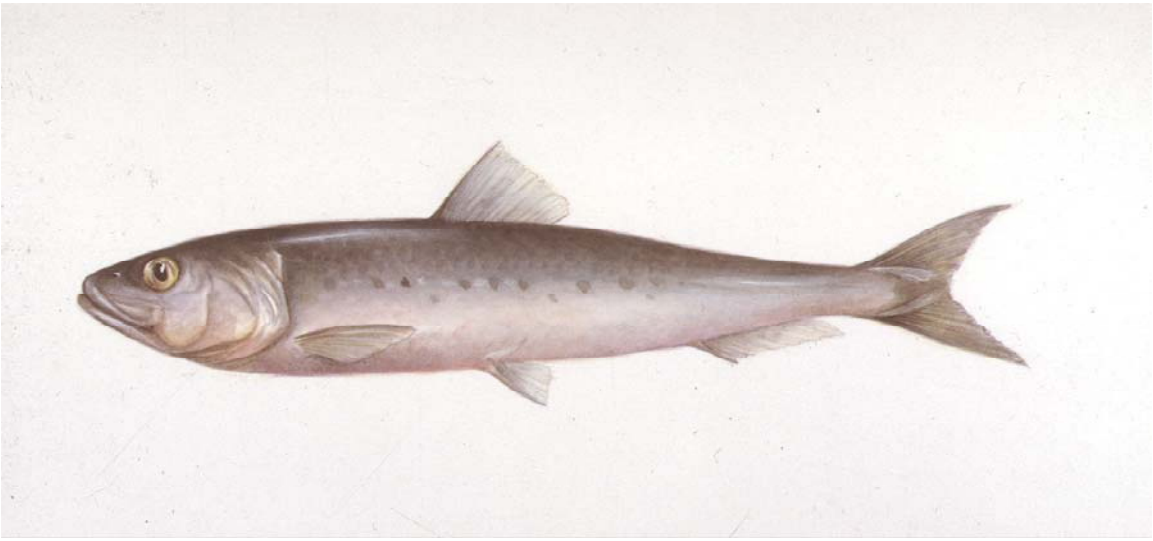
Seafood Watch
Seafood Report:

Sardines

Volume I



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Pacific sardine
Sardinops sagax

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final
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About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as species, whether fished or farmed, that can exist into the long-term by maintaining or increasing stock abundance and conserving the structure, function, biodiversity and productivity of the surrounding ecosystem. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the web (www.montereybayaquarium.org) or obtained from the program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and to shift the buying habits of consumers, restaurateurs and other seafood purveyors to support sustainable fishing and aquaculture practices.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Proceed with Caution" or "Avoid". In producing the Seafood Reports, Seafood Watch seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch Fishery Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch program at Monterey Bay Aquarium by calling 831-647-6873 or sending an email to seafoodwatch@mbayaq.org.

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Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fishery science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Executive Summary:

The Pacific sardine *(Sardinops sagax)*, a small, pelagic plankton-feeding fish, reproduces rapidly and prolifically. Pacific sardines supported the United States' largest and most lucrative commercial fishery from the 1910s through the 1940s. Sardine stocks then entered a steep decline, probably due to natural oceanographic cycles: fossil evidence suggests that Pacific sardines have experienced such "boom-and-bust" cycles about every 60 years over the last 1,700 years, independent of fishing. In any case, the U.S. fishery collapsed in the 1950s and commercial fishing ceased altogether in the 1960s. However, since the 1970s, the Pacific sardine has rebounded, and currently enjoys excellent abundance and a high growth rate. California fisheries managers consider the resource recovered, although managers note that the developing sardine fishery must be carefully regulated to avoid any impact on the ongoing expansion of the population. Management is attentive and proactive, with an FMP in place and an innovative system of catch quotas based on environmental conditions. In 2001, NMFS listed Pacific sardines as "not overfished" and "with no overfishing occurring" throughout Washington, Oregon, and California. In British Columbia, the northern edge of the recovering population's range, Canada's DFO considers the sardine "not at risk". Pacific sardines are usually taken with purse-seines, a method that, in this fishery, produces little bycatch and negligable habitat damage.

List of Five Component Ranks	Green	Yellow	Red	Avoid
Inherent Vulnerability	√			
Status of Stocks	√			
Bycatch	√			
Habitat Effects	√			
Management Effectiveness	√			

Overall Seafood Rank: **Best Choices**

A Note on Outside Review:

Seafood Watch is indebted to the outside experts who graciously volunteered their time to review the facts presented in this report for completeness and scientific accuracy: Dr. Kevin Hill, NOAA Fisheries; Jean McCrae, Oregon Department of Fisheries and Wildlife; and Daniel Waldeck, NOAA Fisheries. **It is important to note that scientific review does not constitute an endorsement of Seafood Watch on the part of the reviewing scientists; the Seafood Watch staff is solely responsible for the conclusions reached in this report.**

Introduction: Sardines

This is Volume I in a two-part series on sardines.

