759

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Catch Temperatures for Some Important Marine Species off California

James L. Squire, Jr.

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA TECHNICAL REPORTS

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751. The barge *Ocean 250* gasoline spill, by Carolyn A. Griswold (editor). November 1981, iv+30 p., 28 figs., 17 tables.

752. Movements of tagged summer flounder, *Paralichthys dentatus*, off southern New England, by F. E. Lux and F. E. Nichy. December 1981, iii+16 p., 13 figs., 3 tables.

753. Factors influencing ocean catches of salmon, *Oncorhynchus* spp., off Washington and Vancouver Island, by R. A. Low, Jr. and S. B. Mathews. January 1982, iv+12 p., 6 figs., 7 tables.

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldridge, Secretary
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John V. Byrne, Administrator
National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

CONTENTS

Figures

Tables

Catch Temperatures for Some Important Marine Species off California

JAMES L. SQUIRE, JR.[1]

ABSTRACT

Airborne sea surface temperature surveys using infrared techniques were conducted monthly off the central and southern California coast, 1963 through 1968, by the National Marine Fisheries Service in cooperation with the U.S. Coast Guard. The resulting temperature data were matched to commercial sportfishing boat catch data to determine the relationship between catch and temperature for the following major sport species: chinook and silver salmon, *Oncorhynchus tshawytscha* and *O. kisutch*; yellowtail, *Seriola dorsalis*; Pacific bonito, *Sarda chiliensis*; Pacific barracuda, *Sphyraena argentea*; white seabass, *Atractoscion nobilis*; and albacore, *Thunnus alalunga*.

Part I presents graphs for each of the above species for areas having high catches, the month during which most fish were caught, sea surface temperature at which most fish were caught, mean catch temperature and its standard deviation, and temperature range.

Part II describes how catch and catch-per-unit-effort (CPUE) are related to temperature. A series of weekly airborne temperature surveys were flown over a high catch rate area off San Diego, Calif., April through October, in 1972, 1973, and 1974. These temperature data were compared with catches of yellowtail, Pacific barracuda, and Pacific bonito by the sportfishing fleet within the survey area. Graphical Kolmogorov-Smirnov cumulative preference curves of catch versus temperature for yellowtail, Pacific barracuda, and Pacific bonito show increased catch rates through the midrange temperatures 17.8° to 20.0°C (64° to 68°F) with a reduction in rates above 20.5°C (69°F).

For a 31-wk period starting on 1 April 1972, 1973, and 1974, the temperature at the 20th percentile of the catch temperature curve was slightly above the 20th percentile of the cumulative temperature curve, indicating that fewer fish were taken at the very lowest temperatures; otherwise, catch for the three species appears representative of the temperature distribution. The average yearly temperature for large catches of Pacific barracuda, yellowtail, and Pacific bonito (30% or more above mean) fluctuated from 16.2°C (61.2°F) to 23.0°C (73.5°F), with a mean value of 19.5°C (67.1°F) for Pacific barracuda, 18.5°C (65.4°F) for yellowtail, and 19.6°C (67.4°F) for Pacific bonito. Nonparametric rank correlation tests (Spearman and Kendall) for catch and CPUE versus temperature showed consistently higher correlations for catch than for CPUE, indicating an increase in effort with increasing catch. In analyses of temperature and CPUE by species and year for 12-, 17-, and 31-wk periods, about one-half of the individual cases tested were, on the average, statistically significant at the .05 level.

Temperature distributions within 20th percentile ranges of the cumulative CPUE curves obtained for the three species combined indicate that the lowest temperature range, 12.7° to 15.5°C (55° to 60°F), is the only area where catch rates were lower than expected.

There is little evidence for a preferred temperature within the range of 15.5° to 21.1°C (60° to 70°F). Conclusions from this study indicate that fishery data are by no means optimal for examining the hypothesis of preferred temperature, due to confounding of cause and effect between catch and effort. Lack of simultaneous observation of the spatial distribution of species and environmental measurements over the extent of distribution over time are limiting factors in determining the true relationship of species to the environmental factor of sea surface temperature.

INTRODUCTION

Normal and anomalous changes in the ocean environment, as measured by sea surface temperature (hereafter referred to as "temperature"), produce a variety of effects upon the apparent abundance and geographical distribution of coastal and oceanic pelagic marine species. The coastal marine environment consists of biological, chemical, and physical factors which may independently, or in combination, influence the abundance and distribution of fishery resources. Although temperature is a commonly observed environmental variable, only limited statistical information is available comparing the catch of fish in waters of different temperature. A recent comparative temperature study in the northeast Pacific was prepared by Radovich (1975).

Development of management programs for coastal pelagic fisheries requires knowledge of the distribution of pelagic species, with regard to natural fluctuations in the physical marine environment. It may be possible to use environmental information to improve estimates of population size and distribution, and to evaluate the effect of environmental changes on catch. However, in order to apply fully effective resource management, we must learn more about how coastal species respond to changes in their environment.

Temperature is one physical variable which is relatively easy to measure. The ocean's surface layer temperature reflects the exchange of thermal energy from solar, atmospheric, and subsurface sources. The relationship between temperature and the distribution and migration of marine and anadromous fishes has long interested researchers. Along the west coast of the United States and Canada during years of unusually warm surface water, pelagic species common to the lower latitudes in the northeast Pacific have been recorded far north of their normal range, and, in some cases, changes in coastal migratory patterns have been recorded (Hubbs and Schultz 1929; Walford 1931; Radovich 1961; Royal and Tully 1961). Since a relationship exists between anomalous temperature and the occurrence of pelagic species, temperature may provide a means of predicting, within seasonal and statistical limits, the occurrence or distribution of coastal marine and anadromous species. The objective of this study was to define the relationships between catch (as a measure of apparent abundance), and temperature, for selected species in different geographical and environmental areas.

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Part I of this paper uses data from monthly airborne infrared temperature surveys off central and southern California conducted during the 5-yr period 1963-68, and catch data from sportfishing boats as collected by the California Department of Fish and Game (CF & G), to determine the temperature at which several important species were caught by the recreational fishery fleet.

Part II describes the results of a more detailed airborne temperature study which took place at an important recreational fishing area off San Diego from April through October in 1972-74. This second series of airborne surveys used increased survey intensity (weekly vs. monthly) over a high catch rate area for the sportfishing fleet, in order to determine the correlation of catch-per-unit-effort (CPUE) to temperature and the statistical significance of differences in temperature-dependent catch rates. The statistical analysis of the data collected off San Diego is presented in the analysis and conclusions section of Part II. Data presented in Part II apply to the general temperature-catch relationships in Part I.

PART I—CATCH AND TEMPERATURE OBSERVED FOR SEVERAL RECREATIONAL AND COMMERCIAL SPECIES OFF CENTRAL AND SOUTHERN CALIFORNIA

In August 1963, the National Marine Fisheries Service (then the U.S. Fish and Wildlife Service, Tiburon Marine Laboratory, Tiburon, Calif.) initiated a program in cooperation with the U.S. Coast Guard to conduct monthly airborne temperature surveys using infrared techniques to measure temperature over three important coastal fishing areas off the west coast. These airborne temperature surveys were continued by the U.S. Coast Guard into 1979. Results of the first 5 yr of surveys (1963-68), in the form of individual survey and monthly average temperature charts for the three areas, were published by Squire (1971). Although those airborne infrared temperature surveys are useful to many fields of environmental research, they were primarily intended to develop temperature data which could be analyzed with catch data to provide insight into catch temperature relationships for some of the more important coastal species.

The central survey area off the California coast from Point Arena to Point Sur and offshore about 50 nmi (Fig. 1a), and the survey area off southern California (Fig. 1b), supplied the temperature data for this paper. The southern area extended to about 110 nmi offshore at its widest point, and from off the coast of Point Arguello, Calif., to Point Salsipuedes, Baja California, Mexico. Data from the northern survey area, which covered the coastal waters from Cape Flattery, Wash., to Cape Lookout, Oreg., for about 50 nmi offshore, were not included. From the published monthly survey data, the temperature was obtained for each CF & G block area (10′ longitude × 10′ latitude geographical area) by month, and these data were used in the calculations for Part I.

Monthly catch data recorded by the commercial sportfishing fleet for the period August 1963 through July 1968 were obtained through the cooperation of the CF & G, Marine Resources Laboratory, Long Beach, Calif. Fishes selected for study included two species of salmon (chinook, *Oncorhynchus tshawytscha*, and silver salmon, *Oncorhynchus kisutch*), which enter the catch off the San Francisco, Bodega Bay, and Monterey Bay area. Data on these species were combined in the CF & G sportfishing boat catch records. Off southern California and northwestern Mexico, catch data were obtained for yellowtail, *Seriola dorsalis*; Pacific bonito, *Sarda chiliensis*; Pacific barracuda, *Sphyraena argentea*; albacore, *Thunnus alalunga*; and white seabass, *Atractoscion nobilis*. All of the latter group are important to the marine sport and/or commercial fishing industry of the United States, and some are important to Mexico. Albacore is taken in substantial quantities by the southern California sportfishing fleet, but most of the catch is taken outside the boundaries of the area

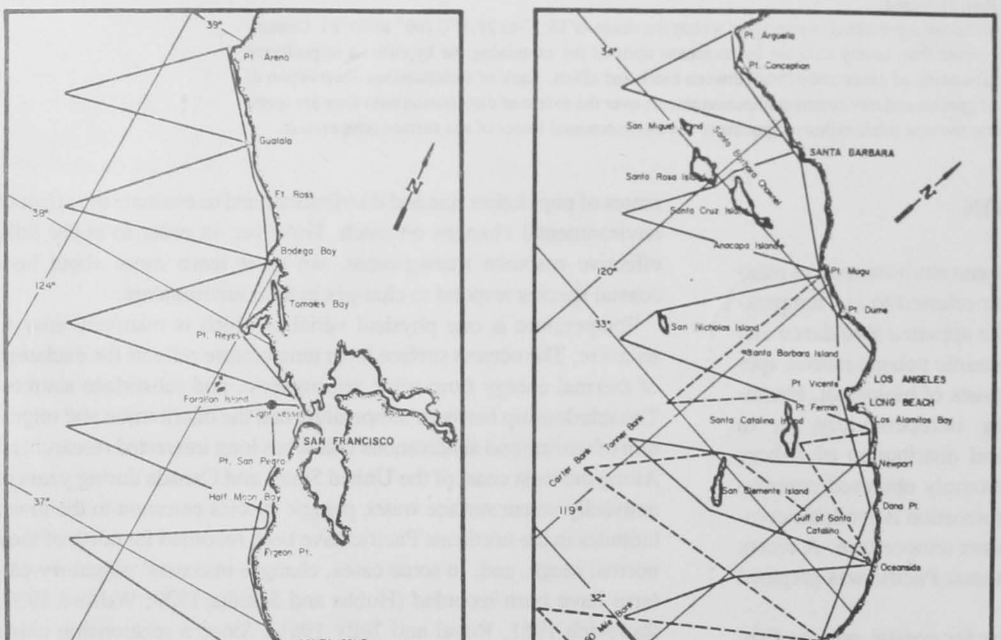


Figure 1.—Airborne infrared sea surface temperature survey tracks: left, central survey area; right, southern survey area.

surveyed. Only catch temperature data for albacore catches within the survey area are given.

Each sportfishing boat operating for hire from California is required by CF & G to maintain a daily fishing log of the catch by species, location of catch (block area number), and number of fishermen on board. Catch records do not indicate species targeted by anglers, or the fishing technique used. A species-preference order is known to exist with the coastal recreational fishermen; in the north, salmon is a highly desirable species, and off southern California, albacore, yellowtail, Pacific barracuda, and white seabass are high on the preference list. In addition, species-specific lures and/or live bait are fished near the surface, in midwater, or close to the bottom. The lack of detailed catch data prevents the allotment of "effort" to the catch of any one species. However, the catch and numbers of anglers participating may be related, particularly for those species that are of high priority to the marine angler. Reports of better-than-average fishing, whether true or not, usually result in increased fishing effort; therefore the catch may or may not be a reflection of increased availability in localized fishing areas. The relationship of catch to number of anglers for data collected in 1972 through 1974 is discussed in Part II.

Basic environmental data for the analysis involved monthly temperature measurements derived from isotherm charts drawn from airborne infrared temperature data for the period August 1963 through July 1968. The surveyed region included 40 block areas off central California having a reported catch of salmon (2,460 temperature observations), and 130 block areas off southern California in which catches of either yellowtail, Pacific bonito, Pacific barracuda, albacore, or white seabass were reported (7,800 temperature observations). Temperature data developed from continuous analog measurements in degrees Fahrenheit are given as Celsius and Fahrenheit.

Monthly catch locations for the 5-yr period were obtained from the CF&G sportfishing boat log records for catches of 347,867 salmon, 161,375 yellowtail, 4,047,292 Pacific bonito, 2,439,512 Pacific barracuda, 129,535 albacore, and 42,328 white seabass.

Results

Data on catch by species for each month from August 1963 through July 1968, and monthly temperature data for the 5-yr survey period, were processed by the Northwest Fisheries Center, Seattle, Wash. A computerized data analysis determined the following: the mean catch temperature, $\bar{X}=\frac{\Sigma(f1\times1+f2\times2+\ldots)}{\Sigma(f1+f2+\ldots)}$; the standard deviation about the catch temperature mean (α); and the array of catch by temperature as well as the number of fish in each sample for each species by total area, and by individual block area, month, and year. Temperature ranges, means, and standard deviations were calculated for the same geographical areas and time groups as the species data.

