PACIFIC SARDINE

Sardinops sagax

PRODUCED BY:

CALIFORNIA SEAFOOD

Western United States Seafood PROMOTION PROGRAM

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History of the Fishery

A sustained fishery for Pacific sardines (*Sardinops sagax*) first developed in response to the demand for food during World War I. Demand grew, and fishing effort and landings increased from 1916 to 1936, when the catch peaked at over 700,000 tons. Pacific sardine supported the largest fishery in the Western Hemisphere during the 1930s and 1940s, with landings occurring in British Columbia, Washington, Oregon, and California. The fishery collapsed beginning in the late 1940s and declined, with short-term reversals, to less than 1,000 tons-per-year in the late 1960s. There was a southward shift in the catch as the fishery decreased, with landings ceasing in the northwest in the 1947-1948 season and in San Francisco in 1951-1952. Through the 1945-1946 season, most California landings were at Monterey and San Francisco, but San Pedro accounted for most subsequent landings.

Sardines were used primarily for reduction to fishmeal and oil, and canned for human consumption, with small quantities taken for live bait. Although most fish landed north of California were reduced, California processors began as canners, and expanded to reduction as a lucrative supplement. Reduction was often more profitable, and for many years reduction tonnage exceeded tonnage canned. An extremely lucrative dead bait market for sardines developed in central California in the 1960s, and was primarily responsible for continued fishing on the depleted resource.

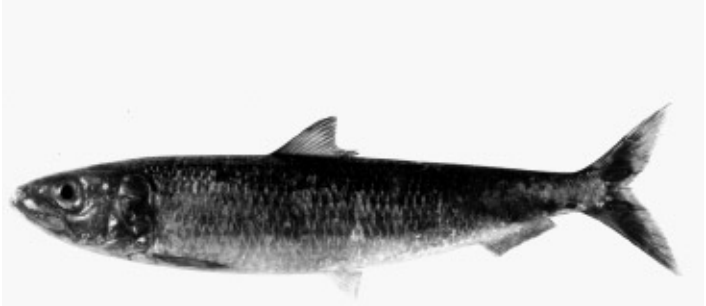
Prior to 1967, management of the sardine resource in California was mostly limited to: 1) control of tonnage of whole fish used for reduction; 2) case pack requirements (specified number of cases of canned fish per ton of whole fish); and 3) restriction of the fishing season. The first two controls were intended to lower the quantity of sardines used for reduction, since this was regarded as a less desirable use and demand for reduction products was high. The third control was designed to limit canning to periods when sardines were in prime condition and to improve the market for canned products. The total catch, however, was not regulated. From 1967 to 1973, California landings of sardines were limited to an incidental take of 15 percent sardines by weight mixed with other fish. Liberal provisions for use of incidental catch, and later a 250-ton dead bait quota still supplied the demand for bait. In 1974, a moratorium on fishing sardines was established, which restricted landings to the 15 percent incidental limit and eliminated the use of sardines for dead bait. This legislation also established the state's intent to rehabilitate the resource. Through 1981, sardine landings were less than 50 tons per year.

In the early 1980s, sardines were taken incidentally in the southern California Pacific and jack mackerel fishery. Most sardines from this source were canned for pet food, with a lesser amount canned for human consumption. A small directed fishery for sardines limited to 1,000 tons per year was permitted annually 1986 through 1990. The quota (excluding bait fisheries) was increased to 8,150 tons in 1991.

At the present time, sardines landed in the directed fisheries in southern and central California are primarily processed for human consumption (fresh or canned), pet food, or export. The majority of frozen exports are used as animal feed in Australian bluefin tuna aquaculture facilities. Small quantities are harvested for dead bait and live bait. With the exception of 1,217 tons reported in the PacFIN database for 1996, no reduction of sardines, other than waste produced from other processing operations, is taking place in California. Total annual landings of sardines have increased, from less than 100 tons in the 1970s, to an average of 13,400 tons per year through the 1980s, and 30,400 tons per year through the 1990s. Total sardine landings in California in 1999 were 62,600 tons.

Landings of sardines in Mexico increased from an annual average of 1,600 tons during the 1980s, to an average of nearly 42,000 tons per year through the 1990s. The total and average annual harvests by Mexico exceeded those for California over the period 1980 through 1999. Mexican landings of Pacific sardines, mackerels and herrings, are primarily used for reduction into fishmeal, with approximately 20 percent used for human consumption.