Volume I: Pacific sardines, *Sardinops sagax*

Volume II: Atlantic "sardines", East Coast, North America, *Clupea harengus*

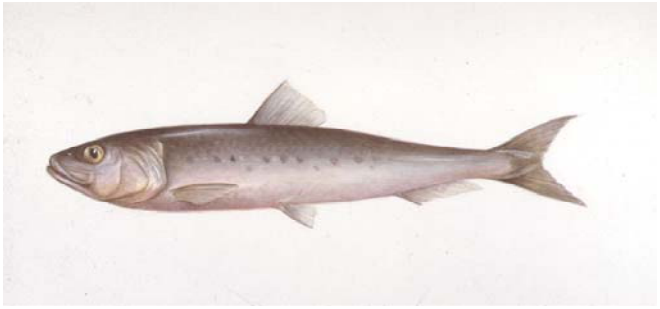
The name "sardine" is applied to dozens of small pelagic fishes of the herring family [Clupeidae] [FishBase 2002; NEFSC 2002]. These include the "true sardines" (genus *Sardinops*) as well as related fishes of the genera *Harengula*, *Sardina, Sardinella* and *Sprattus* [FishBase 2002; USFDA 2002]. Variously known as sardines, sprats, brisling, herring, and pilchard, small fish of each of these genera are marketed in the U.S. in a variety of canned and smoked forms [USFDA, 2002; NMFS, 2002]. From the 1920s through the 1940s, the Pacific sardine *(Sardinops sagax)* supported the United States' largest and most lucrative fishery; fishing and canning took place up and down the U.S. West Coast, but was concentrated in central California [Wolf et al., 2001]. On the U.S. East Coast, the "sardines" caught for canning are actually herring *(Clupea harengus)* [Overholz,2000].

All of these species are relatively small (less than 16 inches (40 cm) long at full size), and all are pelagic plankton-feeders which travel in enormous schools [FishBase, 2002]. All are prolific breeders which mature quickly, but are subject to large population fluctuations as oceanographic conditions affect recruitment [Bowen & Grant, 1997]. These fishes are caught in vast numbers in pelagic trawls and purse seines. All are marketed, to various degrees, for human consumption, often as canned product. All have also been sought, to various degrees, as baitfish and as raw material for fishmeal and fish oil [Wolf et al. 2001; Overholz 2000].

PACIFIC SARDINE

Species Biology

Scientific Name: *Sardinops sagax*



Illustration© Monterey Bay Aquarium

Small pelagic fishes of the herring family, the genus *Sardinops* has representatives along the coasts of most warm temperate oceans worldwide (Bowen and Grant,1997). The Pacific sardine ranges throughout the temperate Pacific, from Australia and New Zealand past Japan and along the coasts of North and South America [Murphy, 1966].

The Pacific sardine usually occur in the same areas and habitat as anchovy, hake, and mackerel [Barnes et al., 1992]. Near the base of the food chain, sardines are important prey for many larger fishes, as well as seabirds and marine mammals. A partial list of sardine predators includes tunas, bonito, yellowtail, barracuda, marlin, mackerel, salmon, hake, sharks, pelicans, gulls, cormorants, seals, sea lions, dolphins, porpoises and whales [Wolf et al., 2001; PFMC, 2003b]. Sardines are a key food for Pacific salmon (Francis, 1994); historical catch records show that salmon populations tend to track the rise and fall of sardine populations in the Pacific basin (Beamish, 1999).

Pacific sardines can reach 16 inches (40 cm) long and live as long as 13 years. However, most sardines taken in both historical and recent fisheries are five years old or younger. Northern populations tend to grow faster than southern ones; also, as sardine biomass declines, the fish seem to reach sexual maturity at a smaller size and younger age [Hill et al., 2000]. When there are few sardines, most reach sexual maturity by age 2, while at higher biomass levels, very few are sexually mature before age 3 [Hill et al., 2000].

Range:
Recent studies suggest three stocks of Pacific sardines along the North American west coast: a Gulf of California stock, a stock off the Pacific side of Baja California, and the main northern stock which historically ranged up the coast from Baja California to Alaska [Murphy, 1966].

Historically, the northern stock was known to migrate, heading north as far as British Columbia in the summer and returning to Southern California and Baja California in the winter. The migration pattern was complex and depended at least in part on oceanographic conditions [Ahlstrom & Radovich, 1970]. The northern stock has recovered from a dramatic decline and is currently found mostly off Central and Southern California—occasionally extending as far north

as Vancouver, British Columbia [Hill et al., 2000]. There is now evidence for a significant summer presence of sardines off Oregon and Washington, near the outflow plume of the Columbia River. The summer sardine fishery off Oregon and Washington has increased dramatically since its beginnings in 1999, with 37,800 tons landed by this fishery in the summer of 2002 [Hill,2003].

