

RECOVERY OF THE PACIFIC SARDINE AND THE CALIFORNIA SARDINE FISHERY

PATRICIA WOLF

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

ABSTRACT

The Pacific sardine (*Sardinops sagax*) supported the largest fishery in North America in the 1930s and 1940s, but was severely depleted by the 1970s. A moratorium on fishing sardines was enacted in 1974 and remained in effect until 1986, when a small directed fishery was allowed. As the population increased, small quotas for live and dead bait were established, and the directed quota was increased in 1991 and 1992. Management efforts were designed to ensure the continued recovery of the sardine while providing a small catch and minimizing the impact of the incidental catch of sardines in the mackerel fishery. A series of management workshops in recent years generated estimates of sardine abundance, and strategies for managing the recovering resource. With the traditional fleet in economic difficulty and offshore fishing by factory trawlers a possibility, the future of the sardine fishery is uncertain.

RESUMEN

La sardina del Pacífico, (*Sardinops sagax*), sostuvo la pesquería mas grande de Norteamérica durante los 30 y los 40; sin embargo, durante los 70 el stock se encontraba sumamente diezmado. En 1974 se estableció una moratoria a la pesca, permaneciendo en efecto hasta 1986, año en que se autorizó una pequeña captura. A medida que la población incrementó, se permitieron pequeñas capturas de sardina a usarse como carnada. Los tamaños de captura directa permitida aumentaron en 1991 y 1992. La administración de esta especie fué diseñada con el objetivo de asegurar su recuperación continua, permitiéndose a la vez una captura pequeña, y para minimizar las capturas incidentales del recurso en la pesquería de la macarela. Una serie de talleres sobre la administración de la sardina produjeron estimaciones de la abundancia del recurso y, por otro lado, estrategias para la recuperación del mismo. Debido a las dificultades económicas que enfrenta la flota tradicional y a la posibilidad de una pesca de altura por buques-factoría de arrastre, el futuro de la pesquería de la sardina es incierto.

INTRODUCTION

The Pacific sardine (*Sardinops sagax*) fishery began in central California in the late 1800s and developed in response to a demand for food during World War I (Schaefer et al. 1951). From the mid 1930s to the mid 1940s the fishery was the largest in the Western Hemisphere (Frey 1971a; Ahlstrom and Radovich 1970), with peak landings of over 790,000 short tons¹ in the 1936–37 season, and average landings over 600,000 tons per season (figure 1). The fishery began to collapse a few years later, and catches declined over the next two decades, with short-term reversals, to less than 100 tons per year in the 1970s. Sardine biomass (figure 2) declined from nearly 4 million tons in the mid 1930s to levels thought to be as low as 5,000 tons by the 1970s (Murphy 1966; Smith 1972; MacCall 1979).

Most sardine landings during the historical fishery were made in California (figure 1). The fishery collapsed first in the north, with landings ceasing in the Pacific Northwest in 1949–50 and in northern California in 1952–53. The catch was insignificant by the early 1960s, and most subsequent landings have occurred in southern California and Baja California, Mexico (Radovich 1982).

Sardines harvested in the historical fishery were primarily canned or reduced to fish meal and oil, although small amounts were used for live and dead bait. Reduction of sardines began as a means to utilize offal from the canning process, but whole sardines were soon used because the production of meal and oil was often more profitable than canning. The state of California favored human consumption over reduction, and most regulations were designed to limit the excess reduction of edible fish (Schaefer et al. 1951).

Before 1967, management of the sardine fishery consisted almost exclusively of controls on tonnage of whole fish used for reduction under permits issued to noncanning processors; case pack requirements to limit the amount of reduction by canners; and restriction of the fishing season to ensure that fish were in prime canning condition and that markets were not saturated (Schaefer et al. 1951; Frey 1971a). Reduction ships operated in waters beyond the jurisdiction of the state from about 1930 to 1938, until a voter-approved initiative restricted vessels

¹Commercial landings, biomass estimates, tonnages specified in legislation, and quotas are reported in short tons throughout this paper.

