

## REVIEW OF ACTIVITIES

### 1 July 1956-1 January 1958

In April, 1947, representatives of the California Academy of Sciences, California Department (then Division) of Fish and Game, the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service, and the University of California's Scripps Institution of Oceanography met and drafted a document that has since served in a sense as the charter of activities under the California Cooperative Oceanic Fisheries Investigations.

To this enterprise they brought a distinguished history of research. As long ago as 1920, W. F. Thompson of the Division of Fish and Game had drawn up a long-term program of research on the sardine (W. F. Thompson, "The proposed investigation of the sardine," *California Fish and Game*, vol. 6, no. 1, pp. 10-12, January, 1920). The State's investigations along these lines revealed much information on the fishery, all of which has served as part of the strong foundation upon which the CCOFI program has been built.

From April, 1929, to September, 1932, the early life history of the sardine was subject to an intensive oceanographic-biological survey by the combined efforts of the California Division of Fish and Game and Hopkins Marine Station of Stanford University. A great deal was learned about the early life history of the sardine and the distribution of its eggs and larvae (Eugene C. Scofield, "Early life history of the California sardine (*Sardina caerulea*) with special reference to distribution of eggs and larvae," *Fish Bull.*, no. 41, 48 pp., 24 figs., 1934).

In 1937 the California Division of Fish and Game cooperated with the Scripps Institution of Oceanography in a study of surface currents off the southern California coast (Richard B. Tibby, "Report on returns of drift bottles released off Southern California, 1937," *Fish Bull.*, no. 55, 36 pp., 22 figs., 1939).

By the 1930s, the sardine fishery had become the largest in the country. In 1937, the U. S. Bureau of Fisheries (now a part of the U. S. Fish and Wildlife Service) established a laboratory at Stanford to work in this field. From this group came another influential paper on methods of studying the sardine (Oscar E. Sette, "Studies on the Pacific pilchard or sardine (*Sardinops caerulea*) I: Structure of a research program to determine how fishing affects the resource," U. S. Fish and Wildlife Service, *Special Scientific Report No. 19*, 1943).

From 1939 through 1941, the Fish and Wildlife Service cooperated with the Scripps Institution of

Oceanography in additional combined oceanographic-biological cruises off our coast. Though small in scale as compared to the CCOFI cruises, all these earlier cruises have provided invaluable data to the present investigations (H. U. Sverdrup and the staff of the Scripps Institution of Oceanography, "Oceanographic observations on the *E. W. Scripps* cruises of 1940 and 1941," Univ. Calif., Scripps Inst. Oce., *Records of Observations*, vol. 1, nos. 3 and 4, pp. 161-408, and Oscar E. Sette and Elbert H. Ahlstrom, "Estimations of abundance of the eggs of the Pacific pilchard (*Sardinops caerulea*) off southern California during 1940 and 1941," *J. Mar. Res.*, vol. 7, no. 3, pp. 511-542, 4 figs., 1948).

The University of California's Scripps Institution of Oceanography was brought into the conference because of the recognition that it would be impossible fully to understand pelagic fisheries without a look at the ocean for an explanation of variations not explained by biology and the statistical analysis of the catch and fishery.

The California Academy of Sciences was represented in this conference since the facilities of Steinhart Aquarium could be used to study such matters as the schooling habits of sardines and their reactions to light and electricity.

In writing of such a meeting it is regrettably easy to ignore the fact that human beings, not cold institutional entities, were the participants. Three persons of remarkable abilities were the chief architects of the CCOFI program. None is connected with the Investigations now. Dr. Oscar E. Sette of the U. S. Fish and Wildlife Service is chief of the service's Ocean Research group. Dr. Frances N. Clark, for many years the Director of the Department of Fish and Game's State Fisheries Laboratory, retired in 1957. Dr. Harald U. Sverdrup, the world's greatest physical oceanographer, then Director of the Scripps Institution of Oceanography, died in his native Norway in August, 1957.

The program drawn up by these scientists has been printed before (Progress Report, California Cooperative Oceanic Fisheries Investigations, 1 July 1953-31 March 1955), but since it is germane to the present review, it is reprinted below:

#### BIOLOGICAL RESEARCH

##### I. Recruitment.

- a. Measurement of amount of spawning.
- b. Measurement of the abundance of larvae.

- c. Measurement of the relative abundance of year-class before it enters the fishery.
  - d. Measurements of the sizes of year-classes in the commercial fishery.
  - e. Studies of the spawning stock on the spawning grounds.
- II. Availability of the stock to the fishermen.
- a. Analysis of the commercial catch.
  - b. Exploratory work on and off the fishing grounds during the fishing season.
  - c. Exploratory food studies.
- III. Investigation of rapid methods of plankton collection and analysis.
- IV. Physiological studies of behavior, feeding, and nutrition.
- V. Dynamics of the sardine population and fisheries.

### PHYSICAL AND CHEMICAL OCEANOGRAPHY

(No detailed program in oceanography was drawn up at this time.)

After the establishment of the Marine Research Committee, a Technical Advisory Committee was appointed by the Marine Research Committee. It consisted of one member from each of the four (later five) cooperating agencies. At a meeting of the Technical Advisory Committee on 10-11 June 1953 the following amplified consensus of CCOFI objectives and problems was reached:

#### CCOFI objectives:

To determine what controls variations in population size and availability in oceanic fishes off the west coast of North America.

The attendant problems, solution of which is necessary to attainment of these objectives, are, in brief:

- (1) How many subpopulations are there?
- (2) What is the size of each subpopulation?
- (3) What controls variation in the growth rate of individual fish?
- (4) What controls variation in year-class size?
- (5) What controls variations in mortality rates of the adult fish?
- (6) What controls variations in the availability of the fish to the fishery?

These objectives and problems are now being critically reviewed in the light of recent findings.

In 1951, the Hopkins Marine Station of Stanford University agreed to conduct studies of the oceanography of Monterey Bay, a type of highly detailed oceanographic study not feasible under the broader sort of investigations being conducted at the Scripps Institution.

In the ensuing paragraphs, each agency reports on its recent work under the CCOFI program.

### CALIFORNIA ACADEMY OF SCIENCES

#### *Effects of Light and Darkness on Schooling Behavior of the Pacific Sardine (*Sardinops caerulea*)*

The experiments of 1955 and 1956, conducted in 1,000 gallon tanks, showed that maintenance of the school as a unit and the movement of the school in a circular path (so-called "circling" or "milling") are mediated through the fish's eye. Vision therefore appears to be the most important factor in schooling behavior of the sardine. Experiments showed that a sudden darkening of the tank at night would immediately result in breaking up the school, causing the fish to disperse in all directions. At such times the sardines, being scattered throughout the tank, seemed to swim about aimlessly at much reduced speed. Their swimming had no oriented direction, and resulted in complete disorganization of the school. At such times each fish seemed to be independent of any other as a point of reference. In total darkness any fish might occupy any stratigraphic position in the tank from the very bottom to the very surface. There was no concentration at any particular level.

A striking phenomenon of loss of body equilibrium has usually been noted immediately after turning off the light. Up to 90 percent of the sardines in a school have exhibited a definite effect of the sudden darkness. A series of flash photographs revealed them "standing on their tails" and slowly progressing head-upward toward the surface. This behavior lasted only a few minutes—up to 10 at a maximum—after which a normal swimming position was resumed. But in no case were they able to form a school in complete darkness. When illumination was again provided the sardines required from 5 to 10 minutes to resume normal schooling behavior, including the characteristic circling movement at normal speed.

#### *Effect of an Intermittent Beam of Light*

The experiment was tried of directing an intermittent beam of light of low intensity through the middle of a tank of sardines otherwise in total darkness. The light was directed from front to rear of the tank, and flashed at a rate of 60 times per minute. This appeared to frighten the sardines and effectively prevented their re-forming a school.

When a constant beam of light of the same intensity was directed through the tank, the sardines resumed normal schooling behavior almost as quickly as if the tank were fully illuminated. At first they avoided the direct beam of light, circling in areas of the tank dimly illuminated by light scattered or reflected from the beam, but gradually they moved more and more into the brightly illuminated area and soon were milling without regard to brighter and darker zones, passing freely through both.

The fact that sardines avoid a flashing beam of light is in accord with the practice of sardine fisher-

men of using a flashing light to prevent the escape of sardines from a purse seine as the net is being closed. The principle seems likely to be of considerably wider practical application in altering or directing the movements of fish.

**Effect of Colored Lights on Sardine Behavior**

Lights of the primary colors, red, blue, and green, of various measured intensities and of known wavelength, were experimentally applied to illuminate a tank containing sardines. Neither blue nor green light produced any significant change in behavior, but the red light, regardless of its intensity over the rather wide range used, produced an immediate reaction, initially similar to the behavior in total darkness described above. At the moment of switching from white to red light, the school came to a complete halt. This was followed by a state of confusion and loss of body equilibrium, referred to above as "standing on their tails."

At first it was surmised that the fish might simply be unable to see in red light, but this was not borne out by their subsequent behavior. The state of confusion as a rule rapidly disappeared and the school re-formed, but the fish appeared excited or alarmed. Although the experiments with the red light were continued an hour at a time, the school never settled down to normal behavior, but swam at an accelerated speed with frequent change of direction and pattern of formation.

