# HISTORICAL PATTERNS FROM 74 YEARS OF COMMERCIAL LANDINGS FROM CALIFORNIA WATERS

JANET E. MASON
Pacific Fisheries Environmental Laboratory
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
1352 Lighthouse Avenue
Pacific Grove, California 93950
janet.mason@noaa.gov

## ABSTRACT

California's commercial fisheries harvested many different species of finfish and invertebrates from 1928 to 2001. A time series of the landings from waters off California was created to examine changes in the species composition, weight, and value of the landings. Small coastal pelagic fishes dominated the landings weight until the late 1980s, when landings of invertebrates increased. Tunas, groundfish, salmon, crabs, sea urchins, and squid have all contributed significantly to the value of the landings. Value and landings were affected by domestic and international market conditions. The availability of certain species, especially coastal pelagics, has varied in response to decadal-scale changes in environmental conditions, and tunas, herring, and squid varied with interyear environmental warming from California El Niño events. The depletion and subsequent regulation of many of the stocks, including several rockfish, have contributed to declines in their landings over time. Invertebrates became more important in both the weight and value of landings in the 1990s. The declining trend in the total value of landings, despite increased total landings, raises concern for the future of the fishing economy.

## INTRODUCTION

California's fisheries have experienced wide changes in abundance of targeted species, leading to the collapse of some fisheries, including Pacific sardine (*Sardinops sagax*), Pacific mackerel (*Scomber japonicus*), and certain groundfish species. Many fisheries have maintained high landings for only ten to twenty years, and new fisheries have been developed to replace those that have declined. Changes in the size and type of fish landed on the U.S. Pacific Coast were described for four periods from 1888 to 1976 by Deimling and Liss (1994). In this article, a continuous series of California landings from 1928 to 2001 will be examined.

At the beginning of the twentieth century, California's fisheries were generally assumed to be inexhaustible. Among the first fisheries to be regulated were those that had been heavily exploited in the rivers and estuaries, such as salmon (*Oncorhynchus* spp.)(Fry 1949) and sturgeon (*Acipenser* spp.)(Nelson 1949). California barracuda (*Sphyraena argentea*) was among the early marine species to be regulated, beginning in 1915 (Ally and Miller 2001). The notion that our fisheries are inexhaustible was proven untrue by the collapse of the Pacific sardine population and fishery in 1952. Sardines staged a slight recovery in the late 1950s but then continued to decline until a moratorium was placed on their sale in 1974. Heavy fishing pressure on spawning stocks (Murphy 1966) and ocean environmental conditions (Chavez et al. 2003) contributed to the changes in sardine availability.

The groundfish fishery expanded after the collapse of the sardine fishery, when many vessels converted from the sardine fleet to the groundfish fleet. Groundfish landings reached a peak in the 1980s but then decreased as more regulations were created to slow the harvest and protect certain species from overfishing. In 1996, the goal of sustainability was incorporated into federal management strategies in the revision of the Magnuson-Stevens Fishery Conservation Act, and quotas and trip limits were placed on many species to order to achieve that goal. Recent estimates of rockfish productivity were lower than previously modeled, and some species became overfished despite intensive management (PFMC 1998b). To protect certain overfished rockfishes, the Pacific Fisheries Management Council closed about half the bottom-fishing grounds on the continental shelf of the West Coast in 2002.

How sustainable have California fisheries been? The duration of fisheries and changes between fisheries will be examined for the last 74 years from records of California commercial landings published by the California Department of Fish and Game (CDFG). Landings are not an unbiased representation of the abundance or availability of species in the area, but they do indicate changes in the fisheries, which were also affected by market demand and fishing regulations. To better indicate the market's effects on the fisheries, the value of the landings will also be examined.

[Manuscript received 23 February 2004.]

## METHODS

The weight and value of the catch brought to shore for sale (the landings) are recorded by fish buyers, markets, and canneries and compiled by CDFG. The monthly commercial landings of fish and invertebrates are taken from summary tables published in CDFG's *Fish Bulletin* series for 1928-1976 (numbers 44, 49, 57, 58, 59, 63, 67, 74, 80, 86, 89, 95, 102, 105, 108, 111, 117, 121, 125, 129, 132, 135, 138, 144, 149, 153, 154, 159, 161, 163, 166, 168, 170). The published tables include California landings of fishes caught either north or south of California's borders; the majority of these landings were tropical tunas. In order to track the variability of species from California waters, this data set includes only the landings recorded as caught off California. The initial year for our data set was 1928, the first year that monthly landings from southern waters were distinguished from those caught off California.

Published landings after 1976 in *Fish Bulletin* 173 did not indicate catch from north or south of California nor monthly values, so the 1977–1980 data were taken from unpublished reports of monthly landings produced by the Statistics Branch of CDFG. Beginning in 1981, the monthly landings were obtained in a digital file from PacFIN (Pacific Fisheries Information Network) with data supplied by CDFG. The extract of the PacFIN data was limited to waters off California and was standardized to dressed weights (rather than round weights) for all species, to be consistent with CDFG tables before 1981. The landings data can be accessed through the live-access server on the Web page www.pfeg.noaa.gov.

Landings are recorded by market categories; many of them contain a single species, but some contain several species caught and sold together. Over time, the number of categories used each year has increased from 67 to over 300. Most of this increase stems from the subdivision of existing categories, such as unspecified sole (Pleuronectidae), into separate species categories, but some is from the harvest of formerly unexploited groups, such as red sea urchins (*Strongylocentrus franciscanus*). Pacific mackerel and jack mackerel (*Trachurus symmetricus*) were landed together as unspecified mackerel from 1977 to 1990; the CalCOFI table of landings of pelagic wetfishes was used to separate landings of those two species for those years (CDFG Marine Region 1998). For this analysis, market categories were combined into major groups plotted as stacked-column time series of total landings. The composition of each major group is also broken down in a separate plot to show more detail, but only seven species or groups with significant shares of the landings can be clearly displayed in each figure.

The value of the landings paid to fishers (ex-vessel value) for market groups was also recorded in CDFG's *Fish Bulletins* beginning in 1939. This was put into a second data set. To remove the value of the landings caught north or south of California's borders, the value of those landings was calculated for each market group, using that group's average price per pound for that year and subtracted from the value of the landings. PacFIN data were used to extend the series from 1981 through 2000, and tables from the United States Bureau of Fisheries (1928–1938) were used to extend the series of values back from 1938 to 1928. To remove the effects of inflation, all values were then standardized to year 2000 dollars with the Consumer Price Index (Bureau of Labor Statistics 2002).

The time series of commercial landings does not necessarily reflect the relative abundance or availability of different species in the ocean off California. Instead, it is a composite of abundance, availability, market demand (which sets price and maximum trip weight), and each fisher's preference (based largely on economics, experience, gear, and type of vessel) for catching one species or group over another. Fishing regulations, such as catch quotas, also play a part in limiting some fisheries, particularly since the 1980s. Thus the relative increase or decrease of a species in the landings may reflect more than just a change in abundance.