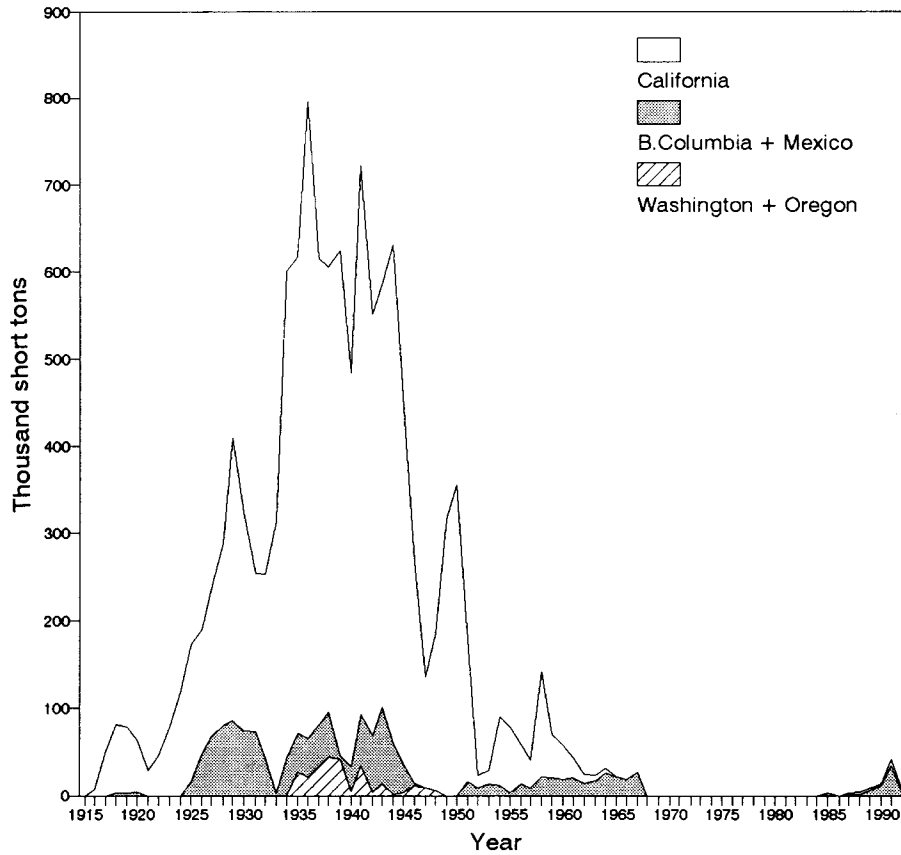
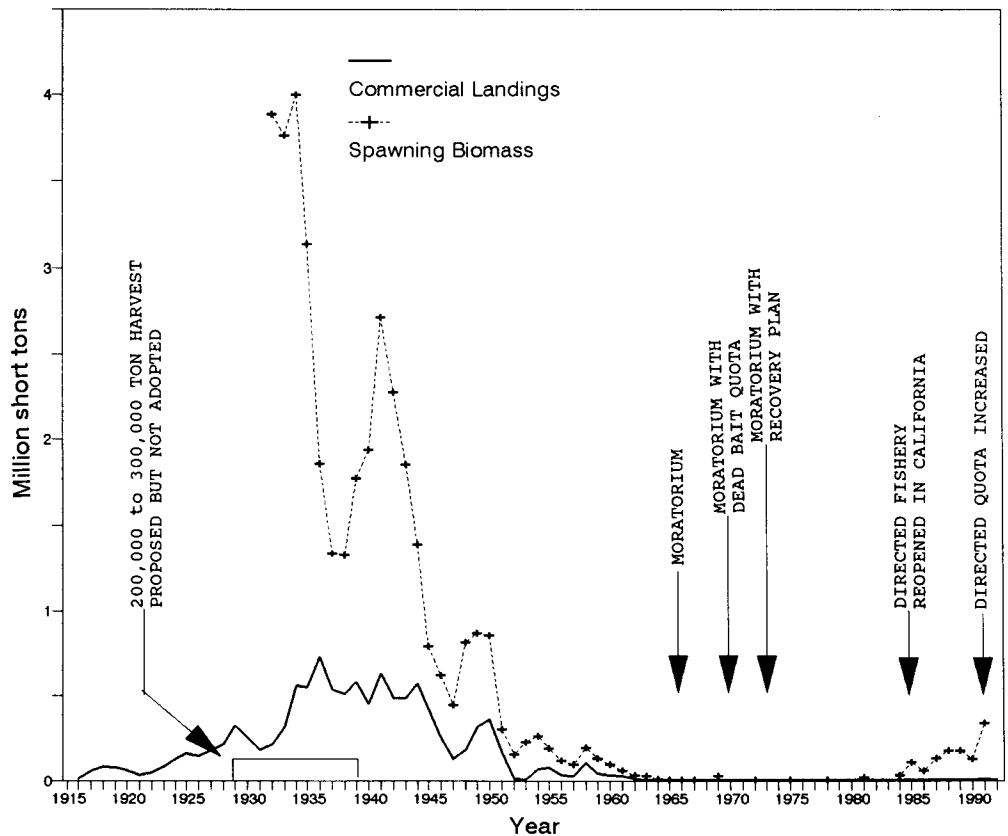


Figure 1. Sardine landings in short tons from 1916 through June 1992. The gray portion of the curve shows British Columbia landings before 1949, and Ensenada, Mexico, landings after 1950. California landings from Frey 1971a for years 1916-69 and from CDFG records for years 1970-June 1992. British Columbia, Washington, and Oregon landings from Radoovich 1982 (seasonal landings were assigned to calendar year of the first half of season). Ensenada landings from MacCall 1979 for seasons 1951-52 to 1965-66; Barnes et al. 1992 for years 1983-91; and Walterio Garcia, Instituto Nacional de Pesca, pers. comm., through June 1992.

Figure 2. Sardine landings (California and Ensenada, Mexico) and spawning biomass (fish age 2+) in short tons. California landings from Frey 1971a for years 1916-69 and from CDFG records for years 1970-June 1992. Ensenada landings from MacCall 1979 for seasons 1951-52 to 1965-66 (seasonal landings were assigned to calendar year of the first half of season); Barnes et al. 1992 for years 1983-91; and Walterio Garcia, Instituto Nacional de Pesca, pers. comm., through June 1992. Before 1951, and from 1966 to 1982, Ensenada landings are not available. Biomass is from Murphy 1966 for years 1932-44, MacCall 1979 for years 1945-65, and Barnes et al. 1992 for years 1966, 1967, 1969, 1972, 1975, 1978, 1981, 1984-91.



that fished in state waters from delivering to the reduction ships, and market conditions also declined.

The regulatory history of the sardine fishery might best be described as "too little too late." Regulatory authority for the sardine fishery in California rested with the legislature, which delegated only limited authority to the Fish and Game Commission. State biologists expressed concern about the size of the sardine fishery and the threat of resource depletion as early as 1930 and suggested that authority to regulate the total catch be given to the state fisheries division (Schaefer et al. 1951). Recommendations to limit total catch of sardines to levels ranging from 200,000 to 300,000 tons were made as early as 1929, and by various researchers over the next several years (Scofield 1932, 1934; Clark 1939), but no such action was taken (figure 2). Industry opposed any regulation of total catch, and a long and intense debate ensued over whether the decline of the sardine fishery and population was due to overfishing or environmental factors (Clark and Marr 1955). Although the sardine crisis gave rise to extensive and innovative research (Scheiber 1990), the debate also clouded the issue and deferred measures that were necessary for effective control of the fishery (Radovich 1982).

In 1967, well after the fishery had collapsed, the California legislature passed an "emergency" bill (Assembly Bill [AB] 743) declaring a two-year moratorium on fishing sardines (figure 2). Ahlstrom and Radovich (1970) characterized this as the most decisive management action in the 50-year history of the fishery, and as an acknowledgment that the fishery had ceased to exist. The law eliminated direct harvest of sardines for reduction and canning, but allowed an incidental catch of 15% by weight mixed with other fish in a load. Most of the incidentally landed sardines were supplied as dead bait to a lucrative market in central California and sold for \$200 to \$400 per ton, which was considerably higher than the \$70–\$75 price for sardines landed at the canneries (Hardwick 1968).

