Stock Assessment of Pacific Sardine with Management Recommendations for 2002

Executive Summary

by

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

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Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, OR 97220

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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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Dedication

This paper is dedicated to the late Dr. Garth Murphy, who passed away during 2001. Dr. Murphy was a world-renowned population biologist and a genuine pioneer in the study of Pacific sardine. Without his diligent, conscientious, and truly innovative efforts, this work would not have been possible.

Introduction

The following summary presents pertinent results and harvest recommendations from a stock assessment conducted on Pacific sardine (*Sardinops sagax*). It is an update to the stock assessment carried out last year (Conser et al. 2001), and is intended for use by the Pacific Fishery Management Council (PFMC) when developing management goals for the upcoming fishing season for sardine beginning January 2002.

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, **C**atch-at-age **AN**alysis for **SAR**dine - **T**wo **A**rea **M**odel, 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 2001) were used to develop the following time series: (1) catch (in mt)-Table 1 and Figure-1; (2) catch-at-age in numbers of fish; and (3) estimates of weight-at-age. 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; (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 (Hill et al. 1999 and Conser et al. 2001). 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. As in the previous assessment, the Aerial Spotter Index was assumed to primarily track pre-adult fish (ages 0 and 1 plus a portion of age 2 fish). All of the other fishery-independent indices were used as indices of the spawning stock biomass, which can be approximated by the biomass of ages 1+ sardine.

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.

Results

Pacific sardine landings for the directed fisheries off California, U.S. and Ensenada, Mexico decreased from the high levels that were reached during 2000 (109,000 mt), with a total 2001 harvest of roughly 86,000 mt (Table 1, Figure 1); however, note that semester 2 landings in 2001 reflect projected estimates based on landing patterns observed in the fisheries during the mid to late 1990s (Table 1). Both California and Ensenada landings in 2001 are expected to decrease from the 2000 level, with a more notable decrease in the projected Ensenada landings (51,000 mt in 2000, decreasing to 35,000 mt in 2001). 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 2001 (135,000 mt), with roughly 62,000 mt (46% of harvest guideline) landed through September 2001 and over 72,000 mt of the quota remaining (the fishing year ends on December 31, 2001).

Estimated stock biomass (≥1-year old fish on July 1, 2001) 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 1.1 million mt (Table 3 and Figure 7). Estimated recruitment (age-0 fish on July 1) during the past three years has declined considerably from that estimated for the strong 1998 year-class (Table 3 and Figure 8). However, it should be noted that recent recruitment (6-11 billion recruits) is not estimated precisely (Figure 8), and another 2-3 years of data may be needed to ascertain whether the sardine population biomass has reached a plateau at the 1.1 million mt level (Figure 7).

Estimates of Pacific sardine biomass from the 1930's (Murphy 1966 and MacCall 1979) indicate that the sardine population may have been more than three times its current size prior to the population decline and eventual collapse in the 1960's (Figure 9). Considering the historical perspective, it would appear that the sardine population, under the right conditions, may still have growth potential beyond its present size. However, per capita recruitment estimates derived from the current assessment (Figure 10) show a downward trend in recruits per spawner that may be indicative of a stock that has reached a plateau under current environmental conditions.

Harvest Guideline for 2002

The harvest guideline recommended for the U.S. (California, Oregon, and Washington) Pacific sardine fishery for 2002 is 118,442 mt. Statistics used to determine this harvest guideline are discussed below and presented in Table 4. To calculate the proposed harvest guideline for 2002, 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:

$$HG_{2002} = (\text{TOTAL STOCK BIOMASS}_{2001} - \text{CUTOFF}) \bullet \text{FRACTION} \bullet \text{U.S. DISTRIBUTION},$$

where HG_{2002} is the total U.S. (California, Oregon, and Washington) harvest guideline recommended for 2002, $\text{TOTAL STOCK BIOMASS}_{2001}$ is the estimated stock biomass (ages 1+) from the current assessment conducted in 2001 (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 $\text{STOCK BIOMASS}_{2001}$ 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% (Figure 11).

Based on the T values observed throughout the period covered by this stock assessment (1983-2001), the appropriate F_{msy} exploitation fraction has consistently been 15% (see Figures 6 and 11); and this remains the case under current oceanic conditions (T_{2001} = 17.24 °C). However, it should be noted that the decline in sea-surface temperature observed in recent years (1998-2001) may invoke environmentally-based reductions in the exploitation fraction as early as next year (i.e. in setting the harvest guideline for the 2003 fishing season) – see Figure 11.