Data are presented for salmon off central California, and for yellowtail, Pacific bonito, Pacific barracuda, white seabass, and albacore off southern California (Fig. 2-19c). These illustrate catch, catch temperature, and temperature range on a regional geographical basis (central California and southern California).

Central California (Monterey Bay, San Francisco, and Bodega Bay)

The ocean temperature of the major fishing area for salmon (from Monterey Bay to off Bodega Bay) ranged from 9.4° to 16.7°C (49.0° to 62.0°F). Waters in this area are coolest during January through May or June, with the lowest temperature recorded in April. Temperatures increase slightly from June through September when the peak average temperature occurs, then drop again after September.

Major peaks in the salmon catch for the fishing area off San Francisco occur in March and July (Fig. 2). To the north of Bodega Bay, the peak catch is in July, and south of Monterey two catch peaks occur, one in May and one in July. Chinook are the salmon most often caught, because as the Sacramento River system holds spawning chinook salmon during most of the year and these pass through the major ocean fishing areas off central California. However, the fall run of chinook salmon is the largest, and fish congregate off the San Francisco Bay area for the spawning migration.

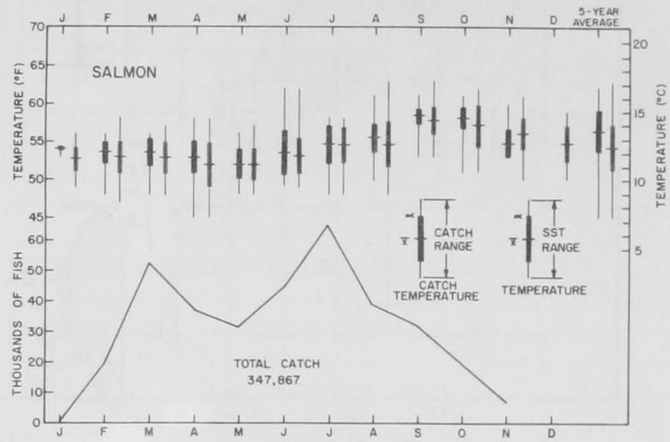


Figure 2.—Distribution of salmon catch off northern California (Monterey Bay to Bodega Bay) by month, August 1963–July 1968, for total catch, catch temperature, and sea surface temperature range and means, and the standard deviation about the means.

The catch temperature mean for all salmon catches off San Francisco for the 5-yr period is greater than the sea surface temperature mean, except for November (Fig. 2). The monthly catch temperature mean is equal to or greater than the temperature mean from January through October, which indicates that more salmon were caught when the temperature was greater than its monthly mean. The catch temperature mean was below the temperature mean during November; however, this was a period of near zero salmon catch. Figure 3 indicates those blocks having a recorded catch of 1,000 salmon or more during the survey period, the month having the greatest catch, the temperature at which most salmon were caught, the mean catch temperature, and the number of salmon in the sample.

The major fishing area off San Francisco early in the year is in the vicinity of Point Reyes, south of Drakes Bay and Duxbury Reef (March/blocks 447, 448, and 449). The major fishing area moves to near the Farrallone Islands and the San Francisco Light Buoy during the summer (June-July/blocks 456, 457, 458). In late summer the fishing area moves closer to the Golden Gate (August-September/blocks 446, 455). Mean catch temperature ranged from 11.2° to 13.6°C (52.2°-56.5°F).

The review of the three leading block areas (448, 446, 457) in catch is given in Figure 4a, b, c, showing for each block area the distribution of catch by temperature and by month for catch, temperature at which most salmon were taken, the monthly mean catch temperature, and standard deviation of the mean catch temperature.

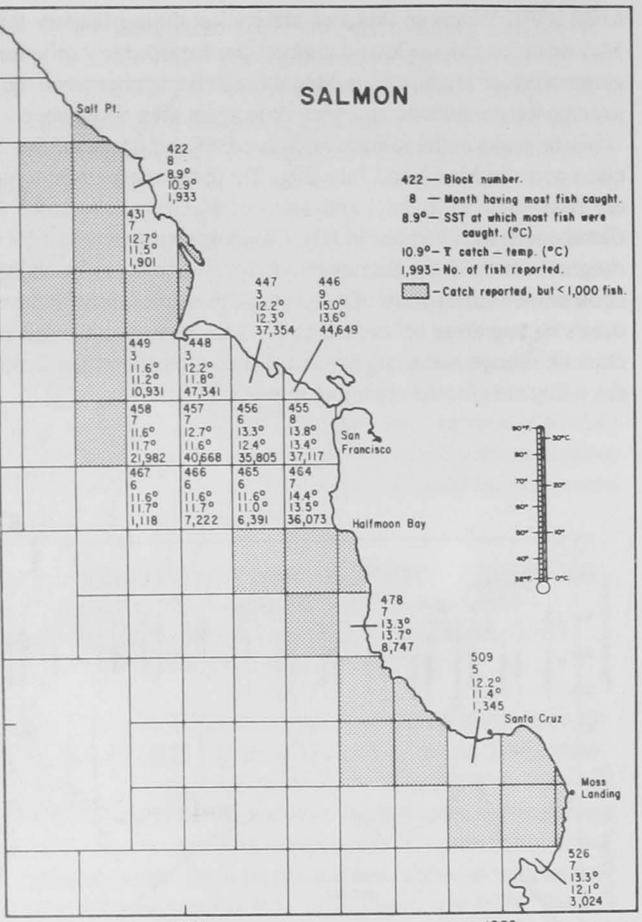
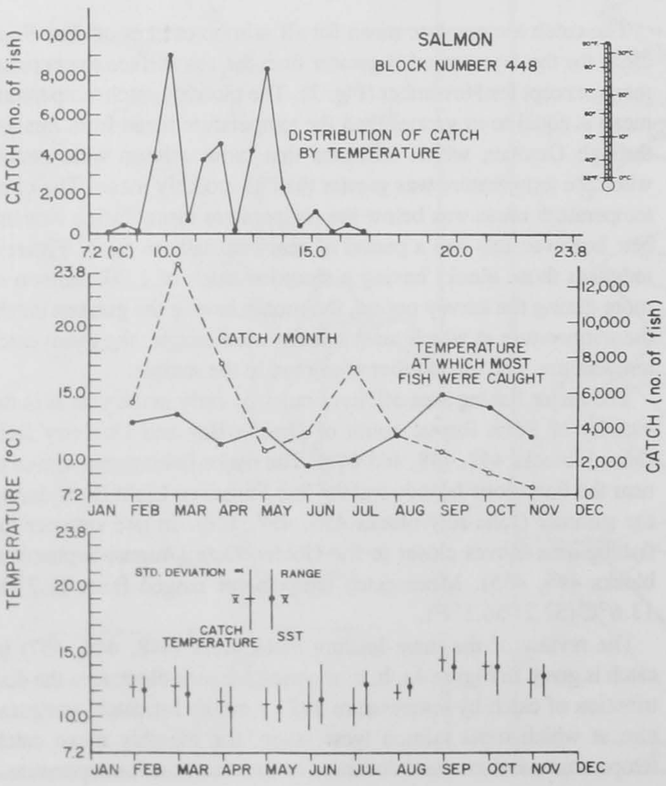
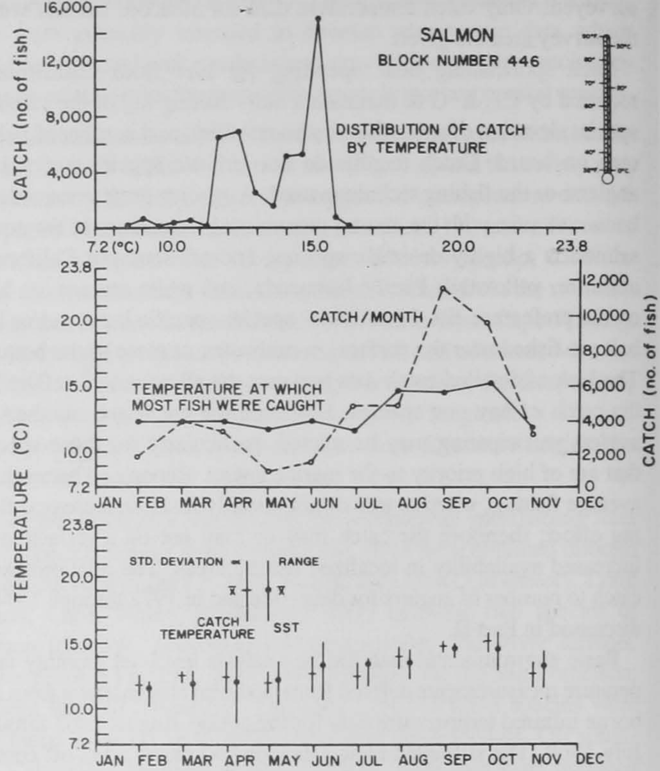


Figure 3.—Catch and temperature data by block area for salmon caught off northern California.





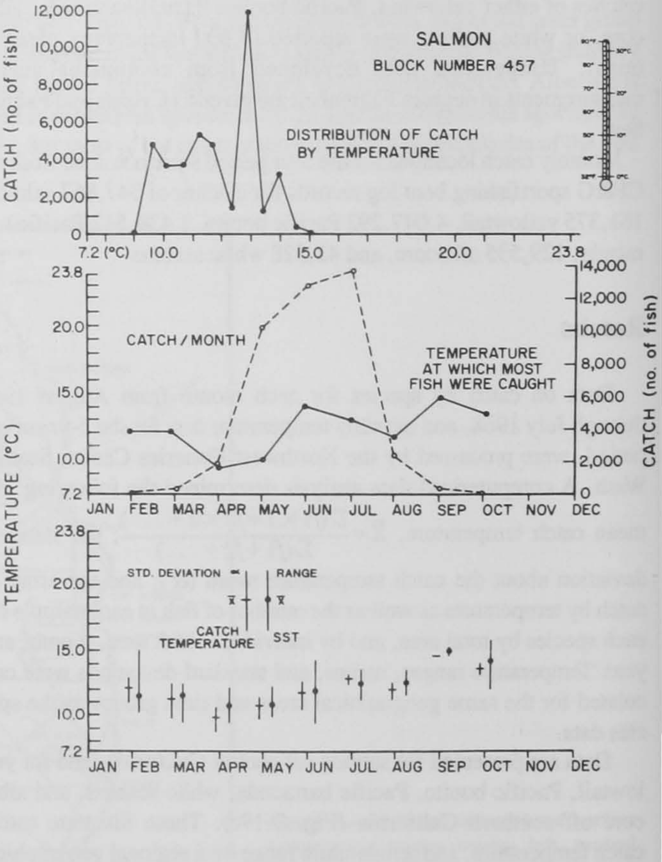


Figure 4.—Distribution of catch by temperature and by month for catch, temperature at which most salmon were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having salmon catches. Left, block 448; top, block 446; bottom, block 457.

Southern California (Point Conception to Coronado Islands, Mexico)

During the surveys, temperatures off southern California ranged from 9.4° to 23.3°C (49.0°–74.0°F). The coldest temperatures were in areas near Point Conception and the Santa Barbara Channel Islands, and the warmest temperatures occurred offshore southwest of Dana Point. Mean temperatures ranged from 12.0°C (55.1°F) off the Point Conception-Santa Barbara Channel Islands area, to 20.8°C (69.5°F) off Dana Point.

Yellowtail.—The yellowtail is a pelagic coastal migratory species and commonly ranges from the southern tip of Baja California, Mexico, to near Point Conception, Calif. It is one of the most important sport fishes in southern California and an important commercial species in Mexico. The major sportfishing areas for yellowtail at the northern portion of their range are the Coronado Islands, Mexico, the kelp beds off Point Loma and La Jolla, Calif., and Catalina Island. These fish are caught off southern California in quantity only during the summer migration north from off the Baja California coast. The distribution of yellowtail catch and temperature off southern California (Fig. 5) shows that the catch temperature mean is higher than the sea surface temperature mean in all months except September, October, and November. These results indicate that greater catches are made in months when temperature is above the mean.

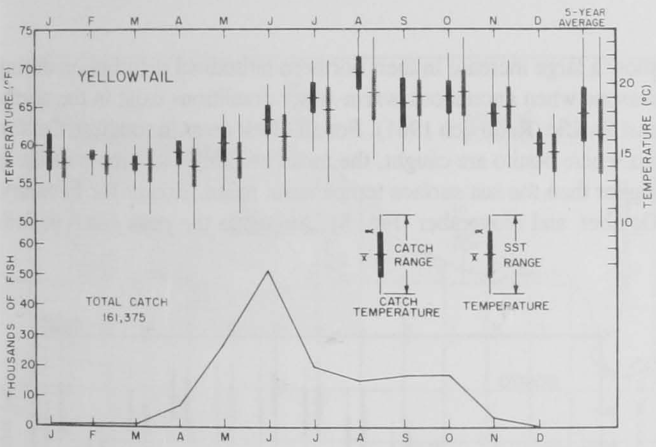


Figure 5.—Distribution of yellowtail catch off southern California and northern Mexico by month, August 1963–July 1968, for total catch, catch temperature, and sea surface temperature range and means, and the standard deviations about the means.