In 1969, AB 564 was enacted to permit 250 tons of sardines to be landed annually for dead bait, with the provision that boats could possess and land no more than 3 tons per day. The price had increased to \$300–\$500 per ton (Frey 1971b). The value of sardines as dead bait and the new quota resulted in an increase in the harvest during 1970–72 (Crooke 1972). Sardines landed incidentally after the quota was reached could be used for canning, preserving, and reduction only. After the passage of AB 564, this bait market remained the most significant economic factor in the sardine fishery (Haugen 1973).

In 1974, Senate Bill (SB) 192 established a complete moratorium on directed fishing for sardines. The incidental catch provision continued, except that use was restricted to canning or reduction to eliminate the dead bait market. This measure also required the California Department of Fish and Game (CDFG) to monitor the status of the resource annually, and provided for a 1,000-ton directed fishery when the spawning biomass reached or exceeded 20,000 tons. In addition, this legislation established the intent of the legislature to rehabilitate the sardine resource and authorized CDFG to regulate total catch: as the spawning population increased above 20,000 tons, the seasonal quota could be increased, but only to the extent that the population could continue to increase, and with the long-term objective of maximizing the sustained harvest. The moratorium appears to have been successful, because sardine biomass has apparently increased (Barnes et al. 1992). Following the moratorium, and in accordance with SB 192, a small directed fishery was first allowed in 1986, and has recently been increased.

The purpose of this paper is to describe management and monitoring efforts during the moratorium, and to review management and fishery developments in California during the early recovery of the Pacific sardine resource following the moratorium.

THE MORATORIUM, 1974–1985

Monitoring and Management

From 1974 through 1978, sardines occurred rarely as incidental catch in the mackerel fishery (consisting of jack mackerel, *Trachurus symmetricus*, and Pacific mackerel, *Scomber japonicus*); rarely or not at all in CDFG night-light surveys and midwater trawl surveys for young-of-the-year pelagic fish; and rarely in California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton surveys (Klingbeil 1975, 1976, 1977, and 1978). Beginning in 1979 and continuing through 1981, live bait fishermen in southern California reported more frequent encounters with juvenile sardines; sardines increasingly appeared in young fish surveys; and sardines appeared more frequently in mackerel landings, although still in small amounts (Klingbeil 1979, 1980, 1981). Incidental landings of sardines in the mackerel fishery increased steadily to 145 tons in 1982, and to 388 tons in 1983 (table 1). This was the largest take since 1966, before moratorium regulations were established. Mackerel and live bait fishermen reported increased sightings of sardine schools, and sardines

TABLE 1
 Landings (Short Tons) in Sardine Fisheries, 1974–1991

Year	Incidental				Directed			Dead bait				Live bait	Total
	North	South	Total	Percentage*	North	South	Total	North	Central	South	Total		
1974		7	7										7
1975		3	3										3
1976		27	27										27
1977		6	6										6
1978		5	5										5
1979		18	18										18
1980		38	38									14	52
1981		31	31									9	40
1982		145	145									41	186
1983		388	388									213	601
1984	70	188	258									68	326
1985	37	615	652	1.3								16	668
1986	45	797	842	1.4	79	363	442					21	1,305
1987	20	1,863	1,885	3.1	22	401	423					238	2,546
1988	11	3,075	3,087	5.0	0	1,085	1,085					55	4,227
1989	4	2,871	2,875	4.4	258	924	1,182				250	111	4,418
1990	69	1,395	1,464	3.9	269	1,369	1,638	0	188	50	238	599	3,939
1991	0	1,295	1,295	3.4	1,075	5,747	6,822	0	424	70	494	300	8,911

*Percentage by weight of sardines in total mackerel (Pacific mackerel, jack mackerel, and sardine) landings. Before 1985, sardines were less than 1% of total.

in the live bait fishery and CDFG sea surveys increased as well (Klingbeil and Wolf 1984).

Concern about the increasing availability and incidental take of sardines resulted in two pieces of legislation in 1983. AB 394, passed as an urgency measure in April, required CDFG to monitor incidental catch of sardines, and allowed the percentage of sardines that could be taken incidentally to increase or decrease. Specifically, the tolerance would increase from 15% to 25% if the overall percentage of sardines in the mackerel fishery (consisting of Pacific mackerel, jack mackerel, and sardines) exceeded 5% in the preceding month. Subsequent increases in 10% increments (up to 45%) would result if the percentage of sardines exceeded one-third of the previously established tolerance. Similarly, the tolerance level would decrease by 10% increments (down to 15%) if the percentage of sardines in the mackerel catch was less than one-fourth the tolerance limit of the preceding three months. This legislation was designed to lessen the impact of the recovering sardine resource on other fisheries, particularly the mackerel fishery.

AB 457, which took effect in January 1984, allowed the first 250 tons of sardines taken incidentally during the year to be used for any purpose (table 2). This measure once again made sardines available for the dead bait market, but since the market was then primarily supplied by imported sardines, it was expected that demand for local fish landed in California would be moderate. After the first 250 incidental tons were landed, incidentally

landed sardines could be used for live bait, reduction, and canning, but not for dead bait. As a result, fresh fish markets without canning or reduction facilities could sell sardines as fresh fish during part of the year (before the 250-ton quota was filled), and incidentally caught sardines could be used for live bait.

In 1984 incidental landings of sardines declined in comparison to 1983 landings, but the frequency of sardines in CDFG midwater trawls remained high, and sardines occurred incidentally with the mackerel catch in Monterey. The incidental catch in the live bait fishery also increased.

AB 3403, which was passed in September 1984, extended the statutes regulating incidental take of sardines until July 1, 1986. In addition, this bill established a 75-ton annual live bait quota (table 2) for sardines under a revocable permit, and required fishermen who took live bait to submit logbooks. Both of these provisions were again intended to minimize the impact of the increasing sardine population on fishermen and dealers.