Finally, although the 2002 harvest guideline (118,442 mt) is less than the 2001 level (134,737 mt), recent fishery practices indicate that it may not be constraining with regard to fishery landings (Figure 12). However, should the recent declining recruitment trend estimated in this assessment be confirmed with future work, and should the sea-surface temperature continue to decline, it is likely that harvest guidelines in the out years will constrain fishery practices and removals.

References

Barnes, J.T., M. Yaremko, L. Jacobson, N.C.H. Lo, and J. Stehy. 1997. Status of the Pacific sardine (*Sardinops sagax*) resource in 1996. NOAA-TM-NMFS-SWFSC-237.

Conser, R.J., K.T. Hill, P.R. Crone, and D. Bergen. 2001. Stock Assessment of Pacific Sardine with Management Recommendations for 2001. Stock Assessment and Fishery Evaluation (SAFE) Reports. Pacific Fishery Management Council, Portland, OR.

Jacobson, L.D., and A. MacCall. 1995. Stock-recruitment models for Pacific sardine (*Sardinops sagax*). Can. J. Fish. Aquat. Sci. 52:566-567.

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.

Hill, K.T., L.D. Jacobson, N.C.H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine (*Sardinops sagax*) for 1998 with management recommendations for 1999. Calif. Dep. Fish Game, Marine Region Admin Rep. 99-4. 94 p.

Hill, K.T., M. Yaremko, L.D. Jacobson, N.C.H. Lo, and D.A. Hanan. 1998. Stock assessment and management recommendations for Pacific sardine (*Sardinops sagax*) in 1997. Calif. Dep. Fish Game, Marine Region Admin Rep. 98-5. 53 p.

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.

Lo, N.C.H., Y.A. Green Ruiz, M.J. Cervantes, H.G. Moser, and R.J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine *(Sardinops sagax)* in 1994, determined by the daily egg production method. CalCOFI 37:160-174.

MacCall, A.D. 1979. Population estimates for the waning years of the Pacific sardine fishery. Calif. Coop. Oceanic Fish. Invest. Rep. 20: 72-82.

Megrey, B. A. 1989. Review and comparison of age-structured stock assessment models from theoretical and applied points of view. American Fisheries Society Symposium 6:8-48.

Murphy, G.I. 1966. Population biology of the Pacific sardine (Sardinops caerulea). Proc. Calif. Acad. Sci. 34: 1-84.

PFMC. 1998. Amendment 8: (To the northern anchovy fishery management plan) incorporating a name change to: The coastal pelagic species fishery management plan. Pacific Fishery Management Council, Portland, OR.

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), 1983-2001. Semester 2 (2001) 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	35,174	22,761	57,935	25,800	25,373	51,173	109,108
01	29,491	21,131	50,622	9,327	25,645	34,973	85,594

Table 2. Pacific sardine time series of survey indices of relative abundance and sea-surface temperature, 1983-2001.

	CalCOFI	DEPM	Spawning area	Spotter plane	Sea-surface temperature
Year	(% positive)	(mt)	(Nmi^2)	(mt)	(C)
83	na	na	40	na	17.25
84	4.4	na	480	na	17.58
85	2.7	na	760	na	17.80
86	1.3	7,659	1,260	23,393	17.87
87	4.3	15,705	2,120	12,294	17.71
88	6.7	13,526	3,120	59,455	17.55
89	9.1	na	3,720	34,915	17.24
90	3.6	na	1,760	22,543	17.19
91	12.8	na	5,550	43,147	17.35
92	10.8	na	9,697	52,149	17.61
93	6.1	na	7,685	89,462	17.84
94	17.0	111,493	24,539	224,109	17.97
95	10.8	na	23,816	200,266	18.04
96	28.0	83,176	25,889	127,108	18.06
97	17.9	356,300	40,592	70,995	18.06
98	17.4	313,986	33,447	125,500	18.44
99	16.7	282,248	55,173	42,827	18.04
00	5.6	1,063,837	32,785	51,157	17.73
01	14.8	790,925	31,663	na	17.24

