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Relation of Sea Surface Temperature Changes During the 1983 El Niño to the Geographical Distribution of Some Important Recreational Pelagic Species and Their Catch Temperature Parameters

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Introduction

In the coastal areas of the northeast Pacific, the distribution and apparent abundance of many species are affected more by environmental changes, as reflected in changes of sea surface temperature (SST), than by the catches in commercial and recreational fisheries. Natural fluctuations in marine populations resulting from changes in the physical and biological environment are known to significantly affect the determination of stock status and the level of catches (Sette, 1961; Ahlstrom, 1961, 1967; Anonymous, 1960; Uda, 1957, 1961; Miller, 1956; Jensen, 1930). Environmental changes such as small changes in SST either above or below the long-term mean significantly affect production by west coast pelagic fisheries. Continued periods of below normal temperatures in the late 1940's contributed to the decline of the Pacific sardine, *Sardinops sagax*, and are believed to have contributed to the abundance of the northern anchovy, *Engraulis mordax*, which was dominant from the mid-1950's to mid 1970's (Anonymous 1960; Sette, 1961, 1969).

The reasons for the extensive northward movement of marine fishes during abnormally warm periods are not well understood. However, these movements appear to be related to changes in the total environment (physical and biological) and reflect the requirements of the animals to sustain life. The interactions between the physical and biological environments are very complex, and the effects of changes in most physical and biological characteristics on the behavior and distribution of marine fishes is little known. Sea surface temperature, one of the more easily measured physical environmental characteristics has been shown to have a positive correlation with the distribution of pelagic fish (Radovich, 1961; Hubbs, 1948).

Periods of unusually warm sea surface temperatures were reported along the northeast Pacific coast for 1859, 1926, 1931, 1941, 1957-58, 1972-73, 1976, and 1982-83. These periods, which are popularly called "El Niño" result from intense warming in the eastern tropical Pacific. This warming results from changes in the near-surface meteorology and oceanography, which in turn are related to a global shift in upper air pressure patterns. Previously, the most intense warm period after the record setting warm period of 1926 was in 1957-1958; however, the 1982-1983 warm period also appeared to be intense, exceeding that of 1957-1958 and possibly equaling that of 1926. The magnitude and duration of positive temperature anomalies observed off southern California during the warm periods of 1957-1958, 1972-1973, 1976-1977, and 1982-1983 are shown in Figure 1.

Warm periods appear to benefit the southern California fisheries for such subtropical species as the yellowtail, *Seriola lalandei*; Pacific barracuda, *Sphyraena argentea*; and Pacific bonito, *Sarda chiliensis*. The southern California recreational fishery also benefits from the northward migration of several other subtropical and tropical species, such as skipjack tuna, *Euthynnus pelamis*; yellowfin tuna, *Thunnus albacares*; and dolphin, *Coryphaena hippurus* (Radovich, 1960; Squire, 1983). Very warm temperatures may also have had a negative effect, as was evidenced during 1957-1958 and 1972-1973 by reductions of albacore, *Thunnus alalunga*, in the California recreational catch and of northern anchovy in the commercial and recreational bait fisheries. Off central California to Washington, catches during warm periods have been reduced in the troll fisheries for species of chinook salmon, *Oncorhynchus tshawytscha*; and coho salmon, *O. kisutch*.

Environmental changes, as reflected in SST changes, may be positive (above-normal SST's, or positive anomalies) or negative (below-normal water temperatures, or negative anomalies). The effects of prolonged high positive anomalies on the distribution of marine fishes off the west coast were well documented by Walford (1931), Radovich (1960, 1961, 1975), Ketchen (1956), Hubbs and Schultz (1929), Hubbs (1948), Bell and Pruter (1958), Royal and Tully (1961), and Fluharty (1984). Because of the impact of prolonged and strong positive temperature anomalies on the southern California catch of pelagic species having centers of distribution off Mexico, short-term intense warming periods have

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also been synonymous with better fishing—particularly off southern California and less so off central and northern California.

The period of above-normal SST's in 1982-83 resulted in some unusual migrations of tropical and subtropical fishes and invertebrates into northern latitudes more commonly occupied by subarctic species. An important factor in the northerly movement of species from tropical and subtropical areas is the timing and intensity of the higher temperatures (Fig. 1). Though temperatures increased, giving positive anomalies off southern California starting in July 1982, positive anomalies remained only about 2°F (1.1°C) above normal until December 1982, when this margin increased to about 4°F (2.2°C). The distribution and occurrence of species off southern California changed little during the period of slightly above-normal temperatures in summer and fall 1982, although Blesser (1984) noted an increase in catch of Pacific bonito. By January 1983, extensive effects on the changes in seasonality of billfishes off southern California were evident. Swordfish, *Xiphias gladius*, remained very abundant through January 1983 (an unusual condition), and good commercial catches were being made by drift gillnets when the season closed on 1 February, 1983. Striped marlin, *Tetrapturus audax*, were observed near Tanner Bank (west of San Clemente Island) in January 1983, although past catch records for southern California showed no catch of striped marlin in December or later. Early in 1983, red crabs, *Pleuroncodes planipes*, were abundant in the waters and on the beaches of southern California, indicating an increased development of the northeasterly coastal countercurrent (the Davidson Current), which in turn resulted in the northward movement of more-southerly forms of pelagic invertebrates. The strong countercurrent indicated that changing oceanographic conditions accompanied the positive temperature anomalies, resulting in more favorable conditions for the catch of tropical and subtropical pelagic species off southern California and northward.

The persistence of the 1983 warm period along the west coast is important.

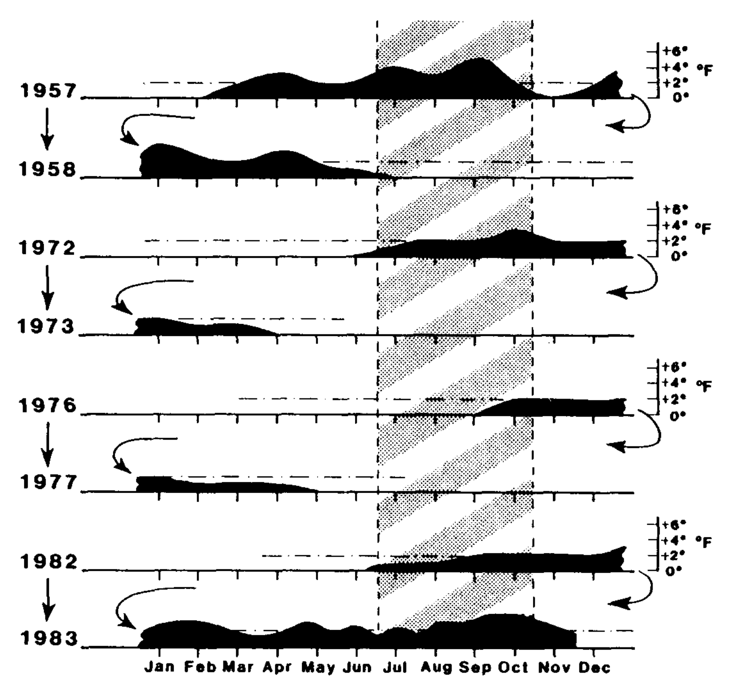

Figure 1.—Positive anomalies in SST's observed off southern California during the warm periods of 1957-58, 1972-73, 1976-77, and 1982-83. Striped area represents the major catch period off southern California, for yellowtail, Pacific barracuda, Pacific bonito, white seabass, chub mackerel, yellowfin tuna, and striped marlin.

Although positive temperature anomalies were not as high as in 1957, they lasted longer: 15 months (September 1982-November 1983) of positive anomalies 2°F (1.1°C) or more off southern California led to environmental changes that in turn resulted in significant changes in west coast recreational and commercial fisheries and in the geographical distribution of the fishery resources.

In 1983 several important southern California recreational and commercial species were reported much farther north than normal.[1] Most recent reports (Fluharty, 1984) give the following northernmost distributions in 1983.

Yellowtail, *Seriola lalandei*: Port Orford, OR.

Pacific barracuda, *Sphyraena argentea*: Ketchikan, AK and Uyak Bay, Kodiak Isl. AK.

White seabass *Atractoscion nobilis*: Westport, WA.

Chub mackerel, *Scomber japonicus*: Oregon, Washington, into southern part of Puget Sound and north to Queen Charlotte Isl., B. C., Can.