This suggested a further experiment in which the sardines might have a choice of red, blue, green or white light, or darkness. Small groups of sardines (six at a time) were placed in a long tank, different segments of which were differently illuminated. Intensity and wavelength of the incident light were carefully controlled, although the factor of brightness as registered through the eye of the fish was not taken into consideration. At first three choices were permitted, then the several alternatives were carefully checked in pairs.

The series of experiments shows that sardines prefer blue or green light to white light, but they showed no preference for blue over green or vice versa. Red light was definitely avoided when offered as an alternative to blue, green, or white, but when the fish were offered only the alternatives of red light or darkness, they preferred the red light. It may be concluded that, under the conditions of this experiment, sardines are positively phototropic, and that they have at least some degree of color discrimination.

**Behavior of the Sardine and Herring in an Electrical Field**

In an earlier publication \* it was suggested but not definitely proved that the current density required to

produce controlled directional swimming of sardines in an electrical field varies inversely with the size of the fish. This has now been definitely demonstrated, using sardines ranging from 100 to 230 mm in length, and subjecting them to the effect of half-wave rectified 60-cycle alternating current, with an average current density from less than 1 milliamperere up to 13 milliampereres per square inch of cross-sectional area of the water. The results are shown in the following table:

Length of fish	Optimal current density
100-114 mm -----	9-11 ma
140 mm -----	7- 9 ma
150-155 mm -----	6- 8 ma
170-180 mm -----	5- 7 ma
200-230 mm -----	3- 5 ma

Pacific herring (*Clupea pallasii*) tested in an electrical field displayed patterns of response closely similar to those of the sardine. The relationship between the size of the fish and the current density required to produce controlled directional swimming was found to be identical for the two species.

The northern anchovy (*Engraulis mordax*) behaved erratically and failed to show any consistent response to an electrical current. Only young fish 60 to 95 mm long were available for testing. Further experiments should be made with different size groups to determine the pattern of response in this species.

It is interesting to note that data obtained in these investigations have been used by Keith A. Smith \* in a successful experimental catch of herring under sea conditions.

**CALIFORNIA DEPARTMENT OF FISH AND GAME**

The Department conducts investigations and collects catch statistics on almost all the commercial and sportfishes found off the California coast. The pelagic species, Pacific mackerel, jack mackerel, herring, squid, anchovies, and sardines, are investigated by the Department's Pelagic Fisheries Investigations. Therefore, this report of the Department's activities relating to the CCOFI program is essentially a report of the Pelagic Fisheries Investigations, coupled with pertinent information obtained from certain other investigations of the Department.

Since the start of the CCOFI, the activities of the Pelagic Fisheries Investigations have been directed toward obtaining information on the following phases extracted from the research outline given earlier:

- (1) Measurement of the relative abundance of year-class before it enters the fishery.
- (2) Measurements of the sizes of year-classes in the commercial fishery (in cooperation with Fish and Wildlife Service).

\* Loukashkin, A. S., and N. Grant, 1954. Further studies on the behavior of the Pacific sardine, *Sardinops caerulea*, in an electrical field. *Proc. Calif. Acad. Sci.*, vol. 28, pp. 323-337.

\* Smith, K. A. 1955. Use of an electric attracting and guiding device in experiments with a "fish pump." *Commercial Fisheries Review*, vol. 17, no. 2, pp. 1-7.

- (3) Analysis of the commercial catch.
- (4) Exploratory work on and off the fishing grounds.
- (5) Exploratory food studies (begun by the Department, continued by Scripps Institution of Oceanography and now being conducted by the U. S. Fish and Wildlife Service).
- (6) Dynamics of the sardine population and fisheries.

A description of the fishery and a report of the activities and some of the findings of the Department's Pelagic Fisheries Investigations since July, 1956 follows:

### *The Sardine Fishery in 1956-57*

As in the previous two seasons, concentrations of sardines appeared off the Hueneme-Santa Barbara areas in August. However, by the middle of September 1956, the fish schools were less concentrated than during the same period in either 1954 or 1955. By September, 1956, the sardine schools were observed spreading out and moving down the coast. By the beginning of the sardine fishing season in southern California, 1 October, the southerly movement of fish was well developed.

Although the lack of a price settlement kept most of the San Pedro fleet from fishing until the night of 8 October, a few San Pedro vessels and some from the north fished with the Santa Barbara-Hueneme boats and by 8 October had landed over 5,000 tons of sardines. During this period there was a notable shift of fish toward the south; more and more catches were being made south of Hueneme.

On 8 October, after a price settlement had been made, the San Pedro fleet began fishing and catches were made at widely scattered locations from Hueneme to Oceanside. Commencing 10 October landings at Hueneme dropped markedly. Apparently a substantial portion of the fish from the Hueneme area had moved into the closed area of Santa Monica Bay.

During the night of 11 October the fleet converged on the sardines moving out of Santa Monica Bay and caught over 3,000 tons in the vicinity of Pt. Vicente. Although a large part of the fleet returned to the same area the following night, the catch dropped to less than a third.

After 12 October the fish were difficult to find. Landings were poor and catches were made from various areas, mostly south of San Pedro. On 16 October, the last night of the dark, catches totaling 5,000 tons, the largest of the season, were made just north of the Mexican Border from a southerly moving concentration of fish.

The end of the first dark virtually marked the end of sardine fishing, since 77 percent of the 1956-57 catch of 32,648 tons was taken during the first dark.

Approximately two weeks after the last night of the first dark, the Ensenada fishery experienced a brief flurry which subsided as abruptly as it began. Apparently, the sardines were still moving rapidly south as they passed Ensenada. During the California season 5,971 tons were landed at Ensenada.

The size of the fish caught during the 1956-57 season averaged about 11 mm longer than in 1955-56. An increase in the average size of the fish was not surprising; in fact it was predicted since almost half the fish caught in 1955-56 were the three-year-old 1952-class. As was expected the 1952-class remained dominant in the fishery as four-year-olds in the 1956-57 season. The 1952-class has been the strongest in the fishery since 1948.

The size of the San Pedro fleet is still decreasing, particularly in the number of larger purse seine vessels. In recent years there were additions to the fleet of smaller vessels employing either purse seines or lampara nets, but even the number of these vessels in the fishery decreased in 1956-57. Last season (1956-57) the San Pedro fleet consisted of 98 large purse seiners, 26 small purse seiners, and 36 lampara vessels. This was a decrease from the preceding season (1955-56) of 14 large purse seiners, 1 small purse seiner, and 5 lampara vessels.

Because of the recurrence of concentrations of sardines off the Hueneme-Santa Barbara area prior to the opening of the 1956 sardine fishing season and the abrupt decline in catch as the season progressed, the season was moved forward one month by the 1957 Legislature to start 1 September and end 31 December.

Despite the earlier starting date, a dispute on price has kept the San Pedro fleet idle, and as of 1 November 1957, a price settlement had not been reached; consequently, the vessels fishing out of Hueneme and Santa Barbara have landed almost the entire catch. The sardines have appeared to be widely scattered and not very abundant in 1957.

### *Anchovies*

The commercial landings of anchovies fell short of the 35,000-ton limit during the season 1 April 1956 through 31 March 1957; the catch was 22,598 tons. The 1957 Legislature failed to renew the quota for the 1957-58 season. By late spring of 1957, the market demand for anchovies had improved, thereby giving impetus to substantial landings. In the first six months of 1957, approximately 12,500 tons of anchovies were delivered, almost 2,000 tons more than during the same period in 1956.

Routine sampling of the two principal fishing areas, central and southern California, indicated that in each area two-year-old fish contributed well over half of the numbers of fish caught. Of the incoming year-classes, the 1956 group does not appear to be out-

standing off central California or off southern California. The 1955-class in the latter area appears very strong at present and should aid materially in maintaining a relatively high population of anchovies in the forthcoming season. Early indications point to a strong 1957-class of anchovies off central California.

### **Mackerel**

During the season from July, 1956 to June, 1957 commercial landings of Pacific mackerel were approximately 28,000 tons—100 percent more than in the previous season. Landings of jack mackerel were over 46,000 tons—30 percent higher than in the 1955-56 season.

The heaviest landings occurred in the five-month period from October through February, when 70 percent of the tonnage of each species was taken. In comparison, 57 percent of the tonnage of each species was taken during the same five-month period of the 1955-56 season. The increase in landings in this five-month period is due to fluctuations of the market demand. The subsidiary role the mackerel play in relation to the sardine landings is quite apparent since the market demand for the two mackerel species is inversely affected by that of the sardine. During the sardine season, October through February, orders are placed for alternate species when sardines are not available in sufficient tonnage, thus distributing the daily workload at the processing plants.

During the first half of the season the price per ton of Pacific mackerel was \$45.00 while that of jack mackerel was \$42.50. On 4 January a new price of \$42.50 per ton for either species was agreed on by the canners and fishermen.

Nearly half of the tonnage of Pacific mackerel was taken in the offshore areas between Pt. Fermin and Oceanside. About 20 percent was taken in the vicinity of Santa Catalina Island and about the same tonnage was taken in the area from Pt. Fermin north to Pt. Dume. The remaining 15 percent of the catch was about equally distributed, by point of origin, from Oceanside to the Mexican border, the area around Santa Cruz Island, Port Hueneme, and in the vicinity of San Clemente Island. This distribution of catch localities holds also, in a large measure, for jack mackerel.

Approximately 160 boats, using purse seines and lampara nets, caught the major portion, 84 percent, of the mackerel catch. The landings of the 50 or so scoop boats were composed almost entirely of Pacific mackerel, accounting for 16 percent by weight of the total deliveries of this species. About one percent of the mackerel landings was caught by nearly a score of assorted skiffs and power boats using hook and line.