Fish scales found in sediments of the Santa Barbara Basin reveal that, over the past 1,700 years, West Coast sardine populations seem to follow a 60-year cycle of abundance and disappearance(Baumgartner, Soutar et al. 1992). Sardines and their close relatives appear to follow such boom-and-bust abundance pattern in several other temperate coastal regions (Baumgartner, Soutar et al. 1992; Finney 2002). The most recent West Coast cycle seems related to ocean temperatures [Medaris, 2001]. Historical catch records and fossil evidence suggest that climatic forcing has affected populations of sardines, anchovies, and salmon (Francis 1994; Mantua 1997) throughout the Pacific basin for at least the last 2,200 years (Finney 2002). While otolith fossils confirm that anchovies have inhabited the California coast for more than a million years, the same fossil beds present no trace of sardines older than 7,000 years (Bowen and Grant 1997). Some hypothesize that the "boom-and-bust" cycle of sardine populations is characteristic of a species that has only recently colonized a new habitat (Bowen and Grant 1997).

Pacific sardines travel in schools of up to 10 million individuals [Whitehead, 1985, as cited in McCrae, 1994]. Spawning occurs within the school, with males and females broadcasting gametes into the water column. Spawning takes place in the upper 165 feet (50.3 m) of the water column [Wolf et al., 2001]. Spawning occurs wherever waters are between 55˚ and 63˚ F (13˚ and 17˚C) [Wolf et al., 2001]; this means spawning occurs at different times in different parts of the sardine's range—i.e., sardines spawn off Mexico in the winter months, off southern California in the spring, and off the Pacific Northwest in summer [Hill, 2003]. Each fish spawns several times per year, though exactly how often is not yet known [Wolf et al., 2001]. A large female can produce 200,000 eggs per season [Hart, 1973, as cited in McCrae, 1994]. The spherical eggs, recognized by a characteristic large "space bubble" under the outer membrane, float near the surface and require about three days to hatch at 59˚ F (15˚C). Larvae remain near the surface, feeding on the plankton that will sustain them into their adult life. Sardines are filter-feeders, straining their food out of the water as they swim. They eat a wide variety of plankton, including copepod crustaceans, fish larvae, and phytoplankton. All life stages of copepods are important food for sardines: the eggs and tiny larvae for the larval sardines, the adults for juvenile and adult sardines [Whitehead, 1985, as cited in McCrae, 1994].

Statement on the Availability of Science:
Thanks to its long history of exploitation and its dramatic decline, more high-quality data is available about the Pacific sardine than about many other species [SWFSC, 2003]. From the

website of the Fisheries Resources Division (FRD) of NMFS' Southwest Fisheries Science Center [SWFSC FRD, 2003]:

> "The FRD, working jointly with California Department of Fish and Game, conducts stock assessments and recruitment research in support of management of Pacific sardine, chub mackerel, northern anchovy and market squid. These species are managed or monitored by the Pacific Fishery Management Council under the CPS (Coastal Pelagics) Fishery Management Plan (FMP). Other important coastal pelagic species, (bonito, yellowtail, barracuda, white seabass, etc.) occur in Southern California waters (U.S.) and Baja California (Mexico) waters. However, since they are not in a Federal plan, they are currently not the focus of FRD research. Annual assessments depend upon CalCOFI surveys to provide fishery independent measures of abundance. Cooperative work and sharing of data with Mexican scientists on CPS has been ongoing for over 40 years through the CalCOFI program. More recently, MEXUS-Pacifico, a Federal program, has become the official forum for fishery discussions between the governments of Mexico and the U.S. A May 2000 workshop on sardine (Sardine Symposium 2000), recommended a new forum for international sardine collaboration and information exchange (FISCIE). **FISCIE** would involve NOAA Fisheries and academic scientists and industry representatives from Canada, Mexico and the United States."

Market Information:

After tuna, sardines are the most popular canned fish product in the United States [Johnson, 2001]. Fresh sardines are once again becoming popular in West Coast fish markets [Johnson, 2002]. However, consumer demand is still much reduced, compared to consumer demand for sardines during the 1920s, 1930s, and 1940s [Wolf et al., 2001]. It appears that the collapse of the fishery, coupled with the rising availability of fresh and fresh-frozen fish since 1950, has limited the domestic market for canned sardine products [Wolf et al., 2001]. Currently, the California Department of Fish and Game considers the sardine resource underutilized [Wolf et al., 2001].