Pacific bonito, *Sarda chiliensis*: Klawock, AK (Prince of Wales Isl.) (unverified rep. Kodiak Isl., AK).

Swordfish, *Xiphias gladius*: S. of Vancouver Isl., landed Flores Isl., B. C., Can.

Striped marlin, *Tetrapturus audax*: Off Monterey Bay and San Francisco area.

Yellowfin tuna, *Thunnus albacares*: Avila to Morro Bay, CA (reported from Monterey Bay, CA).

[1]Fluharty, D., S. Crooke, and J. Fulton. Seattle, Wash. Personal commun.

Changes in coastal distribution of species common to southern California into the northern latitudes in past have been well documented. Miller and Lea (1972) recorded the northern distributional limits of important pelagic species common to southern California and Baja California, Mexico, as:

Yellowtail	S. Washington
Pacific barracuda	Kodiak Isl., AK
White seabass	Juneau, AK
Chub mackerel	Gulf of Alaska
Pacific bonito	Gulf of Alaska
Striped marlin	Oregon
Swordfish	Oregon
Yellowfin tuna	Pt. Buchon, CA

The northern distribution limits observed for these fishes in 1983 are not substantially different form past records, although yellowfin tuna and swordfish may have established northern coastal distribution records in 1983. Southern distribution records are sometimes set for northern species during warm periods; Phillips (1958) described such southerly extensions for three species caught off California in 1957.

Most literature on the effects of the warm period on fish catch involves descriptions of the geographical extent of distribution. Some west coast researchers have reviewed the catch of fish off California in relation to variable sea surface temperature, and others the effects of temperature changes in northern waters to catch (Radovich, 1960, 1961; Hubbs, 1948; Ketchen, 1956; Bell and Pruter, 1958.) Here I present information on mean sea surface temperatures at the point of capture ("catch temperatures") that have been observed for several species common to southern California recreational fisheries, and on the geographical extension of these optimal catch temperatures into the northern latitudes off the west coast during the 1983 period of intense warming.

Materials and Methods

In 1963 monthly studies of coastal sea surface temperatures by airborne infrared surveys were started by the Tiburon Marine Laboratory (now the Tiburon Laboratory of the National Marine Fisheries Service, Southwest Fisheries Center) in cooperation with the U.S. Coast Guard. The studies were done to obtain fine-scale SST data for use in relating surface temperatures to fish catch. The results of these temperature surveys, and a special series of surveys off San Diego, Calif., which were done for studies on the relation of temperature to the catch of pelagic species, were published by Squire (1971, 1978). The mean catch temperature, temperature ranges, and standard deviation from the mean by month for a number of species for various areas (10′ long. × 10′ lat.) off central and southern California were determined by Squire (1982). Figure 2 illustrates these temperature and catch distributions (for yellowtail). Chinook and coho salmon data were reviewed for central California, and yellowtail, Pacific barracuda, white seabass, Pacific bonito, and chub mackerel data were reviewed for southern California. Data for these studies were collected during a period of nearly normal SST in 1963-1968.

The latitudinal increase in SST during periods of warming results in a displacement northward of mean catch temperature parameters and may indicate the possible extent of a parallel northward displacement of these species. From published catch-temperature data (Squire, 1982) and unpublished observations, I developed data on mean catch temperatures for several pelagic species off southern California, for salmon off central California, and for two oceanic pelagic species (striped marlin and yellowfin tuna) that are frequently caught off southern California in summer. I have also compiled the monthly mean ($\bar{x}$ct) and standard deviation about the mean ($\bar{x}$); high mean (H$\bar{x}$ct), and low mean (L$\bar{x}$ct) catch temperatures and the range of temperatures at which these species were observed (Table 1). I examined SST charts produced semimonthly during 1983 by the Inter-American Tropical Tuna Commission and the National Weather Service and noted the geographical extent of mean catch temperatures for each time period. Throughout the area south of the most northward geographical extension of the low mean catch temperatures (Fig. 3-7 and 9), all sea surface temperatures equaled or exceeded the low mean catch temperature.

Results

Observations of the changes in mean catch temperatures in relation to SST changes off the U.S. west coast are reviewed separately here for various coastal pelagic species.

Yellowtail

The pelagic coastal migratory yellowtail commonly ranges from the southern tip of Baja California, Mex. to near Point Conception, Calif. It is one of the most important recreational fishes in southern California and an important recreational and commercial species in Mexico. The major sport fishing areas at the northern end of the range are the Coronado Islands, Mex., and kelp beds off San Diego and Catalina Island, Calif. Yellowtail are caught off sourthern California in large numbers only during their summer northward migration from Baja California and are rarely caught north of Point Conception except during years of anomalous warm SST's.

The mean catch temperature for yellowtail caught off southern California was 63.2°F (17.3°C) with a standard deviation of ±3.6°F (2.0°C). The low mean catch temperature of 57°F (13.9°C) was recorded during March and the high mean catch temperature of 70.0°F (21.1°C) during August; the total catch in March was only 2 percent of that in August. The range of temperatures at which yellowtail were observed to be caught off southern California was 51.0°-74.0°F (10.6°-23.3°C).

The shift of the warmer SST environment northward during summer 1983 was presumably responsible for the taking of yellowtail north of Point Conception; catches were also reported as far north as Port Orford, Oreg., In August 1983. Figure 3 illustrates for semimonthly periods from 16 April to 30 November, 1983, the movement of the geographical position to mean catch temperature, the latitudinal extent of SST's within one standard deviation, and the monthly low and high mean catch temperatures.

The southern California mean catch temperature of 63.7°F (17.3°C) was at about lat. 28°N in late April through May (Fig. 3); at the latitude of southern Cali

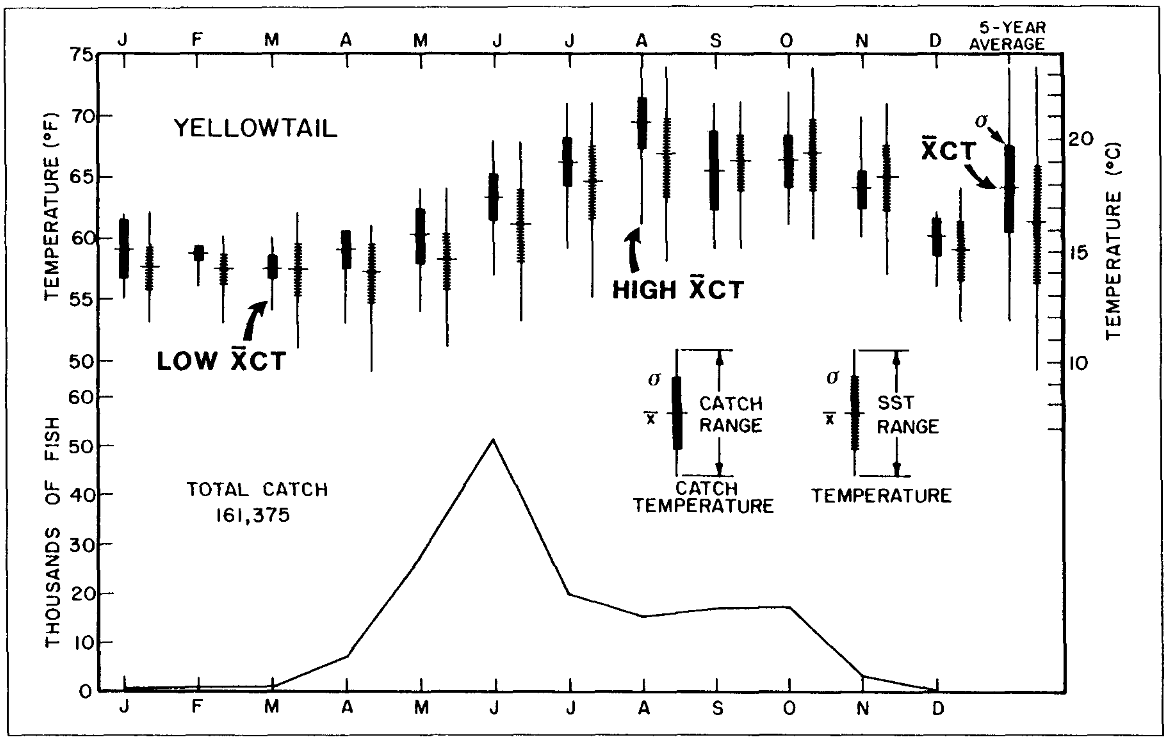

Figure 2.—Distribution of yellowtail catch off southern California and northern Mexico by month, August 1963-July 1968 for total catch, catch temperature, and SST range and means, and the standard deviations about the means (from Squire, 1982).