## RESULTS

Most of California's landings come from four categories: groundfishes, coastal pelagic fishes, tunas, and invertebrates. A few other significant fisheries that do not fit into these categories are grouped here as "other fishes." Within each fishery, the dominant species landed has changed over time. Different kinds of vessels and equipment are used in each of these fisheries, and this limits the opportunity to change from one fishery to another.

Groundfishes comprise several different types of fish caught on or near the bottom, including flatfish (Pleuronectidae and Bothidae), rockfish (*Sebastes* spp.), thornyheads (*Sebastolobus* spp.), sablefish (*Anoplopoma fimbria*), and Pacific hake (*Merluccius productus*). Most groundfishes are caught with otter trawls towed from boats 50 feet or longer; some are caught in midwater, particularly widow (*Sebastes entomelas*) and yellowtail rockfish (*S. flavidus*) and hake. Some sablefish are caught with traps, some sablefish and thornyheads are caught on longlines, and since the 1990s a small percentage of rockfishes have been caught on hooks in shallow water for the live-fish market. Gill nets were also used for rockfishes and California halibut (*Paralychthys californicus*) in the 1980s and earlier, but gill nets were restricted to progressively deeper water in the 1990s to prevent bycatch of diving birds and mammals.

There were two periods of rapid growth for total groundfish landings, one in the mid-1940s and the other in the 1970s; and there was a period of steady decline in

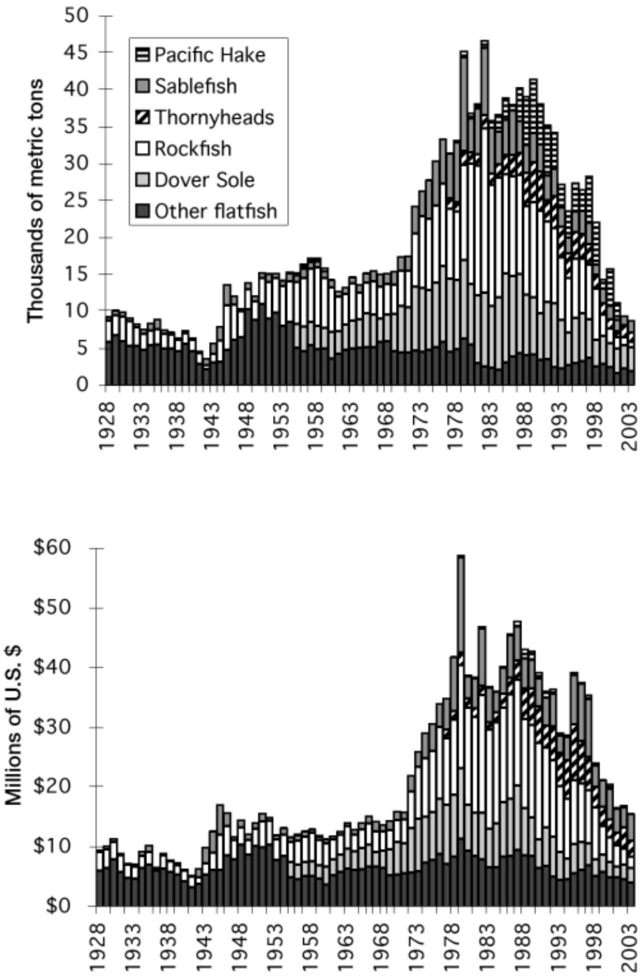


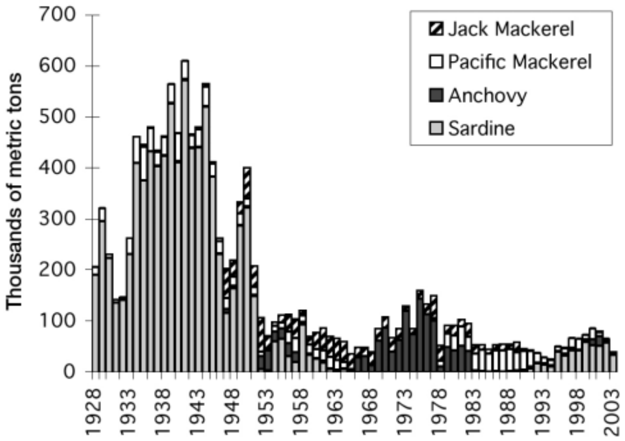

Figure 1. Landings of groundfishes, by weight (*top*) and value (*bottom*). Stacked columns represent cumulative total of species groups.

the 1990s (fig. 1a). Groundfish landings increased in the late 1940s because of improved technology with the development of the balloon trawl, and because of increased markets for frozen fillets of rockfishes and flatfishes to the U.S. military during World War II (Phillips 1949; Lenarz 1987). Dover sole (*Microstomus pacificus*) landings were part of the 1940s increase and reached 8 million pounds by 1948 (Henry et. al 2001); however, flatfishes were not separated by individual species in the published tables (nor are they in fig. 1) until 1955. Dover sole continued to increase until the mid-1970s, stabilized for a decade, and then declined after the mid-1980s, dropping to 34% of the 1980s average by 2000. The "other flatfishes" category includes all species of soles (except Dover sole after 1955), flounders, turbots, and halibuts; their combined landings were steady from 1955 to 1980 but declined in the late 1990s as restrictions were placed on the harvest of certain associated rockfishes.

The increase in groundfish landings from 1972 to 1982 came primarily from increased landings of Dover sole, rockfishes, especially widow rockfish (Pearson and Ralston 1990), and sablefish. Rockfishes were the largest component of groundfish in the 1980s but declined in weight in the 1990s, and by 2000 had dropped to only 12% of their 1980s average. Sablefish landings grew to a maximum in 1979 as an export market in Japan was developed and traps were used, but their landings declined after 1982, when regulations limiting their harvest were imposed. Thornyheads, deepwater relatives of the rockfishes, increased in landings in the late 1980s as fishing expanded into deeper water and as a market developed in Japan. In recent years, total groundfish landings declined as sablefish, thornyheads, and certain rockfish species became increasingly regulated to prevent overfishing and to rebuild certain depressed stocks. Pacific hake (Pacific whiting) is a perishable fish that did not have a large U.S. market through the 1970s. From 1966 to 1976, Pacific hake was fished by foreign fleets off California and by joint-venture fisheries with U.S. vessels delivering landings to foreign-processing vessels at sea (Quirollo et al. 2001), but those catches were not landed in California and do not appear in this data set. Shoreside processing in northern California developed in the late 1980s, and all landings have been domestic since 1991; only domestic landings are included in Figure 1a.

Total groundfish value (fig. 1b) followed the same general trends as the landings. However, certain species of the "other flatfishes" category, especially California halibut and petrale sole (*Eopsetta jordani*), commanded a higher price (adjusted to year 2000 dollars), and therefore "other flatfishes" contributed a higher proportion to the groundfish value. The average price per pound of rockfish doubled between 1998 and 2001 as live and premium-quality rockfish became a higher proportion of the landings. Thornyheads and sablefish brought a high price for export to Japan in the 1990s. The price for hake was relatively low, so it contributed only a small percentage of groundfish value despite the high landings. The main cause of the drop in total value of groundfish has been the decline in their landings from 1989 to 2001.