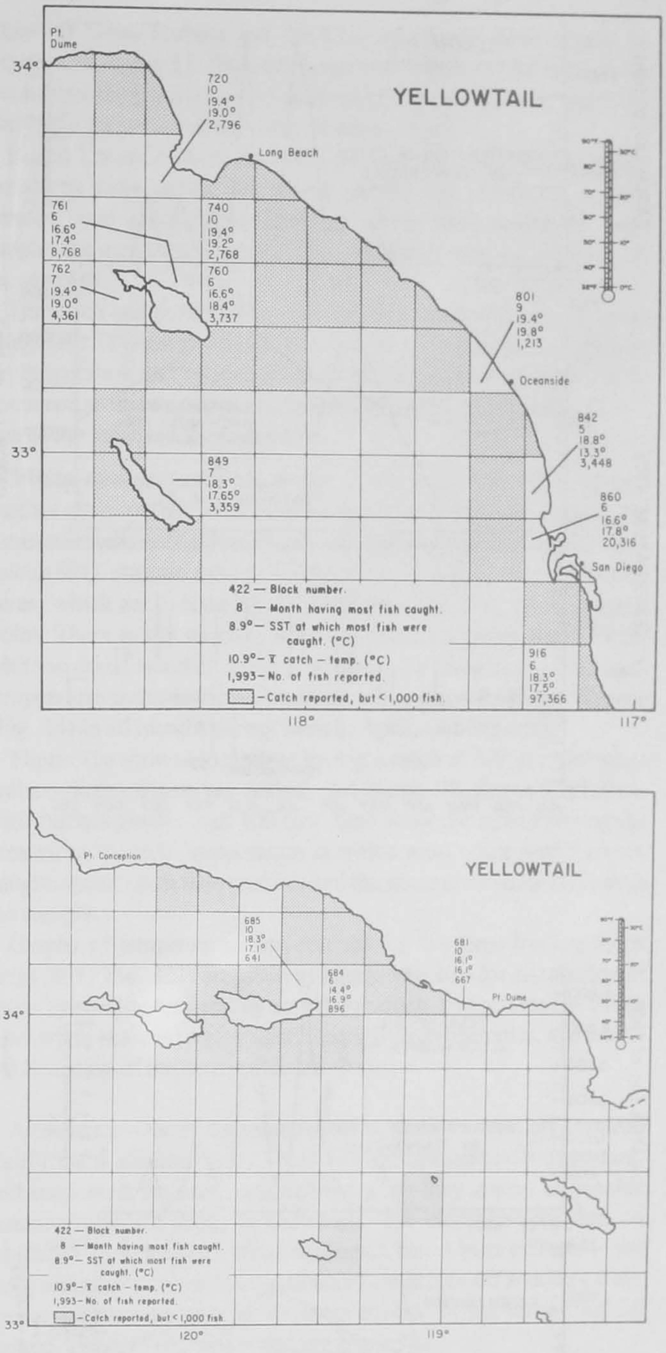
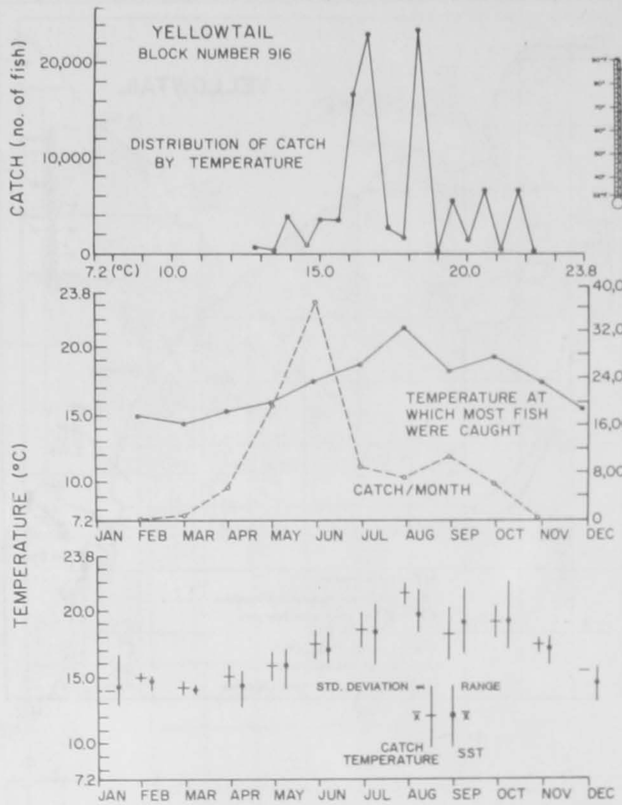


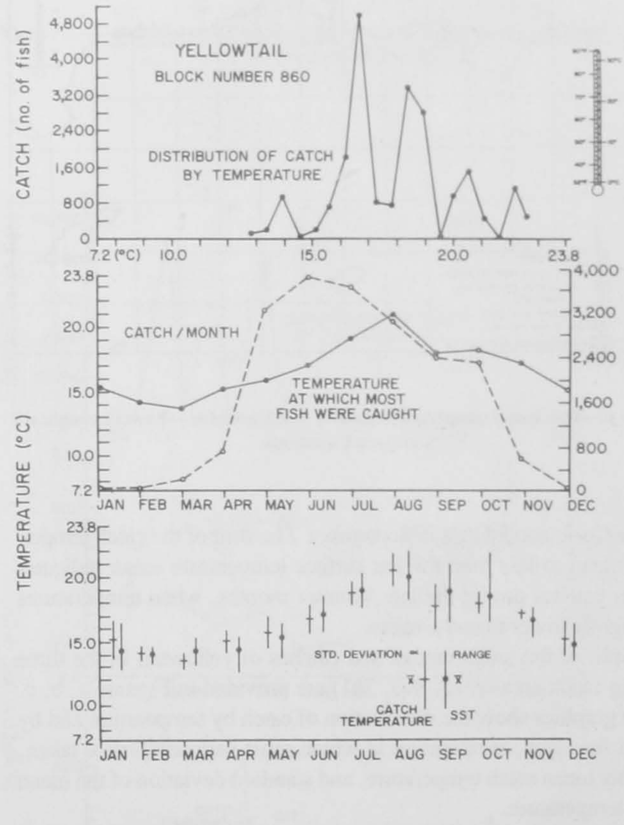
Figure 6.—Catch and temperature data by block area for yellowtail caught off southern California.

Figure 6a and b give the following information by block area for those areas having a catch of 1,000 or more yellowtail during the survey period: the month of the greatest total catch; temperature at which most yellowtail were caught; the mean catch temperature; and the number of yellowtail in the sample. The yellowtail's seasonal migration northward can be detected by examining the dominant catch by block area by month. Near the Coronado Islands (block 916), the first catch peak is recorded in June (block 860). The catch peak is also in June off Point Loma and La Jolla; however, yellowtail is taken for a long period during the summer months in this nearshore area. For block areas 761 and 762 north of Catalina Island, the peak catches are in June and July. Fishing along the coast near the greater Los Angeles area (block 720) peaks in October, as it does along the coast west of Los Angeles and off Santa Barbara. There is evidence of a late summer southward migration, as a second catch peak occurs off the Coronado Islands in September. The shift of the catch temperature mean to less than the sea surface temperature mean indicates greater catches during the late summer months, when temperatures are slightly lower than the mean.

Graphs of the temperatures and catches of yellowtail in the three leading block areas (916, 860, 761) are provided in Figure 7a, b, c. These graphics show the distribution of catch by temperature and by month for catch, temperature at which most yellowtail were taken, monthly mean catch temperature, and standard deviation of the mean catch temperature.

Pacific bonito.—Bonito is a species that is known to migrate considerable distances along the coasts of Baja California, Mexico, and into southern and central California. Like the yellowtail, these fish





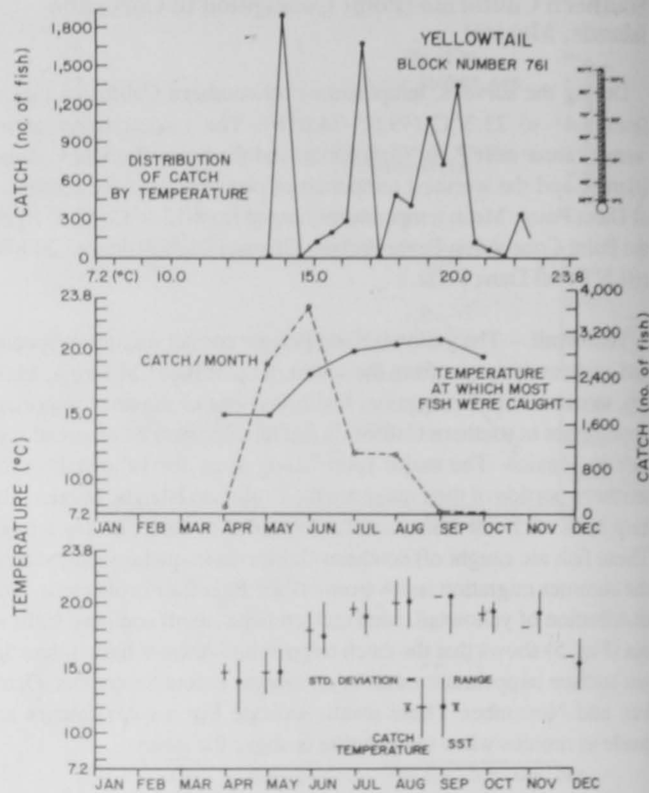


Figure 7.—Distribution of catch by temperature and by month for catch, temperature at which most yellowtail were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having yellowtail catches. Top left, block 916; bottom left, block 860; top right, block 761.

show a large increase in their northern latitudinal distribution during seasons when anomalous warm-water conditions exist in the northeast Pacific (Radovich 1961). For all block areas in southern California where bonito are caught, the mean monthly catch temperature is higher than the sea surface temperature mean, except for February, October, and November (Fig. 8). August is the peak catch period,

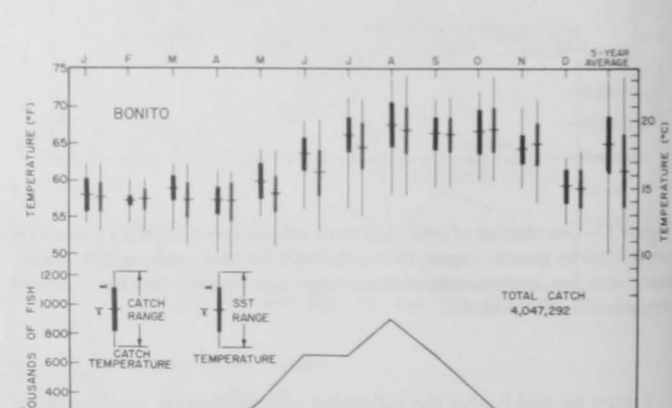


Figure 8.—Distribution of Pacific bonito catch off southern California and northern Mexico by month, August 1963–July 1968, for total catch, catch temperature and sea surface temperature range and means, and the standard deviation about the means.

and block 860 located off Point Loma/La Jolla in the San Diego area has the largest recorded annual catch. Figure 9a and b give the following information for block areas having a catch of 20,000 bonito or more during the survey period: the month having the greatest total catch, temperature at which most bonito were caught, the mean catch temperature, and the number of bonito in the sample.

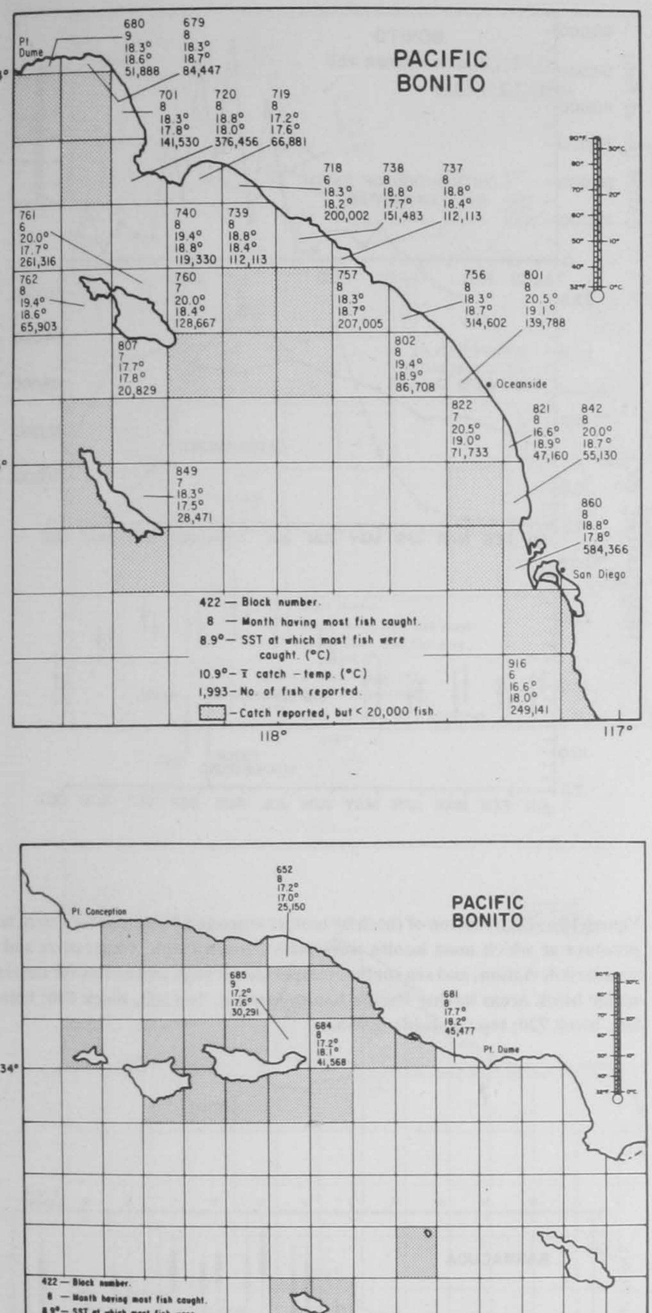


Figure 9.—Catch and temperature data by block area for Pacific bonito caught off southern California.