Table 1.—Mean catch temperatures and temperature ranges for salmon caught off northern California and for other species caught off southern California.

	Mean catch temperature observed									
	High $\bar{x}$ (H$\bar{x}$ct)[1]		Low $\bar{x}$ (L$\bar{x}$ct)[2]		Overall $\bar{x}$ ($\bar{x}$ct)[3]		SD.		Temperature range	
Species	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
Yellowtail	70.0	21.1	57.0	13.9	63.2	17.3	3.6	2.0	51.0-74.0	10.6-23.3
Pacific barracuda	69.0	20.5	57.8	14.3	64.4	18.0	4.6	2.8	51.0-74.0	10.6-23.3
Pacific bonito	67.0	19.4	54.0	12.2	64.8	18.2	3.6	2.0	51.0-73.0	10.6-22.8
White seabass	67.0	19.4	56.8	13.8	65.2	18.4	4.5	2.4	52.5-75.0	11.4-23.8
Chub mackerel	68.0	20.0	57.0	13.9	64.0	17.8	4.0	2.2	50.0-73.5	10.0-23.0
Salmon	58.5	14.7	52.0	11.1	56.8	13.8	3.2	1.8	45.5-62.5	7.5-16.9

[1]H$\bar{x}$ct highest monthly mean temperature.
[2]L$\bar{x}$ct · lowest monthly mean temperature.
[3]$\bar{x}$ct -- overall mean catch temperature.

fornia from late June through July; and slightly north of the latitude of Point Conception from August through mid-September. The low mean catch temperature observed for yellowtail off southern California reached latitudes north of 50°N during only one period—1-15 August during the period when a specimen was reported at Port Orford, Oreg. Sea surface temperatures cooled slightly in the northern latitudes in late August, but when they warmed again in early September the geographical position of the southern California mean catch temperature was displaced further north by late September to the approximate latitude of Monterey, Calif. (lat. 37°N). Sea surface temperatures declined in early October southward, to a point where the geographical point of the mean catch temperature was below Point Conception by early November. In 1983 yellowtail were reported off central California and SST's were high enough to extend the low mean catch temperature northward to lat. 50°N, making it reasonable to assume from temperature data that yellowtail may have migrated farther northward than recorded.

Pacific Barracuda

High catch areas in southern California are normally along the coast off San Diego, near San Clemente, and off Huntington Beach; peak catches are usually recorded in September. A few barracuda are taken off Santa Barbara and the Channel Islands from August to October. Pacific barracuda are not common north of Point Conception.

The mean catch temperature for Pacific barracuda caught off southern California was 64.4°F (18.0°C) with a standard deviation of ±4.6°F (±2.8°C). The SST range at which Pacific barracuda were caught off southern California was 51.0°-74.0°F (10.6°-23.3°C). The monthly mean catch temperature was lowest in February at 57.0°F (13.9°C) and highest in August at 69°F (20.6°C). The catch in February was only 12.5 percent of that in August.

In summer 1983 in the more northern latitudes (> lat. 35°N), increased SST was associated with a northward movement of Pacific barracuda. The low mean catch temperature of 57.0°F (13.9°C) extended well north of Point Conception (the normal northern ecological boundary for the species) in early June 1983, and above lat. 50°N in early August and September (Fig. 4). The mean catch temperature of 64.4°F (18.0°C) was present slightly north of Point Conception in early August through mid-September, and was further north, off Monterey Bay, in late September. By early November it moved progressively southward to a point south of Point Conception. From July through mid-September temperatures favorable to Pacific barracuda were common along the California, Oregon, and Washington coasts and suitable temperatures for more northward migration appeared to be present in early August through mid-September. Catches were reported off Oregon, Washington, and as far north as Ketchikan, Alaska, (28 August, 1983) and at Uyak Bay, Kodiak Island, Alaska (August 1983).

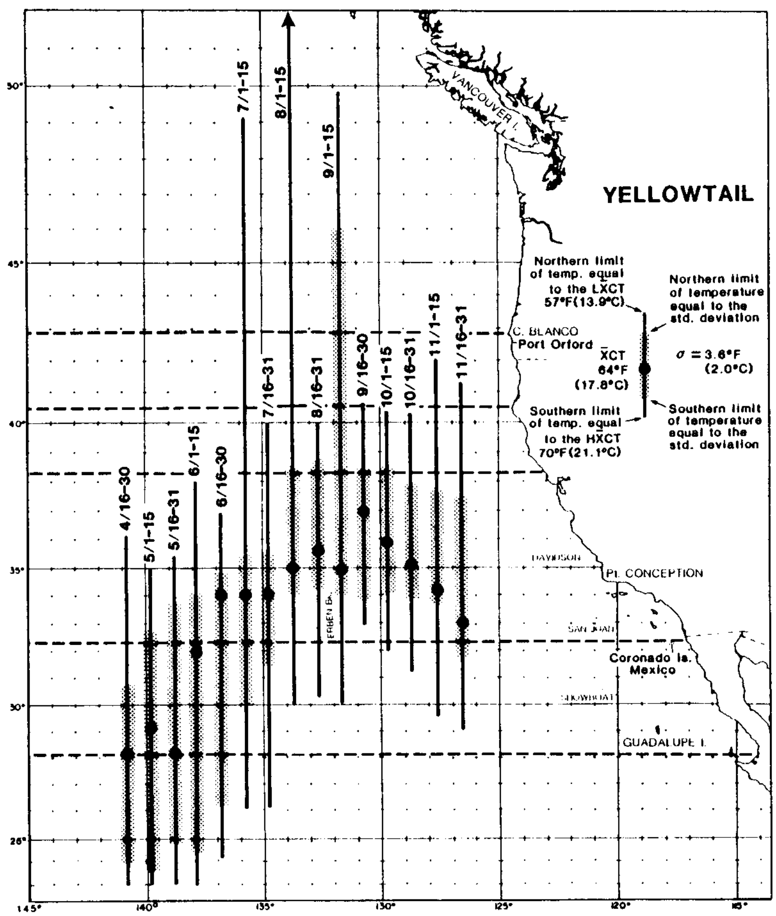

Figure 3.—Latitudinal extent semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct), shown by vertical bars, and mean catch temperature ($\bar{x}$ct; solid circles) ± one standard deviation (irregular lines above and below the means) for yellowtail caught off southern California.

Pacific Bonito

The Pacific bonito migrates considerable distances along the coast of Baja California, Mex., and into southern and central California. As with the Pacific barracuda, northern latitudinal distribution expands greatly during periods of anomalous warm-water conditions in the northeast Pacific (Radovich, 1961). Catches off southern California usually peak in August.

The distribution of the Pacific bonito is usually considered to be centered off Baja California, Mex. It was uncommon off southern California from the late 1930's until the warm year of 1957. It moved northward during the warm years of 1957-58. After declines in the population of Pacific sardine, chub mackerel, and jack mackerel, *Trachurus symmetricus*, in the early 1960's, the southern California purse seine fleet increased its fishing effort on the Pacific bonito. Apparent abundance levels decreased substantially in the late 1960's until the warm period of 1972, when northward movement of Pacific bonito from the south again resulted in an increase in apparent abundance and commercial catch off southern California (Squire, 1983). The Pacific bonito resource then decreased in the mid-1970's to lower levels of abundance and catch, as it did in the late-1960's.