The coastal pelagic fishes include Pacific sardine, northern anchovy (*Engraulis mordax*), Pacific mackerel, and jack mackerel—all schooling species caught by setting seine nets around the schools, generally within a few miles of shore. The fish were mostly canned or reduced to fish meal and fish oil through the 1970s, and frozen by the 1990s. Dominant species of coastal pelagics and their total landings changed after the first 20 years of the series. In 1928 (fig. 2a), the sardine fishery was already well underway, having grown tenfold during World War I, and another threefold by 1928 (Scofield 1936). Sardines dominated the statewide landings until



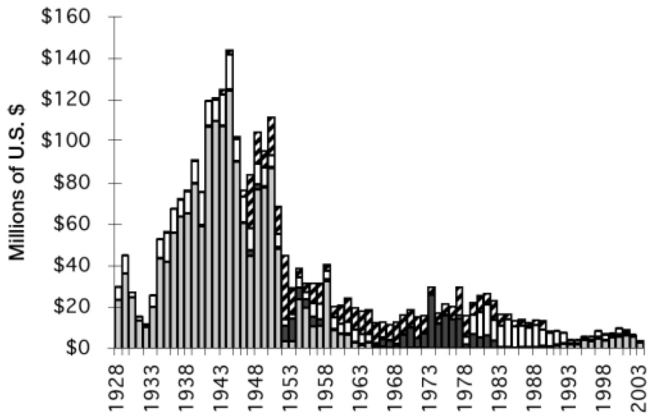




Figure 2. Landings of coastal pelagic species, by weight (*top*) and value (*bottom*).

the collapse of the fishery in 1952. No other species has come close to the magnitude of the 1940s sardine landings. Coastal pelagic fisheries were relatively steady in total landings after 1952, but their species composition changed markedly over time. Landings of Pacific mackerel, which were the second highest landings in the 1940s, declined along with sardine landings in the 1950s. Jack mackerel became the leading coastal pelagic species in the early 1960s. Northern anchovy appeared in the 1950s landings but did not dominate until after 1965, when reduction of anchovy without associated canning was permitted (Bergen and Jacobson 2001). The viability of the anchovy fishery was closely related to the production and price of fish meal worldwide. A 40% decline in the price of fish meal in the worldwide market from the winter of 1981 to the summer of 1982 (Durand 1998), along with a gradual decline in anchovy abundance, led to the virtual end of anchovy reduction in California by 1983. The harvest of coastal pelagics then shifted to Pacific mackerel as its population recovered in the 1980s, and then to sardine in the 1990s as Pacific mackerel became less available and the sardine population recovered enough to allow fishing within quotas. In all, there have been five periods in the landings of coastal pelagics dominated by different species: sardine until 1951, an increasing proportion of jack mackerel until 1965, anchovy until 1977, increasing Pacific mackerel until 1990, and sardine through 2002.

The value of the coastal pelagics generally followed the pattern of their landings (fig. 2b), but mackerels brought a slightly higher price per ton than sardine and anchovy. The overall value of coastal pelagic fishes has declined since the 1980s, despite steady total landings, as the dominant species shifted from mackerels to sardine. The fishery for anchovy as live bait is not included in the landings data set, but it may well exceed the value of the landed catch after 1983 (Bergen and Jacobson 2001).

Tunas are migratory species caught as they pass seasonally through waters off California. They move through different parts of the North Pacific depending on species, age, and ocean conditions, so California landings represent their occurrence in waters off California rather than their total abundance. The total landings of tuna caught in waters off California varied less than the landings of small coastal pelagics, but changes in tuna species are apparent (fig. 3a). Three different fisheries caught most of the tunas: trolling, purse seine, and live-bait. Bluefin tuna (*Thunnus thynnus*) were caught by purse seine, and their landings were highest in the 1930s, dropped in the late 1940s, then increased during and immediately after the 1957 El Niño. Albacore (*Thunnus alalunga*) were caught on hooks with live bait in the early years, but after 1980 they were caught almost exclusively by trolling (Crone 2001). Albacore landings grew from the 1940s to their peak in 1963, and from 1948 to 1981 landings of albacore were greater than those of bluefin or any other tuna species. Bonito (*Sarda chiliensis*) are included in Figure 3, although they cannot be marketed as tunas and were not as valuable as the tunas. Bonito, caught with purse seines, increased in landings in the late 1960s and early 1970s but dropped in the 1990s. Yellowfin (*Thunnus albacares*) and skipjack (*Euthynnus pelamis*) tunas were caught by bait boats before the 1960s and by purse seines more recently. Yellowfin and skipjack tunas increased in landings from California waters in the early 1980s, especially in 1983 and 1984, during and after El Niño. As albacore landings disappeared in the late 1980s, yellowfin and skipjack tunas maintained the quantity of tuna landings until 1997 but then declined, leaving albacore as the principal tuna species. The large tuna purse seine fleet based in southern California from the 1950s through the 1970s caught yellowfin and skipjack tunas in the tropical Pacific; therefore, their landings are not included here. All the tuna canneries except one closed in southern California as the tropical tuna fleet shifted

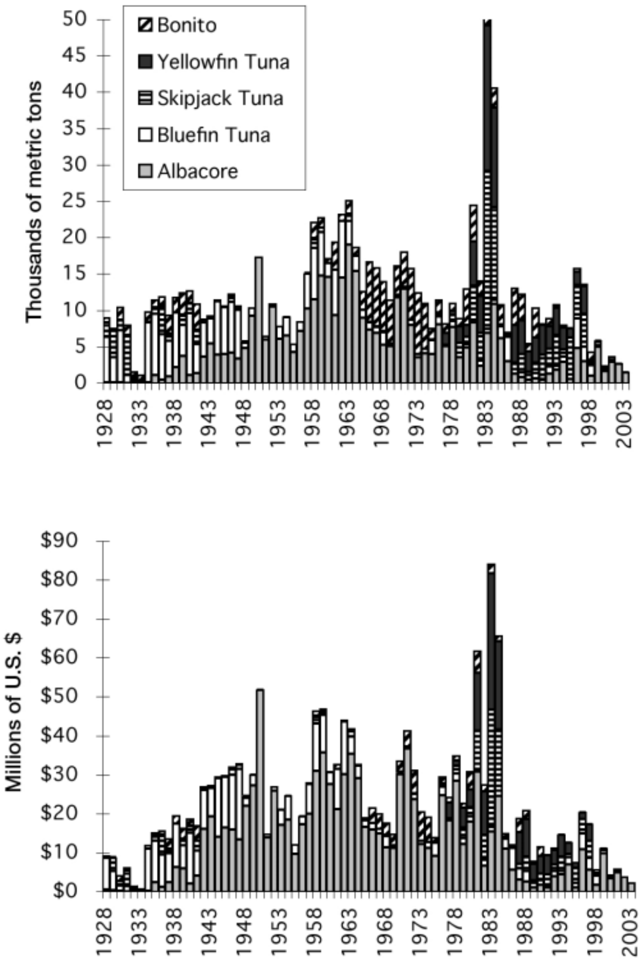



Figure 3. Landings of tuna, by weight (*top*) and value (*bottom*).