Graphs of the temperatures and catches of bonito in the three leading block areas (860, 720, 756) appear in Figure 10a, b, c for distribution of catch by temperature and by month for catch, temperature at which most bonito were taken, the monthly mean catch temperature, and standard deviation of the mean catch temperature.

Pacific barracuda.—Barracuda are caught mainly off Point La Jolla (block 860), near the city of San Clemente (block 756), and off Huntington Beach (block 718). Catch peaks occur off La Jolla during August and in Huntington Beach in September, with a few barracuda taken off Santa Barbara and the Channel Islands from August to October. In Figure 11, the catch temperature mean is higher than the sea surface temperature mean in all months except January and February; the means are about equal in those months.

Figure 12a and b show, for block areas having a catch of 5,000 barracuda or more during the survey period: the month having the greatest total catch, temperature at which most barracuda were caught, the mean catch temperature, and the number of barracuda in the sample.

The catch and temperature data for the three leading block areas (860, 756, 718) are given in Figure 13a, b, c for distribution of catch by temperature and by month for catch, temperature at which most barracuda were caught, mean catch temperature, and standard deviation of the mean catch temperature.

White seabass.—All six major block areas for white seabass catches are along the coast from Point Loma to Dana Point, with the greatest numbers of white seabass recorded near Oceanside, Calif. (block 801). August is the peak catch period for the three major block areas, which are located off the coast from near Oceanside to Dana Point. There is still much to learn about the migratory habits of the white seabass, whether inshore, offshore, or alongshore. The catch temperature mean is higher than the sea surface temperature mean (Fig. 14) in all months except March, April, and November.

Figure 15a shows block areas having a catch of 500 or more white seabass during the survey period, and Figure 15b shows block areas with catches greater than 100 fish: both show the month having the greatest total catch, temperature at which most white seabass were caught, mean catch temperature, and the number of white seabass in the sample.

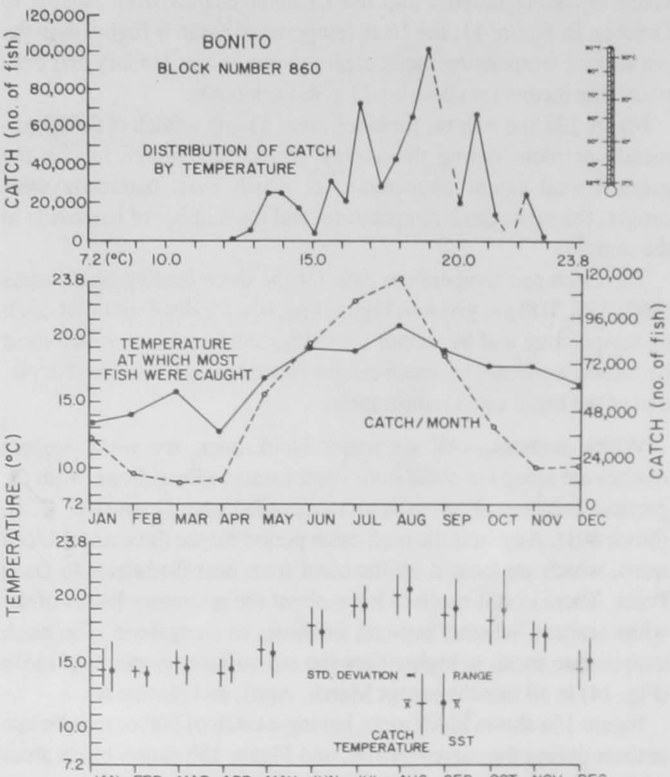
Graphs of temperatures and catches for the three leading block areas (801, 756, 822) are given in Figure 16a, b, c for distribution of catch by temperature and by month for catch, temperature at which most white seabass were caught, mean catch temperature, and standard deviation of the mean catch temperature.

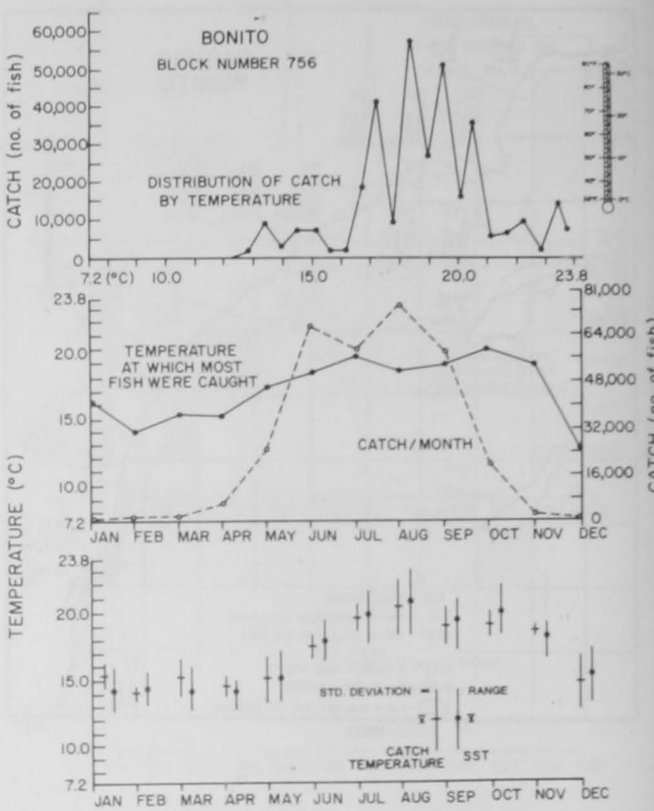
Albacore.—One of the most desirable species caught off southern California is albacore tuna. These fish are commercially important, and support an intensive sportfishery when they appear in fishable concentrations off southern California. The environmental data on which the albacore catch temperatures are based were collected over only the inshore portion of the albacore catch area off southern California and are valid only for the areas covered by the survey and for the sportfishery which provided the catch data.

Figure 17 shows that the peak catch is made during the months of July and August, with minor catches in October and November. A comparison of the catch temperature and temperature means shown in the figure indicates that the catch temperature mean is higher than the sea surface temperature mean in June, but falls below the temperature mean during the peak catch period of August and September. These comparisons indicate that peak catches in the survey area were made in months when temperatures were below the mean.

Block 882 west of San Diego includes the 43 Fathom Bank and is the leading catch area within the area covered by this study. Figure 18a and b give catch and temperature data by block areas having a catch of 1,000 or more albacore: the month having the largest total catch, temperature at which most fish were caught, the mean catch temperature, and the number of albacore in the sample.

Catch and environmental data are given for the three leading block areas (882, 916, 866) in Figure 19a, b, c, for distribution of catch by temperature and by month for catch, temperature at which most albacore were caught, mean catch temperature, and standard deviation of the mean catch temperature.





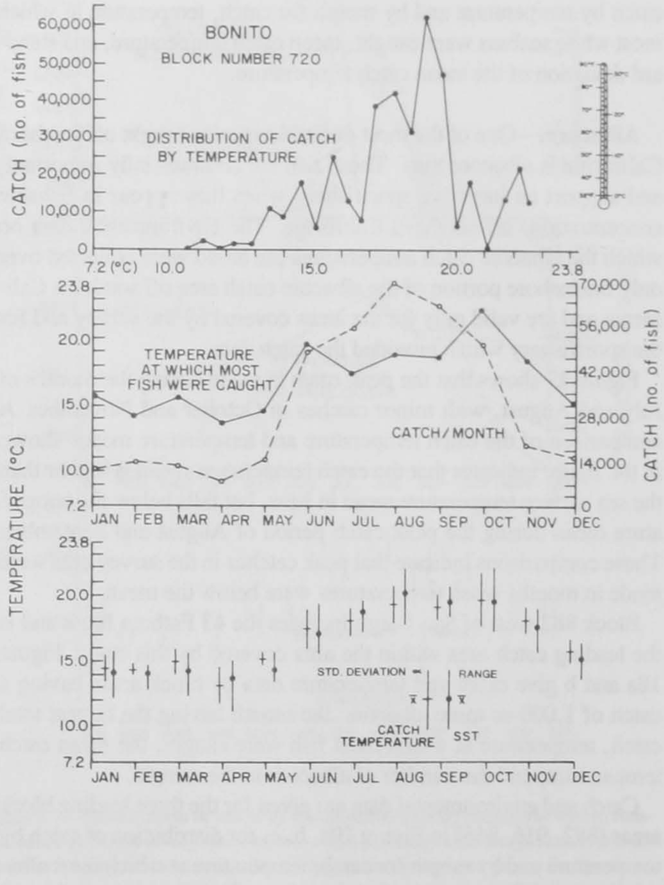


Figure 10.—Distribution of catch by temperature and by month for catch, temperature at which most bonito were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having Pacific bonito catches. Top left, block 860; bottom left, block 720; top right, block 756.

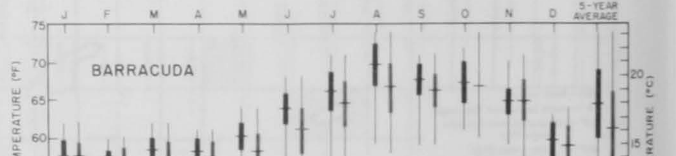


Figure 11.—Distribution of Pacific barracuda catch off southern California and northern Mexico by month, August 1963–July 1968, for total catch, catch temperature and sea surface temperature range and means, and the standard deviation about the means.

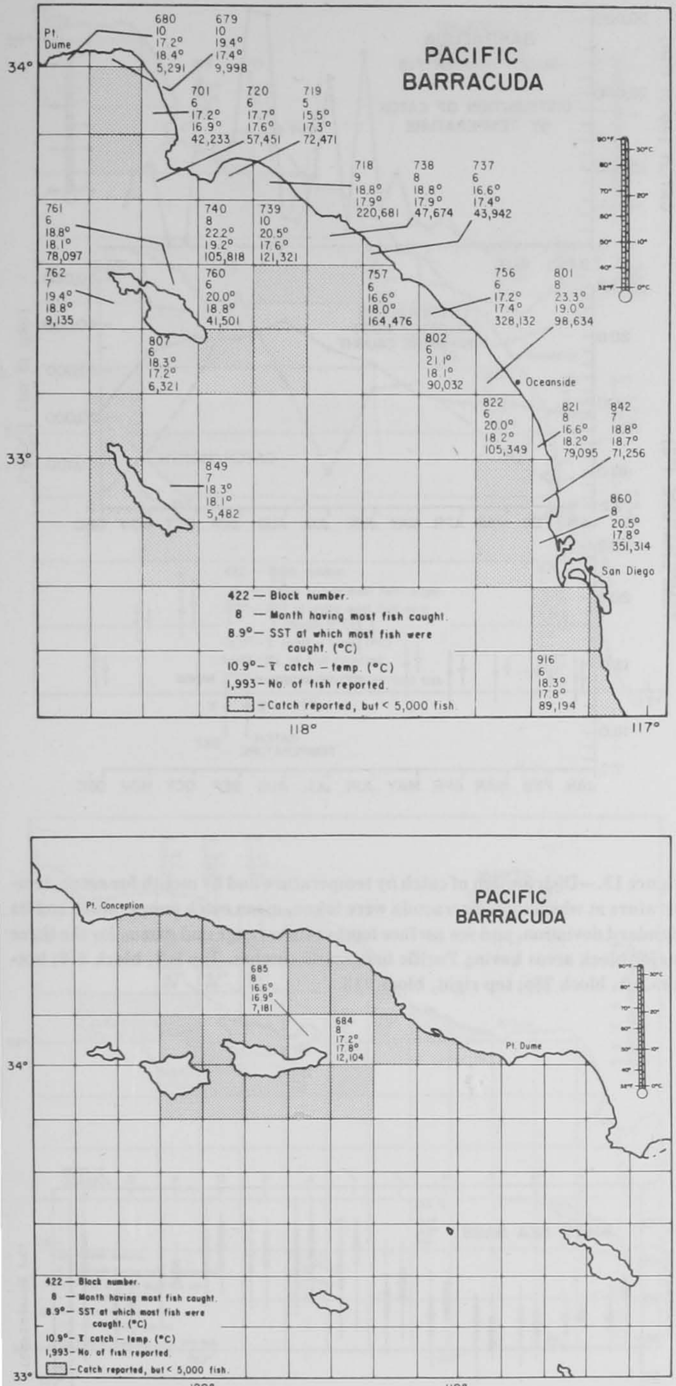


Figure 12.—Catch and temperature data by block area for Pacific barracuda caught off southern California.

PART II—SEA SURFACE TEMPERATURE AND ITS RELATION TO THE CATCH OF THE PELAGIC MIGRATORY SPECIES OF YELLOWTAIL, PACIFIC BONITO, AND PACIFIC BARRACUDA OFF SAN DIEGO

The airborne temperature surveys described in Part I were conducted monthly over a large geographical area. The survey track lines were not specifically designed to cross the geographical centers of sportfishing. Sportfishing effort is concentrated in localized areas along the southern California coast and around the offshore islands (Squire and Smith 1977). Two of the important marine sportfishing areas in southern California are located off San Diego. The Coronado Islands, located southwest of San Diego in Mexico, are in block area 916, a high catch area for yellowtail by the sportfishing fleet. The second high catch area for yellowtail is block area 860 off Point La Jolla. Block area 860 is also the leading catch area for the Pacific barracuda and Pacific bonito, while block area 916 is the third-ranking catch area for Pacific bonito.