Most of the Pacific sardine now caught in U.S. fisheries is "low-value, high-volume" product [PFMC,2003b] frozen and exported to Australia for feeding penned tuna [PFMC,2003b] or to Japan for use as bait fish [Hill, 2003]. Some of the catch is also exported as frozen blocks to Brazil and other nations, where the fish are canned and sold for local human consumption [Hill 2003; PFMC,2003b]. Much smaller amounts of sardine are taken for high-value markets, including : live bait sold to recreational anglers; fresh fish for domestic consumption or import; and fresh fish for use in domestic canneries [PFMC,2003b.]

There are some regional differences in the marketing of sardines. Sardines taken in the southern and central California fishery are sold fresh or canned for human consumption, processed into pet food, or frozen for export. Much of California's frozen export is used as food for bluefin tuna in Australian tuna ranching facilities [Hill et al., 2000]. From the early days of the fishery, small quantities of sardines were taken as live bait. In the 1960s, a new and highly profitable market developed for sardines as dead bait. California's dead-bait fishery was largely responsible for the last commercial fishing on the depleted resource [MacCall, 1979]. While use of sardines for dead bait continues, California's live-bait sector has become increasingly important. About 5,000 mt/year of California sardines are landed for local use as live bait in recreational fisheries; live bait sardines are worth more than $4,000/ton and so comprise a very lucrative component of the California fishery [Hill 2003; PFMC,2003b]. Sardines landed in the Pacific Northwest, on the other hand, are more likely to be exported to Japan, where some are consumed as fresh fish, and others are used as bait in Japan's extensive longline fisheries [Hill, 2003].

The only sardine material now rendered in California is trimmings from fish landed for other purposes [Hill et al., 2000].

Market Names:
Alternate market names for the Pacific sardine *(Sardinops sagax)* include sardine, pilchard, California sardine, Chilean sardine, sardina, South American sardine, and California pilchard [USDA, 2002].

Seasonal Availability:
The West Coast sardine fishery opens January 1 [PFMC, 2000]. Fresh local sardines are normally available January-August [Johnson, 2002], and sometimes into October [PFMC, 2002b]. The availability of fresh sardines tracks the migration of the stocks from north to south throughout the season [PFMC, 2002b]. Canned sardines are available year-round.

Fishing Methods:
Pacific sardines are taken primarily via purse-seine [Waldeck, 2003], although small amounts have also been taken as incidental catch in various midwater trawl fisheries [Wolf et al. 2001; PFMC 2002], including the midwater whiting fishery [Hill 2003; McCrae, 2003b]. British Columbia's experimental sardine purse-seine fishery reports very low levels of bycatch, on the order of 1% of the total catch [PFMC, 2002]. Their bycatch consisted largely of marketable species such as chum salmon, dogfish, and Pacific hake, which are, indeed, landed and marketed [PFMC, 2002; PFMC,2003b].

Recent catch data suggest that sardines begin to be vulnerable to the fishery before their first birthday (age 0) and are fully vulnerable by age 3 [Hill et al., 2000]. "Vulnerable," in this case, means they've grown too big to escape through the mesh of regulation-size nets.

History of the Fishery:
The West Coast fishery for Pacific sardines began in 1916, in response to a national demand for new food sources during World War I [Ahlstrom & Radovich, 1970]. The fishery expanded rapidly throughout the 1920s, peaking in 1936 at more than 700,000 tons [Ahlstrom & Radovich, 1970]. Throughout the 1930s and 1940s, Pacific sardines supported the largest fishery in the Western Hemisphere [Ahlstrom & Radovich, 1970]. The fish were landed from British Columbia to California. But the fishery began to collapse in the 1940s. Catches in the northern part of the range ceased first. In this era of the fishery's decline, the last Washington and Oregon landings were recorded in 1948, the last San Francisco landings in 1952 [Ahlstrom & Radovich 1970; McCrae 1994]. Before 1946, most of California's sardine catch was landed in Monterey and San Francisco [Ahlstrom & Radovich, 1970]. However, with the southward movement of the sardine stocks, most California catches after 1946 were landed in San Pedro [Ahlstrom & Radovich, 1970].

While the fishery initially produced canned fish for human consumption, the value of canned sardines was soon surpassed by that of fish oil and fishmeal, used in animal feed and agricultural fertilizer [MacCall, 1979]. "Reduction", or rendering of the fish into meal and oil, was often more profitable than canning them for human consumption, and, throughout the 1920s and 1930s, reduction tonnage often exceeded tonnage of sardines canned [MacCall, 1979].

The reduction fishery proved very profitable, and heavy landings of sardines for reduction led to the first management laws for the species. Historically, fisheries managers have considered reduction a less-desirable use of sardines than canning for human consumption [MacCall, 1979]. Before 1967, management of California's sardine fishery consisted of control of tonnage of fish used for reduction; "case pack requirements" (specifying a certain number of cases of canned fish be produced from each ton of whole fish); and fishing seasons designed to limit catch to when the fish were in prime condition for canning (an effort to boost demand for canned sardines) [MacCall, 1979].