Mean catch temperature for Pacific bonito off southern California was

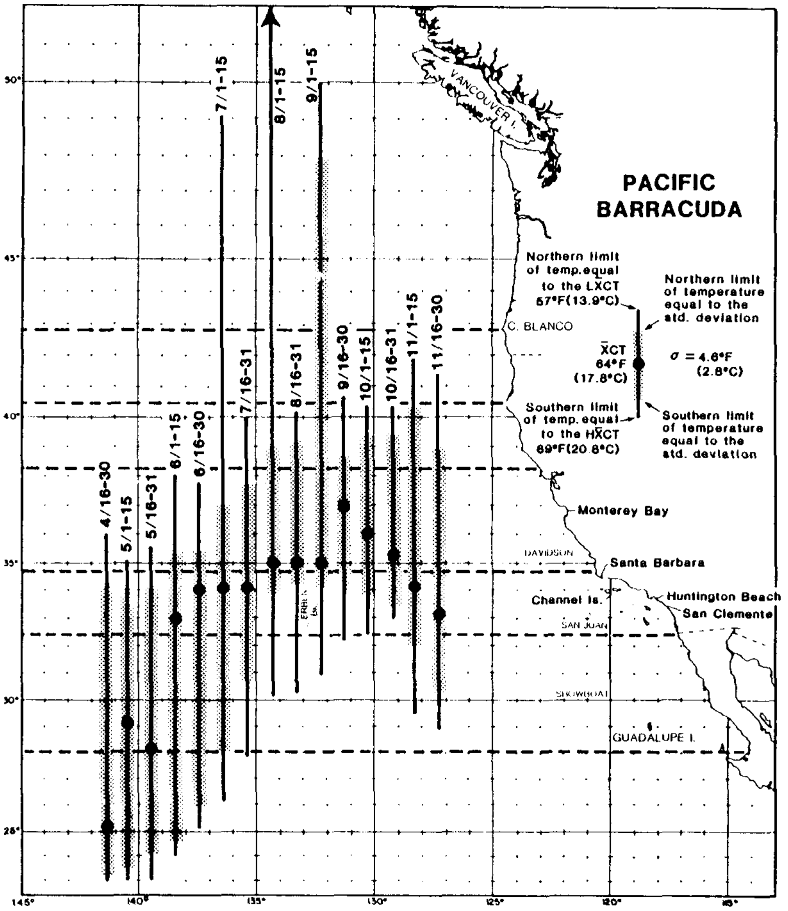

Figure 4.—Latitudinal extent by semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct, shown by vertical bars, and mean catch temperature ($\bar{x}$t; solid circles) ± one standard deviation (irregular lines above and below the means) for Pacific barracuda caught off southern California.

64.8°F (18.2°C) with a standard deviation of ±3.6°F (±2.0°C), and SST's at which Pacific bonito were caught ranged from 51.0° to 73.0°F (10.6°-22.8°C). The mean catch temperature was observed to be lowest in February at 54.0°F (12.2°C) and highest in August at 67.0°F (19.4°C); catches during February were only 5.6 percent of those during August.

Pacific bonito appear to be highly responsive to warming in the northern latitudes and are frequently caught off the coasts of northern California, Oregon, and Washington, and into the Gulf of Alaska during warm years. As shown by the geographical locations of mean catch temperatures as observed from 15 April through 30 November, 1983 (Fig. 5), the shift toward more northern latitudes of the low and mean catch temperatures observed off southern California suggests more optimum conditions for northward migration of Pacific bonito than for yellowtail or Pacific barracuda. Mean catch temperatures were south of southern California until July, off southern California until mid-August, and then moved north of Point Conception. The low mean catch temperature extended into latitudes above 52°N for most of the period from July through mid-September, indicating favorable temperatures for the species in the areas off Canada and into the Gulf of Alaska. Pacific bonito were reported caught during the summer off Kalawock and Kodiak Island, Alaska.

White Seabass

Major catch areas for white seabass along the southern California coast are from San Diego to Dana Point, with the greatest numbers being caught near Oceanside. The catch peaks in August.

White seabass have been caught in Monterey Bay and off San Francisco during warm-water years (Frey, 1971) and off Juneau, Alaska (Miller and Lea, 1972). A population of white seabass is also reported in the northern portion of the Gulf of California; however, the center of distribution for the Pacific population is considered to be between Point Conception, Calif., and Ballenas Bay, Baja California Sur, Mexico. Both recreational and commercial catches have declined substantially since the 1950's, and the recreational fishery catch off southern California declined to very low levels after the late 1950's (Young, 1969).

The mean catch temperature observed off southern California for white seabass was 65.2°F (18.4°C) with a standard deviation of ±4.5°F (±2.4°C) and ranged in southern California from 52.5° to 75.0°F (11.4°-23.8°C). The mean catch temperature was highest in August at 67.0°F (19.4°C), and lowest in April at 56.0°F (13.3°C). Catches during April were 16.6 percent of those during August.

Geographically, the mean catch temperature for southern California in 1983 was near the latitude of Cedros island in late April through May (Fig. 6), had moved northward to off southern California in early July, and reached a point north of Point Conception in late August through October. The low mean catch temperature for southern California was north of lat. 52°N from late July through mid-September. White seabass were recorded off Westport, Wash., during mid-July 1983.

Chub Mackerel

Abundance of chub mackerel was low in the early 1960's. Beginning in 1976, a series of good year classes made this species one of the more important commercial and recreational species in southern California by 1980. Recreational fishing areas produce substantial catches of chub mackerel off San Diego, Dana Point, and Santa Monica Bay, and near Catalina Island. Catches were low during November-May, and peaked in August.

Mean catch temperature for chub mackerel off southern California was 64.0°F (17.8°C) with a standard deviation of ±4.0°F (±2.2°C), and SST's observed where Pacific mackerel were caught off southern California ranged from 50.0° to 73.5°F (10.0°-23.0°C). The monthly mean catch temperature was highest at 68.0°F (20.0°C) in August, and lowest in February at 57.0°F (13.9°C). The catch during February was 20.0 percent of that observed in August.

The mean catch temperature observed for chub mackerel off southern California shifted from the waters off Baja California, Mex., in April and May to waters off southern California by early June (Fig. 7), to a point north of the latitude of Point Conception by early August, and a point near lat. 32°N (Monterey and San Francisco) by late September. The point of mean catch temperature remained north of Point Conception until late October. The low mean catch temperature was above lat. 50°N during the period 1-15 August, 1983. Pacific mackerel were reported caught off the northern California, Oregon, and Washington coasts; into the southern part of Puget Sound, Wash.; and north to the Queen Charlotte Islands, B.C., Can., during the period June-September 1983.

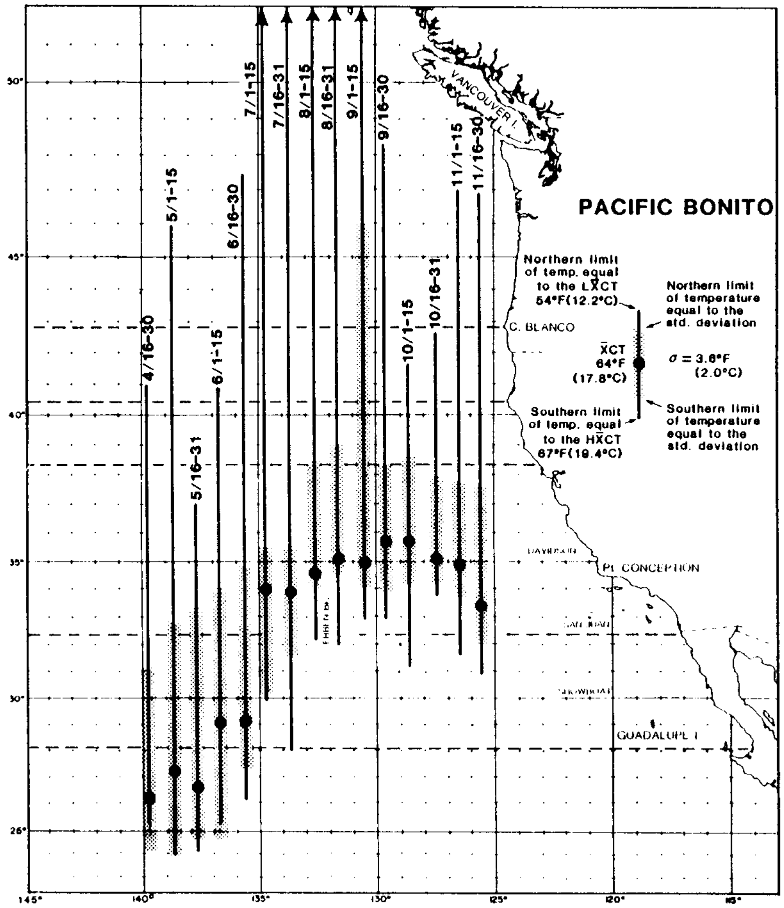

Figure 5.—Latitudinal extent by semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct, shown by vertical bars, and mean catch temperature ($\bar{x}$ct; solid circles) ± one standard deviation (irregular lines above and below the means) for Pacific bonito caught off southern California.