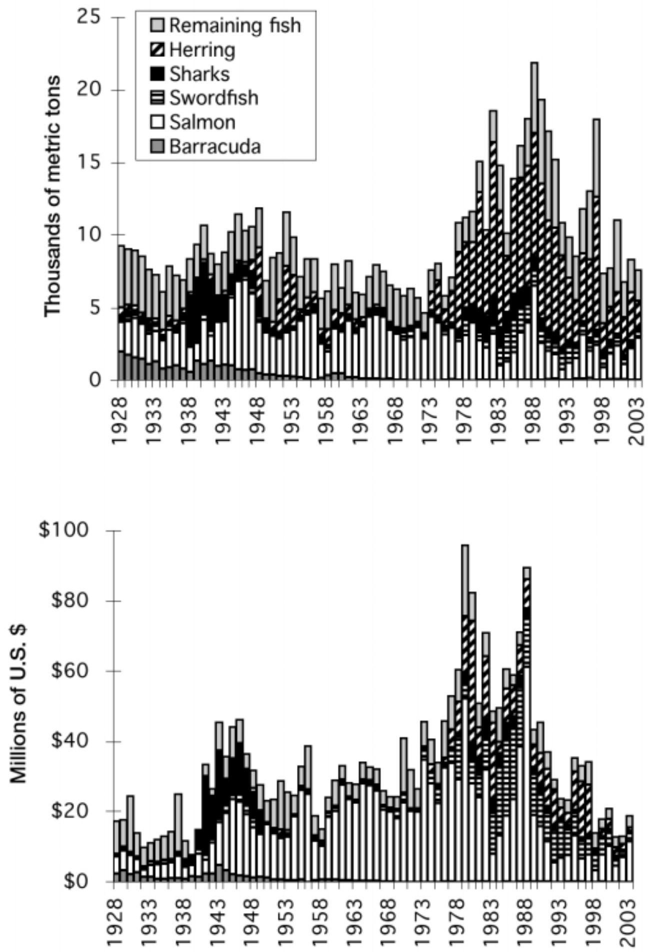



Figure 4. Landings of other species, by weight (*top*) and value (*bottom*).

operations to other ocean areas and other ports in the 1980s and 1990s.

Tuna values (fig. 3b) have generally followed the pattern of their landings. Albacore commanded the highest market price, followed by bluefin, yellowfin, and skipjack tunas, and bonito. Highest total tuna ex-vessel values occurred in 1981 through 1984 because of the unusual availability of skipjack and yellowfin tunas off California. Total tuna value was lower in the 1990s and beyond, reflecting the lower landings.

In addition to tunas, coastal pelagics, and groundfish, many other fish species have contributed smaller amounts to the total landings. The most important of these were salmon, Pacific herring (*Clupea pallasii*), swordfish (*Xiphias gladius*), and sharks (Squaliformes and Lamniformes), as shown in Figure 4a. Most of the salmon were taken by trolling in the ocean, but salmon were also fished in rivers and bays with gill nets until 1956, and during World War II this method caught nearly half of the salmon landed (Fry 1949). Salmon contributed the most in landings and value among these "other fish" from the 1950s through the 1970s. Salmon landings are quite variable from year to year but have gradually declined since 1956 except for record high landings in 1988. Salmon's contribution to total value declined in the mid-1990s (fig. 4b) as imported farmed salmon undercut the price of locally caught salmon, but both landings and price per pound increased in 2003.

Among these "other fish," Pacific herring contributed the most landings in the 1980s. There was an early herring fishery (1947–1954) for canning when sardine became unavailable, but canned herring was not as profitable, and this fishery soon ended. A second herring fishery, for herring roe exported to Japan, was more valuable. It was conducted primarily in San Francisco Bay by purse seines and gill nets from 1973 to 1998 and then with gill nets alone. Herring landings were lower during and after the El Niño events of 1984, 1994, and 1998. Herring landings since the 1980s have probably been closely tied to abundance, since quotas were based on biomass assessments (Watters et al. 2001), but lower catches in earlier years reflected the limited demand.

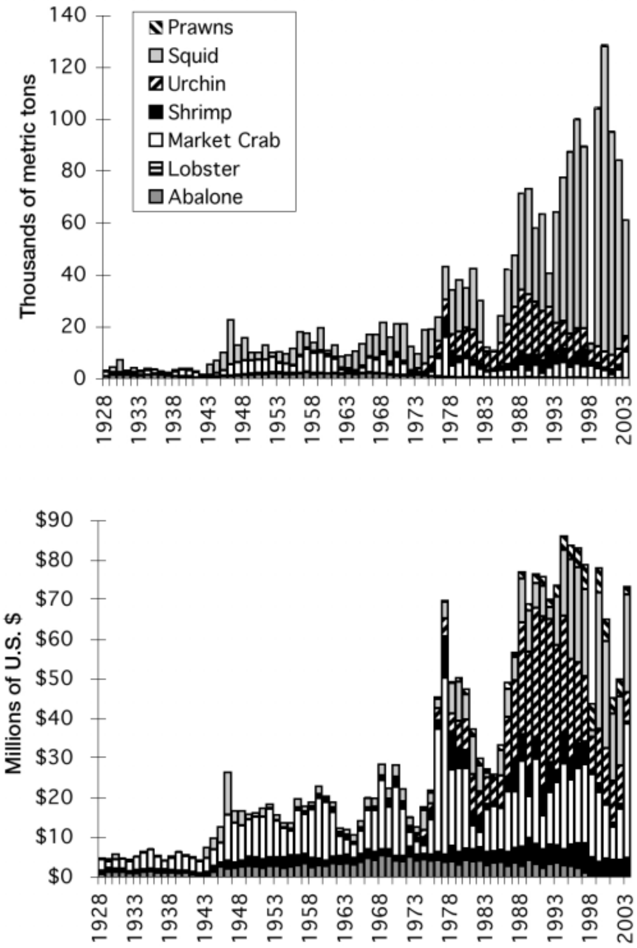



Figure 5. Landings of invertebrates, by weight (*top*) and value (*bottom*).