In 1967, catch limits were introduced for the first time [MacCall, 1979]. Catch was limited to incidental take of 15% by weight mixed with other fish. Fishing for the dead-bait market was still permitted, with a yearly catch limit of 250 tons [MacCall, 1979]. In 1974, directed fishing for sardines was halted, and the dead-bait market was eliminated. Incidental catch up to the 15% limit was still permitted. From 1974 to 1981, sardine landings were less than 50 tons per year [Wolf et al., 2001].s

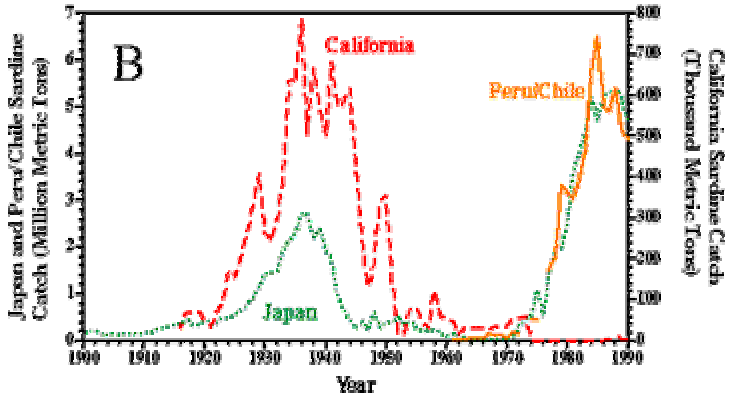


Figure 1: Landings of Pacific sardine, 1900-1990. Please note difference in scale for California data. *Source: Northeast Pacific Program, 2001.*

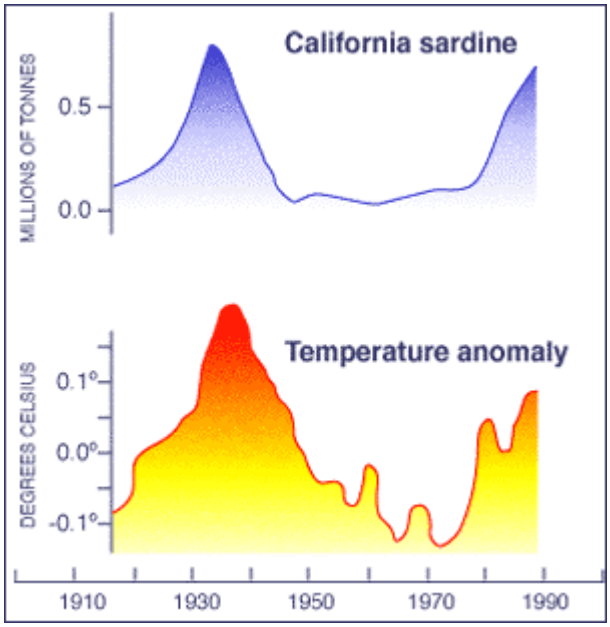


Figure 2: Correlation between Pacific sardine abundance and water temperature *Source: Medaris, 2001.*

In the early 1980s, moderate numbers of sardines began to appear in the southern California mackerel fishery. In 1986, a small directed fishery was permitted, with annual limit of 1,000 tons [Wolf et al., 2001]. In 1991, continued increase in the sardine population prompted managers to raise the limit to 8,150 tons per year [Wolf et al., 2001].

The Fishery Today:
In the United States, Pacific sardines are landed by a limited-entry fleet managed under the Coastal Pelagic Species (CPS) FMP. This fleet of mostly-small vessels targets the species regulated under this FMP--Pacific sardine, Pacific mackerel, jack mackerel, northern anchovy, and market squid—and some participants also fish for Pacific bonito, Pacific herring, and Pacific northern bluefin tuna [PFMC,2003b]. In 2003, the limited-entry fleet consisted of 65 vessels [PFMC,2003b]. Fifty-five of these hold permits to catch market squid in California waters [PFMC,2003b]. The squid are taken using the same boats and essentially the same purse-seine gear as the sardines (Pomeroy, 2002). This can mean that an active squid season takes California fishermen out of the sardine fishery, as occurred in 2002 [PFMC, 2002; CPSMT Report, 2003].

Total annual landings in the California sardine fishery, which were less than 100 tons per year in the 1970s, averaged 13,400 tons/year during the 1980s and almost 42,000 tons/year through the 1990s [Hill et al., 2000]. In 1999, California landings totaled 62,600 tons [Hill et al., 2000] and were about 74,554 mt in 2002 [PFMC, 2003b]. The California fishery is the largest component of the total fishery: in 2001, 87% of Pacific sardine was landed in California. In 2002, that figure had dropped to 77%, due to an ongoing expansion of the Oregon and Washington fisheries [PFMC, 2003b].