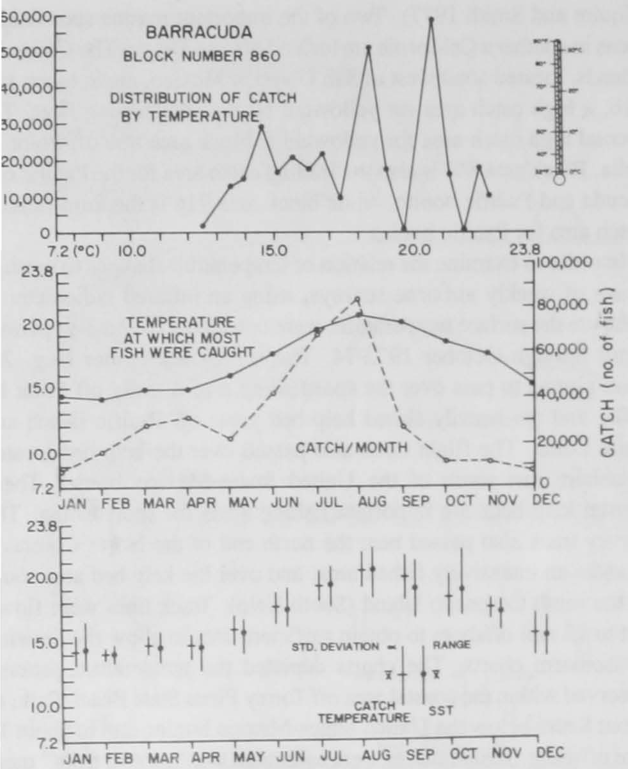
In order to examine the relation of temperature changes to catch, a series of weekly airborne surveys, using an infrared radiometer to measure the surface temperature, were conducted over a 3-yr period, April through October 1972-74. The survey track lines (Fig. 20) were plotted to pass over the sportfishing area directly off Point La Jolla, and the heavily fished kelp bed areas off Pacific Beach and Point Loma. The flight track also passed over the kelp bed located nearshore just south of the United States-Mexico border. These coastal kelp beds are important fishing areas for sportfishing. The survey track also passed near the north end of the North Coronado Islands, an intensively fished area, and over the kelp bed area south of the south Coronado Island (South Kelp). Track lines were flown out to 15 nmi offshore to obtain sufficient data to allow the drawing of isotherm charts. The charts depicted the temperature patterns observed within the coastal area off Torrey Pines State Beach Park, to about 8 nmi below the United States-Mexico border, and to about 15 nmi offshore. Temperatures were calibrated to a "ground truth" measurement, obtained by a simultaneous sea surface temperature measurement made while passing directly over the U.S. Navy Undersea Center (NUC) Oceanographic Tower located about 1.5 nmi offshore from Mission Beach. The results of temperature observations made during the 90 surveys over the 320 nmi survey track conducted during the 3-yr period, and a review of isotherm patterns observed, were published by Squire (1978).

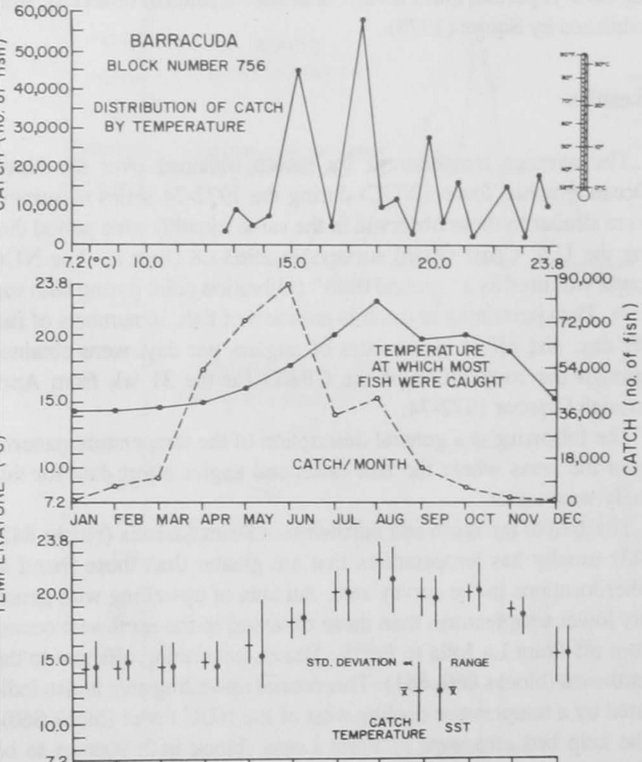
Results

The average temperatures by month obtained over the Naval Oceanographic Tower (NUC) during the 1972-74 series of surveys were similar to those observed in the same monthly time period during the U.S. Coast Guard surveys in 1963-68 (Part I). The NUC tower was used as a "ground truth" calibration point during both surveys. Data pertaining to catch in numbers of fish, in numbers of fish per day, and effort in numbers of anglers per day, were obtained through the cooperation of the CF&G for the 31 wk from April through October 1972-74.

The following is a general description of the temperature patterns from the areas where the fish catch and angler effort data for this study were taken.

The area to the north and northwest of Point La Jolla (blocks 842, 843) usually has temperatures that are greater than those found in other locations in the survey area. An area of upwelling with generally lower temperatures than those observed to the northwest occurs from off Point La Jolla to Pacific Beach, continuing offshore to the southwest (blocks 860, 861). This coastal upwelling area is also indicated by a temperature decline west of the NUC tower (block 860). The kelp bed area west of Point Loma (block 860) appears to be slightly warmer than the area to the north off Pacific Beach. South of Point Loma and about the San Diego harbor entrance channel (block 878), a significant drop in temperature is usually observed. Temperatures south of Point Loma peninsula tend to remain lower than those found to the west, and remain low to the southeast of Point Loma and off the Coronado Strand, increasing slightly inshore off Imperial Beach.





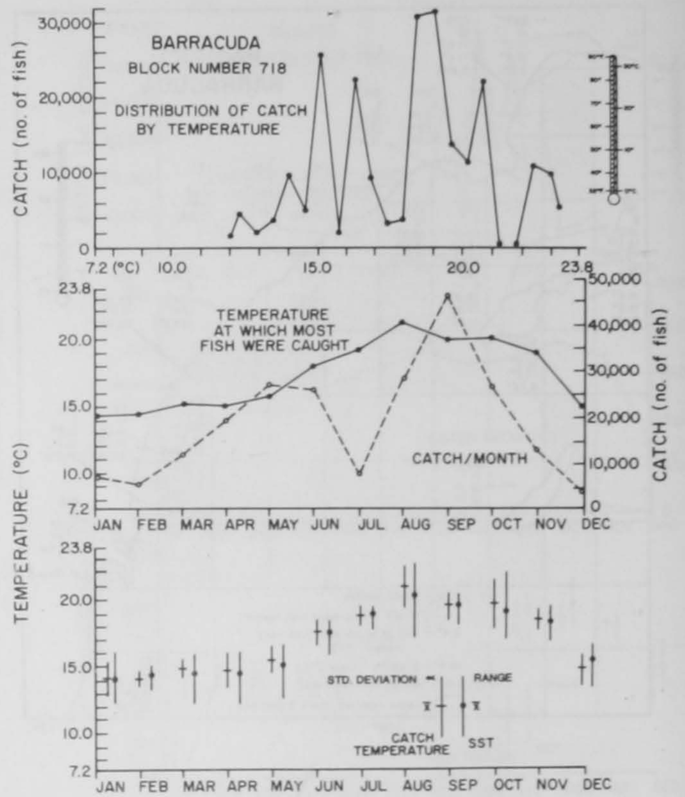


Figure 13.—Distribution of catch by temperature and by month for catch, temperature at which most barracuda were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having Pacific barracuda catches. Top left, block 860; bottom left, block 756; top right, block 718.

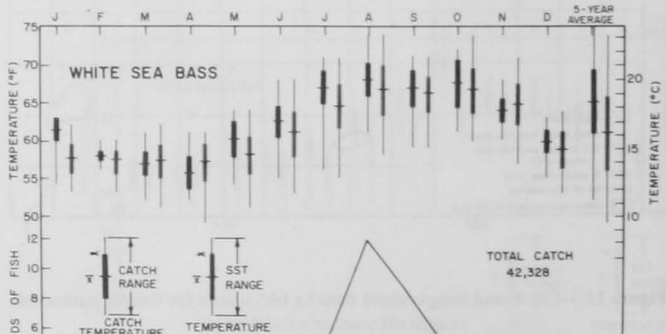


Figure 14.—Distribution of white seabass catch off southern California and northern Mexico by month, August 1963–July1968, for total catch, catch temperature and sea surface temperature range and means, and the standard deviation about the means.

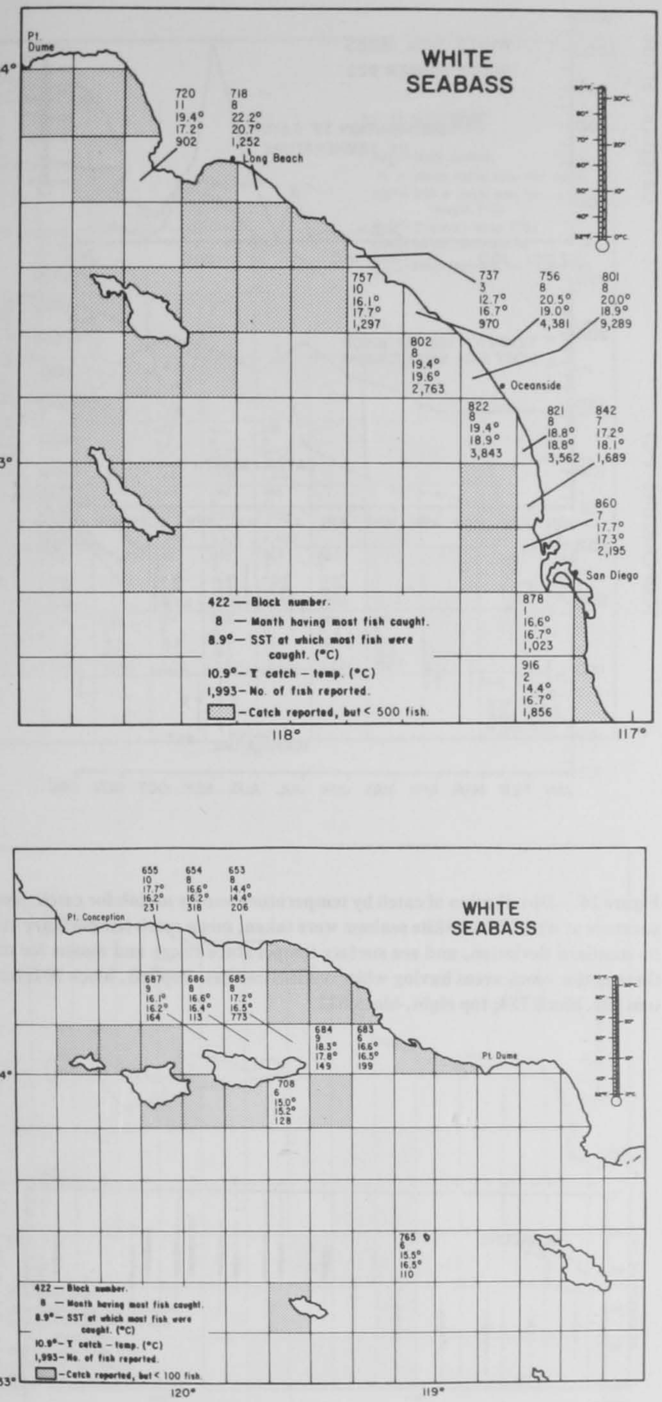


Figure 15.—Catch and temperature data by block area for white seabass caught off southern California.

Along the coast south of the United States-Mexico border, the northern boundary of an extensive coastal upwelling zone is frequently observed. The upwelling increases along the shore to the south and often extends further offshore. Temperatures warmer than those found near the coast of Mexico occur offshore about the Coronado Islands (block 916); these temperatures are more typical of those found nearshore off Point La Jolla in the northern portion of the survey area.

The 3-yr survey period off San Diego showed that 1973 was cooler than 1972, which was a year with above-normal warming along the west coast of North and South America ("El Nino" year). The average temperatures in 1974 were warmer than those in 1973, but not as warm as those in 1972. In 1974, however, an anomalous short-term warming period occurred in early July off southern California, and the highest temperatures for the 3-yr period were recorded at that time.

Species of yellowtail, Pacific barracuda, and Pacific bonito were selected for study, since statewide maximum catches of these three species were recorded in 1963-68 surveys from block areas within the study area. These blocks gave the greatest catch sample, and if a relation between catch and temperature exists it may be evident in the data for these block areas.

The temperatures obtained during the surveys, catch in numbers of fish, and the CPUE are given by weeks in 1972–74 for species of yellowtail (block 916), Pacific bonito (block 860), and Pacific barracuda (block 860) in Figure 21, 22, 23 a, b, c.