A federal fishery management plan (FMP) for coastal pelagic species in U.S. waters off the West Coast, including sardines, was implemented by the Pacific Fishery Management Council (PFMC) in January 2000, which transferred management authority from the California Department of Fish and Game (DFG) to the National Marine Fisheries Service (NMFS) through the PFMC. To calculate the 2000 harvest guideline, a formula selected by the PFMC in the federal management plan was used. Based on the 1999 estimate of total biomass, the 2000 sardine fishery opened January 1, with a harvest guideline of 205,902



Pacific Sardine, *Sardinops sagax*
Credit: DFG

Commercial Landings 1916-1999, Pacific Sardine
Data Source: DFG Catch Bulletins and commercial landing receipts. Data includes sardines caught for reduction fishery between 1916 and 1969.

tons for the California fishery, a 65 percent increase over the 1999 DFG quota.

The price of sardines landed incidentally with mackerel decreased from about $190 per ton in the mid-1980s to about $150 per ton in 1991. The price for sardines landed in the directed fishery and canned for human consumption ranged from $80 to $100 per ton in the late 1990s. Only limited markets exist for canned products currently being produced. It remains to be seen whether new markets will develop to utilize the fully recovered population of Pacific sardines.

Status of Biological Knowledge

Sardines are small pelagic fish and members of the herring family, Clupeidae. The genus *Sardinops* occupies the coastal areas of warm temperate zones of nearly all ocean basins. The genus is considered monotypic, and *Sardinops sagax* is the correct scientific name for sardine populations in the Alguhas, Benquela, California, Kuroshio, and Peru currents, and for populations off New Zealand and Australia. In the northeast Pacific Ocean, as in most other areas, the Pacific sardine occurs with anchovy, hake, and mackerel. It is generally accepted that the Pacific sardine population consists of three subpopulations or stocks: a Gulf of California subpopulation, a southern subpopulation off Baja California, and the principal northern subpopulation ranging from northern Baja California to Alaska. These stocks were distinguished on the basis of serological techniques. A fourth, far northern subpopulation was also postulated. Recent electrophoretic studies and examination of morphological variation showed no genetic variation among sardines from central and southern California, the Pacific coast of Baja California and the Gulf of California.

Historically, the northern subpopulation of sardines made extensive migrations, moving north as far as British Columbia in the summer months and returning south to southern California and northern Baja California in the fall. Northward movement was greater with increased age. The migration was complex, and the timing and extent of movement were affected to some degree by oceanographic conditions. At present, the population is currently expanding, found primarily off central and southern California and Baja California, but extends as far north as Vancouver, British Columbia. Contraction and expansion of range and spawning area has been associated with changes in sardine population size around the world.

Estimates of sardine abundance from AD 280 to 1970 have been derived from the deposition of fish scales in sediment cores from the Santa Barbara basin. Significant sardine populations existed throughout the time period and varied widely in size, typically over periods of roughly 60 years. Population declines and recoveries averaged about 36 and 30 years, respectively. Scale data indicate that sardine populations were much more variable than anchovy populations. Studies of deposits of otoliths have shown that, while the anchovy has been present for a million years or more, no trace of sardines has been found that is more than seven thousand years old. The tendency for tremendous variations in sardine biomass may be a characteristic of a species that has only recently occupied its habitat.

Pacific sardines reach about 16 inches and live as long as 13 years but are usually less than 12 inches and eight years old. Most sardines in the historical and recent commercial catch were five years and younger. There is a good deal of regional variation in growth rate, with average size attained at a given age increasing from south to north. Sardine size and age at maturity may decline with a decrease in sardine biomass, although latitudinal and temperature effects may also play a part. At low biomass

levels, sardines appear to be fully mature at age two, while at high biomass levels, only some of the two-year-olds are mature.

Sardines age three and older were nearly fully vulnerable to the historical fishery until 1953, but two and three year old fish became less available as the population declined and fewer southern fish moved northward. Recent catch data indicate sardines begin to become available to the fishery at age zero, and are fully vulnerable by age three. Sardines probably become vulnerable to the live bait fishery, which is located close to shore, at a younger age.