The 1985 incidental catch totaled 652 tons (table 1), the largest annual take in 20 years. For the first time, landings in the Monterey mackerel fishery accounted for a sizable fraction (6%) of the statewide catch, and fishermen in the area reported sighting "pure" sardine schools on several occasions (Klingbeil 1986). A decline in sardine landings for live bait during 1985 was attributed to decreased demand, since live bait haulers often targeted on squid that had recently become available (Klingbeil 1986). The

TABLE 2
 Quotas and Incidental Tolerance Limits for Sardine Fisheries, 1974–1991

Year	Incidental tolerance (by weight)	Quotas (short tons)			Total
		Live bait	Directed	Dead bait	
1974–82	15%	—	—	—	
1983	15%	—	—	(250) ^a	
1984	15%	75	—	(250)	75 + ^b
1985	15%	150	—	(250)	150 +
1986	15%	150	1,000	(250)	1,150 +
1987	25%	350	1,000	(250)	1,350 +
1988	35%	350	1,000 ^c	(250)	1,350 +
1989	35%	350	1,000	250 ^d	1,600 +
1990	35%	350	1,000	250 ^e	1,600 +
1991	35%	350	6,150	500	10,000 ^f
1992	35%	1,000	20,500	500	25,000

^aDead bait landings were included in incidental catch: the first 250 tons of incidental catch could be used for any purpose, including dead bait.

^bTotal incidental catch was unrestricted and variable.

^cDirected quota was allocated 20% for north, 80% for south.

^dSeparate 250-ton dead bait quota was established (500 tons if directed quota is 2,500 tons or more).

^eDirected quota allocation was changed to 1/3 for north, 2/3 for south.

^fIncidental catch (3,000-ton reserve) was included in total harvest.

sardine live bait quota was increased from 75 to 150 tons by AB 426, which became effective on January 1, 1986.

Population Assessment

From 1974 through 1985, annual assessments of the sardine population were limited to a qualitative examination of various sources of information, including incidental and live bait fishery data, CDFG sea-survey catches of young sardines, the occurrence of sardine eggs and larvae in CalCOFI ichthyoplankton surveys, observations by aerial fish spotters employed by industry, and anecdotal information. The data were sufficient to indicate trends in sardine biomass, but no direct estimates of the biomass were attempted. The annual assessment requirement established by SB 192 was met by a statement that the sardine resource appeared to remain below 20,000 tons, and the moratorium continued (Klingbeil 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983a; Klingbeil and Wolf 1984; Wolf 1985).

The indirect information available in 1985 indicated that sardine biomass might be approaching 20,000 tons, so attempts were made to estimate the biomass directly. Wolf and Smith (1985) used the extent of spawning area, defined by the number of sampling stations in which sardine eggs were present, to determine if the sardine spawning biomass was greater than 20,000 tons. The first spawning area survey was conducted in 1985, and the spawning area (670 n.mi.²; table 3) indicated that the spawning biomass was at least 20,000 tons (Wolf and Smith 1986). As a result, CDFG announced a 1,000-

ton fishery for the 1986 season, thus ending the 12-year moratorium (Wolf and Smith 1986).

THE EARLY RECOVERY, 1986–1991

Fishery Management

1986. The 1986 directed sardine fishery opened on January 1, 1986, with a quota of 1,000 tons (table 2). Landings were steady, but averaged only about 150 tons per month, since fishermen continued to fish for mackerel during this period. The fishery was closed on July 11, when the quota was reached. All landings of sardines made during the open fishing period, including "pure" loads and sardines caught incidentally with other species, were counted against the quota. Directed landings totaled 79 tons in northern California and 363 tons in southern California, and were used primarily as dead bait for the central California striped bass fishery. Incidental landings continued after the close of the quota season, with a total of 842 tons taken incidentally with mackerel during the year (table 1), and canned with mackerel as pet food. Sardines contributed 1.4% of the total mackerel catch, and occurred in about 60% of the landings.

Sardine live bait catch totaled 21 tons, and was well below the 150-ton quota. The availability of squid, often a preferred bait for big game fish, again resulted in a decreased demand for sardines. Landings from all sources totaled 1,305 tons in 1986 (table 1).

1987. The 1987 directed sardine fishery opened on January 1 with a quota of 1,000 tons. Landings aver-

aged 325 tons per month until the quota fishery was closed on April 17. The 1987 fishery lasted a little more than half as long as the 1986 fishery. Directed landings totaled 423 tons (401 tons in northern California and 22 tons in southern California) and accounted for 32% of the 1,000-ton quota. Following the closure of the directed fishery, the incidental tolerance limit was increased from 15% to 25% by weight (table 2) because sardines constituted 5% of the total mackerel landings in March. Incidental landings for 1987 totaled 1,885 tons. Sardines composed 3.1% of total mackerel landings during the year.

Sardines were an important component of the live bait fishery in the first half of 1987, primarily because schools of northern anchovy (*Engraulis mordax*) were unavailable. To alleviate the effects of poor bait availability on the sportfishing industry, AB 1093 was enacted to increase the live bait quota from 150 to 350 tons (table 2). The live bait catch totaled 238 tons for the year. Landings from all sources totaled 2,546 tons in 1987 (table 1).

1988. The 1988 directed sardine fishery opened on January 1 with a quota of 1,000 tons, and differed considerably from the directed fisheries of the previous two years. The quota was landed in only two weeks, and the fishery was closed on January 15. The increasingly shorter duration of the directed fishery, and the large proportion (81%) of pure loads suggested that sardines were more available to fishermen and that pure schools were more common. About 59% of landings in 1986 and 65% of landings in 1987 in the directed fishery were incidental and mixed with mackerel. Most of the landings in 1986 were made by a single vessel, but in 1988 several purse seine boats were fishing for sardines. In 1988, for the first time since the late 1960s, sardines were canned for human consumption, and the product was test-marketed. Some of the catch was still canned for pet food, but considerably less was used for dead bait.

Directed landings totaled 1,085 tons, and were made entirely in southern California. Incidental landings for the year totaled 3,087 tons, of which only 11 tons were landed in Monterey. The tolerance limit for sardines landed incidentally with mackerel was increased from 25% to 35% in April (table 2), because sardines constituted 11% of total mackerel landings during March. Fishermen in southern California complained that sardines were so abundant they interfered with fishing on traditional mackerel grounds, particularly around the northern Santa Barbara Channel Islands. Even though incidental landings of sardines dropped below 8.75% during

subsequent three-month periods, CDFG did not reduce the 35% tolerance limit. The catch of sardines in live bait totaled 55 tons. Landings from all sources in 1988 totaled 4,227 tons (table 1).