Yellowfin Tuna

One of the most unusual occurrences off southern California of a tropical species infrequently caught there was reflected in the large catch of yellowfin tuna in the recreational fishery in 1983. Historical catch data for recreational fishing in southern California indicated that warm periods, such as those of 1957 and 1972, produced substantial increases in catches of skipjack tuna and dolphins. However, yellowfin tuna catches increased only slightly in 1957-58 (Squire, 1983). Recreational catches recorded by Young (1969) were nil in 1953 and 1954, 1 fish in 1955, 78 in 1956, 325 in 1957 (the warm year), 13 in 1958, and 4 in 1959. During this 7-year period, the number of angler days ranged from 502,000 to 557,000, indicating that angler effort did not change markedly during the period. In April 1983, Squire (1983) forecast the possible effects of the 1982-83 warm period on southern California recreational fishing if the El Niño continued through 1983. Although the forecast (based on historical catch data) did not mention substantial increases in recreational catches of yellowfin tuna, the 1983 recreational catch of yellowfin tuna off southern California clearly set a record: More than 89,000 yellowfin tuna were reported caught by the San Diego commercial sportfishing boat fleet alone during the year (Anonymous, 1984).

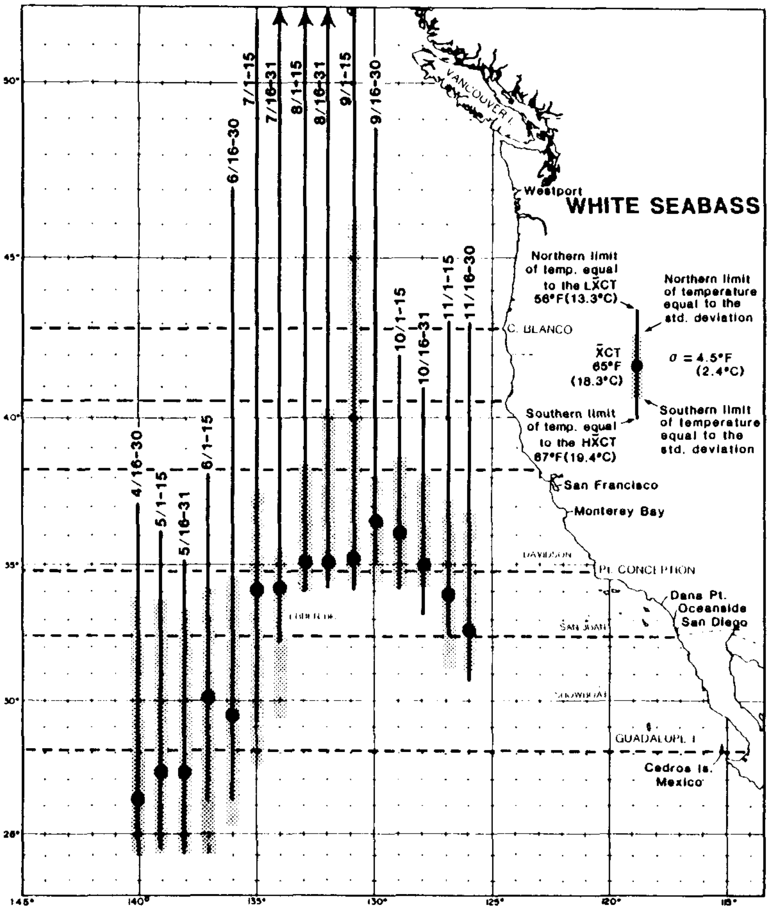

Figure 6.—Latitudinal extent by semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct, shown by vertical bars, and mean catch temperature ($\bar{x}$ct; solid circles) ± one standard deviation (irregular lines above and below the means) for white seabass caught off southern California.

Catches from the commercial sportfishing boats in other southern California ports were substantial, and catches by private boats will further increase the record 1983 total. Skipjack tuna were also caught in large numbers—San Diego landings alone totaled 73,000 fish and about 3,400 bigeye tuna, *Thunnus obesus*, were landed (Anonymous, 1984).

Inasmuch as the catches of yellowfin tuna are relatively uncommon off southern California, catch temperature data for the species in the region are not available. The most northerly area where yellowfin tuna are ordinarily taken in substantial quantities with commercial purse seines extends from west of Cabo San Lucas to south of Cedros Island, Baja Calif., Mex. The seine fishery is common in the area west of Cabo San Lucas in April, May, and June, and shifts northward to the area south of Cedros Island in August to October. Since high mean and low mean catch temperatures for this species in the area of interest are not known,

Table 2.—Monthly mean sea surface temperatures for two yellowfin tuna fishing areas off the west coast of Baja California, Mex.

Month	Mean SST's in °F and (°C) West of Cabo San Lucas	South of Cedros Island
April	70°F (21.1°C)[1]	62°F (16.7°C)
May	70°F (21.1°C)	63°F (17.2°C)
June	72°F (22.2°C)	63°F (17.2°C)
July	79°F (26.1°C)	68°F (20.0°C)
August	82°F (27.8°C)	70°F (21.1°C)
September	83°F (28.3°C)	72°F (22.2°C)
October	82°F (27.8°C)	71°F (21.7°C)
November	80°F (26.7°C)	68°F (20.0°C)
December	74°F (23.3°C)	67°F (19.4°C)

[1]Underscoring indicates average temperature for the month and area having major catches of yellowfin tuna.

I must rely on the determination of average SST by examination of monthly average SST charts (Anonymous, 1969). These charts indicate the mean SST's by month for the area west of Cabo San Lucas and to the south of Cedros Island; temperatures observed are given in Table 2.

The mean temperature during periods of high catches in the area west of Cabo San Lucas was 70.7°F (21.5°C) and 71.0°F (21.7°C) south of Cedros Island. These data indicate that 71°F (21.7°C) could be considered as an optimum catch temperature. Use of this value indicates that the optimum temperatures for yellowfin tuna were located south of Cedros Island through July 1983 (Fig. 8) Sea surface temperatures increased north of Cedros Island in August, and temperatures approximating the optimum catch temperature were common off southern California in early August through October 1983. The major area of yellowfin tuna fishing by the recreational fishing fleet off southern California extended from northern Baja California, Mex., north to the latitude of Los Angeles.

Striped Marlin

Striped marlin are caught by recreational anglers with rod and reel and sometimes by commercial drift gillnets and harpoons off southern California during late summer and early fall. Striped marlin are common all year in Pacific waters off the west coast of Baja California Sur, Mex. (south of lat. 27°N). The eastern Pacific distribution was described by Miller and Lea (1972) as from Chile to Oregon.

Catch temperature studies off southern California reported by Squire (1974) indicated that the mean temperature at which striped marlin are caught off southern California is 67.8°F (19.9°C) with the standard deviation of ±0.5°F (±0.25°C). Striped marlin are caught off southern California at a temperature range of about 61°-73°F (16.1°-22.8°C). Catches appear to increase at an exponential, but highly variable, rate relative to increases in temperatures (Squire, 1985).

For the period 1 June through 30 November, 1983, the geographical locations of the mean catch temperature and the approximate normal temperature range are shown in Figure 9. Mean catch temperatures were present south of southern California in June and July. Sea surface temperatures increased off southern California in early August, and the mean catch temperature value was observed to be common to these waters from August through October. The low mean catch temperature extended northward to off San Francisco from early September to mid-October. Striped marlin were caught off the San Francisco area by drift gillnets and one was reported caught in Monterey Bay by rod and reel.

Pacific Salmon: Central California

Sea surface temperatures observed for the major recreational fishing areas for Pacific salmon from Monterey Bay to Bodega Bay, Calif., normally range from about 45° to 63°F (7.2°-17.2°C). Water temperatures in this area are low during January through May or June and lowest about April. Temperatures increase slightly from June through September, when the mean temperature peaks, and then usually begins to drop in October.

Peaks in the salmon catch for the fishing area off San Francisco (the major catch area) occur in March and July. To the north, off Bodega Bay, the catches peak in July and August. To the south, off Monterey, two catch peaks occur—one in May and one in July. Chinook salmon are most often caught, because spawning chinook salmon are in the Sacramento River system during most of the year, and these fish pass through the major ocean fishing areas off central California. The fall run of chinook salmon is the largest, and fish aggregate off the San Francisco Bay area before the spawning migration.

