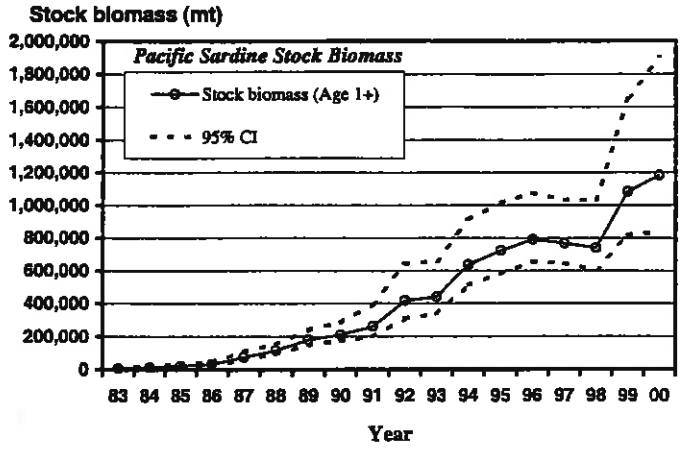

Figure 7. Time series (1983-00) of Pacific sardine stock biomass (≥ 1-yr old fish on July 1 of each year in mt) estimated from an age-structured stock assessment model (CANSAR-TAM, see Hill et al. 1999).

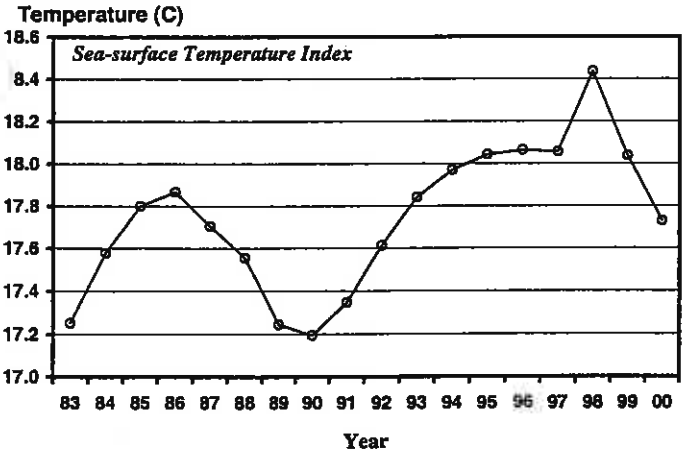

Figure 6. Time series of sea-surface temperature (C) recorded at Scripps Pier, La Jolla (1983-00). Annual estimates reflect 3-year 'running' averages, see Jacobson and MacCall (1995).

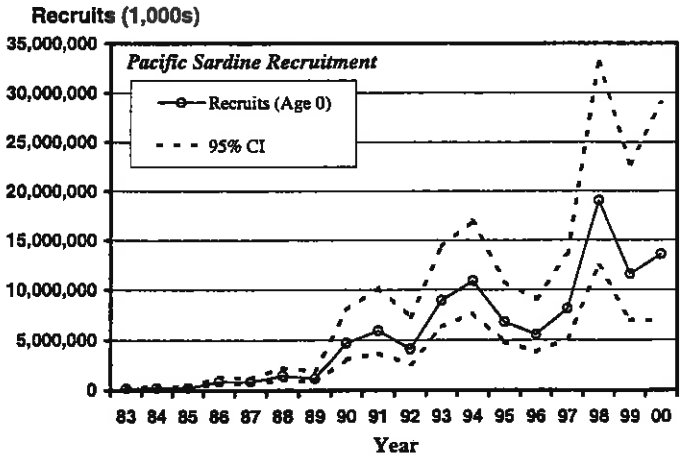

Figure 8. Time series (1983-00) of Pacific sardine recruitment (0-yr old fish on July 1 of each year in 1,000s) estimated from an age-structured stock assessment model (CANSAR-TAM, see Hill et al. 1999).