Table 3. Pacific sardine time series of stock biomass (>age-1 fish in mt) and recruitment (age-0 fish in 1,000s) 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	5,160	5,160	2,838	10,593	136,715	81,424	247,317
84	12,631	12,697	8,633	21,818	219,570	140,150	380,174
85	20,229	20,700	14,833	33,546	214,612	144,140	355,474
86	29,015	30,549	23,149	47,123	881,452	626,663	1,376,263
87	73,890	77,335	59,908	114,700	848,884	606,457	1,272,934
88	107,881	117,451	94,475	161,783	1,514,815	1,068,053	2,360,016
89	165,712	184,806	150,033	257,873	1,137,582	774,913	1,922,349
90	178,364	212,005	172,399	294,998	4,557,052	2,967,789	8,105,133
91	218,867	255,720	192,889	400,869	5,419,305	3,386,492	9,434,244
92	331,042	396,653	296,490	613,863	3,853,609	2,423,474	6,997,714
93	310,159	414,063	316,699	627,553	8,438,703	5,672,733	14,107,041
94	452,187	597,933	469,907	871,270	11,079,031	7,774,557	17,875,746
95	498,620	699,738	555,514	1,001,197	7,349,791	5,138,966	11,552,173
96	551,579	801,400	655,898	1,109,174	5,967,108	4,188,319	9,481,244
97	512,049	799,611	667,520	1,071,563	9,702,305	6,703,749	15,457,928
98	489,991	814,152	670,965	1,106,158	18,533,895	12,607,022	29,697,885
99	717,496	1,128,472	887,194	1,598,895	8,735,328	5,417,935	15,248,587
00	681,209	1,136,424	878,663	1,640,441	10,645,970	5,819,861	20,781,050
01	595,901	1,057,599	750,750	1,648,778	5,537,943	2,937,915	11,255,609

Table 4. Proposed harvest guideline for Pacific sardine for the 2002 fishing season. See ***Harvest Guideline for 2002*** section for methods used to derive the harvest guideline.

Total stock biomass (mt)	Cutoff (mt)	Fraction (%)	U.S. Distribution (%)	Harvest guideline (mt)
1,057,599	150,000	15%	87%	**118,442**

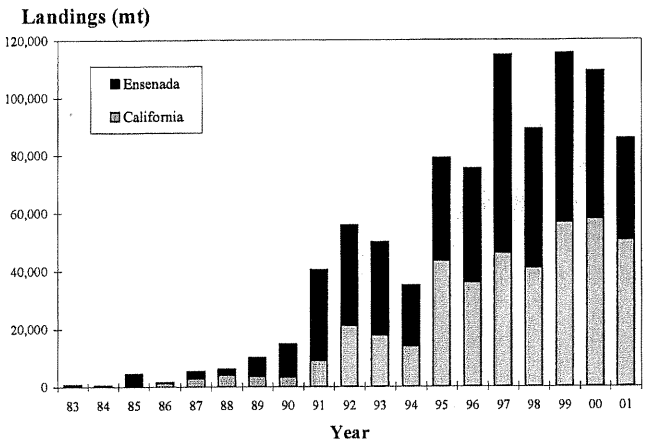

Figure 1. Pacific sardine landings (mt) in California and Baja California (Ensenada), 1983-01.

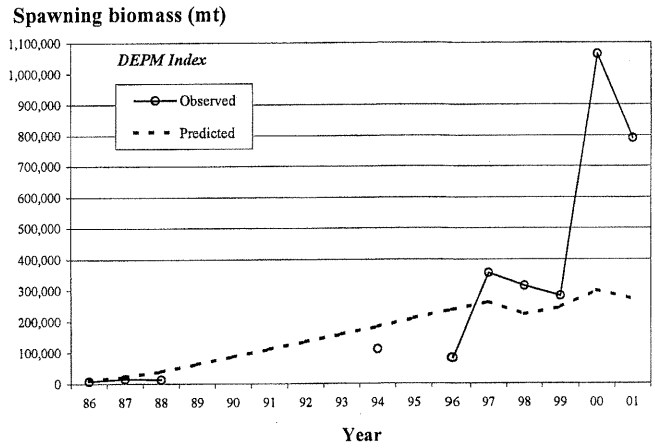

Figure 3. Index of relative abundance of Pacific sardine spawning biomass (mt) off California based on daily egg production method (DEPM) estimates from ichthyoplankton survey data (1986-01). Note no sample data (Observed estimates) were available for years 1989-93 and 1995.