Fishermen reported that they were setting on schools with a high percentage of sardines but not landing the fish because of low tolerance limits and because the canneries generally would not buy such loads, since the fish were marketed as mackerel. Legislation (AB 4064) was passed in 1988 allowing the tolerance limit to be increased based on fish taken or wrapped in a net rather than only landed. This was largely a symbolic gesture, however; higher tolerance limits were rarely exceeded because of the cannery restrictions. Provisions of AB 4064 also allocated the directed fishery quota between northern and southern California (20% of the quota was reserved for fishermen landing their catches north of Point Buchon, San Luis Obispo County, and 80% for fishermen landing their catches south of Point Buchon). This allocation assured Monterey fishermen and processors access to sardines. Monterey boats usually participated in the Pacific herring (*Clupea harengus*) fishery in January, and local fishermen and processors complained that sardines were generally not available in central California until later in the year when the sardine quota had been taken by fishermen in the south. AB 4064 also established a 250-ton quota (500 tons if the directed quota was increased to 2,500 tons or more) specifically for dead bait purposes; this quota was available beginning on March 1 of each year.

1989. The 1989 directed fishery opened on January 1 with a 1,000-ton quota (200 tons allocated to landings in northern/central California and 800 tons allocated to southern California). Directed landings in southern California totaled 924 tons, and the fishery closed on January 12, three days earlier than the previous year. No landings were made in northern/central California until February, and the fishery remained open until early April. Directed landings in the north totaled 258 tons, and consisted almost entirely of pure loads of sardines. Most of the catch in both areas was canned for human consumption. Incidental landings totaled 2,875 tons, and almost all were made in southern California. Sardines contributed 4.4% of total mackerel landings.

The 250-ton dead bait fishery for 1989 was closed on March 20, when it was estimated that the quota had been filled. This quota was difficult to monitor because processors were not required to specify the use of purchased sardines on landing receipts. Unless a landing exceeded the tolerance limit (35% sardines by weight), sardines in the load were generally

not declared as dead bait. Landings of sardines in live bait totaled 111 tons. Landings from all sources totaled 4,418 tons in 1989 (table 1).

Legislation (AB 2351) was enacted in March 1989 and went into effect on January 1, 1990, allocating the dead bait quota so that 125 tons were reserved for landings south of Point Buchon, 50 tons between Point Buchon and Pescadero Point (San Mateo County), and 75 tons north of Pescadero Point. This bill also specified that all sardine fishing for dead bait required a written order from a processor; all fish had to be landed in a whole condition; and landing receipts had to specify use. These measures were intended to ensure that dead bait allocations were used for that purpose, and to facilitate monitoring of the quota.

1990. The 1990 directed fishery opened on January 1 with a 1,000-ton quota allocated in the same manner as the previous year. The fishery in southern California was closed on January 6 after only six days of fishing, with a total catch of 1,369 tons. Sardines were abundant and available near the Los Angeles Harbor. Fishing in northern California began in late January and was closed on April 25, with a total take of 269 tons. Most of the directed catch was used for human consumption, the remainder for dead bait and pet food. Incidental landings totaled 1,464 tons and represented 3.9% of the total mackerel catch. This represented a 49% decline in incidental landings, and was the third year the proportion of sardines in the incidental catch declined. However, the decline in incidental landings was largely attributable to a decline in the mackerel catch.

The dead bait fishery opened coastwide on March 1, 1990. The southern California fishery was closed on March 2, after 188 tons were landed (125-ton allocation) in only two days of fishing. The central California allocation (50 tons) was met on April 10. No landings were made against the northern allocation (50 tons). The sardine live bait catch totaled 599 tons; landings exceeded the 350-ton quota because of an error in tallying the logbook catch. Landings from all sources totaled 3,939 tons in 1990 (table 1).

AB 3861, passed in March 1990, modified the allocation formula for the directed fishery by reserving one-third of the quota for fishermen landing their catches north of San Simeon Point (San Luis Obispo County) and two-thirds for fishermen landing their catches south of that point. An opening date of August 1 was established for the northern area directed fishery. In addition, the allocation formula for the dead bait quota was changed to reserve 62 tons for fishermen landing their catches north of

Pescadero Point, 62 tons for fishermen landing their catches between Pescadero Point and San Simeon Point, and the remainder for fishermen landing their catches south of San Simeon Point. Such quota allocations were of a political rather than management nature, and in general CDFG maintained a neutral position in such decisions. The boundary between northern and southern California was changed to discourage southern California boats that fished in southern California from landing their catches in a port north of the boundary and thus against the northern quota allocation; landings were made in Morro Bay (north of Point Buchon and south of San Simeon Point) during 1990 and trucked south.

AB 3211, enacted in September 1990 and effective immediately, allowed sardines taken incidentally to be used for any purpose. Use restrictions on incidentally taken sardines were eliminated because sardine abundance was increasing, because there was now a separate dead bait quota, because dead bait demand had apparently decreased as a result of a decline in the central California striped bass fishery, and so that incidentally harvested sardines could be used for human consumption.

1991. Initial quotas in 1991 were based on a total harvest target of 5% of the estimated spawning biomass of 100,000 tons. In addition to the 350-ton live bait quota and the 250-ton dead bait quota (which were fixed by statute), 3,000 tons were reserved for expected incidental landings. The initial directed quota was set at 2,499 tons, with one-third (833 tons) reserved for the northern allocation and two-thirds (1,667 tons) for the southern allocation. The directed quota was 79% higher than a strict 5% harvest would dictate (1,400 tons, given the incidental reserve and fixed quotas), but less than 2,500 tons, which was the level of directed quota that would trigger an increase in the dead bait quota from 250 to 500 tons. The low incidental catch in 1990 and the reduced allocation percentage of the directed quota for southern California were also considered in setting the initial directed quota for 1991. This was the first time the directed fishery quota was higher than the 1,000-ton level, and represented a change in management to control the total harvest, including consideration of the incidental catch.

The 1991 directed fishery opened in southern California on January 6. In an effort to minimize landings over the quota, the southern directed fishery was opened for one day (24-hour period) per week until the quota was reached. This strategy was designed to provide adequate time for mailing notices of fishery closures to sardine fishermen as required

by law, and helped prevent overharvests (such as occurred in 1990) resulting from the large daily landing capacity of the fleet and the relatively small quota. A total of 1,879 tons was landed against the 1,667-ton quota during two 24-hour fishing periods, and the fishery was closed on January 14, 1991.