Oregon's directed fishery for sardines ceased in 1950 [McCrae, 1994] and did not resume again until 1999 [McCrae, 2003b]. In the early 1990s, small amounts of sardine appeared as incidental catch in Oregon's gillnet fisheries [McCrae, 1994]. An experimental purse-seine fishery for sardines began in Oregon and Washington in1999, and has grown dramatically since [Hill, 2003; McCrae 2003b; WaDFG, 2001]. Oregon's landings jumped from 1.7 million pounds in 1999 to over 50 million pounds in 2002 [McCrae, 2003]. Combined total landings of the Oregon and Washington fisheries were about 37,800 mt in 2002 [Hill, 2003]. About 90% of the catch in this fishery is taken by the Oregon fishery, 10% by the Washington fishery [McCrae, 2003b]. In this purse-seine fishery, incidental catch that may be retained and marketed includes anchovy, Pacific mackerel, jack mackerel, and squid. The Oregon fishery also allows incidental catch of Pacific herring and shad [McCrae, 2003b]. All other species must be released alive, and salmon could not be brought on deck, but had to be released or dip-netted out before the set was completed [McCrae 2003b; WaDFG, 2001]. The Washington Department of Fisheries and Wildlife places observers aboard vessels in this fishery to document catch and bycatch; in 2000, observers covered about 41% of all sets made [WaDFG, 2001]. Oregon also has observers in place [McCrae, 2003b]. Bycatch has been minimal in the Washington fishery, but has included chinook and coho salmon, dogfish, soupfin shark, and other species. Most by-caught fish were released alive [WaDFG, 2001]. Bycatch in the larger Oregon fishery has also been minimal; in 2002, the latest year for which statistics are available, 280 individual salmon were caught, by 17 vessels making 657 separate landings [McCrae, 2003b]. According to logbooks and observer data, between 50% and 71% of these salmon were released alive [McCrae, 2003b].

Sixty-one vessels and 21 fish processors currently participate in the total CA-OR-WA fishery [PFMC, 2002]. In 2001, landings in the entire CA-OR-WA fishery totaled 74,957 metric tons, worth just over $9 million [PFMC, 2002]. In 2002, CA-OR-WA landings increased to 97,229 mt [Hill, 2003].

Pacific sardines are also landed by Mexico, as part of a mixed fishery that takes sardines, herring and mackerel [Hill et al., 2000]. Eighty percent of these fish are processed into fishmeal, with twenty percent used for human consumption [Hill et al., 2000]. From 1980 through 1999, Mexico's sardine harvest exceeded California's [Hill et al., 2000]. In 2002, Mexico's landings totaled 43,437 mt [Hill, 2003].

The sardine fishery was British Columbia's highest-tonnage, highest-value fishery from 1926 through 1946 [DFO, 2000]. But it was not until 1997 that the population had increased enough for Canada's Department of Fisheries and Oceans (DFO) to allow a small-scale, experimental return to sardine fishing. In 2000, seven vessels purse-seined for sardines in B.C. waters [DFO, 2000]. The total allowed catch in 2000 and 2001 was 1600 mt [PFMC, 2002]. In 2002, this Canadian fishery landed 703 mt [Hill, 2003]. The sardines that migrate into British Columbia are large, mature fish that can supply a high-value niche market: when chilled at sea or maintained in refrigerated seawater, they can be sold as high-quality tuna bait or food for pen-ranched bluefin tuna [DFO, 2000]. These high-quality sardines are also in demand for human consumption in the Japanese market [Hill, 2003]. British Columbia's experimental sardine fishery is limited to purse-seine gear and is required to provide catch data to Canada's DFO, to carry on-board observers, and to fish only in approved areas [PFMC, 2002].

With increasing catches, the price of sardines has declined. From a high of about $190 per ton in the mid-1980s, California sardines of human-consumption quality sold for $80-$100 per ton in the late 1990s [Wolf et al., 2001].

Management:
Before 2000, the California sardine fishery was managed by the California Department of Fish and Game (DFG) [Wolf et al., 2001]. In 2000, a new federal Fisheries Management Plan (FMP) covering Pacific coastal pelagic species came into effect [Wolf et al. 2001; NMFS 2001]. Authority for West Coast sardine fisheries was transferred to the Pacific Fishery Management Council (PFMC) and National Marine Fisheries Service (NMFS). PFMC management recommendations are reviewed and, if approved, implemented by NMFS [NMFS, 2001; Waldeck, 2003].

When the California sardine fishery was managed by the California DFG, the major management tool was a series of state-set recommended catch quotas [Wolf et al., 2001]. States still retain some authority over their sardine fisheries: in 2002, the Washington Department of Fish and Wildlife considered implementing a limited-entry system for its burgeoning sardine fishery (but decided not to) (Wyman 2002).