Swordfish were caught with hand-thrown harpoons until the late 1970s: demand fell in 1971–1972 as a result of public concern over high levels of mercury detected in some swordfish. Swordfish grew in importance in the late 1970s with the development of the drift gill net fishery on thresher sharks and swordfish and reached a maximum in 1985 before implementation of a series of regulations to reduce effort, landings of sharks, and marine mammal bycatch (Hanan et al. 1993; Holts 2001). Landings continued to decline as seasonal area closures were imposed in 2001 on the drift gill net fishery to reduce the bycatch of protected leatherback turtles (PFMC 2002). Catches of swordfish outside the 200 nmi U.S. Exclusive Economic Zone (not included in data set) rose in 1999–2001 as longline boats were displaced from Hawaiian waters by regulations to prevent turtle bycatch around the Hawaiian Islands. Although the drift net fishery was originally developed to target thresher sharks (Alopiidae), swordfish carries a substantially higher value, and concern about depleting shark populations has led to a redirection of this fishery toward swordfish. Highest landings of sharks occurred in the 1940s, when soupfin sharks (*Galeorhinus galeus*), caught with gill nets, supported a valuable fishery for vitamin A from their livers. Shark catch was even higher than reported because sometimes only livers and not whole sharks were landed in the 1940s (Roedel and Ripley 1950).

In addition to the fish groups described above, many different kinds of invertebrates, taken with different gear, have been important in the commercial landings. The dominant species in weight landed has been market squid (*Loligo opalescens*), which increased dramatically from the 1980s to 1999 but declined from 2000 to 2003 (fig. 5a). Squid was harvested with purse seines, and in recent years bright lights have been used to attract squid to the boats. Dungeness crab (*Cancer magister*), California spiny lobster (*Panulirus interruptus*), and some of the spot prawns (such as *Pandalus platyceros*) were caught with traps. The remainder of the spot prawns, ridgeback prawns (*Sicyonia ingentis*), and all ocean shrimp (*Pandalus jordani*) were harvested by trawling. Dungeness crab landings were highly variable through the time series but were second only to squid in invertebrate landings through the 1960s. The ocean shrimp fishery started in the early 1950s and has varied, with maximum landings in 1992. Landings of red sea urchin, harvested by divers, grew from the early 1970s to a maximum in 1989 but then declined.

The value of invertebrate species (fig. 5b) is quite different from their landings because of the great price differences between species. Dungeness crab was the most important invertebrate in total value until it was surpassed by red sea urchin from 1988 to 1997; crab landings and their total value were very high in 2003. Market squid dominated invertebrate landings after 1966, but because of its low price did not surpass urchin in value until 1996. Abalone (*Haliotis* spp.), spiny lobster, and prawns were barely visible in the plot of landings (fig. 5a) but contributed to invertebrate value for decades because of their high price. Shrimp value was highest in 1977–1978 and in the early 1990s but dropped in both weight and value in the late 1990s and beyond as competition from shrimp from other areas reduced the market value (van Zile 2003).

The five major groups are displayed in the total California landings of Figure 6a. Over 90% of landings came from coastal pelagic fishes, mostly sardines, until the 1950s. Other coastal pelagic fishes continued to contribute over half the landings until the late 1970s. Groundfish increased to 31% of the landings by 1985 but dropped to 9% by 2003. Exceptional landings of yellowfin and skipjack tunas in 1983 and 1984 brought tunas up to 28% of total landings in 1983. Invertebrates continued to increase in importance to 50% of the landings by 2003 and were dominated by squid, which

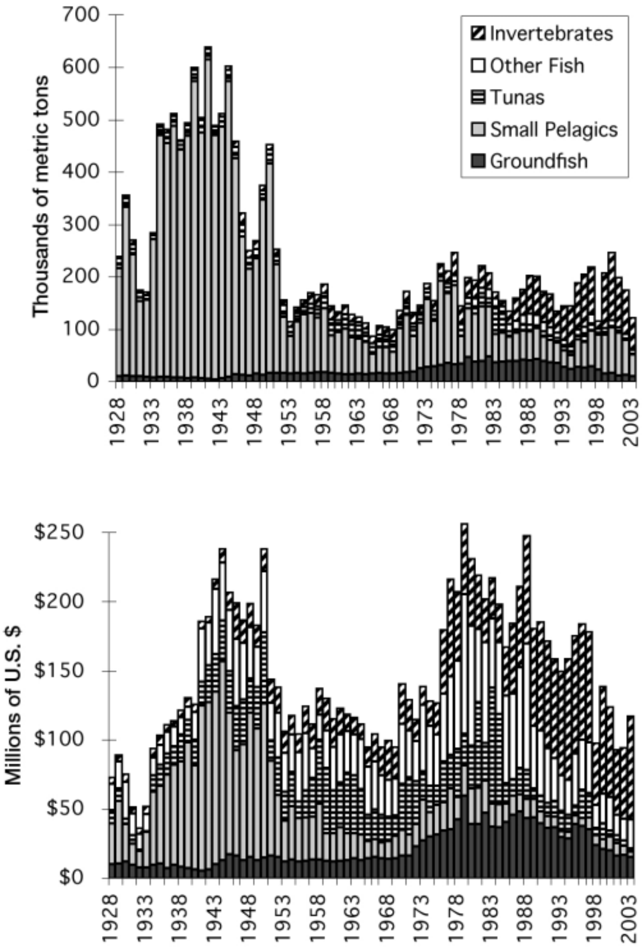



Figure 6. Total California landings, by weight (*top*) and value (*bottom*).

contributed 48% of total landings in 2000 but dropped to 37% by 2003.

The total landings were highest in the 1930s and 1940s, with over 600,000 metric tons. Landings were much lower after 1951, varying from a low of 87,000 metric tons in 1965 to a high of 246,800 metric tons in 1977. The series dips then climbs back from 1993 to reach 246,000 metric tons in 2000, but it drops to 122,000 metric tons by 2003.

The value of landings presents a contrasting view of the relative importance of these fisheries (fig. 6b). There has been a shift over time from coastal pelagics to tunas, other fishes, groundfish, and finally invertebrates. Total value appears high in the 1940s, when total landings of coastal pelagic sardines were highest, but even when they provided 90% of the landings, they contributed only 54% of the value. Total value dropped along with the sardine landings from 1951 to 1968 and remained low despite increased weight from anchovy in the 1970s. But from 1968 the value climbed 61% to a second peak in 1979 while landings increased only 50%. The value grew from increases in landings of tunas (especially albacore in the 1950s) and in value of "other fish": salmon in the 1960s and 1970s, herring in the late 1970s, and swordfish in the 1980s. In the 1970s and 1980s, groundfish landings and value grew, and they retained a fairly constant share of value (about 20%) as their landings declined through the 1990s but fell to 13% in 2003. Tuna values dropped sharply after 1984, along with their landings. The group of high-value "other fishes" averaged only 6% of the landings in the 1970s and 1980s but contributed 30% of the value; by the 1990s, however, these "other fishes" declined to 20% of the total value, and to 13% by 2003. Only invertebrates increased in relative value, from 20% in the 1980s to 48% of the total in the 1990s, to 60% in 2003. Dungeness crab had exceptionally high landings in 2003, contributing 29% of the total value. Among the invertebrates, sea urchin rose to 25% of the total value in 1991 but then declined to 6% by 2003, and squid grew to 21% of the total value by 2003, a year with lower squid landings but a remarkably high price per ton.