Catch Temperature Variation

There is considerable variation in catch temperature relative to the geographical location of the temperature measurements. The 1963–68 observations of yellowtail are one example: in the leading block area near the Coronado Islands (block 916), the mean catch temperature was 17.5°C (63.6°F), while 20 mi away off the Point La Jolla–Pacific Beach area (block 860) it was 17.9°C (64.2°F). Farther north about Catalina Island (block 761), it was 17.4°C (63.4°F), similar to that of the Coronado Islands. However, 30 mi north of Catalina Island along the mainland coast off Point Vincente (block 720), the mean catch temperature rose to 19.0°C (66.2°F).

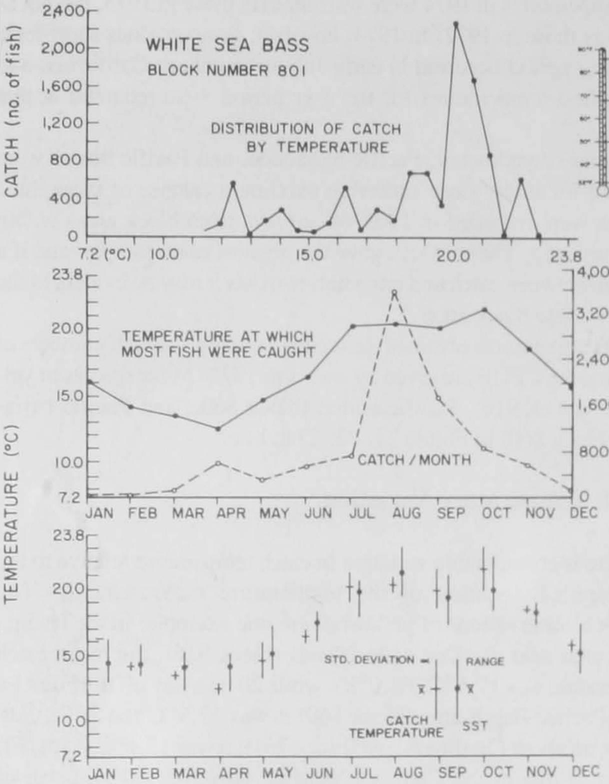
Although catch temperature data are limited for the sport catch of albacore off southern California, catch temperatures west of San Diego averaged 18.3°C (65°F) to 18.9°C (66°F). Airborne temperature surveys off central California observed that commercial albacore fishing operations were in waters of 16.1°C (61.0°F) to 17.2°C (63.0°F) (Squire 1969).

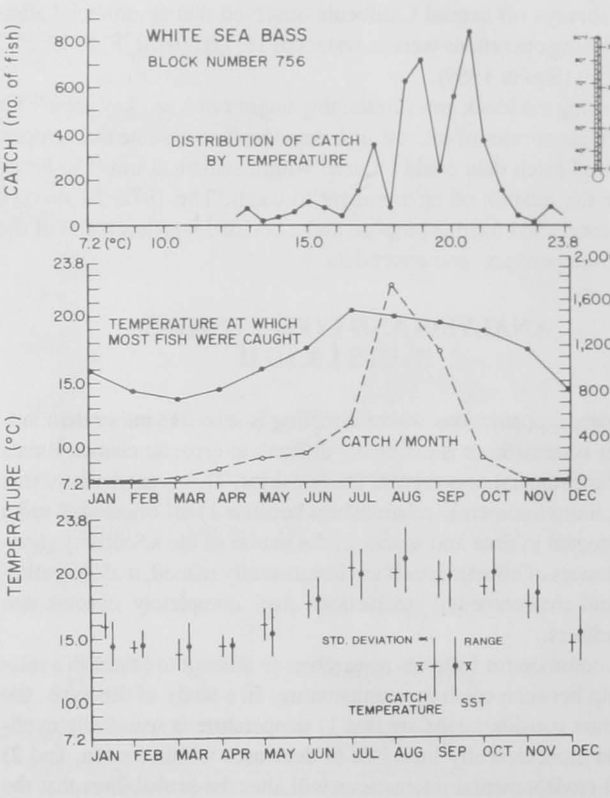
By using the block areas containing major catch as "key areas" for the pelagic species of interest, it is reasonable to assume that temperature and catch data could be used within statistical limits to better define the relation of environment to catch. The 1972–74 surveys were conducted for this purpose and a detailed anaylsis made of the catch, temperature, and effort data.

ANALYSIS AND CONCLUSIONS— PARTS I AND II

In natural populations where sampling is selective rather than random or systematic, it is extremely difficult to separate chance events from fundamental or persistent relationships. This is particularly true of catch-environmental relationships because 1) all organisms seem to aggregate in time and space, 2) the nature of the selectivity (nonrandomness of effort) is itself environmentally related, and 3) spatial-temporal-environmental interactions may completely obscure the main effects.

It is common for fisheries researchers to attempt to establish a relationship between catch and temperature. In a study of this type, the important considerations are that 1) temperature is seasonally cyclical and monotonically increases or decreases within season, and 2) spatial-environmental interactions will alter the probabilites that the population will be within the range of the fishing gear. Thus, in order to establish evidence for temperature preference, one must, at minimum, stratify catch by season and area, and examine the relationship of temperature and catch or CPUE within strata. The limitation of this kind of analysis is that, within strata, the temperature range is





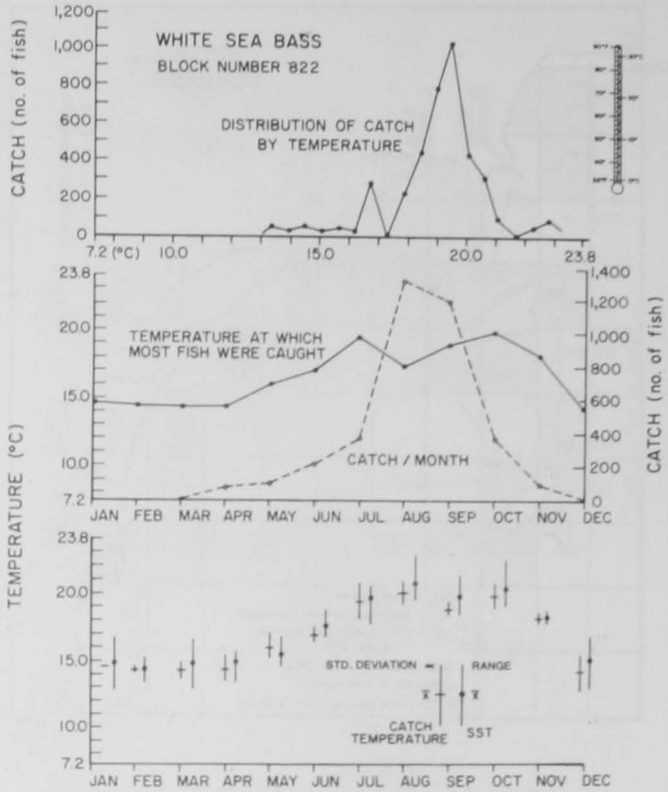


Figure 16.—Distribution of catch by temperature and by month for catch, temperature at which most white seabass were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having white seabass catches. Top left, block 801; bottom left, block 756; top right, block 822.

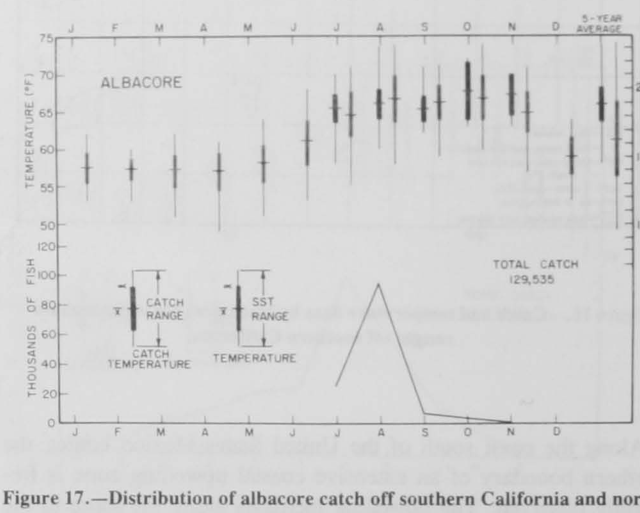


Figure 17.—Distribution of albacore catch off southern California and northern Mexico by month, August 1963–July 1968, for total catch, catch temperature and sea surface temperature range and means, and the standard deviation about the means.

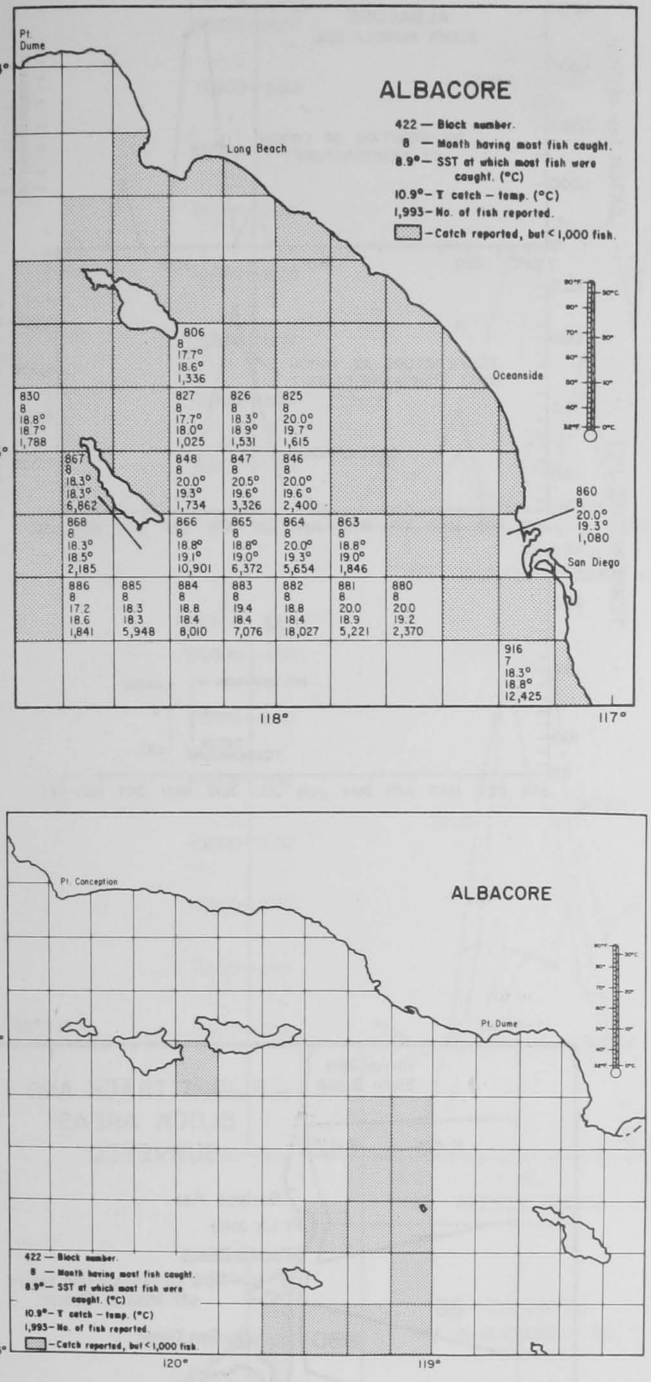


Figure 18.—Catch and temperature data by block area for albacore caught off southern California.

usually small, minimizing the likelihood of significant statistical relationships. It may well be the case that temperature preference can only be established either by 1) the preponderance of evidence in selective sampling investigations, as presented in this report, or 2) intensive investigations within particular temporal-spatial strata.

The catch and temperature data obtained during the 1972–74 surveys were stratified by year and species (Pacific barracuda, yellowtail, and Pacific bonito). For each species, analyses were conducted using the 3 yr of catch in the block area (916 or 860) having the greatest catch for that species. Using data for all 3 yr, cumulative preference curves (Kolmogorov-Smirnov) of catch vs. temperature, and cumulative temperature curves were plotted.

In general, graphs show increased catch rates for all species through the midrange temperatures of 17.8° to 20.0°C (64.0° to 68.0°F), with a reduction in rate above 20.5°C (69.0°F). Table 1 lists the temperature at the 20th, 50th, and 80th percentiles of the catch preference curves for each species. The corresponding percentiles of the temperature curve for the 31-wk period are shown below:

Block	*20%*	*50%*	*80%*
860	16.6°C(62.0°F)	18.6°C(65.5°F)	20.5°C(69.0°F)
916	16.1°C(61.0°F)	18.6°C(65.5°F)	20.2°C(68.5°F)

The average temperature at the 20th catch percentile is slightly above the 20th percentile for temperature, indicating that fewer fish were taken at the very lowest temperatures; beyond that, catch appears representative of the temperature distribution.

Large catches of 30% or more above the means were identified, and the corresponding sea surface temperature for each was recorded. The temperatures for all large catches were averaged by year and are given in Table 2. Overall, large catches ranged in temperature from 16.2°C (61.2°F) to 23.0°C (73.5°F), with a mean value of 19.5°C (67.1°F) for Pacific barracuda, 18.5°C (65.4°F) for yellowtail, and 19.6°C (67.4°F) for Pacific bonito.