Following a reexamination of information about the status of the sardine resource, the 1991 total harvest level was increased to 10%, or 10,000 tons. This resulted in a 6,150-ton directed fishery quota, with 4,100 tons allocated to southern California and 2,050 tons to northern California. The dead bait quota was increased to 500 tons as required; the live bait quota remained at 350 tons; and the incidental catch reserve remained at 3,000 tons (table 2). The southern California directed fishery opened again on March 4, with a 2,434-ton quota. The fishery was closed on March 25 with 2,636 tons landed during four 24-hour fishing periods; the catch was canned for human consumption.

The northern California directed fishery opened on August 1 with a 2,050-ton allocation. The fishery remained open for the rest of the calendar year, and 1,075 tons were landed against the quota. The fishery was closed after only five months because the legislation that changed the opening date of the northern fishery did not provide for a year-round fishery, but rather prohibited fishing north of San Simeon Point before August 1 of each year.

The dead bait fishery opened in all areas on March 1. The southern area fishery was closed on April 8, with 424 tons landed during one 24-hour fishing period. The central area fishery closed on May 24, with 70 tons landed. No landings were made against the northern area quota. The sardine live bait catch in 1991 totaled 300 tons.

In October, CDFG estimated that only 1,000 tons of the 3,000-ton incidental reserve would be landed by the end of the year, and made the remaining 2,000 tons available as a directed quota. The southern California allocation (1,333 tons) opened on October 27, and 1,232 tons were landed in two 24-hour fishing periods. The fishery closed on November 4. There were no additional landings made against the northern allocation. Incidental landings for 1991 totaled 1,295 tons, and represented 3.4% of the total mackerel catch. The incidental catch was low, primarily because of a decrease in mackerel landings. Landings from all sources during 1991 totaled 8,911 tons (table 1).

AB 173, enacted in July 1991 and effective immediately, reestablished the procedures for setting tolerance limits for incidentally taken sardines. The original legislation eliminated this section of the

Fish and Game Code in January, but the 35% tolerance limit was enforced during the interim. AB 173 also extended the 350-ton live bait quota, and allowed CDFG to increase the live bait quota beyond the 350-ton level, provided such increases do not impede the recovery of the sardine resource. This bill allowed sardines taken as dead bait to be sold to commercial fishermen; previously, sardines so caught could be sold only for use by sport anglers.

Summary. With the exception of 1990, total sardine landings increased steadily between 1986 and 1991 (table 1). The largest increase was between 1990 and 1991, mainly because of the increase in the directed quota, and to a lesser degree because of an increase in the dead bait quota. Directed landings increased fourfold between 1986 and 1990, and fourfold between 1990 and 1991. The live bait catch varied between 1986 and 1991, but increased overall. The incidental catch increased between 1986 and 1988, but declined each year thereafter, partly because of the decline in mackerel landings (Wolf 1992). The proportion of sardines in the mackerel fishery peaked in 1988 at 5%, and declined steadily through 1991. Although the occurrence of sardines in the mackerel fishery was believed to indicate sardine abundance, there does not appear to be a relationship. The average ex-vessel value of sardines in all fisheries between 1986 and 1990 was \$183 per ton (Thomson et al. 1992). In general, fishermen have received less for sardines (\$80 to \$105 per ton) than for mackerel (\$120 to \$130 per ton) at the canneries since 1986.

Population Assessments

Spawning area surveys (Wolf and Smith 1985, 1986; Wolf et al. 1987; Wolf 1988a,b, 1989; Barnes et al. 1992) were used exclusively from 1986 through 1989 to evaluate the size of the sardine population relative to 20,000 tons, and were the basis for allowing the 1,000-ton directed fishery each year. Briefly, the area over which a 20,000-ton spawning biomass would be expected to produce eggs was calculated from estimates of the egg production rate per unit area and rates at which adults produce eggs. If the survey detected a spawning area as large as or larger than the predicted spawning area, then the spawning biomass was presumed to be 20,000 tons, and a 1,000-ton directed quota was allowed.

From 1986 through 1988, the sardine spawning area detected by CDFG surveys increased steadily, and in each year indicated a spawning biomass of at least 20,000 tons (table 3). For 1990 and 1991, spawning area surveys conducted by CDFG (Wolf and Larson 1991) were used in conjunction with other

information to assess the status of the sardine population. Spawning area decreased in 1990, and increased substantially in 1991 (table 3).

In September 1989, CDFG convened the first of three annual workshops to review the status of the sardine resource and to develop management recommendations. State, federal, and fishing industry biologists presented data and analyses and discussed management options. Although the group did not develop an estimate of the size of the sardine population during the first meeting, participants agreed that an increase in the directed quota above 1,000 tons was not warranted at that time.

The second sardine assessment and management workshop was held on September 27 and 28, 1990, and involved state, federal, fishing industry, and Mexican federal biologists. To facilitate in-depth discussions, all participants were invited to submit a synopsis of data and analyses concerning the status of the Pacific sardine resource. These synopses were distributed to all participants for review before the workshop. Discussion centered on data sources, options for assessment and analysis, and alternatives for short-term and long-term management of sardines. The goals of the workshop were to identify assessment techniques and set harvest levels to ensure rehabilitation of the resource, and to develop a management plan for a fully rehabilitated stock.

Several sources of data and information were presented, including CalCOFI egg and larval surveys, observations of sardines by aerial fish spotters, CDFG spawning area surveys, catch and age data from current fisheries collected by CDFG and industry biologists, and data from historical fisheries. Barnes et al. (1992) review five analytical approaches used in the workshop and recent trends in sardine abundance. A rehabilitated sardine resource was defined by workshop participants as one that has a spawning biomass (age 2 and older) of at least 1 million tons, and that occupies an area and has an age structure similar to those during previous periods of high abundance. Once the population reaches 1 million tons, management would shift from the goal of rehabilitation to management of a fully rehabilitated stock. Sardines generally increase during periods of warm water (Barnes et al. 1992), and it was recommended that rehabilitation be achieved within the next decade to take advantage of current favorable environmental conditions. Also, management should be based on total harvests, and during periods of poor recruitment total harvests should be reduced. The participants recommended that during rehabilitation, U.S. harvest levels should not exceed 5% of the spawning biomass. In one scenario,

TABLE 3
 Sardine Spawning Area from CDFG Surveys

Year	Predicted spawning area (n.mi. ²)	Observed spawning area (n.mi. ²)
1985	500	670
1986	500	970
1987	500	1,850
1988	500	2,508
1989	2,300*	3,680
1990	2,300	1,480
1991	2,300	3,840

*Predicted spawning area was recalculated in 1989.

the long-term exploitation that could be sustained by sardines was estimated to be about 20%: 10% was subtracted to allow for rehabilitation, and the remaining 10% was split—5% for sardine harvest in Mexico and 5% for the United States. Another scenario was based on the current estimated rate of increase of the population (about 30% per year) and the conclusion that a 5% harvest would allow the population to continue to increase at a rate (about 25% per year) that would achieve rehabilitation within 10 years; the Mexican catch was not explicitly addressed. The group reached a consensus that the spawning biomass in 1990 was about 100,000 tons, and recommended a 5,000-ton harvest.