Studies of the age composition of the catch, fecundity, and food of the Pacific mackerel are now being conducted.

### **Sauries**

With the scarcity of sardines in the latter part of the 1956-57 season some fishing effort was directed toward anchovy fishing; however, the anchovy catch was limited by market demands, and other fish were sought. Therefore, it was not surprising, although certainly very interesting, that several small loads (from 1 to 20 tons) of Pacific sauries were delivered to at least two canners in the Long Beach-San Pedro area in January of 1957.

The fish were located by airplanes and caught by purse seiners. Although used almost entirely for pet food, the sauries, preliminary reports indicated, were substantially higher in protein value than most other cannery fish.

Previous progress reports of the California Cooperative Oceanic Fisheries Investigations have indicated that sauries are quite numerous and that they could support a substantial fishery. These reports also stated that the Japanese land considerable tonnages of this species annually. Much interest has been expressed in the possibility for future exploitation of this species off the California coast.

### **1956 Young-Fish Surveys**

Five cruises were made to assess the relative abundance of sardines. Two thousand and eighty nautical miles were scouted during 76 nights. Three hundred and sixty-six light stations were occupied; 34 samples of sardines were obtained. The sardines were largely concentrated in the area between Ballenas Bay and Pt. Eugenia, Baja California. In this area 28 percent of all stations occupied yielded sardines. Preliminary age analysis of the fish reveals that about 70 percent were of the 1956-class.

As the survey progressed up the coast sardines appeared in less abundance. From Pt. Eugenia to the Border, sardines were sampled at only 17 percent of the stations occupied, and 64 percent of these fish were of the 1956-class. From the Border to Pt. Conception, sardines were quite scarce. Only 2.5 percent of the stations occupied yielded sardines; 20 percent of these were the 1956-class. Although spawning success was better south of Pt. Eugenia the fish of the year were less abundant in 1956 than in 1955. In 1955, 90 percent of the fish sampled in this area were fish of the year.

Pacific mackerel were sampled more often than any other species during the 1956 survey. They were present at 13 percent of all stations occupied, being most abundant along the Baja California coast, notably in Todos Santos Bay and the area from Pt. Eugenia to Ballenas Bay.

With the condemnation of the *Yellowfin* in May, 1956, experiments in electro-fishing were transferred to the *N. B. Scofield*. On 1 February 1957, work was begun installing and checking the electrical equip-

ment and by 1 May experiments were under way at the level left off on the *Yellowfin*.

Wild schools of jack mackerel were night-lighted and successfully sampled with a new positive electrode. A gill net stretched over the electrode acted as a collecting device. Future work will be channeled toward development of a device to entrap fish about the electrode.

### Aerial Surveys

Analyses of the first three years' airplane census data have proved most encouraging and the Department has intensified its aerial program. Methods of determining the area of fish schools from the air have been worked out. Results show that the large masses of fish that occur in the summer and fall are best measured by photographic methods, whereas the smaller, more uniform schools present in spring and any schools that are dim or barely visible are more efficiently measured by a telescope with a graduated reticle. Alterations are now being made to the Department's plane to accommodate special aerial photographic equipment.

The large anchovy concentration reported along the coast of California in the spring of 1956 continued to build up during the summer and fall in the southern California and Baja California areas. The peak of abundance in southern California occurred in late September. Results of the first two flights in 1957 showed a decrease of anchovies along the coast, especially in central California; however, there are good indications that the 1957-class should be a strong one, particularly off central California.

It is noteworthy that on Flight 57-2 (14-24 May) a school group of sardines appeared in the area around the Coronados Islands and Pt. Loma. These fish were reported about 1 May by commercial aerial spotters and samples of live bait collected at San

Diego proved them to be nearly all of the 1955-class. Over the past three seasons sardines were not seen on aerial flights until late in June.

### Bait Sampling

Although the Department has recorded the live-bait catch since 1939, it was not until 1949 that records were kept of the amounts of young sardines less than one year old that were caught for live bait. The reports from bait haulers indicate the numbers of "scoops" of various species taken and these values are converted to weights, based on the average scoop weight of each bait hauler. Young sardines less than a year old have been reported as "firecrackers" since 1949.

In general, adult anchovies and very young sardines (firecrackers) are the preferred live-bait fish. Species making up minor amounts of the catch such as white croaker, queenfish, and smelt are referred to collectively as "junk fish." Jack mackerel, Pacific mackerel, and Pacific herring also are frequently referred to as "junk fish" because of their relatively small contribution to the total live-bait catch.

In 1955, routine bait sampling was inaugurated to improve the estimates of species composition of the live-bait catch, to determine the size and age composition of the anchovies and adult sardines, and to attempt to obtain an index of the strength of the incoming year-class of anchovies and sardines in southern California. During the heaviest sportfishing months, April to October, a sample of bait has been received once each week from bait haulers operating from the major sportfishing ports between San Diego and Morro Bay.

The amounts and percentages of young sardines, adult sardines, anchovies, and miscellaneous species (junk fish) in the bait catch from 1949 through 1956 are shown in the following table.

SPECIES COMPOSITION OF THE BAIT CATCH

Year	Live-bait catch in tons	Young sardines (firecrackers)		Adult sardines		Anchovies		Miscellaneous fish percent
		Tons	Percent	Tons	Percent	Tons	Percent	
1949	4,535.0	0.5	.01	1,454.1	32.06	2,802.4	61.79	6.14
1950	5,528.9	2.1	.04	1,546.8	27.98	3,823.8	69.16	2.82
1951	6,614.2	1.9	.03	1,303.6	19.71	5,141.9	77.74	2.52
1952	7,182.4	12.8	.18	113.8	1.58	6,810.4	94.82	3.42
1953	6,488.9	5.7	.09	9.9	.15	6,391.5	98.50	1.26
1954	6,835.9	1.4	.02	68.8	1.01	6,686.0	97.81	1.16
1955	6,242.7	18.6	.30	40.5	.65	6,125.4	98.12	.93
1956*	6,364.1	0.1	.00	7.8	.12	6,331.8	99.49	.39

\* Preliminary figures.

It is interesting to note that in 1949, 1950, and 1951, the percentage of firecrackers in the bait was very small and subsequently these year-classes were relatively weak in the commercial sardine catch. In 1952, the percentage of firecrackers in the live-bait catches increased materially and the 1952-class has

dominated the commercial catch for the past two seasons.

In 1953, the percentage of firecrackers was somewhat less than in 1952 but better than in the years 1949 through 1951. Thus far, analyses of commercial landings reveal that the 1953-class is somewhat weaker

than the 1952-class. It is too early to tell the contribution to the catch of year-classes since 1953 but, if percentages of firecrackers in the bait indicate the relative year-class strength, the 1955-class may be stronger than the 1952-class.

Since a substantial amount of the total anchovy catch is taken by the live-bait fishery, the bait sampling program inaugurated in 1955 should also prove to be a valuable asset in understanding the dynamics of the anchovy populations off California. The following table shows the tonnages of anchovies caught by the commercial fleet and the live-bait fleets since 1939.

COMMERCIAL LANDINGS AND LIVE BAIT  
Catch of Anchovies in Tons in California, 1939-56  
(Live-bait Catch 1943-45 Not Recorded)

Year	Commercial landings	Live bait	Total	Percent live bait
1939	1,073.9	1,503.2	2,577.1	58.3
1940	3,158.8	2,006.0	5,164.8	38.8
1941	2,052.6	1,581.7	3,634.3	43.5
1942	847.1	257.6	1,104.7	23.3
1943	785.4	--	--	--
1944	1,945.5	--	--	--
1945	808.4	--	--	--
1946	960.8	2,748.1	3,708.9	74.1
1947	9,470.2	2,854.0	12,324.2	23.2
1948	5,417.9	3,725.5	9,143.4	40.7
1949	1,661.1	2,802.4	4,463.5	62.8
1950	2,439.3	3,823.8	6,263.1	61.1
1951	3,477.4	5,141.9	8,619.3	59.7
1952	27,891.4	6,810.4	34,701.8	19.6
1953	42,917.7	6,391.5	49,309.2	13.0
1954	21,205.1	6,686.0	27,891.1	24.0
1955	22,345.7	6,125.4	28,471.1	21.5
1956*	22,598.0	6,331.8	28,929.8	21.9

\* Preliminary figures.

In 1957, there has been an enormous increase in the percentage of young sardines (firecrackers) in the bait. Firm figures are not yet available, but it appears that firecrackers in the bait may exceed 6 percent (as against 0.30 for 1955, the best previous year). Even more significant is the fact that sardines of the 1957-class have been taken by the live-bait fleet off all sportfishing ports from San Diego north to Morro Bay. In addition, sardines of the year have been collected from Monterey Bay for the first time in several years.

It is apparent that 1957 is a year of unusually high water temperatures compared to the others since 1949. Aside from the obviously better survival of the 1957-class of sardines, there has been a phenomenal increase in the catch of many sportfish.

*The Sportfishery in 1957*

The year 1957, unquestionably, will be the best sportfishing year southern California ocean anglers have enjoyed since party boat records were re-established in 1947. Yellowtail have been caught off all southern California sportfishing ports and in large numbers south of Port Hueneme, and the barracuda catch has also increased greatly over the past several years. More bonito and yellowtail have been taken by party boat anglers than in any year previously recorded.