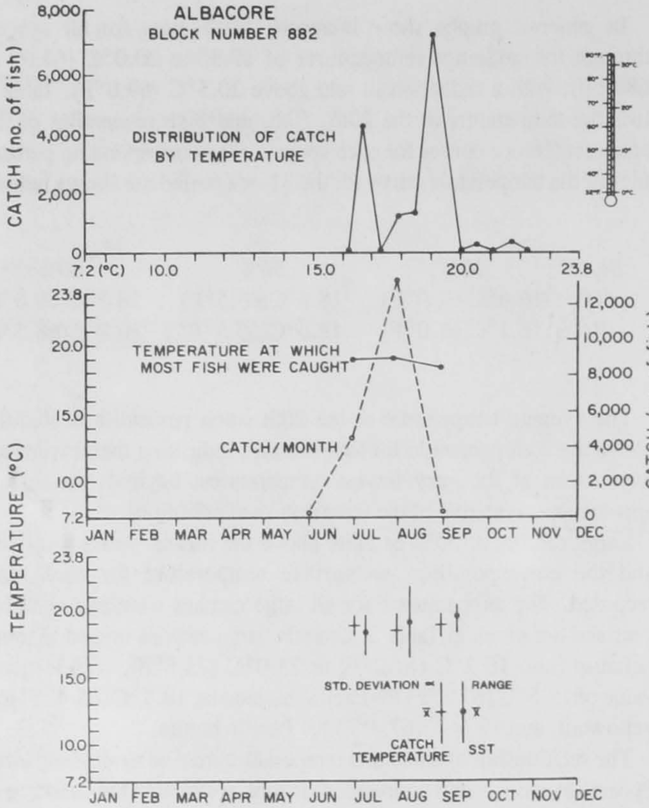
The relationship of catch and temperature may be examined using Spearman and Kendall nonparametric rank correlation tests assuming fishing effort is equally distributed over the temperature range within any time period. The results of these two tests for the relationships of 1) temperature and catch of all species per unit effort, and 2) temperature and catch of all species for the 31 wk, are shown in Table 3. The correlations are consistently higher for catch than for CPUE, indicating an increase in effort with increasing catch. Thus, the temperature and catch relationship will be confounded with changing levels of effort. Therefore, only the relationship of temperature and CPUE was tested in subsequent analyses.

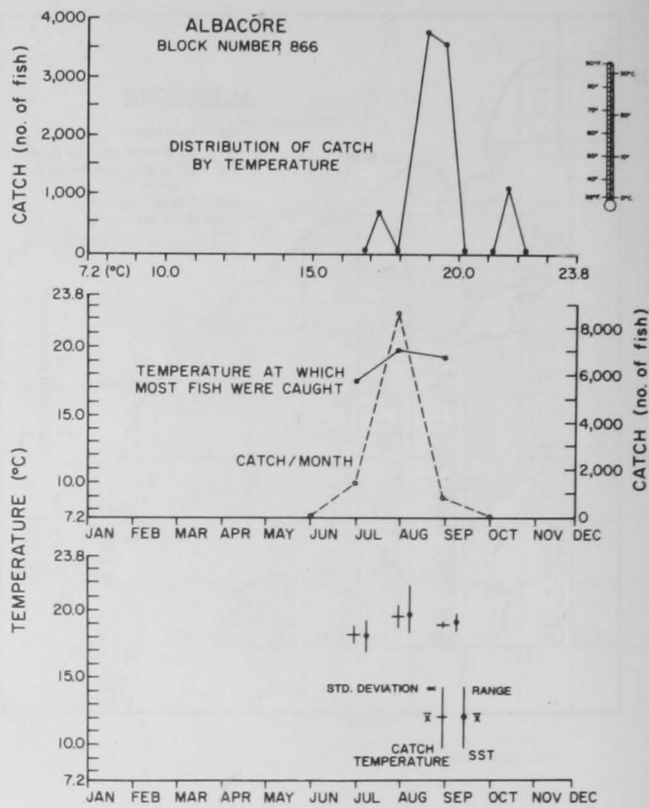
For the 31 wk being analyzed, one of the nine tests was statistically significant at the .05 level using the Kendall test, and two tests were statistically significant using the Spearman test. Since the assumption of equal distribution of effort over the temperature range became less likely as the fishing season progressed, similar tests were carried out for a 17- and a 12-wk period. These results are shown in Table 3. For the 17-wk period, three Kendall and five Spearman tests were statistically significant; for the 12-wk period, two Kendall and six Spearman tests were statistically significant. The Kendall test is more conservative in all cases. On the average, about one-half of the individual tests were statistically significant at the .05 level.

The distribution of catch over the temperature range appeared disproportionate only in the lower temperature range. To examine the possibility of a similar relationship for temperature and CPUE, cumulative CPUE curves were obtained for the three species, and the temperature distribution withing each percentile range (0-20, 20-40, 40-60, 60-80, and 80-100) was recorded. The results for all data combined are shown below. Numbers in parentheses indicate how often catches would be expected in a particular temperature range if temperature had no effect of CPUE.

Cumulative CPUE
(0-observed/E-expected)

	0-20		*20-40*		*40-60*		*60-80*		*80-100*	
	0	*E*	*0*	*E*	*0*	*E*	*0*	*E*	*0*	*E*
12.7°-15.6°C (55°-60°F)	28	(18)	2	(5)	1	(4)	0	(3)	1	(2)
15.6°-18.3°C (60°-65°F)	44	(50)	21	(15)	5	(11)	9	(7)	9	(5)
18.3°-21.1°C (65°-70°F)	69	(73)	19	(23)	25	(16)	11	(10)	6	(8)
21.1°-23.9°C (70°-75°F)	8	(8)	4	(3)	2	(2)	1	(1)	0	(1)





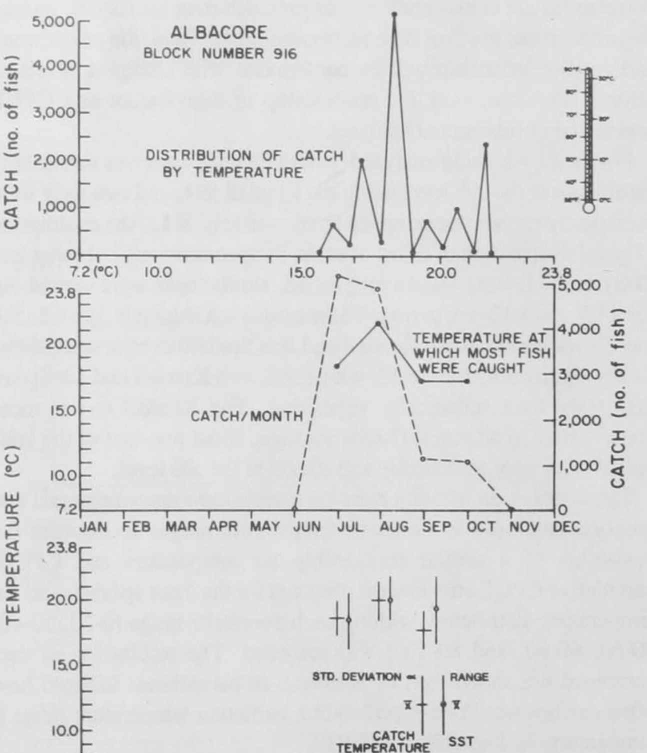


Figure 19.—Distribution of catch by temperature and by month for catch, temperature at which most albacore were taken, mean catch temperature and its standard deviation, and sea surface temperature range and means for the three major block areas having albacore catches. Top left, block 882; bottom left, block 916; top right, block 866.

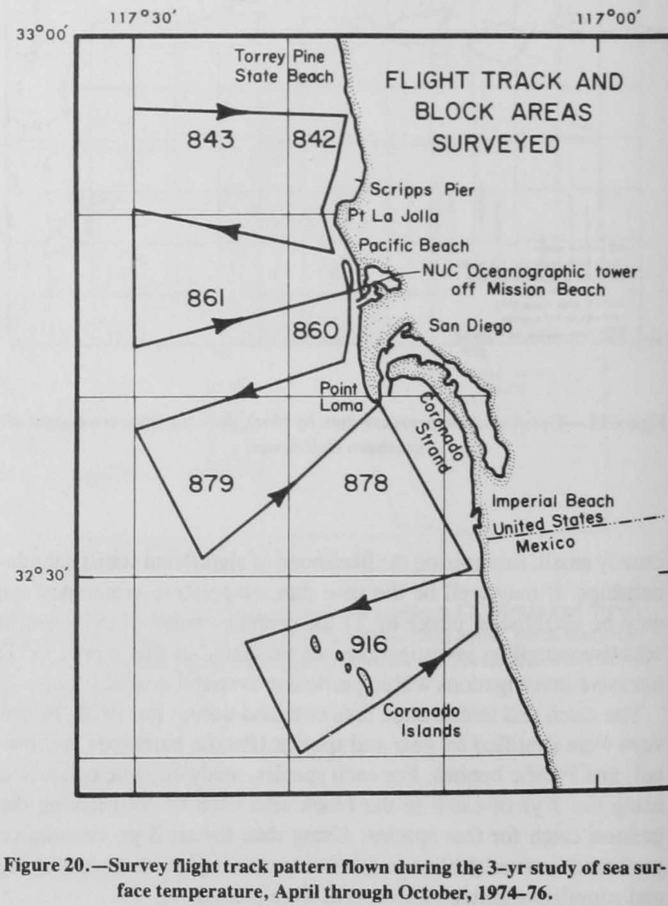


Figure 20.—Survey flight track pattern flown during the 3-yr study of sea surface temperature, April through October, 1974–76.

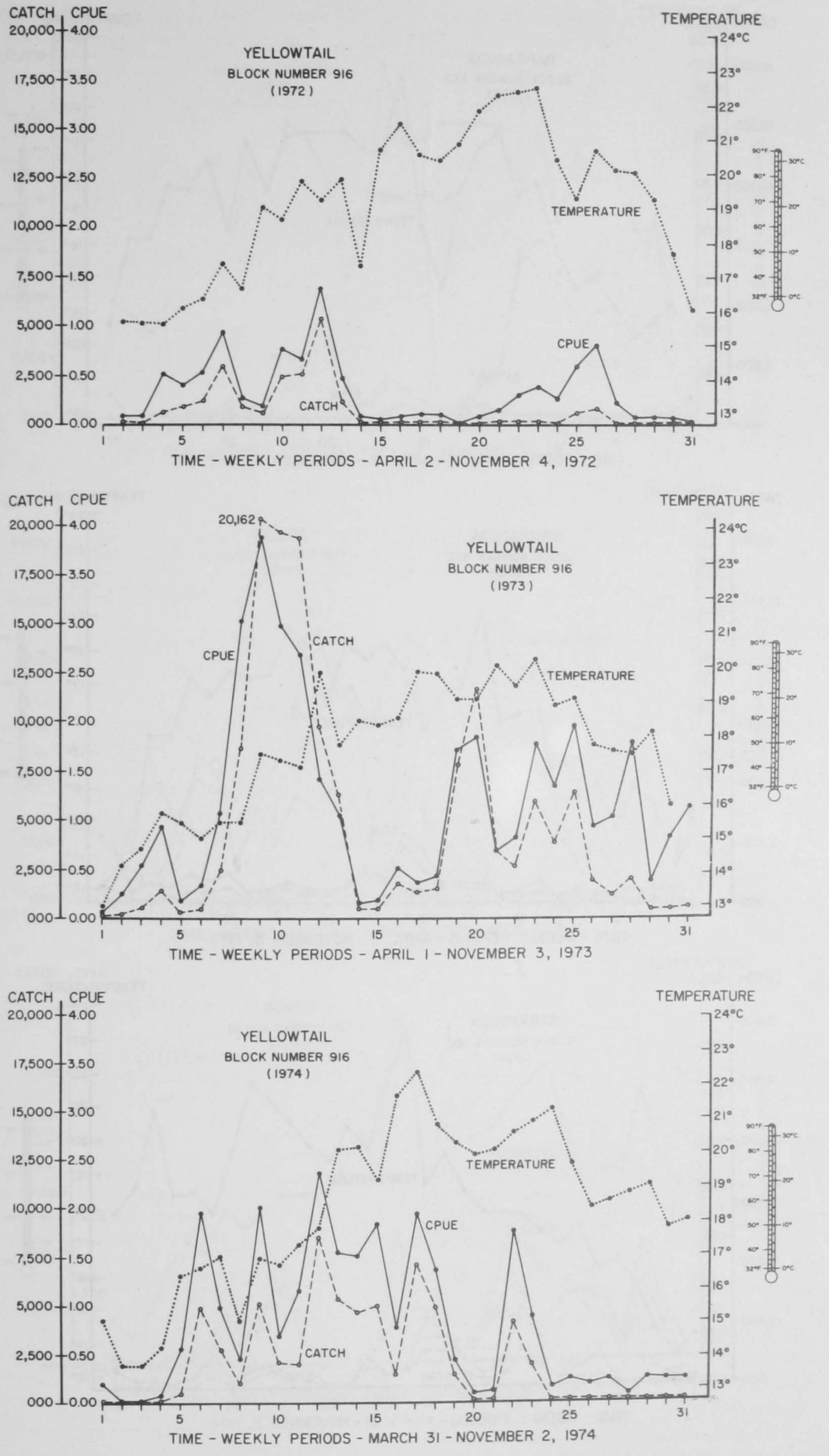


Figure 21.—Plots of CPUE and temperature by weekly periods, April through October 1972 (top), 1973 (middle), 1974 (bottom), for yellowtail catches made in block 916.