Although the total landings have remained high and even increased in the 1990s from increased sardine and squid, the value of the landings has been falling since 1988, the year of highest salmon and sea urchin landings and also high groundfish landings. The declines in the amount of salmon, herring, and swordfish, and the price of salmon contributed to the declining value of "other fish" in the late 1990s. The value of groundfish dropped as landings of valuable sablefish, thornyheads, rockfish, and Dover sole were restricted. Groundfish contributed only 9% of the landings and 13% of the value in 2003. The value of invertebrates fell as the proportion of urchin and crab dropped relative to squid until 2002.

## DISCUSSION

The advantage of examining California landings as a long time series is the broad picture it provides of the dynamic nature of California's fisheries. It emphasizes the changes over time between different fisheries, both in weight of landings and in their value. Three major factors contributing to changes in landings over time are: (1) market demand, (2) ocean variability on multidecadal and interyear scales, and (3) prolonged exploitation.

Changes in demand for a species affect how much markets will pay for it and how much they will buy. The total value of soupfin sharks is an example of change in demand and a redirection of fishing effort to profit from that demand in an unregulated fishery. In 1938, when soupfin shark livers were discovered to contain high levels of vitamin A, in short supply during World War II, landings of shark increased eightfold and value increased tenfold (Roedel and Ripley 1950). Value peaked in 1942 at 130 times the 1937 total value and remained above 50 times the 1937 value until 1947. Demand ended abruptly in 1950 with the development of synthetic vitamin A, and landings and value returned to pre-1938 levels.

Demand for several California species has been increased by the development of international markets, especially in Japan in the 1980s. These markets brought higher prices for herring roe, sablefish, thornyheads, and sea urchin gonads. These high-value export fisheries compensated in part for lower total landings and contributed to maintaining the total value through the 1980s, but the amount of compensation dropped in the late 1990s as landings increased for lower-priced squid and sardine (also primarily exported), and the higher-valued fisheries declined.

Two scales of ocean variability, multidecadal and interyear, are noticeable in California's fishery landings over time. Long-term trends in California landings were examined by Norton and Mason (2003), who found relationships of landings to multidecadal environmental signals in ocean temperature and southward wind stress. The changing coastal pelagic fish populations and possible environmental connections have been the focus of CalCOFI research and discussions for the last 50 years. MacCall (1996) showed the same sequential pattern of coastal pelagic species in California landings and populations shown in Figure 2a. Wide fluctuations in biomass of coastal pelagic fishes and the replacement of one species with another in the fisheries are characteristics of other eastern boundary current-upwelling areas, such as Peru, where fisheries shifted with availability from one species to another, and total landings varied widely over time (Lluch-Belda et al. 1992; Schwartzlose et al. 1992). A similar sequence of replacement species has been noted in the Japanese fishery (MacCall 1996; Schwartzlose et al. 1999). These fluctuations have been linked at least in part to decadal changes in gyre-scale ocean circulation and resulting changes in ocean temperature and stratification (Lluch-Belda et al. 1992; Schwartzlose et al. 1999; Parrish et al. 2000). Similar fluctuations in populations of coastal pelagic species occurred in prefishery times in California, as recorded in sediments from the Santa Barbara Basin (Baumgartner et al. 1992). Environmental conditions, however, were not the only factors contributing to the decline of sardine in the 1950s. The extremely heavy fishing pressure for this valuable species reduced its resiliency to interyear environmental variability. Comparing the harvest rates (catch divided by adult biomass) of the fishery as it declined in the 1950s (MacCall 1979) to the maximum sustainable yield calculated in the 1998 fishery management plan (PFMC 1998a) indicates that the fishing pressure on sardine exceeded the maximum sustainable yield every year from 1953 to 1965 as the population continued to decline.

In addition to these decadal environmental patterns, interyear variability of ocean conditions during El Niño events that produced strong warming off California apparently affected availability of some species, although not equally in all years. Availability of migratory, warm-water, yellowfin tuna and skipjack tuna increased dramatically during the warm 1983–1984 El Niño (fig. 3a). Landings of some other warm-water species—barracuda (fig. 4a) and yellowtail (*Seriola dorsalis*), in decline from the 1930s through the 1950s-increased during the 1957–1959 El Niño (Radovich 1961). In contrast, landings of salmon declined during the El Niño events of 1957–1959, 1983–1984, and 1998, and landings of both herring (fig. 4a) and squid (fig. 5a) declined sharply in 1983–1984 and 1998. Interyear variability may have affected the reproductive success of various species (Radovich 1961; Smith 1985), but the delay of years between reproduction and recruitment to the fishery makes this difficult to detect in the landings data.

In addition to market changes and ocean variability, 70 years of heavy exploitation of marine resources reduced landings for many of California's fisheries. By 1955, barracuda, yellowtail (Crooke 2001), white seabass (*Atractoscion noblis*) (Vojkovitch and Crooke 2001), and giant seabass (*Steriolepsis gigas*) (Domier 2001) landings had each been reduced to less than 5% of the 1930 California levels, although they continued to be harvested off Mexico. These warm-water species may also have been affected by the cooler waters of the 1950s and 1960s, but their landings have not recovered as sardine did in the warmer 1990s. Combined landings of cooler-water rockfish have declined since their peak in the 1980s. Different species have been landed in different periods: canary rockfish (*Sebastes pinniger*) in the 1970s, bocaccio rockfish (*S. paucispinis*) in the 1970s and early 1980s, widow rockfish (*S. entomelas*) in the early 1980s, black rockfish (*S. melanops*) in the late 1980s (MacCall 2002; Pearson and Ralston 1990), and bank rockfish (*S. rufus*) in the mid-1980s (Love and Waters 2001). The large initial catches of long-lived species reflect the harvest of existing biomass as the fishery moves into new areas or depths—referred to as "fishing up" by Ricker (1975)—are followed by lower landings of a species as the fishery becomes dependent on annual recruitment. The groundfish fishery compensated in the 1970s and 1980s by shifting into new areas to find other unexploited species. Invertebrate fisheries harvested by divers have also changed targeted species, first among abalone species as the shallow-water species were depleted and the fishery shifted to deeper water (Karpov et al. 2000), then from abalone to sea urchin as abalone availability declined and a lucrative Japanese market for red sea urchin gonads developed. The original sea urchin biomass present in the 1980s was "fished up" first in the Channel Islands and then in northern California, and catch per diver hour continued to decline in the 1980s and 1990s (Kalvass and Hendrix 1997).

Changes in the degree and type of management of fisheries over time have affected the landings. In the early years, most species were limited only by economics, not regulations. For example, the unregulated soupfin shark fishery severely reduced the local population during World War II before alternative sources of vitamin A reduced the fishery's profitability and led to the fishery's demise (Roedel and Ripley 1950; Ebert 2001). Some fisheries were managed by restricting gear, such as round haul nets for yellowtail in 1933 (Greenhood 1949) and for white seabass in 1940 (Fitch 1949). Other fisheries were managed by area closures and mesh-size requirements (for bottom trawling). Rockfish landings doubled in the early 1970s as that fishery expanded, and doubled again in the early 1980s when large midwater aggregations of widow rockfish (*Sebastes entomelas*) were discovered. After 1982, when widow rockfish harvests were limited to slow their exploitation, the fishery extended to other species including those in deeper water (Pearson and Ralston 1990). In the 1980s, groundfish were managed with quotas to try to prevent overfishing of heavily targeted species, but nonselective multispecies fisheries made it difficult to protect all species, and in the late 1990s rebuilding plans were required for several depressed stocks, further reducing rockfish landings. The difficulty of predicting a sustainable level of harvest for stocks of rockfishes with intermittent recruitment dependent on occasional favorable ocean conditions has left several rockfish stocks at such low levels that many years will be required to rebuild them to sustainable levels (MacCall 2002).