The following table shows the catch in numbers of several game species from 1947 through September of 1957:

TOTAL ANNUAL PARTY BOAT CATCH OF SEVERAL SPECIES IN NUMBER OF FISH FROM 1947 THROUGH SEPTEMBER OF 1957

Year	Barracuda	Yellowtail	Bonito	Yellowfin tuna	Skipjack	Dolphinfish	Angler days
1947	677,449	6,948	36,496	137	698	15	359,426
1948	384,056	13,028	14,519	18	460	0	407,757
1949	366,423	17,710	5,372	11	9	0	469,915
1950	256,367	6,971	2,359	6	31	1	544,264
1951	269,545	23,721	14,475	56	132	0	556,949
1952	336,550	59,263	7,649	34	38	2	562,898
1953	170,550	27,702	6,321	0	279	0	502,146
1954	282,552	40,872	70,078	0	50	12	532,190
1955	154,962	36,468	22,409	1	10	0	496,286
1956	87,603	29,198	61,404	78	13	2	523,063
1957 through September*	490,075	176,849	186,587	425	6,417	2,805	

\* Preliminary report.

Even pier anglers were able to snag small (1957-class) sardines for bait with which to catch large numbers of bonito and occasional barracuda.

In addition to the good fishing for yellowtail, barracuda, and bonito, party boats also encountered skipjack and dolphinfish in greater amounts than during the past 10 years, and they occasionally landed yellowfin tuna.

Equally remarkable as this upsurge in landings of game fish by sportsmen is the fact that many species have been taken much farther north than in recent years. White seabass have been taken off the Golden

Gate in fair numbers both by sportsmen and by commercial fishermen trolling for salmon. A rather substantial sport fishery for white seabass began in Monterey Bay. Meanwhile, commercial albacore fishermen were taking skipjack, dolphinfish, and bonito 30 to 80 miles off the Farallon Islands and as far north as Eureka.

Biologists from Oregon and Washington have reported bluefin tuna taken by commercial fishermen off Cape Flattery, skipjack as far north as Cape Blanco, dolphinfish off Grays Harbor, and white sea-

bass off the Columbia River. Unusually high sea temperatures have been reported all along the coast by the albacore fishermen in the usual offshore albacore fishing areas. Marlin and sailfish have been reported

seen in widely scattered areas and swordfish have been taken off Monterey Bay.

Following is a preliminary list of other warm water species taken in California waters in 1957:

Number taken in 1957	Common name	Scientific name	Years formerly reported	Location of capture in 1957
1	Bullet mackerel	<i>Auris</i> sp.	1918 1919 1935	Coronados Islands
2	Sharpchin flyingfish	<i>Fodiator acutus</i>	1931	Long Beach
1	Tai or Porgy	<i>Calamus brachysomus</i>	1953?	Oceanside
1	Shortnose spearfish	<i>Tetrapturus angustirostris</i>	(Never previously taken off California)	60-Mile Bank
1	Spiny trunkfish	<i>Lactoria diaphana</i>	1932 1933 1949 1951*	Santa Monica Bay
1	Pilotfish	<i>Naucrates ductor</i>	1926 1936 1945	San Clemente Island
3	Triggerfish	<i>Verruculus polydipis</i>	1924 1931 1946 1950 1951*	Santa Monica Bay, Laguna Beach, and San Diego
1	Monterey spanish mackerel	<i>Scomberomorus cowolor</i>	1931 1937 1939 1941 1947 1948 1949 1951*	Santa Barbara
1	Green jack	<i>Caranx cabillus</i>	1858 1924 1945 1953 1955*	Belmont Shore

\* Probably other years, also.

In addition to these warm water species, hammerhead sharks were seen frequently in California waters during 1957 and many were caught. Several green sea turtles were taken, especially by bait haulers in Los Angeles Harbor, and others have been reported sighted as far north as the Farallons.

At Pismo Beach the set of Pismo clams in 1957 was the best to occur at that locality in the past 10 years. This set compares favorably with the best sets since the Department's annual Pismo Clam census was inaugurated in 1923.

The year 1957 is, indeed, unusual compared with the last several, and sportfishing seems more nearly like it was in the years prior to World War II. The question seems to be whether 1957 is unusual or perhaps the only "normal" year in the past 10.

#### HOPKINS MARINE STATION, STANFORD UNIVERSITY

Monterey Bay is historically one of California's richest fishing grounds. It is broadly open to the sea, and conditions in the Bay therefore reflect to a large extent the conditions which occur in the offshore waters of central California.

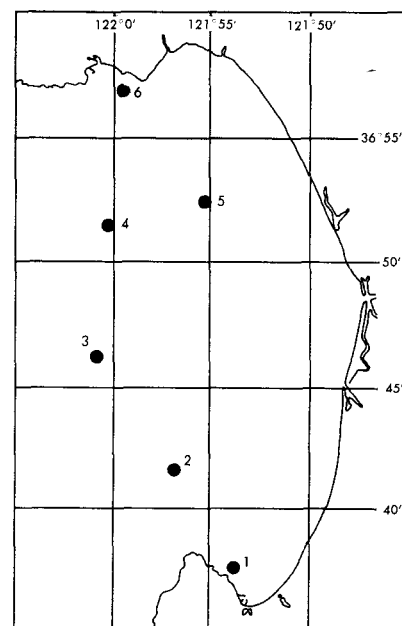


FIGURE 1. Stations occupied in regular oceanographic cruises in Monterey Bay. At each station the vessel records weather and water temperatures, and takes water samples and plankton hauls for analysis.



Since 1951 the Hopkins Marine Station of Stanford University has operated for CCOFI what amounts to an oceanographic "weather station" on Monterey Bay, with approximately weekly cruises that sample the water conditions and plankton organisms at several points in the Bay (Fig. 1).

In the continuing hydrobiological survey in the Monterey Bay area it has been found that the pattern

of surface temperatures provides a good index of the water masses present and is closely correlated with the production of phytoplankton.

The upper series of bars in figure 2 depicts the deviation of the surface temperatures at the individual stations from the average of all of the stations on that particular day. (Data come from the winter of 1955-56 and summer and fall 1956.) For each day,

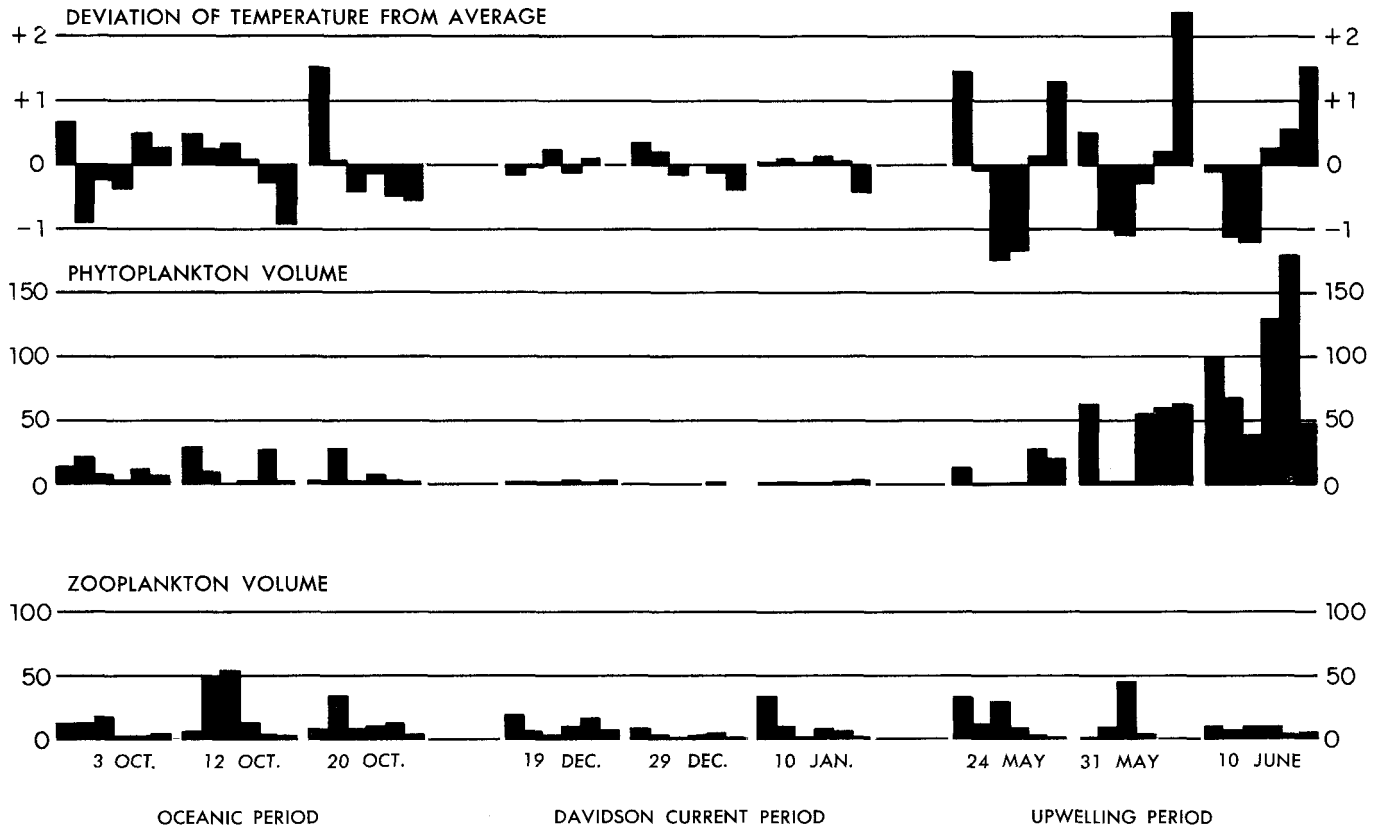


FIGURE 2. Deviation of temperature from average (in degrees Centigrade), phytoplankton and zooplankton volumes (in milliliters per liter) during three periods in Monterey Bay.