Following the workshop, CDFG reexamined the recommendations and considered comments received at an industry meeting. It was suggested that current estimates of sardine productivity obtained at the workshop (30% to 40% per year) were too low, because the observed rates of increase occurred at the same time as annual harvest levels of at least 5%. Better estimates of current productivity might have been 35% to 45%. As a result, CDFG increased the 1991 harvest level to 10%, since it appeared that this harvest would still allow the population to grow at the desired rate.

The third sardine assessment and management workshop was held by CDFG on October 1, 1991, and was attended by state, federal, and fishing industry biologists. As in the previous year, summaries of data and analysis were submitted and reviewed before the workshop. Data sources and analytical methods were similar to the 1990 workshop. The group estimated the adult sardine population to range between 275,000 and 495,000 tons. This estimate was based on incomplete data for 1991. Participants again recommended a 10% total harvest for the U.S. fishery, but also recommended that expected landings of sardines by Mexico be considered as part of the total harvest. Using the range of population estimates, the 10% harvest guideline, and an

expected Mexican catch of 13,500 tons (based on preliminary 1991 landings), the participants recommended a U.S. harvest limit between 14,000 and 36,000 tons. Since the higher biomass estimate was based on preliminary 1991 data, a preliminary 1992 quota between 14,000 and 25,000 tons was recommended. CDFG opted for the higher quota, and set the total U.S. harvest for 1992 at 25,000 tons. Specific fishery quotas included a 3,000-ton incidental reserve, a 1,000-ton live bait quota, a 500-ton dead bait quota, and 20,500 tons for the directed quota (with 6,833 tons allocated to the north and 13,667 tons to the south). In mid 1992, once 1991 data are complete, the biomass estimate and Mexican catch data will be updated, and the quota will be revised as appropriate.

CURRENT FISHERY CONDITIONS

Directed sardine landings during the first half of 1992 were low, and through June totaled only 5,000 tons, or 37% of the southern California quota. The major cannery in southern California is on indefinite furlough while the owners, a local fishermen's cooperative, face possible bankruptcy proceedings. Mackerel have been the mainstay of the southern California purse seine fleet for many years (Klingbeil 1983b), but the value (price per ton) of mackerel has declined over the last decade (Thomson et al. 1992) and, in the last two years, the catch and biomass have decreased. Canneries have been unable to develop a market for canned sardines (at least the current one-pound tall pack), and processors have reportedly been unable to attract the investment capital they require to develop new sardine products and establish new markets without a guaranteed, substantial increase in the quota. The traditional southern California purse seine fleet, which survived the demise of the sardine by fishing anchovies and then mackerel, has been in slow decline for several decades. It is ironic that the California purse seine fleet may cease to exist just as the sardine resource is making its recovery, an event these fishermen have long awaited.

The Pacific Fishery Management Council (PFMC), which includes state and federal authority, began developing a new Coastal Pelagic Species Fishery Management Plan in 1991. Responsibility for management of Pacific sardines, Pacific mackerel, and jack mackerel will shift from the state of California to PFMC when the plan is implemented in 1993. PFMC already manages the northern anchovy resource and fisheries. The development of a coastal pelagic species plan was undertaken because fisheries based on a rehabilitated sardine population

may operate outside the jurisdiction of California in federal waters, Mexican waters, and state waters off Oregon and Washington, as well as on the high seas. Another factor contributing to the decision was the possibility that factory trawlers may fish for jack mackerel in waters beyond state jurisdiction, and thus not be subject to any management controls. Effective management of coastal pelagic species will be enhanced by a cooperative state and federal effort, particularly in light of the current shortage of resources for management and assessment at both state and federal levels.

A bilateral management agreement with Mexico to facilitate the cooperative management of coastal pelagic species is a high priority for the plan. Coastal pelagic species, including anchovy, jack and Pacific mackerel, and sardines, are transboundary stocks that reside off the coasts of both Mexico and the United States, and are exploited by both countries. Recent combined catches of sardines by the United States and Mexico have been high, exceeding 40,000 tons in 1991; landings during the first half of 1992 have been lower (figure 1). Continued high landings and the absence of cooperative management could retard or suppress the recovery of the Pacific sardine.

DISCUSSION

Management of a resource like the Pacific sardine in the early part of recovery requires that the resource be protected, but also that adverse impacts on other fisheries be minimized as much as possible without jeopardizing the recovery process. Management efforts are further complicated by limited information about the status of the population when fisheries are minor or nonexistent, and precise, direct estimates of a relatively small biomass are difficult to obtain because they are too expensive, particularly in the absence of a fishery.

The workshop approach was an effective means of collating available information, and developing useful and timely management recommendations. Consultation with various experts enhanced managers' credibility, particularly with industry, and the inclusion of industry biologists in the process fostered a cooperative, rather than adversarial, approach to solving management and allocation problems. This approach can serve as a model for future management.

ACKNOWLEDGMENTS

I thank Larry Jacobson, Paul Smith, and Gene Fleming for reviewing this manuscript. Paul Smith suggested the sardine recovery as a topic for the CalCOFI symposium. CDFG personnel in the Pe-

lagic Fisheries and Sea Survey projects over many years collected the fishery data, and conducted the CDFG cruises. Participants in the sardine management workshops — particularly Tom Barnes, Larry Jacobson, Alec MacCall, Dick Parrish, and Ed Ueber — provided data, analyses, insights, and recommendations for sardine management. Diego Busatto and Greg Walls prepared the figures, and Diego Busatto also translated the abstract.