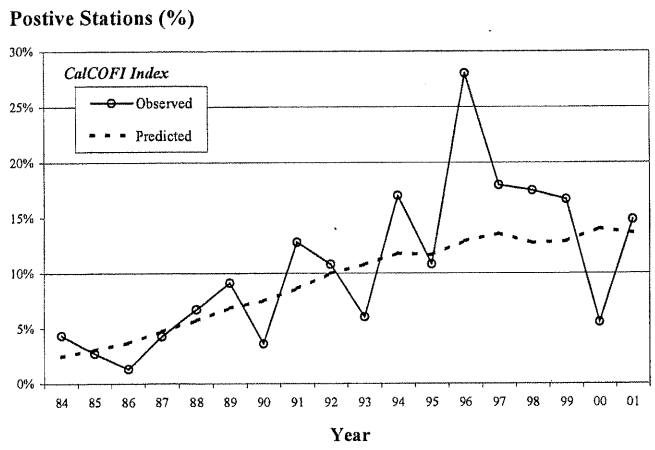

Figure 2. Index of relative abundance of Pacific sardine eggs (proportion-positive stations) off southern California based on CalCOFI bongo-net survey (1984-01).

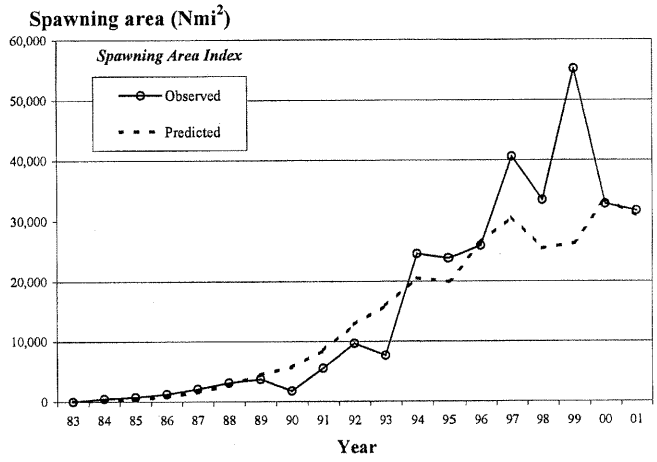

Figure 4. Index of relative abundance of Pacific sardine spawning stock size based on estimates of spawning area (Nmi^2) calculated from CalCOFI and DEPM survey data (1983-01).

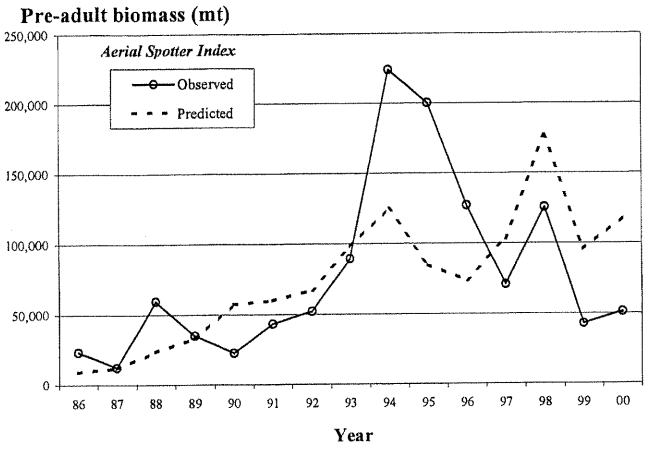

Figure 5. Index of relative abundance of Pacific sardine pre-adult biomass (primarily age 0-2 fish in mt) off California based on aerial spotter plane survey data (1986-01). Note that no sample data were available for 2001.