Station 1 is shown at the left; the other stations follow in numerical sequence to Station 6 at the right. Three consecutive weeks have been selected to show the typical conditions during each of the three phases of the annual cycle. The middle and lower series of bars indicate the comparative size at each station of the phytoplankton and zooplankton populations respectively. They are based on samples obtained by drawing standardized plankton nets vertically through the upper 15 meters of water. The preserved plankton is allowed to settle to constant volume in graduated cylinders and its wet volume recorded in milliliters.

These studies show that the yearly cycle of events in the bay may be divided into three fairly distinct periods: the Oceanic Period (September and October), the Davidson Current Period (November through February), and the Upwelling Period (March to August).

During the Oceanic Period the differences in temperature to be found between the most divergent pairs of stations average about 1.9° C (3.4° F), but it may be as little as 1.4° C (2.4° F) or as great as 3.0° C (5.4° F). The northernmost and southernmost stations are usually the warmest ones, owing to heating of the relatively stable water in the eddies over the sand flats at the extremities of the bay during the clear sunny days typical of fall. On occasion the surface water at one end of the bay or the other may be washed out by winds of short duration and replaced by water from slightly deeper layers. Since at this season the vertical temperature gradient is very abrupt in the upper 10 meters, the station at which the water has thus been replaced is characterized by the lowest temperatures. This situation prevailed at Station 6 on 12 October.

During the Davidson Current Period temperatures are exceedingly uniform. The extreme difference between any pair of stations averages a little less than  $0.5^{\circ}\text{C}$  ( $0.9^{\circ}\text{F}$ ). At times it may be as little as  $0.3^{\circ}\text{C}$  ( $0.5^{\circ}\text{F}$ ), and on rare occasions it may approach  $0.8^{\circ}\text{C}$  ( $1.4^{\circ}\text{F}$ ). No regular pattern of temperature distribution is discernible.

During the Upwelling Period the temperature pattern is strikingly characteristic. Station 3, located directly over the Monterey Canyon, yields the lowest temperatures about 70 percent of the time; this indicates the importance of this topographic feature in channeling the deep waters toward the surface. Whenever Station 3 does not yield the lowest values of the day, these are invariably obtained at either Station 2 or Station 4, the particular one showing whether the trend of the upwelling water is toward the north or the south within the bay. During this period the amplitude of the temperature differences between stations is high but variable, the magnitude of the difference reflecting the magnitude of the upwelling. Differences of  $3.0^{\circ}\text{C}$  ( $5.4^{\circ}\text{F}$ ) between Station 3 and Station 1 or 6 are normal.

Phytoplankton volumes during the Oceanic Period are relatively low and variable, and there is no evident correlation between temperature and productivity.

At the onset of the Davidson Current Period phytoplankton production is reduced to a minimum. It is a very rare station that yields as much as 5 milliliters, and sometimes most or even all of the stations are negative. The figure shows that on 29 December only Station 5 yielded a measurable catch.

Production, reflected in larger phytoplankton volumes, shows a marked increase about three weeks after the onset of upwelling as indicated by the expansion of the temperature differences between the various stations to more than  $1.0^{\circ}\text{C}$ . The period of 24 May to 10 June, which was selected as representative of the Upwelling Period, shows clearly the development of a typical plankton bloom. The first upwelling of the season extended from 27 February to 9 April. It was of minor strength and resulted in a small bloom which reached a peak on the latter date. As the upwelling slackened the phytoplankton declined, apparently because of the browsing by an increased number of small copepods, by dense masses of euphausiids which come from deep water to swarm at the surface during April, and by a heavy influx of the pelagic tunicate *Doliolum* during the latter part of this month. By early May the phytoplankton was at a low level, but a second and much more massive wave of upwelling water, shown by the drastically lowered temperatures at Stations 2, 3, and 4, resulted in a new and heavy phytoplankton bloom. Its development, well illustrated by the figure, is typical. On 24 May the freshly upwelled cold water at Stations 3 and 4 was rich in plankton nutrients

but had only recently been inoculated with elements of the phytoplankton through admixture with surface water; its population was very low. At Stations 1, 5, and 6, where the higher temperatures indicate that the water had remained on the surface for an appreciable period, the floating microscopic plants had had time to multiply and the plankton volumes were considerably greater. On 31 May the upwelling stream had shifted its position slightly to Stations 2 and 3, while an additional week of growth had resulted in a marked increase in the standing crop in the warmer parts of the bay. By 10 June the shift of the upwelling stream toward the south had progressed so far that the temperature at Station 1, although still markedly above those at Stations 2 and 3, was depressed below the average for the bay as a whole. The phytoplankton had again more than doubled, providing an extremely high value at Station 5, and the heavy concentrations had spread to such an extent that even Stations 2 and 3, in the center of the upwelling stream, yielded very respectable values. The comparatively small amount of phytoplankton taken in the warm water at Station 6 on this day probably indicates a decline of the bloom as a result of depletion of nutrients in a relatively stable eddy at the northern extremity of the bay.

Except for the fact that there is a general tendency for the zooplankton volumes to be comparatively low in winter and high during the summer, little can be said about the relationship of the floating animals to the floating plants. The zooplankton volumes are very irregular and do not appear to be correlated with specific fluctuations of the phytoplankton. High values are obtained at isolated stations at irregular intervals. Sometimes the sudden increases occur when the phytoplankton is rich, at other times when it is poor. It has not been possible to clarify the picture by an attempt to find a time lag such as might be expected between phytoplankton and zooplankton peaks. In most cases the high values can be ascribed to injection into the plankton of larval forms as the result of mass spawning of bottom invertebrates, or through the invasion of the layers being sampled by organisms which normally live in deeper waters, or more rarely by swarms of oceanic organisms from the open sea.

The plankton samples indicate that fishes tend to avoid the freshly upwelled water for spawning. At Stations 1, 5, and 6, fish eggs, although somewhat irregular in occurrence, are on the average the second most abundant element in the zooplankton. At Stations 2, 3, and 4, on the other hand, fish eggs rate fourth, and at Station 3 even this position is not secure. It appears that most fishes spawn in water which has "matured" on the surface and in which the developing larvae will have a good chance of finding adequate food.

### Warmer Water Conditions

Monterey Bay and the ocean beyond have shown a definite trend toward warmer conditions since 1955. The year 1955 was cold, with surface temperatures

rarely rising above 14° C, even in inshore waters (Fig. 3). September and October, nearly always the two warmest months of the year, showed monthly average temperatures on the bay of 13.1° C. The year

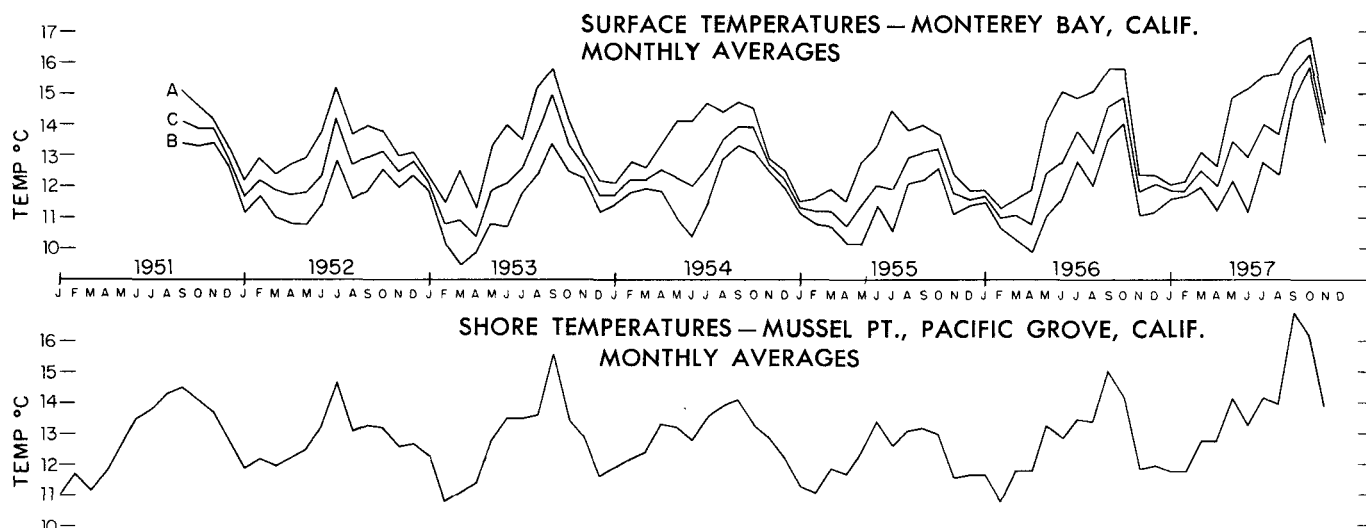


FIGURE 3. (Top) Surface temperatures, Monterey Bay (monthly averages in degrees Centigrade). Curve A—Monthly averages of the highest surface temperature recorded during each weekly cruise. Curve B—Monthly averages of the lowest surface temperature recorded during each weekly cruise. Curve C—Monthly averages of all surface temperatures recorded during each weekly cruise. (Bottom) Shore temperatures, Mussel Point, Pacific Grove (monthly averages in degrees Centigrade). Curve D shows monthly averages of the shore temperatures at the southern end of Monterey Bay, based on daily measurements recorded by Hopkins Marine Station for the Scripps Institution of Oceanography.