LITERATURE CITED

- Ahlstrom, E. H., and J. Radovich. 1970. Management of the Pacific sardine. In *A century of fisheries in North America*, N. G. Benson, ed. Special Publication No. 7, Am. Fish. Soc., Wash. D.C., pp. 183-193.
- Barnes, J. T., L. D. Jacobson, A. D. MacCall, and P. Wolf. 1992. Recent population trends and abundance estimates for the Pacific sardine (*Sardinops sagax*). Calif. Coop. Oceanic Fish. Invest. Rep. 33 (this volume).
- Clark, F. N. 1939. Can the supply of sardines be maintained in California waters? Calif. Fish Game 25:172-176.
- Clark, F. N., and J. C. Marr. 1955. Population dynamics of the Pacific sardine. Progress Rep., Calif. Coop. Oceanic Fish. Invest., 1 July 1953-30 March 1955:12-48.
- Crooke, S. J. 1972. Review of the pelagic wet fisheries for 1970 and 1971. Calif. Coop. Oceanic Fish. Invest. Rep. 16:15-16.
- Frey, H. W., ed. 1971a. California's living marine resources and their utilization. Calif. Dept. Fish Game, 148 pp.
- . 1971b. Review of the pelagic wet-fisheries for 1969 and 1970. Calif. Coop. Oceanic Fish. Invest. Rep. 15:13-14.
- Hardwick, J. E. 1968. Review of the pelagic wet fisheries during the 1966-67 season. Calif. Coop. Oceanic Fish. Invest. Rep. 12:22-23.
- Haugen, C. W. 1973. The status of the Pacific sardine resource and its management. Calif. Dept. Fish Game, Mar. Res. Tech. Rep. No. 13, 15 pp.
- Klingbeil, R. A. 1975. Status of the spawning biomass of the Pacific sardine, 1974-75. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 75-2, 14 pp.
- . 1976. Status of the spawning biomass of the Pacific sardine, 1975-76. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 76-4, 9 pp.
- . 1977. Status of the spawning biomass of the Pacific sardine, 1976-77. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 77-7, 6 pp.
- . 1978. Status of the spawning biomass of the Pacific sardine, 1977-78. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 78-1, 6 pp.
- . 1979. Status of the spawning biomass of the Pacific sardine, 1978-79. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 79-1, 7 pp.
- . 1980. Status of the spawning biomass of the Pacific sardine, 1979-80. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 80-1, 6 pp.
- . 1981. Status of the spawning biomass of the Pacific sardine, 1980-81. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 81-1, 7 pp.
- . 1982. Status of the spawning biomass of the Pacific sardine, 1981-82. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 82-1, 8 pp.
- . 1983a. Status of the spawning biomass of the Pacific sardine, 1982-83. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 83-1, 5 pp.
- . 1983b. Pacific mackerel: a resurgent resource and fishery in the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 24: 35-45.
- , ed. 1986. Review of some California fisheries for 1985. Calif. Coop. Oceanic Fish. Invest. Rep. 27:7-15.
- Klingbeil, R. A., and P. Wolf. 1984. Status of the spawning biomass of the Pacific sardine, 1983-84. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 84-1, 7 pp.
- MacCall, A. D. 1979. Population estimates for the waning years of the Pacific sardine fishery. Calif. Coop. Oceanic Fish. Invest. Rep. 20: 72-82.
- Murphy, G. I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proc. Calif. Acad. Sci. Fourth Series 34(1):1-84.
- Radovich, J. 1982. The collapse of the California sardine fishery: what have we learned? Calif. Coop. Oceanic Fish. Invest. Rep. 23:56-78.
- Schaefer, M. B., O. E. Sette, and J. C. Marr. 1951. Growth of the Pacific coast sardine fishery to 1942. U.S. Fish and Wild. Serv. Res. Rep. 29, 31 pp.
- Scheiber, H. N. 1990. California marine research and the founding of modern fisheries oceanography: CalCOFI's early years, 1947-1964. Calif. Coop. Oceanic Fish. Invest. Rep. 31:63-83.
- Scotfield, N. B. 1932. Report of the Bureau of Commercial Fisheries. Calif. Div. Fish and Game, 32nd Biennial Rep., for 1930-32:64-79.
- . 1934. Report of the Bureau of Commercial Fisheries. Calif. Div. Fish and Game, 33rd Biennial Rep., for 1932-34:47-60.
- Smith, P. E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70:849-874.
- Thomson, C., G. Walls, and J. Morgan. 1992. Status of the California coastal pelagic fisheries in 1991. SWFSC Admin. Rep. LJ-92-25, 47 pp.
- Wolf, P. 1985. Status of the spawning biomass of the Pacific sardine, 1984-85. Calif. Dept. Fish Game, Mar. Res. Admin. Rep. 85-1, 20 pp.
- . 1988a. Status of the spawning biomass of the Pacific sardine, 1987-88. Calif. Dept. Fish Game, Mar. Res. Div., Rep. to the legislature, 9 pp.
- . 1988b. Status of the spawning biomass of the Pacific sardine, 1988-89. Calif. Dept. Fish Game, Mar. Res. Div., Rep. to the legislature, 14 pp.
- . 1989. Status of the spawning biomass of the Pacific sardine, 1989-90. Calif. Dept. Fish Game, Mar. Res. Div., Rep. to the legislature, 8 pp.
- , ed. 1992. Review of some California fisheries for 1991. Calif. Coop. Oceanic Fish. Invest. Rep. 33 (this volume).
- Wolf, P., and M. L. Larson. 1991. Status of the spawning biomass of the Pacific sardine, 1990-91. Calif. Dept. Fish Game, Mar. Res. Div., Rep. to the legislature, 6 pp.
- Wolf, P., and P. E. Smith. 1985. An inverse egg production method for determining the relative magnitude of Pacific sardine spawning biomass off California. Calif. Coop. Oceanic Fish. Invest. Rep. 26: 130-138.
- . 1986. The relative magnitude of the 1985 Pacific sardine spawning biomass off California. Calif. Coop. Oceanic Fish. Invest. Rep. 27:25-31.
- Wolf, P., P. E. Smith, and C. L. Scannell. 1987. The relative magnitude of the 1986 Pacific sardine spawning biomass off California. Calif. Coop. Oceanic Fish. Invest. Rep. 28:21-26.