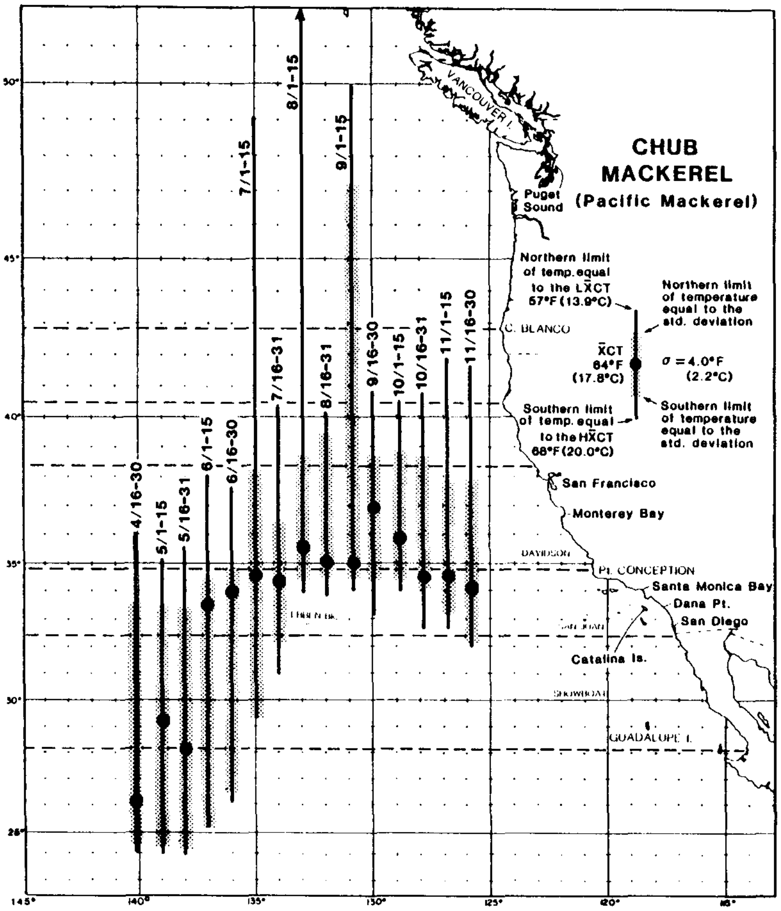

Figure 7.—Latitudinal extent by semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct, shown by vertical bars, and mean catch temperature ($\bar{x}$ct; solid circles) ± one standard deviation (irregular lines above and below the means) for chub mackerel caught off southern California.

Salmon catches off central California in 1983 followed past trends toward lower catches during abnormally warm periods. Before the 1957 warm period, the recreational catch off California (Young, 1969) had increased from about 80,000 to 90,000 fish in 1952 and 1953 to 114,000 fish in 1956. During the warm-water year of 1957, catches dropped to about 45,000 fish and remained at this lower level of 40,000-50,000 fish for several years.

About 50 percent of the salmon catch in the area from Monterey Bay to Bodega Bay is made at water temperatures of 51.8°-56.0°F (11.0°-13.3°C). The mean catch temperatures during the months of highest production ranged from 52.6° to 53.8°F (11.4°-12.1°C), off Monterey in May and June; off San Francisco the best months were June and July at 52.8°-

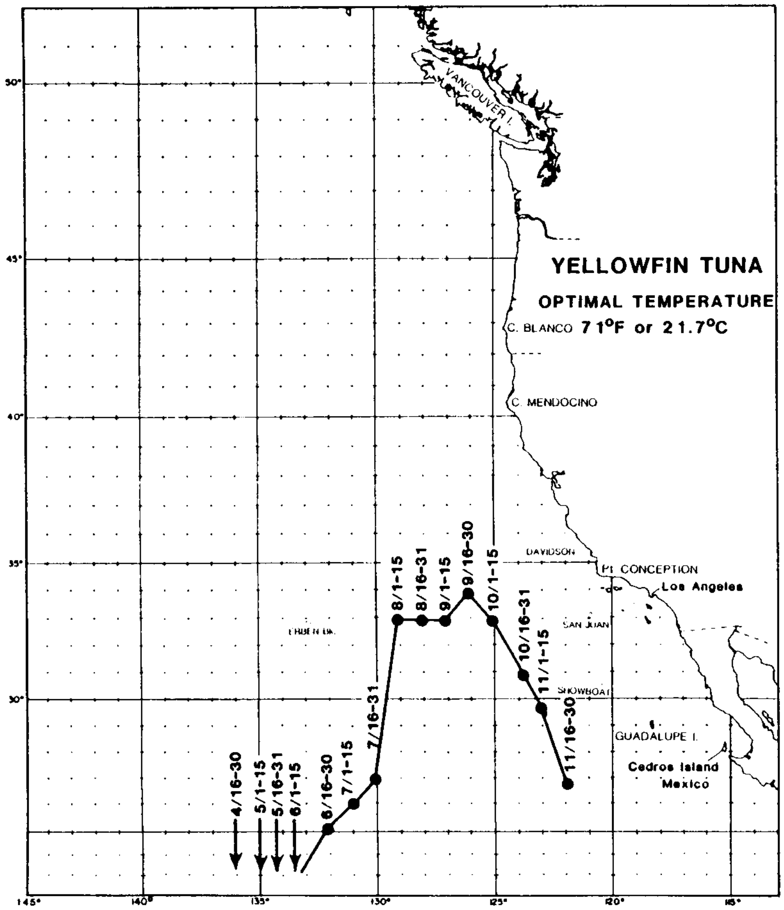

Figure 8.—The semimonthly latitudinal location of optimal catch as observed off Baja California, Mex. (71°F or 21.7°C), for yellowfin tuna during the 1983 fishing season.

54.4°F (11.6°-12.4°C), and off Bodega Bay the best catches were in July and August with a range of 51.6°-52.4°F (10.9°-11.3°C). Using temperatures of 53°F (11.7°C) for the Monterey and San Francisco areas, and 52°F (11.1°C) for off Bodega Bay as values representing optimal catch temperatures, a comparison of these temperatures with those obtained from 15-day coastal SST charts for the period 1 January through 30 October, 1983, shows that all temperature values were found to be above the optimal values observed during normally high catch periods (Table 3).

Discussion and Summary

Analysis of catch temperatures (Squire, 1982) shows that the deviation of catch about the mean catch temperature is considerable. Therefore, the mean catch temperature (high $\bar{x}$, low $\bar{x}$, or $\bar{x}$) must be viewed as it is statistically—a measure of the location of central tendency. The superficial aspects of sea surface temperature in relation to catch should be taken into consideration when one evaluates the semimonthly geographical location of the high and low mean and mean catch temperature given for yellowtail, Pacific barracuda, Pacific bonito, white seabass, and chub mackerel in Figures 3-7, and optimum catch temperatures for yellowfin tuna and striped marlin in Figures 8-9 and salmon in Table 2.

Although fishes and invertebrates are poikilothermic and function over a rather wide range of temperatures (Brett, 1956), they tend to concentrate in environments that are favorable to their metabolic requirements for successful development (Uda, 1961). Subtropical species of yellowtail, Pacific barracuda, Pacific bonito, white seabass, and chub mackerel common to southern California waters have been observed to be caught off southern California at SST's of 50.0°-75.0°F (10.0°-23.9°C), with these species showing a temperature range of from 20°F (11.1°C) to 23.5°F (13.0°C). Observations of SST's in the northeast Pacific during summer and early fall in 1983 would indicate the minimum temperatures at which some of these subtropical pelagic species caught off southern California were commonly observed in the northern portion of the Gulf of Alaska. The degree of environmental change, as exemplified by SST increases in the northern latitudes, results from physical changes in the California Current system (Reid et al., 1958), such as increases in the magnitude of the northward flowing subtropical countercurrent (the Davidson Current) and a reduction in coastal upwelling. These physical changes result in warming of the upper layers of the ocean, enabling such species as chub mackerel and white seabass to migrate to the coasts of Oregon, Washington, British Columbia, and (for some species as Pacific barracuda and Pacific bonito) even further north into the Gulf of Alaska.