1956 was warmer, with September and October average surface temperatures of 14.6 and 14.9° C. The year 1957 has been warmer yet, with September and October monthly averages of 15.7 and 16.4° C, some two and a half degrees warmer than in 1955. Changes in other seasons parallel those indicated above, though differences in winter temperatures are not as large as those given above. For oceanographic conditions this represents a fairly conspicuous change.

### SOUTH PACIFIC FISHERY INVESTIGATIONS, U. S. FISH AND WILDLIFE SERVICE

Descriptive studies have progressed to the stage where it is now possible to suggest a working hypothesis that appears to be in accord with what is known of the biology of the sardine and the history of the fishery. Briefly, the features of this hypothesis are:

- (1) Sardines produced off southern California migrate as far north as the Pacific Northwest and support the fishery in that region, as well as the winter fishery at San Francisco, Monterey, and San Pedro.
- (2) Sardines produced off central Baja California migrate as far north as central California and enter into the fall fishery in San Francisco, Monterey, and San Pedro.
- (3) Lack of spawning success on the southern California spawning grounds since 1943 could account for the observed changes in the fishery.

- (4) This lack of spawning success is attributed to lower (suboptimal) spring temperatures on the southern California spawning grounds.

It is interesting to remark on the possibility of a larger than usual year-class being produced off southern California in 1957 (see below), a year in which spring temperatures approached pre-1943 conditions.

Most of the projects of the South Pacific Fishery Investigations are continuing ones and are carried out in cooperation with other agencies participating in the California Cooperative Oceanic Fisheries Investigations. Age analyses of the commercial landings of sardines and anchovy are carried out cooperatively with the California Department of Fish and Game. Oceanographic-biological survey cruises are made in cooperation with Scripps Institution of Oceanography.

The oceanographic-biological cruises during the past year were of four kinds:

- (1) Egg and larval survey cruises designed to determine the distribution and abundance of sardine spawning and the rate of survival of sardine larvae and those of associated pelagic species.
- (2) Hydrographic-biological survey cruises in the Gulf of California.
- (3) Cruises for the collection of sardines on the spawning grounds.
- (4) Cruises made in conjunction with the commercial sardine fleet to study factors influencing the availability of sardines to the fishermen.

### *Egg and Larval Survey Cruises*

The egg and larval survey cruises off California and Baja California cover an area that has been continuously surveyed since 1949. During both 1956 and 1957, the extensive survey cruises were confined to the first seven months of the year, January through July, with the widest and most intensive coverage being made in April through July. The January, April, and July cruises had complete hydrographic coverage of the area as well as biological coverage; the other cruises were primarily egg and larval survey cruises, with limited hydrographic observations. Hydrographic observations on egg and larval cruises consist of the following: temperature and salinity observations at 10 and 50 meters depth at each station, bathythermograph casts at and between stations, continuous record of surface temperature, geomagnetic electrokinetograph observations on some vessels.

A preliminary estimate has been obtained of the amount of sardine spawning in 1956:  $206 \times 10^{12}$  eggs. This value is a preliminary estimate only, but the comparative figures for the two preceding seasons are the final estimates. These are:

	<i>No. eggs</i>	<i>No. spawning fish</i>
1954 -----	$355 \times 10^{12}$	$7.1 \times 10^6$
1955 -----	$163 \times 10^{12}$	$3.3 \times 10^6$
1956 -----	$206 \times 10^{12}$	$4.1 \times 10^6$

In 1956, about 43 percent of the spawning occurred in the "northern" spawning center off southern California and adjacent Baja California, the remainder in the "southern" center off central Baja California. (Sardine spawning in the Gulf of California is not considered in this connection.) The 1956 distribution was rather similar to that found in 1954 and 1955, except that a larger portion of the spawning in the "northern" center occurred to the south of Ensenada.

Preliminary results for 1957 indicate that it was an unusual year off southern California and, indeed, over the area from Peru to Alaska and as far westward as the Hawaiian Islands. Locally, 1957 has been one of the warmest years on record. Coincident with this sharp change, certain sportfishes such as yellowtail, barracuda, and white seabass have been exceptionally available and many southern forms have been found far north of their usual range.

Sardine spawning off southern California has also been unique. Spawning on the usual, offshore grounds was limited and discontinuous. The larger portion of the spawning took place in a coastal band from Punta Baja to San Pedro (Station lines 90-107).

For the first time in several years, some sardine spawning has occurred to the north of Pt. Conception. Sardine eggs and/or larvae were taken at five stations on lines 67 to 77 in June; spawning north of Pt. Conception was observed in July. The northernmost locality was off Monterey Bay.

Early in the year, sardines of the 1955-class were taken in the southern California live-bait fishery. Later in the year, sardines of the 1957-class have been taken in the live-bait fishery and have been commonly observed by sardine fishermen fishing out of Port Hueneme. Sardines of the 1957-class have also been reported from north of Pt. Conception, at least as far north as Monterey Bay.

Survival of the 1957-class of sardines off southern California has undoubtedly been better than in recent years. It is possible that the 1957-class will prove to be a large one. Judgment should be reserved, however, since these juveniles may be over-available owing to their inshore origin.

As already noted, the peculiarities of sardine spawning and survival off southern California in 1957 have been associated in time with an unusually warm year. Oceanic conditions in 1957 represent the greatest change yet observed by CCOFI.

A number of plankton samples collected off California during the June and July cruises of 1957 have been examined in order to determine if there was anything unusual about the distribution of plankton organisms during this period. Inasmuch as there had been marked incursions of warm water fish into the area, it was of interest to ascertain whether there were incursions of plankton animals associated with tropical or central Pacific water. These preliminary investigations indicate no evidence for the incursion of a tropical water mass into the area during June and July. At some stations in June a species with affinities for central Pacific water was collected. This species may approach close to the coast at times, but its presence supports the physico-chemical evidence of an incursion of central Pacific water. Except for this species, the plankton in the area off California was made up of species associated with the California Current, and hence did not differ materially in June and July 1957 from the plankton of these months in other years.

### *Hydrographic-biological Survey Cruises in the Gulf of California*

Except for a cruise of the *Black Douglas* into the southern part of the Gulf of California in late 1952, no work had been done on sardine spawning in the Gulf prior to February 1956. Since then cruises have been made in February, April, and December, 1956 and February, April, June, and August 1957.

The station grid in the Gulf consists of 12 lines on which stations are spaced 15 miles apart, together with a fairly large number of inshore stations located between station lines. On some cruises, between-line stations are placed in the "deeps" rather than inshore.

Sardine spawning in the Gulf is heaviest in the middle third, between Carmen and Tiburon Islands, although it has been shown to occur more or less throughout the Gulf. Interestingly, the distribution of spawning in February 1957 was strikingly similar to that found in February 1956, with the heavy spawning occurring on the two station lines immediately to the south of Guaymas.

Gulf cruises were spaced at bi-monthly intervals during the spawning season in order that an estimate of the amount of sardine spawning in the Gulf could be obtained. It is evident from the results of the 1956 surveys that the spawning population in the Gulf must be a large one.

Although the Gulf of California has been proved to be an important spawning area for the sardine, Pacific mackerel, and other species, no cruises are presently planned into the Gulf in 1958. The relationships of the fish of the spawning areas off southern California and Baja California to each other and to the fishery must first be determined. Once answered for these groups, the same questions can be asked concerning the sardines spawning in the Gulf. In the meantime, only monitoring activities, if any, will be continued in the Gulf.

#### *Collection of Spawning Sardines*

The August and September 1956 cruises were devoted in part to the sampling of adult sardines for use in fecundity and subpopulation studies, in part to egg and larval surveys of fall sardine spawning. During both months, sardines were sampled in the area between Pt. Eugenia and Pt. Abreojos, mostly by gill nets.

A large percentage of the sardines have developing gonads, and several females were approaching spawning condition. In August the females that contained yolked eggs were between 177 and 222 mm in standard length; in September, they were between 160 and 188 mm. The fish were mostly one and two years of age. In fact, less than 5 percent of the fish collected were older than two years.

The fish were markedly smaller in size than fish of the same age taken in the California commercial catch. Two-ring fish, 1954-class, in the commercial catch ranged in standard length from 208 to 242 mm, with an average length of 224 mm; the same year-class in "spawning" sardine collections ranged from 162 to 226 mm, with an average length of 182 mm. This is 42 mm smaller, on the average, than the two-ring fish taken by the California commercial catch. The marked difference in size between sardines from the two areas is evidence that they did not enter into our commercial catch in any numbers in the 1956-57 season. It also adds support to the thesis that the

fall-spawning sardines constitute a separate subpopulation.

#### *Availability Studies*

In October, November, and December 1956, the *Black Douglas* made nightly plankton and temperature collections in areas scouted by the San Pedro sardine fleet. As soon as the area of most intense fishing was ascertained on any given night, the *Black Douglas* executed a pattern of observations that included the fishing area as well as some portion of the surrounding area that had been scouted without success. Once started, each pattern was continued until a half-hour before dawn.