Spawning occurs in loosely aggregated schools in the upper 165 feet of the water column, probably year-round, with peaks from April to August from Point Conception to Magdalena Bay, and from January to April in the Gulf of California. The main spawning area for the northern subpopulation is between San Francisco and San Diego, out to about 150 miles offshore, with evidence of spawning as far as 350 miles offshore. Sporadic occurrences of spawning have been observed off Oregon and British Columbia in recent years.

Most spawning occurs between 55° and 63° F, with an apparent optimum between 59° and 61° F, and a minimum threshold temperature of 55° F. The spatial and temporal distribution of spawning is influenced by temperature; the center of sardine spawning shifts northward and continues over a longer period of time during warm water conditions. Pacific sardines are serial spawners and spawn several times each season, although the number of spawnings is not known. Eggs and larvae are found near the surface. The eggs are spheroid, have a distinct, large perivitelline space, and require about three days to hatch at 59° F.

Recruitment of Pacific sardines is highly variable. Analyses of the stock-recruitment relationship have been inconclusive and controversial, with some studies showing a density-dependent relationship and others finding no relationship whatsoever. From 1932 to 1965, mean recruitment only slightly exceeded potential replacement of spawners at all levels of abundance, indicating little resilience to fishing. Recruitment occurs in strings, with several years of successful recruitment followed by similar periods of poor recruitment. The timing and duration of these strings has a large effect on population growth.

A significant relationship exists among sardine reproductive success, spawning biomass and average sea surface temperature (SST). Recruitment, as well as predicted equilibrium biomass and maximum sustainable yield (MSY) are lower when temperatures are cooler.

Sardines are filter feeders and prey on crustaceans, mostly copepods, and other plankton, including fish larvae and phytoplankton. Larval sardines feed extensively on the eggs, larvae, and juvenile stages of copepods, as well as other zooplankton and phytoplankton.

Through all life stages, sardines are eaten by a variety of predators. Eggs and larvae are consumed by an assortment of invertebrate and vertebrate planktivores. Although it has not been demonstrated in the field, anchovy predation on sardine eggs and larvae has been postulated as a possible mechanism for increased larval sardine mortality during the 1950s and 1960s. Juvenile and adult sardines are consumed by other fish, including yellowtail, barracuda, bonito, tunas, marlin, mackerel, hake, and sharks; sea birds, such as pelicans, gulls, and cormorants; and marine mammals, including sea lions, seals, porpoises, and whales. It is likely that sardines will become more important as prey for numerous species, including species such as the state and federally listed California brown pelican, as the sardine resource continues to increase.

The Pacific sardine and other closely related species undergo similar interannual changes in abundance in several other temperate coastal regions of the world. Scientists in several countries have conducted joint studies of recruitment and biomass of these coastal pelagic stocks under the Sardine-Anchovy Recruitment Program. Knowledge of the population dynamics and variability of these clupeoid fishes may eventually contribute to the detection of the oceanographic effects of global climate change.

Status of the Population

Spawning biomass of the Pacific sardine averaged 3,881,000 tons from 1932 to 1934, and fluctuated from 3,136,000 to 1,324,000 tons from 1935 to 1944. The population then declined steeply over the next two decades, with some short reversals following periods of particularly successful recruitment, to less than 100,000 tons in the early 1960s. During the 1970s, spawning biomass levels were thought to be as low as 5,000 tons. Since the early 1980s, the sardine population has increased, and the total age-one-plus biomass was estimated to be greater than 1.7 million tons in 1998 and 1999.

Maximum sustained yield of Pacific sardine in the historical northern subpopulation was estimated to be 250,000 tons or about 22 percent per year, far less than the catch of sardines during the height of the fishery. Although combined landings in the U.S. and Mexico are still well below this level, landings have increased substantially in recent years. In the absence of a bilateral management agreement between the U.S. and Mexico, combined U.S. and Mexican catches of Pacific sardine have the potential for accelerating the next population decline.

Disagreement over whether the decrease in the sardine population was due to overfishing or to natural changes in the environment has persisted for many years. It is now apparent that both factors are important. Following the cessation of fishing and with the development of favorable environmental conditions, the sardine resource is now recovered.

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