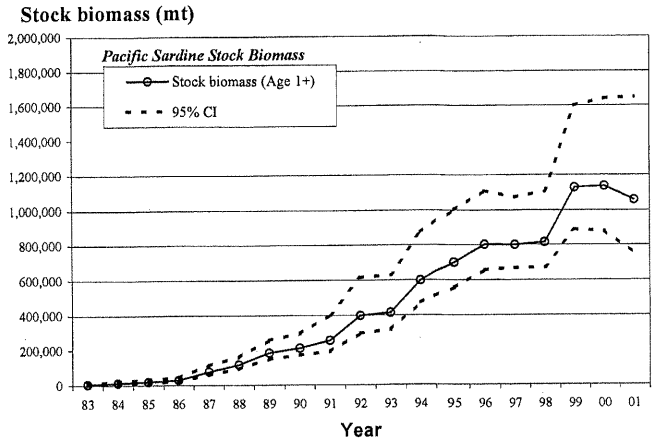

Figure 7. Time series (1983-01) of Pacific sardine stock biomass (≥1-yr old fish on July 1 of each year in mt) estimated from an age-structured stock assessment model (CANSAR-TAM, see Hill et al. 1999).

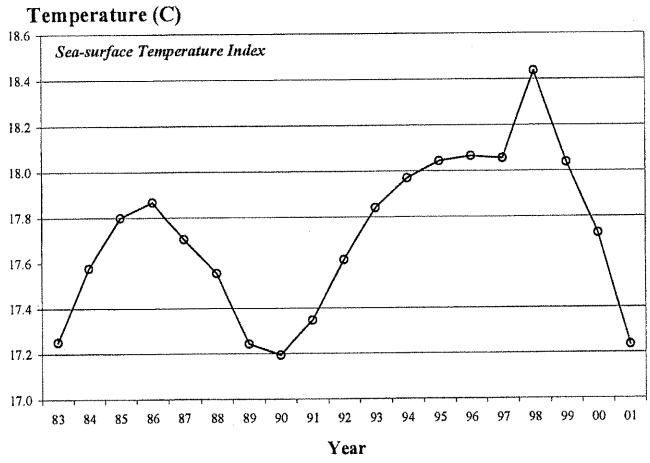

Figure 6. Time series of sea-surface temperature (C) recorded at Scripps Pier, La Jolla (1983-01). Annual estimates reflect 3-year 'running' averages, see Jacobson and MacCall (1995).

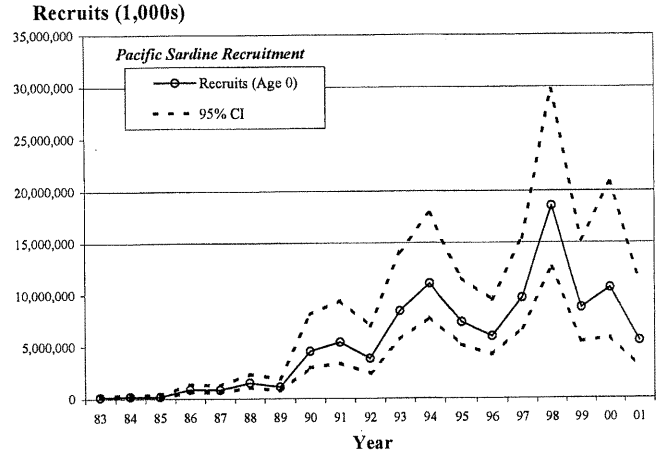

Figure 8. Time series (1983-01) of Pacific sardine recruitment (0-yr old fish on July 1 of each year in 1,000s) estimated from an age-structured stock assessment model (CANSAR-TAM, see Hill et al. 1999).

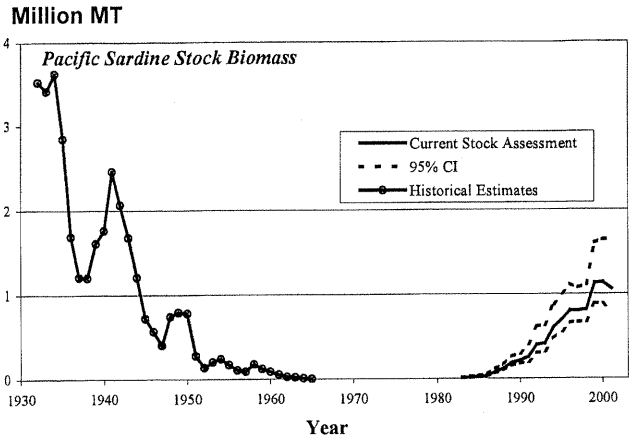

Figure 9. Time series (1983-2001) of Pacific sardine stock biomass (>1-yr old fish on July 1 of each year in million mt) and associated 95% confidence intervals estimated in the current stock assessment (cf. Figure 7); and historical stock biomass estimates (1932-65) from Murphy (1966). Confidence intervals or other measures of precision are not available for the historical estimates. No stock assessment-based estimates are available for the period 1966-82. The sardine fishery was closed much of this period and biomass was at very low levels.