Like the DFG before it, the PFMC regulates the Pacific sardine fishery through recommended catch quotas, or "harvest guidelines". These guidelines apply to the entire U.S. West Coast stock, which is fished from the Canadian border to the Mexican border (PFMC 2002). The fishery is managed as two subareas, a northern and a southern. Within those subareas, there are three

sectors of the fishery: Southern California; Monterey Bay/Northern California, and Oregon/Washington. While the sardine season runs all year long, January 1 through December 31 (PFMC, 2002b), each of the three fishery sectors operate over a unique schedule, based upon sardine migration and abundance [CPSMT Report, 2003]. Generally, the Southern California fishery starts harvesting sardine January 1 and continues throughout the year. Monterey Bay/Northern California starts in August and runs through January or February of the following year (influenced by availability of market squid and adverse weather). Oregon and Washington have a much more abbreviated season, June through October (affected by sardine availability and adverse weather) [CPSMT Report, 2003]. Because these sectors operate on very different schedules, annual allocations help to ensure that each sector receives a reasonable fishing opportunity [CPSMT Report, 2003]. (see below for a discussion of 2003 changes to harvest allocations). Landings in all three sardine-fishery sectors are driven by domestic and international market forces. [CPSMT Report, 2003].

According to the Pacific Coastal Pelagics FMP, nine months after the start of the sardine season (i.e., on October 1), any uncaught portion of the quota is to be totaled and reallocated, with 50% going to each subarea (PFMC 2002). (The specifics of these regulations were changed in 2003—see below.) The harvest guideline is then in effect until Dec. 31, or until the entire quota has been caught (PFMC 2002).

Catch quotas are set based on biological and oceanographic data [Hill, 2003]. Each year, the PFMC conducts an early-season egg-production survey of sardine biomass (PFMC 2002), [Hill, 2003]. Using this survey data and other inputs, statistical catch-at-age population models are used to calculate stock abundance and set harvest guidelines [Hill, 2003; Waldeck, 2003]. In 2000, the PFMC specified a harvest guideline of 205,902 tons (209,206 mt)—a 65% increase over the 1999 limit, when the fishery had been regulated by the California DFG [PFMC, 2000]. With an apparent dip in the population evident in the 2001 survey, the 2002 harvest guideline was set at 118,442 mt (PFMC 2002). In winter 2002, the total sardine population was estimated at 999,871 mt, and PFMC set a provisional harvest guideline of 110,908 mt for the 2003 season (PFMC, 2002b).

In September 2002, the PFMC considered a recommendation from their Coastal Pelagic Species Subpanel to revise the regional allocation guidelines (PFMC 2002). Some northern subarea fishermen contend that the current allocation of 66% of the harvest quota to the southern fishery is unfair to the northern fishermen and out-of-step with the current state of the stocks. When the allocation system was set, most of the sardines were concentrated in the southern part of their range, but as the population has expanded northward, so has the fishery. According to the northern-subarea fishermen, the current allocation model often closes the northern fishery while there are still plenty of sardines in northern areas. Then, as the fish migrate south, the smaller southern fishery takes less than their allocated portion of the quota--with the result that the total quota goes unfished. Northern fishermen contend that it would be a better use of fishing resources to allow them to catch more of the total quota (PFMC 2002).

In 2002, the PFMC asked its Coastal Pelagic Species Management Team to review this situation and recommend alternatives at the November 2002 Council meeting (PCNews 2002). This was done, and, at its April 2003 meeting, the PFMC changed the fishing rules as follows [PFMC, 2003]:

> --the definition of the northern and southern subareas was changed by moving the geographic boundary dividing the two northward to Point Arena. Effectively, this means that the "northern fishery" is now the Oregon-Washington fishery and the "southern fishery" now includes the large Monterey Bay California fishery.
> --moved the date of the yearly harvest reallocation from October 1 to September 1
> --changed the percentage of unharvested sardine that is reallocated to both subareas. Instead of reallocating any surplus quota 50-50, the new rule allocates 80% of any unharvested quota to the southern subarea and 20% to the northern subarea.
> --a second reallocation will be conducted December 1, to allow harvest of any remaining portion of the quota by any segment of the fishery.

The PFMC intends these measures to reduce the risk of too-early closure of the northern fishery while minimizing risk of early closure for the traditional California fisheries [PFMC, 2003]. NMFS published final regulations implementing these measures in September, 2003 [NMFS Press Release, 2003]. These new allocation rules are intended to be in place for 2003, 2004, and 2005, allowing some stability for the fishers and fish processors while managers work on a longer-term allocation plan [PFMC, 2003; NMFS Press Release, 2003].