This survey is a field approach to the problem of sardine availability. Large concentrations of sardines do not necessarily appear in the same spot on successive nights. It is reasonable to hypothesize that such fluctuations are related to variations in one or more features of the environment. Since it was not known at the outset which environmental factors might be critical, it was decided to measure plankton and temperature, which have been related to fish distribution in a few other fisheries. Plankton was collected with a Hardy continuous plankton recorder, approximately one and one-half linear miles being sampled for each two-inch length of the collecting silk. Surface temperature was recorded continuously, and bathythermograms were taken at frequent intervals.

The plankton collections and the temperature data are now being studied. Small copepods are by far the most numerous organism, and they fluctuate by a factor of three or four during the course of one night. In one case, the area of highest density for the more abundant categories appears to be associated with a geographical feature of the adjacent coastline. The center of fishing, however, was in an area of lower plankton density about four miles away.

Since the 1956-57 season was relatively poor, no really large sardine catches were made while the *Black Douglas* was operating. Obviously, the significance of plankton and temperature distributions as factors in sardine availability cannot be determined until collections are obtained on some number of good as well as poor nights of fishing.

The Scripps research vessel *Orca* covered a regular grid of hydrographic-biological stations off southern California each month during the period that the *Black Douglas* was working with the commercial fleet. A striking fact brought out by the *Orca* cruises was the marked lowering in temperature that occurred in the southern California area between the October and November cruises, amounting to about two degrees over much of the area. This cooling was associated in time with the southward movement of sardines from

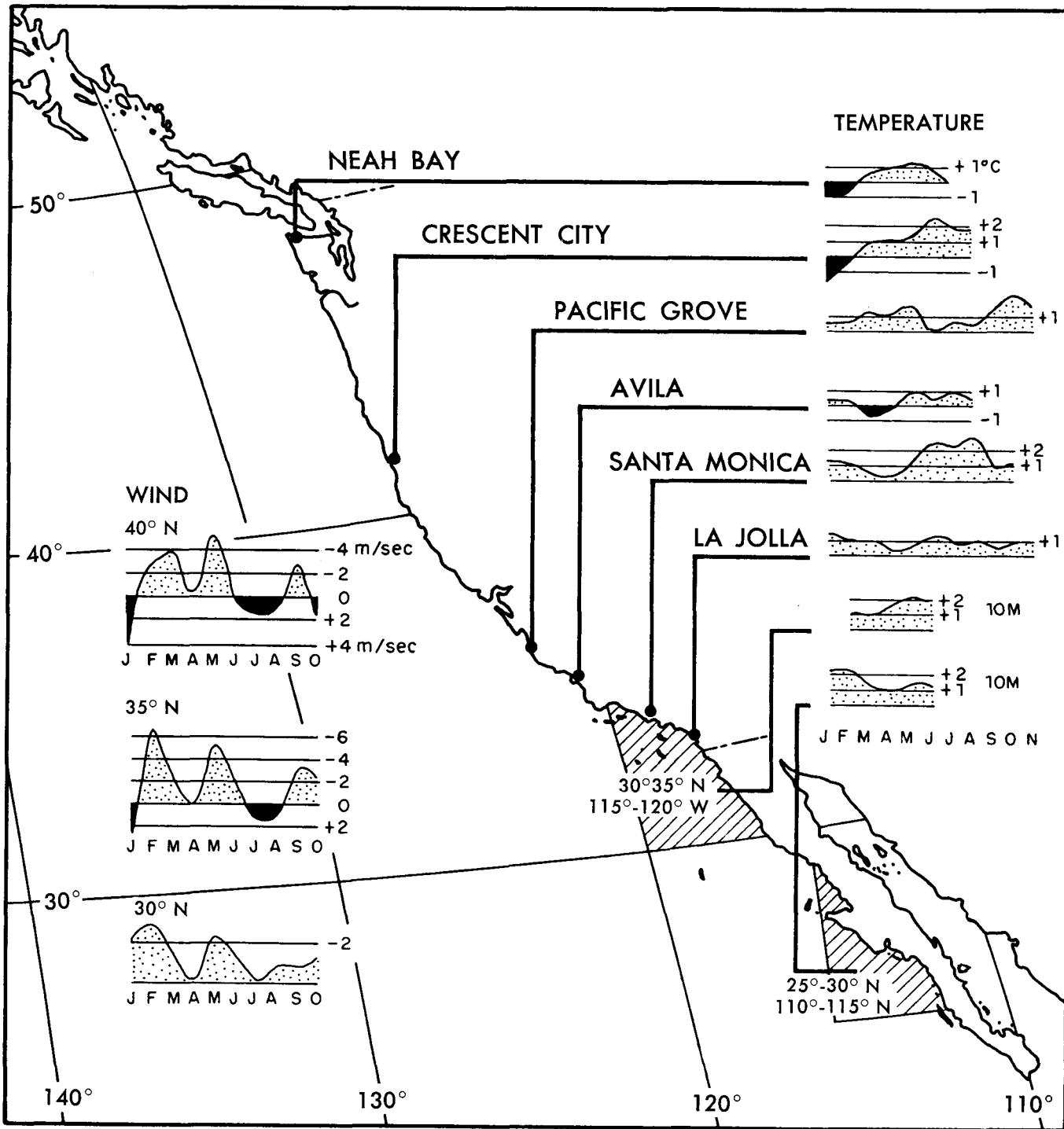


FIGURE 4. Temperature and wind anomalies at shore stations, 1957 compared to the 1949-56 means. Wind anomalies show variations in the northerly component of the geostrophic winds (computed from pressure charts). A negative anomaly means that the northerly component was weakened. Positive temperature anomalies indicate warmer water.

the southern California fishing grounds to areas off the coast of Baja California in 1956.

**Genetic Studies**

Genetic studies of subpopulations of sardines have been initiated. Research is directed toward determin-

ing whether genetically isolated or partially isolated groups exist along the Pacific coast. The approach is through a serological study. A large body of precedental information is available in this field, mostly developed on domestic animals. Several species of fish have also been investigated and individual differences

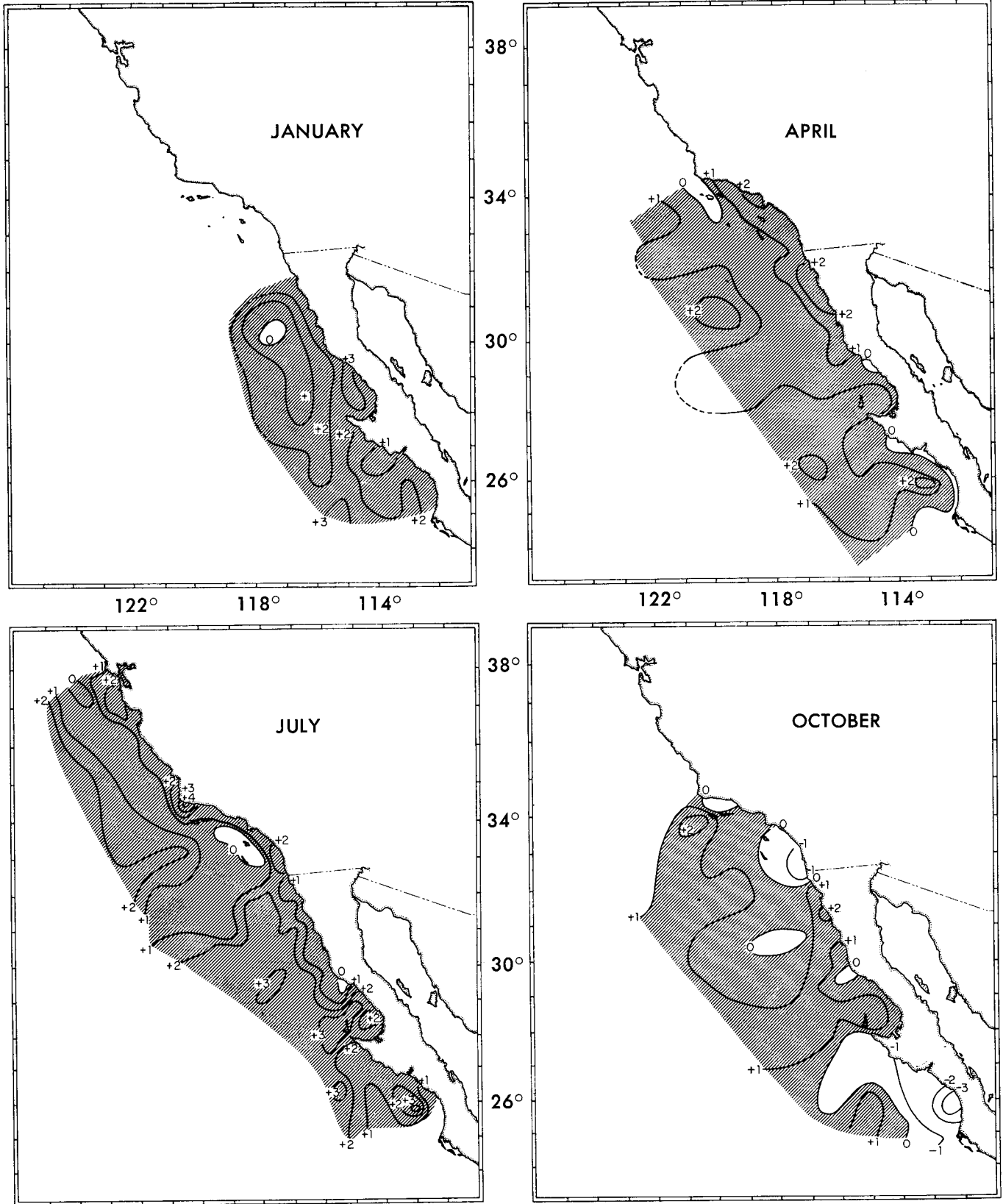


FIGURE 5. Differences between sea surface temperatures in 1957 and in earlier periods. Upper left, January 1957 compared with the 1949-55 average. Upper right, April 1957 compared with 1949-54 average. Lower left, July 1957 compared with 1949-54 average. Lower right, October 1957 compared with 1949-54 average. Differences are expressed in degree centigrade. Shading indicates warming.

with respect to erythrocyte antigens have been shown to exist. The existence of discrete individual differences with respect to erythrocyte antigens already has been demonstrated for the Pacific sardine (*Sardinops caerulea*) by means of antibodies found in the serum of certain wild and domestic animals.