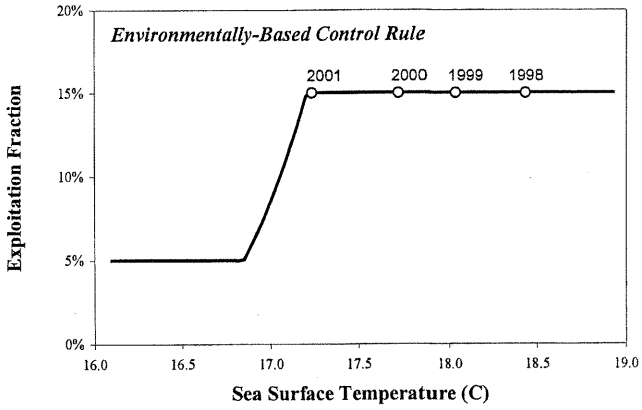

Figure 11. Environmentally-based harvest rate control rule for Pacific sardine as specified in the Coastal Pelagic Species Fishery Management Plan (PFMC 1998). For any given year, sea surface temperature (X-axis) is the running average sea surface temperature at Scripps Pier (La Jolla, CA) during the three preceding years. The exploitation fraction (Y-axis), which can range between 5-15%, is an explicit part of the algorithm used to determine the annual harvest guideline (quota) for the coastwide U.S. fishery – see Table 4. Open circles illustrate the sea surface temperature and exploitation fraction for recent years (1998-2001).

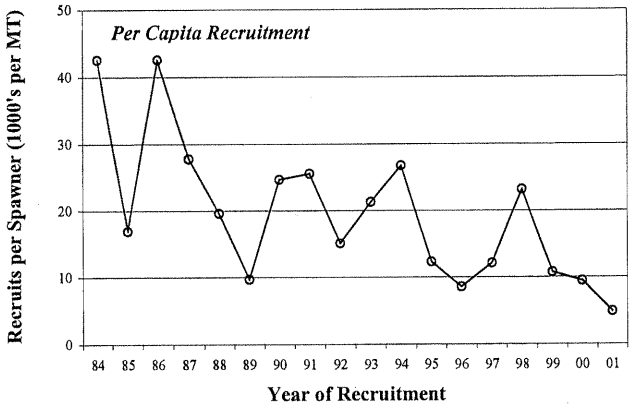

Figure 10. Ratio of Pacific sardine recruitment (1000's of 0-yr old fish) to stock biomass (Age 1+ in MT) during the previous year. Estimates of recruitment and Age 1+ biomass are taken from the stock assessment model (see Figures 7 and 8). Age 1+ biomass is used as a proxy for the spawning stock biomass of Pacific sardine.

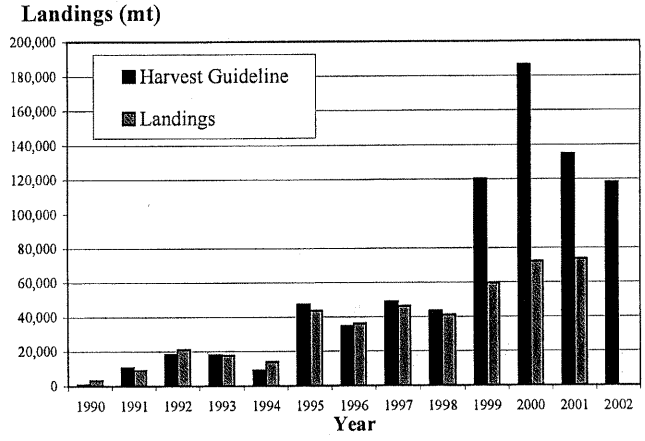

Figure 12. Time series (1990-02) of Pacific sardine harvest guidelines ('quotas') and actual landings (mt). State-based (California) regulations were in place for 1990-99, with federal-based (California, Oregon, and Washington) regulations beginning in 2000. Note that landings in 2001 represent an estimate projected through the end of the year. The 2002 harvest guideline is based on the 2001 stock biomass estimated in this assessment (Figure 7).