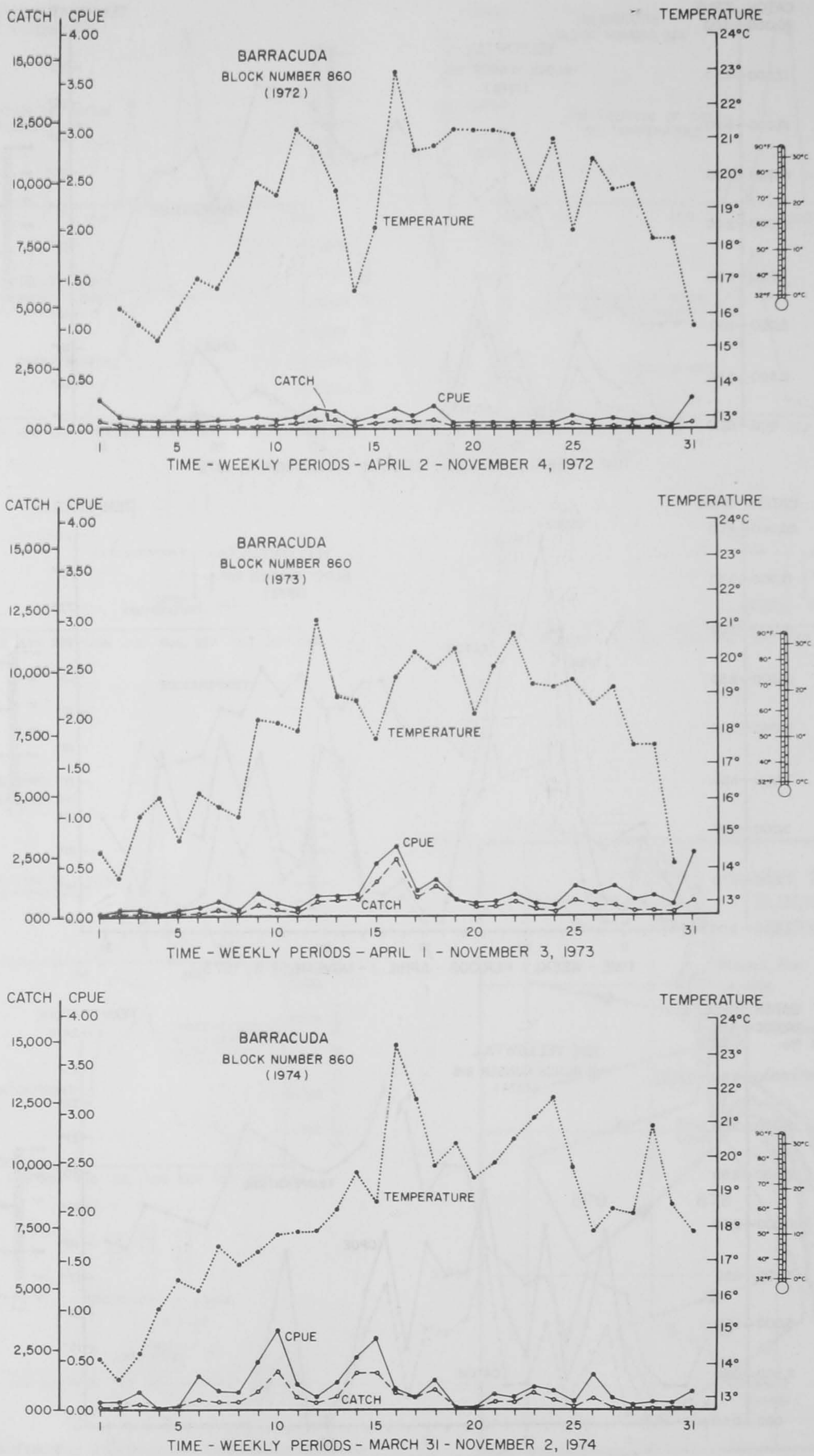


Figure 22.—Plots of CPUE and temperature by weekly periods, April through October 1972 (top), 1973 (middle), 1974 (bottom), for Pacific barracuda catches made in block 860.

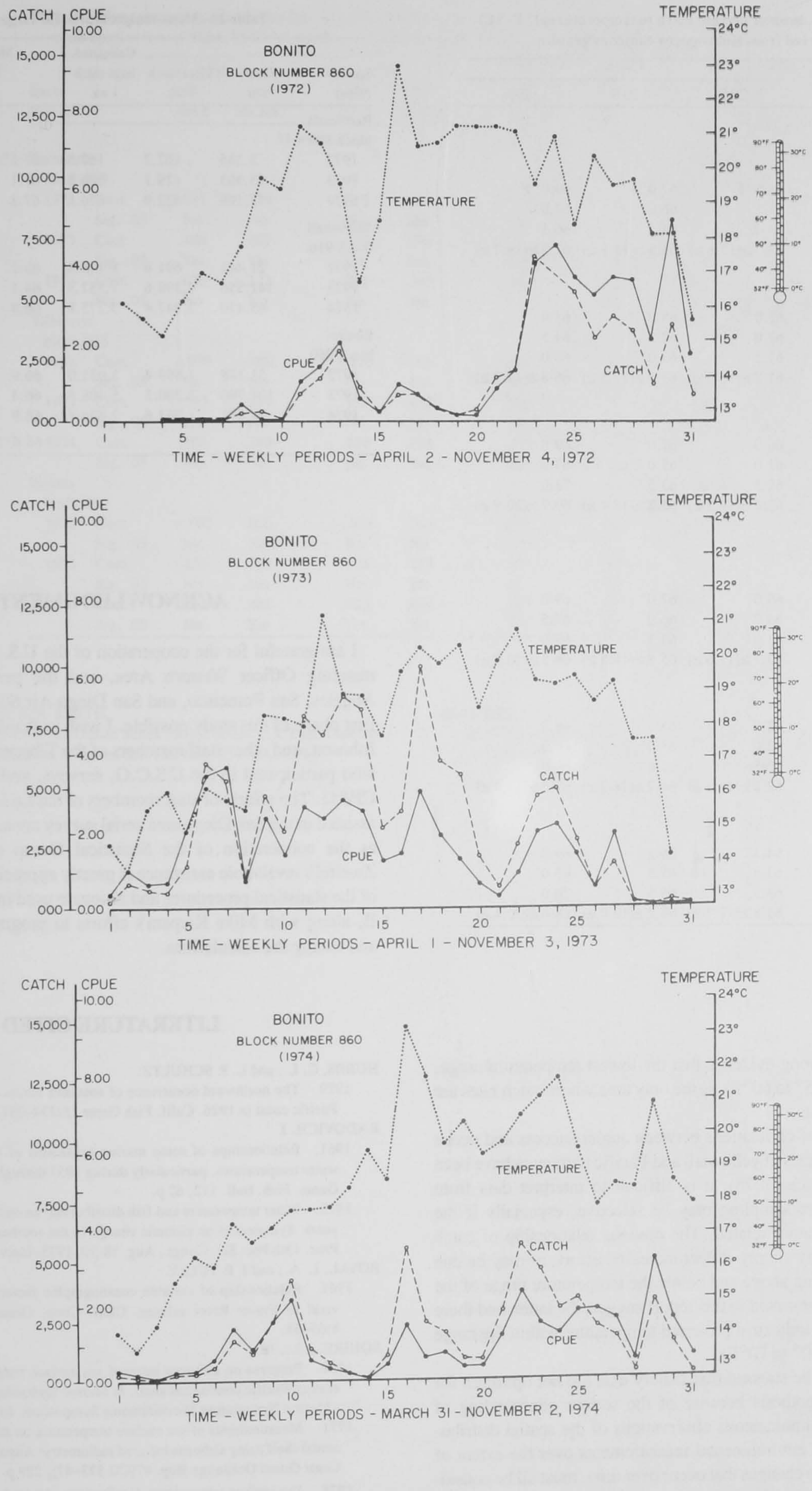


Figure 23.—Plots of CPUE and temperature by weekly periods, April through October 1972 (top), 1973 (middle), 1974 (bottom), for Pacific bonito catches made in block 860.

Table 1.—Breakdown of percent catch to temperatures (° F–° C) observed from Kolmogorov-Smirnov graphs.

Period	Catch 20%	Catch 50%	Catch 80%
17 Weeks			
Barracuda block 860			
1972	64.5° F	67.0° F	69.0° F
1973	63.5	66.0	67.0
1974	63.0	64.5	66.5
$\bar{x}$	63.7 ≥(17.6 ≥)	65.8 ≥(18.8 ≥)	67.5 ≥(19.7 ≥)
Yellowtail block 916			
1972	62.0	65.0	68.0
1973	62.0	62.5	64.5
1974	61.5	63.0	68.0
$\bar{x}$	61.8 ≥(16.5 ≥)	63.5 ≥(17.5 ≥)	66.8 ≥(19.3 ≥)
Bonito block 860			
1972	66.0	67.0	69.0
1973	61.0	65.0	67.0
1974	62.5	63.5	73.0
$\bar{x}$	63.2 ≥(17.3 ≥)	65.2 ≥(18.4 ≥)	69.7 ≥(20.9 ≥)
31 Weeks			
Barracuda block 860			
1972	64.0	67.0	69.0
1973	64.0	66.0	67.5
1974	63.0	64.5	69.0
$\bar{x}$	63.7 ≥(17.6 ≥)	65.8 ≥(18.8 ≥)	68.5 ≥(20.3 ≥)
Yellowtail block 916			
1972	62.0	65.0	68.5
1973	62.0	63.0	66.0
1974	62.5	66.0	69.0
$\bar{x}$	62.2 ≥(16.8 ≥)	64.7 ≥(18.2 ≥)	67.8 ≥(19.9 ≥)
Bonito block 860			
1972	64.5	66.5	69.0
1973	63.5	65.5	67.0
1974	63.5	66.5	70.0
$\bar{x}$	63.8 ≥(17.7 ≥)	66.2 ≥(19.0 ≥)	68.6 ≥(20.4 ≥)

Again there is strong evidence that the lowest temperature range, 12.7° to 15.6°C (55° to 60°F), is the only area where catch rates are lower than expected.

While evidence of correlations between angler success and ocean temperature for species of yellowtail and Pacific barracuda have been reported by Radovich (1975), it is difficult to interpret data from investigations where sampling may be selective, especially if the selection is temperature related. The obvious relationship of catch and temperature may simply reflect increased effort, or may be due primarily to sampling above and below the temperature range of the species. The data presented in this report suggest the latter, and there is little evidence to indicate a preferred temperature within the range 15.6° to 21.1°C (60° to 70°F).

Again, it should be stressed that fishery data are not optimum for examining this hypothesis because of the serious confounding of cause and effect. Simultaneous observations of the spatial distribution of the species, environmental measurements over the extent of distribution, and the changes that occur over time, must all be considered before the true relationship of these pelagic species to the environmental factor of sea surface temperature can be established.

Table 2.—Mean temperatures for large catches.

Species-Period	Catch 1 yr	Mean catch 1 wk	Calculated large catch 1 wk	Mean temperature for large catches 1 yr (°F-°C)	
Barracuda block 860					
1972	3,245	107.7	167.5	67.5° F	67.1° F (19.5° C)
1973	13,303	429.1	686.6	66.1	
1974	13,109	422.9	676.6	67.8	
Yellowtail block 916					
1972	21,441	691.6	1,106.6	65.2	65.3° F (18.5° C)
1973	142,556	4,598.6	7,357.8	64.1	
1974	63,470	2,047.4	3,275.8	66.8	
Bonito block 860					
1972	51,148	1,899.4	3,031.0	66.9	67.4° F (19.6° C)
1973	104,790	3,380.3	5,408.5	66.4	
1974	54,672	1,763.6	2,821.8	68.9	
				$\bar{x}$ 66.6° F (19.2° C)	

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Table 3.—Nonparametric correlation for sea surface temperature and catch of all species per unit effort and catch of all species (no. of fish), 1972-74, for 31-, 17-, and 12-wk survey periods, and significance at the .05 level.

		KENDALL		SPEARMAN		KENDALL	SPEARMAN	KENDALL	SPEARMAN
Species		SST	SST	SST	SST	SST	SST	SST	SST
Block no.		/CPUE	/No. fish	/CPUE	/No. fish	/CPUE	/CPUE	/CPUE	/CPUE
		31 weeks				17 weeks		12 weeks	
Barracuda									
block 860									
1972	Corr.	.031	.310	.018	.424	.558	.746	.472	.628
	Sig. .05	No	No	No	Yes	Yes	Yes	No	Yes
1973	Corr.	.465	.607	.643	.796	.356	.498	.614	.769
	Sig. .05	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
1974	Corr.	.035	.173	.061	.263	.602	.792	.384	.518
	Sig. .05	No	No	No	No	Yes	Yes	No	No
Yellowtail									
block 916									
1972	Corr.	-.070	-.081	-.170	-.131	-.069	-.076	.453	.625
	Sig. .05	No	No	No	No	No	No	No	Yes
1973	Corr.	.100	.311	.159	.438	.164	.202	.605	.761
	Sig. .05	No	No	No	No	No	No	No	Yes
1974	Corr.	.208	.283	.280	.378	.390	.732	.837	.928
	Sig. .05	No	No	No	Yes	Yes	Yes	Yes	Yes
Bonito									
block 860									
1972	Corr.	-.102	.000	-.098	.043	.346	.582	.600	.771
	Sig. .05	No	No	No	No	No	No	No	No
1973	Corr.	.153	.363	.276	.537	.347	.505	.290	.518
	Sig. .05	No	Yes	No	Yes	No	Yes	No	No
1974	Corr.	.292	.481	.423	.646	.237	.313	.515	.699
	Sig. .05	No	Yes	Yes	Yes	No	No	No	Yes

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