Some single-species fisheries have provided significant landings for many years; these include Chinook salmon, herring, and crab. The Chinook salmon fishery has been more stable than most California fisheries, generally maintaining annual landings of over 2 million pounds, despite year-to-year variability (fig. 4a). In recent years, however, wild stocks have declined and much of the production has come from hatcheries (PFMC 1996; Yoshiyama et al 1998). Salmon was relatively valuable, with a high price per pound until the 1990s, when the price of ocean-caught salmon fell because of competition with low-priced farmed salmon (fig. 4b).

The herring roe fishery has remained productive for more than 20 years under close management. Active management with quotas based on annual biomass estimates produced a healthy sustained fishery despite interyear variability until the 1998 El Niño warming (Watters et al. 2001). Annual monitoring of the biomass and condition of herring as they enter shallow bays for spawning allowed annual adjustment of quotas and a reduced fishery since the 1998 El Niño. The high value of herring roe exported to Japan drives the fishery.

Dungeness crab maintained a strong fishery for 74 years despite high interyear variability (fig. 5a). The fishery in the San Francisco area collapsed in the late 1950s, but northern areas remained productive. The crab fishery harvests a relatively short-lived species managed with seasonal closures, size limits with good survival of undersized released animals, and protection of all female crabs. The herring and crab fisheries are single-species fisheries that are not generally complicated with bycatch of other restricted species, as are the groundfish trawl fisheries.

Prospects are not favorable for the return of California's fisheries to the high value of landings before 1998. Although total landings have remained relatively stable for the last three decades, with a slight increase from 1993 to 2000, the total value has declined. Total value in 2001 was down 63% from 1988 and down 50% from 1997 but increased slightly in 2003 because of the high value of crab and squid. The fisheries have historically maintained the value of landings by switching effort from declining species to those not yet fully exploited, but this is no longer possible: we are running out of marketable unexploited species.

A second strategy for maintaining value has been to switch to more valuable species; however, lower catches since the mid-1990s of more valuable swordfish, salmon, herring, and ocean shrimp, combined with lower world market prices, competition from fisheries in other areas, and lower exchange rates (van Zile 2003), reduced their total value. The more valuable species are now less available, and the bulk of the landings are coming from lower-value squid and sardines, contributing to a severe decline in the value of landings. The relative value of finfish in the landings has dropped along with their weight, down from a high of $205 million (80% of landings value) in 1979, to $98 million (55%) in 1997, to $46 million (50%) in 2001. The value of invertebrates dropped from a high of $88 million in 1994 to only $67 million in 2000 ($48 million in 2001), despite increased landings through 2000, as landings of valuable urchin, shrimp, and crab have declined.

A third strategy for improving the value of some species has been through special handling. The live rockfish fishery commands several dollars per pound for fish that would sell for less than one dollar per pound if dead. However, the fishery can use only shallow-water species, and management to protect them has reduced their landings since 1998 (Osario and Leos 2003). The sea urchin and herring roe fisheries have also maximized the value of their landings by careful handling for export markets (Kalvass and Hendrix 1997). Maximizing value and seeking optimal markets will remain important to the economic survival of California's fisheries.

The period of expansion of fisheries to relatively unexploited species in California appears to be coming to an end. The fisheries have already expanded to cover the whole length of the state and have fished all reasonable depths. There are very few unexploited species of finfish left. In addition, it is difficult to switch to an existing fishery because of limited entry programs or reduced quotas for most of the remaining fisheries. California may continue to receive bonuses of tunas or swordfish passing through when ocean conditions are favorable but will not be able to control the availability of these highly migratory species. California's fishers will now have to live with the annual production of local resources and management restrictions that prevent overharvesting.

In the last decade, the contrast between the dominance of low-value species in weight and high-value species in total value suggests that the economic recovery of the fisheries will depend on higher-value species or value-added fisheries such as those for live fish. Increased landings of low-value species will not be enough for the fisheries to attain the economic values they had in the 1980s.

## CONCLUSIONS

Invertebrates had greater increases than finfish in both landings and value in the 1990s, and they have contributed more than half the total value of landings from California waters since 1999. Decadal-scale environmental ocean variation affects the recruitment of coastal pelagic species. Interyear ocean variability affects the local availability of migratory warm-water species such as tunas and yellowtail, as well as local squid, ocean shrimp, and herring. The strategy of "fishing up" an unexploited population and then switching to an alternate species is limited by management regulations to protect reduced populations.

Higher-value fisheries appear to be the best hope for the economic survival of California's fisheries. Harvesting smaller quantities of higher-value species and processing landings from lower-value, high-volume fisheries to enhance their value may be two ways to compensate for decreased landings. Many high-value species are sold overseas and will be subject to fluctuations in world economics and competition from fisheries in other countries. We must be cautious in developing new high-value fisheries so that we do not reduce the productivity of their populations before bringing them under appropriate management.

## ACKNOWLEDGMENTS

Thanks to Gerry Kobylinski for providing PacFIN data, Jerry Norton for helping develop the value database and investigating decadal trends, Lynn DeWitt for developing Web site access to the landings data, Richard Parrish for review and guidance, and the comments of three anonymous reviewers.

## LITERATURE CITED

Ally, J. R., and K. Miller. 2001. California barracuda. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 219–221.

Baumgartner, T. R., A. Soutar, and V. Ferreira-Bartina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin. Calif. Coop. Oceanic Fish. Invest. Rep. 33:24–40.

Bergen, D. R., and L. D. Jacobson. 2001. Northern anchovy. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 303–305.

Bureau of Labor Statistics. 2002. Handbook of Labor Statistics. U.S. Department of Labor.

California Department of Fish and Game Marine Region. 1998. Review of some California fisheries for 1997. Calif. Coop. Oceanic Fish. Invest. Rep. 39:9–24.

Chavez, F P., J. Ryan, S. E. Lluch-Cota, and M. C. Niquen. 2003. From anchovies to sardine and back: multidecadal change in the Pacific Ocean. Science 299:217–221.

Crone, P. 2001. Albacore. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 317–321.

Crooke, S. 2001. Yellowtail. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 212–214.

Deimling, E. A., and W. J. Liss. 1994. Fishery development in the eastern North Pacific: a natural-cultural system perspective, 1888–1987. Fish. Oceanogr. 3(1):60–77.

Domeier, M. L. 2001. Giant sea bass. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 209–211.