The population sizes of coastal pelagic species of Pacific barracuda, white seabass, and yellowtail were considerably smaller in 1982-83 than during the warm period of 1957-58 (MacCall et al.[2]), whereas the populations of Pacific bonito and chub mackerel were only moderately reduced. Consequently the probability of

[2]MacCall, A. D., G. Stauffer, and J. P. Troadec. 1974. Stock assessments for southern California recreational and commercial marine fisheries. NMFS Southwest Fish. Cent. Admin. Rep. LJ-74-24, 144 p.

recovering Pacific bonito and chub mackerel was higher than that of recovering specimens of the other three species.

Along the coast from about Cedros Island, Baja California, to near Cape Blanco, Oreg., during the summers of normal years, a series of SST changes appear to be related to the northward coastal migration of many subtropical and tropical species (Hubbs, 1948). The southern upwelling area (Fig. 10) extends from north of Cedros Island (lat. 28°N) to about southern California (lat. 32°N). South of this area, SST's are generally higher. Increases in temperature during warm years have resulted in exponential increases in catches of striped marlin off southern California. Catches of Pacific bonito, dolphin, skipjack tuna, and yellowtail increase off southern California when upwelling is reduced in the area south of southern California.

Because the southern California Bight (area near U.S.-Mexico border to Point Conception) is characterized by a counterclockwise current flow, SST's in the northern portion (between long 119° and 120°W) are only slightly lower than those in the southern portion (Gulf of Catalina). Fish migrating into the Southern California Bight from the south encounter few environmental temperature barriers until they reach the Point Conception area (lat. 34°30′N). Point Conception is at the southern end of the major upwelling area that extends north to about Cape Blanco, Oreg. (Fig. 10), and is recognized as an ecological barrier to the northward migration of subtropical fishes (Hubbs, 1948). The upwelling

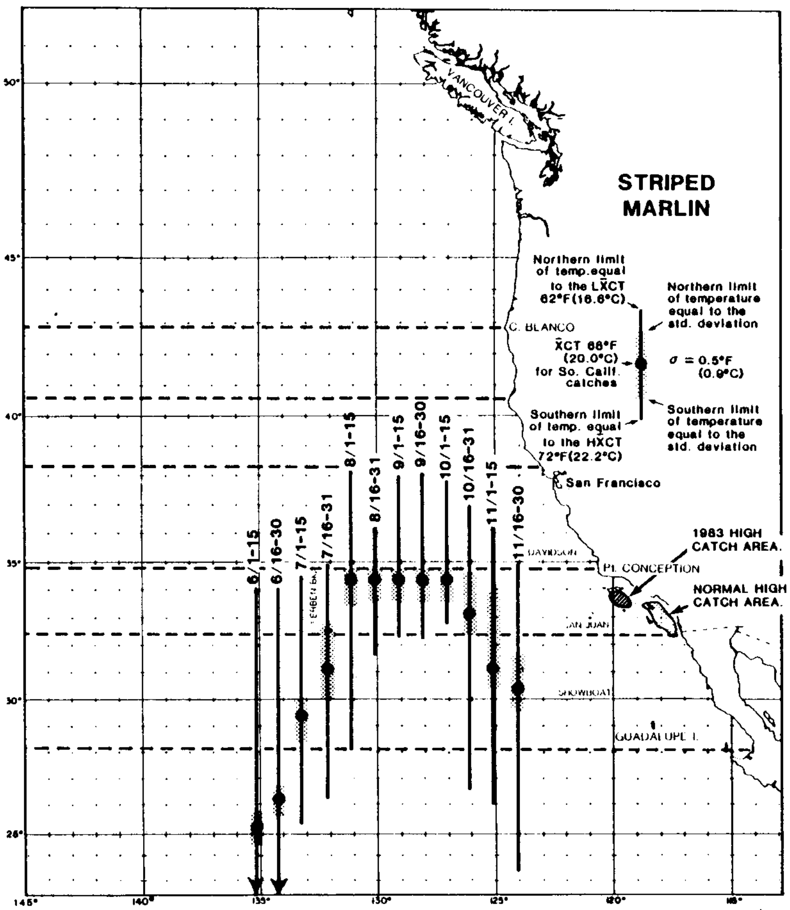

Figure 9.—Latitudinal extent by semimonthly periods in 1983 of the high mean catch temperature (H$\bar{x}$ct) and low mean catch temperature (L$\bar{x}$ct, shown by vertical bars, and mean catch temperature ($\bar{x}$ct; solid circles) ± one standard deviation (irregular lines above and below means) for striped marlin caught off southern California.

Table 3.—Upward (positive) deviation of sea surface temperatures observed in 1983 off Monterey Bay, San Francisco, and Bodega Bay in relation to optimal catch temperature values.

Locality and optimal catch temperature	January 1-15	January 16-31	February 1-15	February 16-29	March 1-15	March 16-31	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-31
Monterey Bay	6	6	5	5	3	4		4	4	2	6	6	6	6	10	9	16	10	11	10
53°F (11.7°C)	3.3	3.3	2.8	2.8	1.7	2.2		2.2	2.2	1.1	3.3	3.3	3.3	3.3	5.6	5.0	3.3	5.6	6.1	5.6
San Francisco	5	5	5	4	3	4		3	4	2	5	5	6	6	10	8	11	11	10	9
53°F (11.7°C)	2.8	2.8	2.8	2.2	1.7	2.2		1.7	2.2	1.1	2.8	2.8	3.3	3.3	5.6	4.4	6.1	6.1	5.6	5.0
Bodega Bay	5	5	5	4	4	4		4	4		5	4	5	7	10	9	9	10	11	9
52°F (11.1°C)	2.8	2.8	2.8	2.2	2.2	2.2		2.2	2.2	2.8	2.8	2.2	2.8	3.9	5.6	5.0	5.0	5.6	6.1	5.0

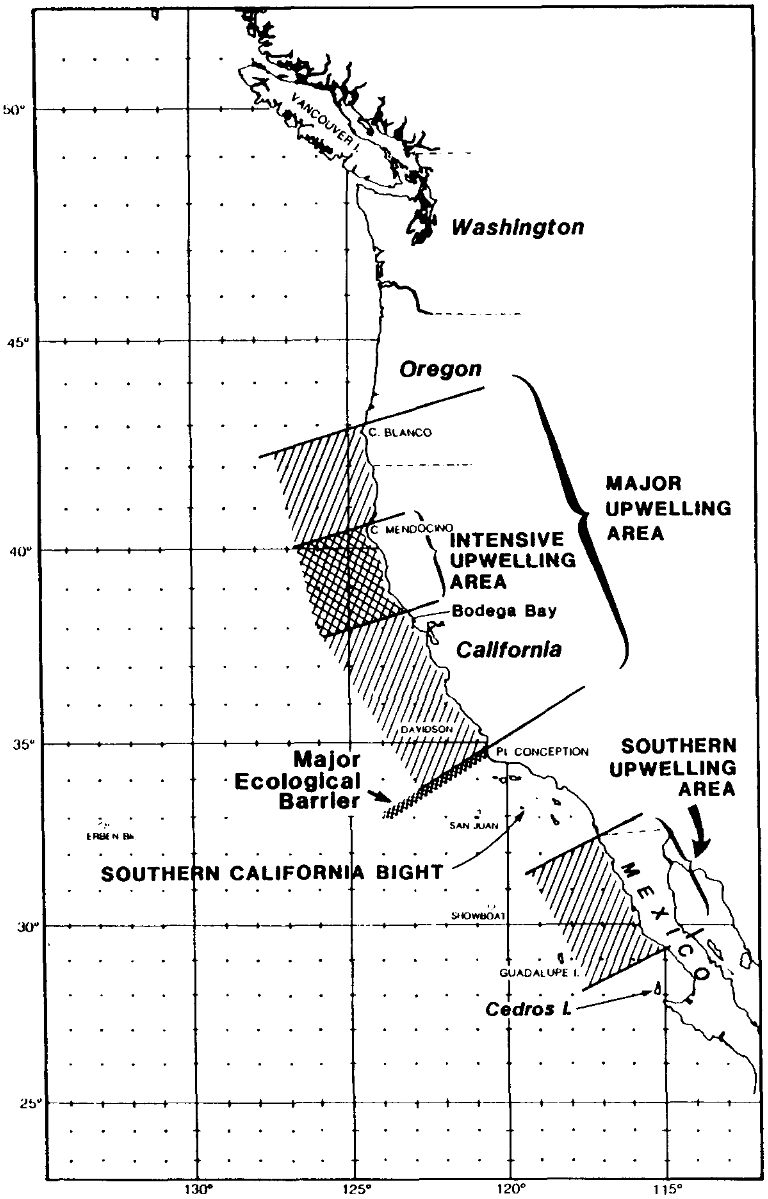

Figure 10. -- Major ecological SST barrier areas to the northward migration of subtropical and tropical coastal pelagic species.

area to the north has within it areas of intensive upwelling that produce some of the lowest temperatures observed along the U.S. west coast. The area from north of Bodega Bay to Cape Mendocino, Calif., is recorded as having consistently low temperatures (Squire, 1971). Sea surface temperatures in this coastal and offshore area may provide an environment that in most years inhibits the movement of the more southern species north of San Francisco.