Status of the Stocks

Because of the extensive fishery, the history of the Pacific sardine stock is well known. Between 1932 and 1934, spawning biomass averaged about 3.9 million metric tons. Between 1935 and 1944, the population fluctuated between about 3.1 and 1.3 million tons. The population then entered a drastic decline, dropping to 100,000 metric tons in the early 1960s and to less than 5,000 mt in the early 1970s [MacCall, 1979]. However, since the late 1970s, the trend has reversed, and the population has been on the increase, with a high growth rate [Barnes et al., 1992]. In 2003, managers reported that the Pacific sardine population has been increasing at a rate of about 30% per year for the past 15 years [SWFSC, 2003]. In 1998-1999, the total biomass of sardines one year of age or more along the U.S. West Coast was estimated at 1.7 million metric tons [Hill et al., 2000]; in 2003, this biomass was estimated at 1.1 million mt [Conser et al, 2003]. (Managers suspect that total Pacific sardine biomass has now leveled off at about 1 million mt, but require another 2-3 years of data to be certain) [Conser et al, 2003]. One million metric tons is considered a healthy stock, though managers note that it is still three times less the peak biomass of the 1930s. Managers are not sure whether sardine biomass will continue to increase, or whether 1 million mt is the approximate carrying capacity under current environmental conditions [Conser et al, 2003].

Catch reports from Japan and Chile show a parallel recovery around the range of the Pacific sardine [Northwest Pacific Program, 2001]. Chavez et al. (2003) explain this as an effect of a hitherto-unrecognized oceanographic cycle, which shifts the Pacific basin between a cool-water regime favorable to anchovies and a warm-water regime favorable to sardines.

At the height of sardine abundance, the maximum sustained yield [MSY] of the northern subpopulation was estimated at 22%, or 250,000 tons/year [MacCall, 1979]. Fisheries took far less than this [Wolf et al., 2001]—evidence that fishing alone was not responsible for the drastic decline. Combined landings of the U.S. and Mexican fisheries are still well below this MSY. However, landings have increased substantially in recent years. Some researchers believe that the current recovery of the stocks was slowed by the fact that, after oceanographic conditions turned, the remnant sardine population was depleted by ongoing fishing during the 1960s [Barnes et al., 1992]. Moreover, Chavez et al. (2003) suggest that the sardine population's current recovery is the result of a shift to a warmwater regime that began in the 1970s but ended in the 1990s. They assert that a shift back to the cool-water "anchovy regime" occurred in the late 1990s [Chavez et al., 2003]. This suggests that the sardine population may soon begin to decline, and that managers should take climatic cycles into account when setting sardine quotas. Indeed, U.S. managers have developed an innovative process in which sea surface temperature is used in calculating harvest guidelines [Waldeck, 2003; Hill, 2003; Conser et al, 2003]. Under these rules, F_{msy} varies between 5% and 15% of total biomass, based on sea-surface temperature [Conser et al, 2003]. This formula raises catch quotas during warm years and reduces catch levels when the ocean cools and productivity decreases [Hill, 2003; Conser et al, 2003]. This harvest formula also shuts the fishery off when biomass is below 150,000 mt, and it never allows more than 200,000 mt of landings, regardless of how high the biomass goes [Hill, 2003; Conser et al, 2003].

Between 1983 and 2003, sea-surface temperatures have remained warm, and managers have been able to use the more generous F_{msy} value of 15% [Conser et al, 2003]. For 2003, managers calculated maximum sustained yield [MSY] of West Coast Pacific sardine at 15% of total biomass, or about 165,000 mt/year. In 2003, this MSY was used to set a harvest guideline of 110,908 mt, of which about 94,000 mt were actually caught [Conser et al, 2003]. For 2004, the PFMC has set the harvest guideline 11% higher, at 122,747 mt [Conser et al, 2003].

There is as yet no bilateral management agreement in place between Mexico and the United States. California fisheries managers note that, in the absence of such an agreement, combined U.S. and Mexican catches have the potential to accelerate the next population decline [MacCall, 1979].

Whether the Pacific sardine crash was caused by overfishing or by natural environmental factors has been debated for decades by fishermen, scientists and fisheries managers. According to the California Department of Fish and Game, "(i)t 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" [Wolf et al., 2001].

As of 1999, the California Department of Fish and Game considered the California sardine resource recovered [Hill et al., 2000]. The PFMC's October 2003 Stock Assessment finds the population to be holding steady at a "relatively high abundance level"[Conser et al, 2003].

In 2001, NMFS listed Pacific sardines as "not overfished" and "with no overfishing occurring" throughout Washington, Oregon, and California [NMFS, 2001].

In British Columbia, the northern edge of the recovering population's range, Canada's DFO considers the sardine "not at risk" (Gross 2002). Until recently, the sardine had been listed as a species of "special concern" [DFO, 2001], but, thanks to the strong ongoing recovery of the stocks, the designation was changed in May 2002, with the approval of Canada's Committee on the Status of Endangered Wildlife (Gross 2002). However, the DFO's Pacific Scientific Advice Review Committee notes that "we do not know enough about sardine biology at this point, so the development of the(British Columbia) fishery should proceed cautiously" [DFO, 2001].

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