Durand, M-H. 1998. Fishmeal price behaviour: global dynamics and short-term changes. *In* Global versus local changes in upwelling systems. M-H Durand, P. Cury, R. Mendelssohn, C. Roy, A. Bakun, D. Pauly, eds. Éditions de l'Orstom, pp. 465–480.

Ebert, D. 2001. Soupfin shark. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 255–256.

Fitch, J. E. 1949. White seabass. *In* The commercial fish catch of California for the year 1947 with an historical review 1916–1947. Calif. Dep. Fish Game, Fish Bull. 74:126–128.

Fry, D. H. Jr., 1949. Salmon. *In* The commercial fish catch of California for the year 1947 with an historical review 1916–1947. Calif. Dep. Fish Game, Fish Bull. 74:37–49.

Greenhood, E. C. 1949. Yellowtail. *In* The commercial fish catch of California for the year 1947 with an historical review 1916–1947. Calif. Dep. Fish Game, Fish Bull. 74:146–148.

Hanan, D. A., D. B. Holts, and A. L. Coan Jr. 1993. The California drift gill net fishery for sharks and swordfish, 1981–82 through 1990–91. Calif. Dep. Fish Game, Fish Bull. 175, 95 pp.

Henry, F. D., N. Chyan-huei Lo, and D. Thomas. 2001. Dover sole. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 382–385.

Holts, D. 2001. Swordfish. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 322–324.

Kalvass, P. E., and J. M. Hendrix. 1997. The California red sea urchin (*Strongylocentrotus franciscanus*) fishery: catch, effort, and management trends. Mar. Fish. Rev. 59(2):1–17.

Karpov, K. A., P. L. Haaker, I. K. Taniguchi, and L. Rogers-Bennett. 2000. Serial depletion and the collapse of the California abalone (*Haliotis* spp.) fishery. *In* Workshop on rebuilding abalone stocks in British Columbia, A. Campbell, ed. Can. Spec. Pub. Fish. Aquat. Sci. 130:11–24.

Lenarz, W. H. 1987. A history of California rockfish fisheries. *In* Proceedings of the international rockfish symposium, Lowell Wakefield fisheries symposium, Anchorage, Alaska, October 20–22, 1986, B. R. Melteff, coordinator. Univ. of Alaska, Alaska Sea Grant Rep. 87-2:35–41.

Lluch-Belda, D., R. A. Schwartzlose, R. Serra, R. Parrish, T. Kawasaki, D. Hedgecock, and R. J. M. Crawford. 1992. Sardine and anchovy regime fluctuations of abundance in four regions of the world oceans: a workshop report. Fish. Oceanogr. 1:339–347.

Love, M., and D. Waters. 2001. Bank rockfish. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 378–379.

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

———. 1996. Patterns of low-frequency variability in fish populations of the California current. Calif. Coop. Oceanic Fish. Invest. Rep. 37:100–110.

———. 2002. Use of known-biomass production models to determine productivity of West Coast groundfish stocks. N. Am. J. Fish. Mgmt. 22:272–279.

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

Nelson, H. L. 1949. Miscellaneous species. *In* The commercial fish catch of California for the year 1947 with an historical review 1916–1947. Calif. Dep. Fish Game, Fish Bull. 74:176–180.

Norton, J. G., and J. E. Mason. 2003. Environmental influences on species composition of the commercial harvest of finfish and invertebrates off California. Calif. Coop. Oceanic Fish. Invest. Rep. 44:123–133.

Osario, D., and R. Leos. 2003. Nearshore live-fish *In* Review of some California fisheries for 2002. Calif. Coop. Oceanic Fish. Invest. Rep. 44:20–23.

Parrish, R. H., F. B. Schwing and R. Mendelssohn. 2000. Mid-latitude wind stress: the energy source for climatic shifts in the North Pacific Ocean. Fish. Oceanogr. 9(3):224–238.

Pearson, D. E., and S. Ralston. 1990. Trends in landings, species composition, length-frequency distributions, and sex ratios of 11 rockfish species (genus *Sebastes*) from central and northern California ports (1978–88). NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-145, 65 pp.PFMC (Pacific Fisheries Management Council). 1996. Review of 1995 ocean salmon fisheries. Pacific Fisheries Management Council, Portland, Ore.

———. 1998a. The coastal pelagic species fishery management plan including draft supplemental environmental impact statement, Amendment 8. Pacific Fisheries Management Council, Portland, OR.

———. 1998b. Status of the Pacific Coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998: stock assessment and fishery evaluation, updated. Pacific Fisheries Management Council, Portland, OR.

———. 2002. Fishery management plan and environmental impact statement for U.S. West Coast fisheries for highly migratory species. Pacific Fisheries Management Council, Portland, OR.

Phillips, J. B. 1949. Rockfish. *In* The commercial fish catch of California for the year 1947 with an historical review 1916–1947. Calif. Dep. Fish Game, Fish Bull. 74:116–120.

Quirollo, L. F., V. G. Wespestad, and M. W. Dorn. 2001. Pacific hake. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 393–397.

Radovich, J. 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures, particularly during 1957 through 1959. Calif. Dep. Fish Game, Fish Bull. 112, 62 pp.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Res. Bd. Can. 191, 382 pp.

Roedel, P. M., and W. E. Ripley. 1950. California sharks and rays. Calif. Dep. Fish Game, Fish Bull. 75, 88 pp.

Schwartzlose, R. A., J. Alheit, A. Bakun, T. R. Baumgartner, R. Cloete, R. J. M. Crawford, W. J. Fletcher, Y. Green-Ruiz, E. Hagen, T. Kawasaki, D. Lluch-Belda, S. E. Lluch-Cota, A. D. MacCall, Y. Matsuura, M. O. Nevarez-Martinez, R. H. Parrish, C. Roy, R. Serra, K. V. Shust, M. N. Ward, and J. Z. Zuzunaga. 1999. Worldwide large-scale fluctuations of sardine and anchovy populations. S. Afr. J. Mar. Sci. 21:289–347.

Scofield, W. L. 1936. California's sardine catch. *In* The commercial fish catch of California for the year 1935. Calif. Dep. Fish Game, Fish Bull. 49:11–15.

Smith, P. E. 1985. The year-class strength and survival of 0-group clupeoids. Can. J. Aquat. Sci. 42, suppl. 1.

United States, Bureau of Fisheries. 1928. Fishery industries of the United States: appendix XIV to the report of Commissioner of Fisheries for the fiscal year 1929. U.S. Bureau of Fisheries Doc. 1067.

van Zile, D. 2003. Pacific pink shrimp: dock price is anemic but fishery is keeping West Coast boats afloat. National Fisherman 83(10):17.

Vojkovich, M., and S. Crooke. 2001. White seabass. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 206–208.

Watters, D. L., K. T. Oda, and J. Mello. 2001. Pacific herring. *In* California's living marine resources: a status report, W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, eds. Univ. Calif. Agricul. Nat. Res. SG01-11, pp. 456–459.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. N. Am. J. Fish. Mgmt. 18:487–521.