The eastward moving North Pacific Current, toward the coasts of central Oregon, Washington, and British Columbia and into the Gulf of Alaska (the Alaska gyre), tends to moderate coastal SST's north of lat. 45°N, which are often several degrees warmer than those found off central and northern California. Once the coastal pelagic fish common to the more southern latitudes reach a point north of the major west coast upwelling area, the isotherm structure provided by the counterclockwise Alaskan gyre may enable these fishes to move northward off the coasts of Washington and British Columbia and into the Gulf of Alaska. For example, Pacific bonito were reported in the summer of 1983 off Klawock and Kodiak Island, Alaska, and Pacific barracuda off Ketchikan, and Kodiak Island. Mean SST charts for semimonthly periods developed by the National Weather Service, National Meteorological Center, were examined for the periods in 1983 when the low mean catch temperatures for yellowtail, Pacific barracuda, white seabass, Pacific bonito, and chub mackerel were geographically above lat. 52°N (Fig. 3-7). The geographical extent of the mean low catch temperature into the Gulf of Alaska area is shown in Figure 11.

Positive SST anomalies off southern California (Fig. 1) during the warm period of 1957-1958 (McGary, 1960) peaked in September 1957 and were greater by 2°F (1.1°C) in 1957 than in 1983. Since September normally has high SST's and is a high catch-rate month off southern California for many of the subtropical pelagic species, the 1957 temperature peak came at a favorable time. In the El Niño period of 1972, positive SST anomalies peaked off southern California in October, but with less intensity of 2°-4°F (1.1°-2.2°C); however, the period was still near the time that subtropical and tropical species migrate northward. In contrast, during the warming off southern California in 1983, positive anomalies peaked first in February—not a period of northward migration of tropical and subtropical species into

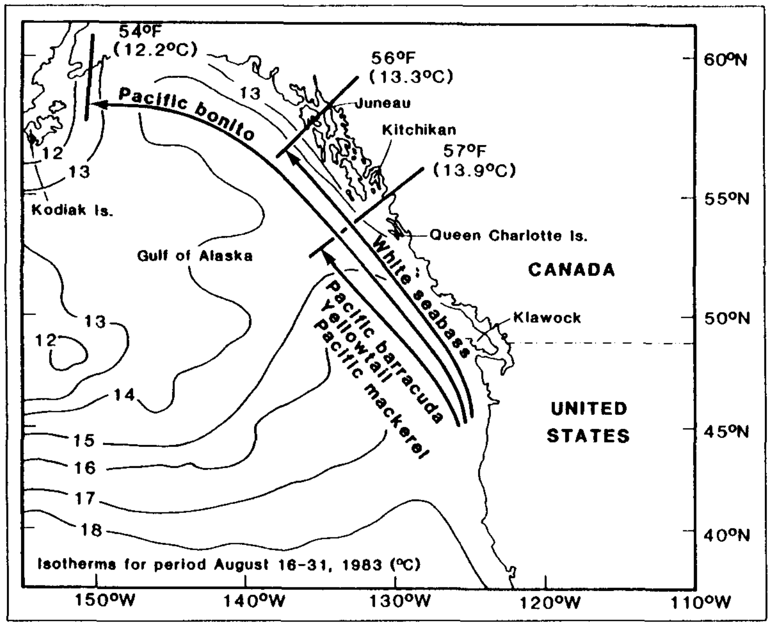

Figure 11.—Northern coastal geographical limits in 1983 of low mean catch temperature as observed off southern California for Pacific bonito, white seabass, Pacific barracuda, yellowtail, and chub mackerel.

southern California. The SST declined slightly in spring 1983 but resurged to levels of about 3°-4°F (1.7°-2.2°C) above normal from August through October, providing a sustained warm period of about 15 months during which positive anomalies of 2°F (1.1°C) or more allowed a northward extension of the distribution range for many pelagic species.

Geographical location of the temperature representing the lower limit of one standard deviation about the mean catch temperature appeared to reach its maximum northern latitudinal extent during the period 1-15 September, 1983 (see Fig. 3-7). This maximum indicated that the SST was most favorable for movement of the subtropical fishes to more northern latitudes of Oregon and Washington in early September. The geographical position of one standard deviation value below the mean was north of Point Conception for chub mackerel from July through November; yellowtail, August to October; white seabass from July through November; Pacific bonito, July through November; and Pacific barracuda, June to late November.

Species common to southern California during the summer and early fall fishing season that have mean catch temperature limits indicative of a greater northward migration than yellowtail and Pacific barracuda, are the Pacific bonito (Fig. 5, 11) and white seabass (Fig. 6, 11). The geographical position of the low mean catch temperature for Pacific bonito was north of Point Conception in mid-1983 and remained further north of lat. 52°N for a longer period than did the low mean catch temperature parameter for white seabass. On the basis of monitoring in previous warming periods and in 1983, the northward movement of the Pacific bonito appears to have exceeded that for white seabass. In 1983, the tendency for northward migration was less evident for yellowtail and white seabass than for Pacific bonito and Pacific barracuda. The mean catch temperature for yellowtail and Pacific barracuda was less frequently observed at latitudes north of Cape Blanco (lat. 43°N) and at or above lat. 52°N. Chub mackerel was caught over a wider range of temperatures than any other of the coastal pelagic species studied, and the geographical position of its low mean catch temperature (57°F or 13.9°C) was often at or above the latitude of San Francisco. Mean catch temperature values were north of Point Conception from August to 15 October, 1983. In terms of the potential for occurrence in northern latitudes, chub mackerel would rank between Pacific bonito and yellowtail. They were common from the central coast of California to British Columbia, and extended into the southern portion of Puget Sound.

The mean catch temperature at which yellowfin tuna are taken off the southwestern coast of Baja California was observed off southern California as early as August 1983 and was common there through October 15. Record-setting catches of yellowfin tuna were made during this period, in addition to good catches of skipjack tuna. Yellowfin tuna were not taken in substantial quantity west or northwest of long. 120°W (southeast of Santa Barbara, Calif.). The reason for the markedly higher catches of yellowfin tuna in 1983 than in 1957 is not apparent.

The mean catch temperature for striped marlin was first observed off southern California in August and remained off this area through 15 October 1983. Analysis of 20 years of SST and striped marlin catch data off southern California indicated an exponential increase in catch through a mean temperature of 72°F (22.2°C) (Squire, 1985). Sea surface temperature charts for the region off southern California show that temperatures are highest in the Gulf of Catalina, a part of the southern half of the Southern California Bight. Although SST's of 76°-80°F (24.4°-26.7°C) were reported in this area in September 1983, the average SST charts for this period indicate a maximum temperature of about 72°F (22.2°C). Temperatures in the normal catch areas were reported by fishermen to be considerably above the 72°F (22.2°C) maximum, and this may have resulted in a concentration of striped marlin in the northwest corner of the Southern California Bight in an area of cooler water. Excellent catches were made south of the Santa Barbara Channel Islands (near

Point Conception), along with some catches north of Point Conception near Morro Bay, Calif. The lower catch temperature limits for striped marlin off southern California (62°F or 16.7°C) extended north to the latitude of San Francisco, and catches were made in Monterey Bay and in the offshore area.

Mean catch temperatures observed during non-El Niño years for salmon off the Monterey Bay to Bodega Bay area were compared with temperatures observed in 1983. Temperatures were above optimal catch temperatures from 2° to 9°F (1.1° to 5.0°C) durng the normal high catch periods and were above normal during all semimonthly periods in January through 15 October, 1983. Poor catches in the warm year of 1983 appear to parallel the occurrence of low catches during the warm years of 1957-58.

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