The investigation has not proceeded far enough as yet to determine whether such differences can be used to characterize subpopulations.

#### Other Species

The 1956 collections of fish larvae have been sorted, identified, and standardized. Anchovies continue to be the dominant species in the collections and other species follow in about the same order as in 1955. A comparison of the standard haul totals of fish larvae for 1955 and 1956 follows:

Species	1956		1955	
	Number	Percent	Number	Percent
Anchovy	134,931	33.06	140,183	39.03
Hake	89,857	22.02	60,090	16.73
Rockfish	29,144	7.14	29,341	8.17
Sardine	15,523	3.80	14,121	3.93
Jack mackerel	8,027	1.97	13,246	3.69
Pacific mackerel	1,519	0.37	1,950	0.54
All others	129,139	31.64	100,224	27.91
Total	408,140	100.00	359,155	100.00

There is a small decrease in number of anchovy larvae taken in 1956, as compared to 1955. There are interesting differences in the distribution of anchovy larvae in these two years. In 1955, over 40 percent of the anchovy larvae occurred in the area between Pt. Conception and Punta Baja (Station lines 80-107), while only 20 percent of the larvae were taken in this area in 1956. In both years, about 60 percent of the anchovy larvae were taken off central Baja California (Station lines 110-137). A marked increase in abundance occurred in the area off southern Baja California in 1956; 19 percent as compared with 0.05 percent in 1955.

The 1955 totals do not include NORPAC (August cruise). In 1956, 36,715 larvae were taken in August. Hence if this number is subtracted from the 1956 total, to make the two years more exactly comparable, the totals are remarkably close (359,155 and 371,425).

Since 1957 has been unusual in the abundance of warmer water fishes off California, larval collections made off California during June and July 1957 have been examined to determine if there were similar occurrences of the larvae of these fishes. No such occurrences were noted. However, an exciting finding was the unusual abundance of larger jack mackerel larvae (between 5 and 10 mm in length) in the collections. The survival to these sizes is better than in any recent year. Barring unusual mortality during the juvenile period, the 1957-class of jack mackerel should be a successful one.

#### UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY

In 1957 the climate of the ocean in the CCOFI region changed in sharp contrast to the 1949-56 period. The primary change was warming of the sea water in some areas a depth of more than 400 meters. This short report on the physical changes is only a preview of what took place. Much more time is needed to analyze the data in a comprehensive manner.

The data from the shore stations indicated that warming began south of Port Hueneme as long ago as December 1956. It progressed northward to Monterey Bay in January and reached Puget Sound in March (Fig. 4). The warming along the coast averaged 1° C.

The surface temperature anomaly charts for each cruise show the warming to have covered the entire CCOFI region during the year (Fig. 5). Here the differences between 1957 and the 1949-54 average have been plotted. Warming in various places along the coast and offshore amounted to more than 3° C. A few spots of cooler than average water do appear, but these were small in size and presumably were caused by local upwelling and decreased mixing. In October there was a fairly large area of cooling from Pt. Eugenia southward.

A preliminary analysis has been prepared of the average temperature from the surface to 200 meters and from four selected hydrographic stations. The station locations are given in figure 6. Stations 80.90 and 100.70 were chosen as representative of offshore conditions, Stations 80.60 and 90.45 of inshore conditions. The physical and chemical properties for the months April, July, and October were analyzed and were compared with the average values obtained at the same stations in the same months in the years 1950, 1952, 1953, 1954, 1955, and 1956 for April; 1950, 1952, and 1953 for July; and 1952, 1954, 1955 for October.

#### April

The average temperature from the surface to 200 meters increased over most of the region. A warming of more than 1° C covered about 50 percent of the cruise pattern, with most of it being along the Baja California coast 100 miles offshore and beyond. An area of 2° C increase occurred to the west of Guadalupe Island.

The two inshore stations showed warming in the upper 50 meters. The salinity did not change significantly from earlier years. The two offshore stations showed warming down to 75 meters in the north, 150 meters in the south. The salinity at both these latter stations down to 125 meters increased 0.2 to 0.3 parts per mille. At 200 meters at Station 100.70, there was an average of 0.3 parts per mille less salinity than in



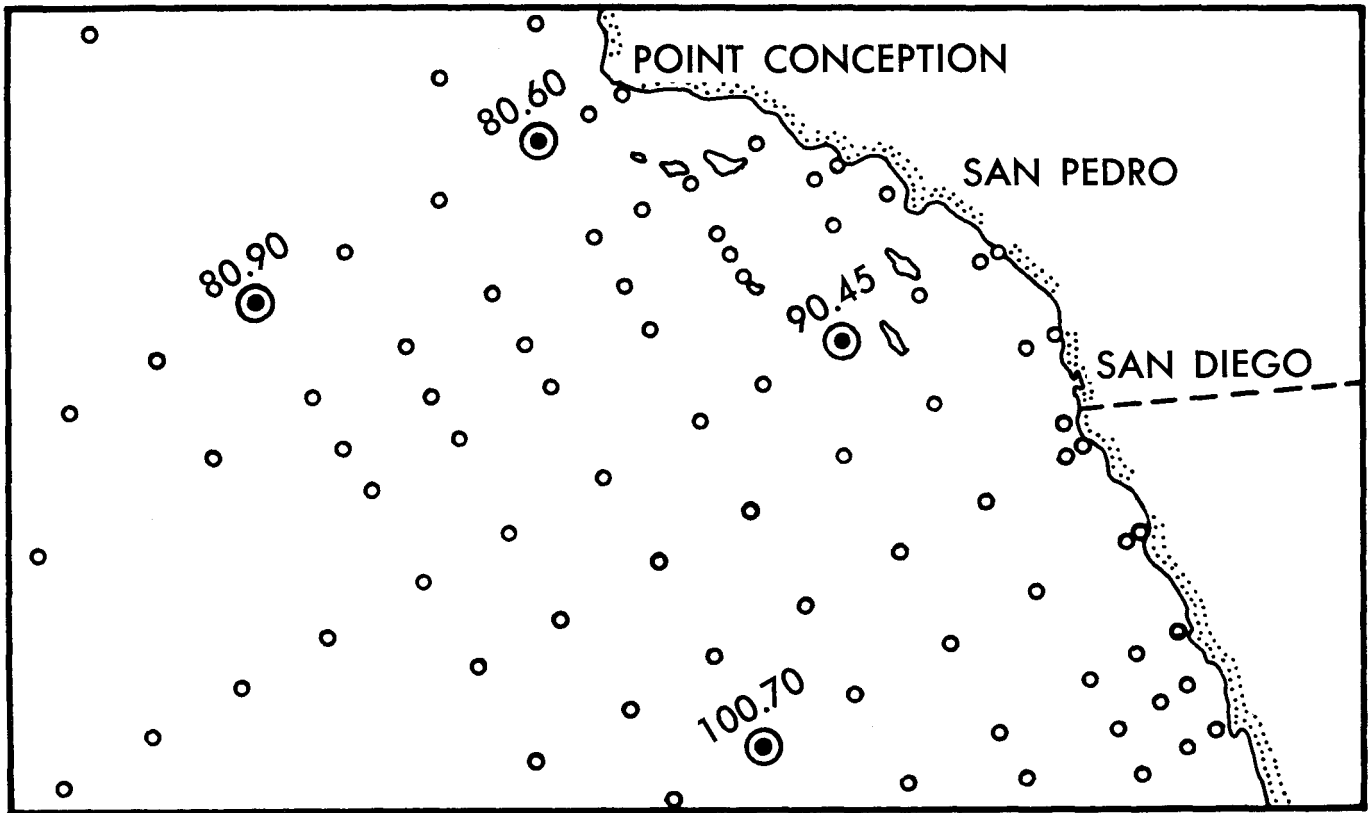


FIGURE 6. Location of four hydrographic stations for which 1957 data have been analyzed.

former years. The depth of the mixed layer and the thermocline—the region where temperature decreases most rapidly—were much the same as in the past years for all four stations.

### July

In the entire region, the average temperature from the surface to 200 meters was only a little higher than in past years. In comparing a few stations with past data, over the entire region from San Francisco to southern Baja California, the warming was slightly less than  $1^{\circ}\text{C}$ .

Warming occurred in the upper 75 to 100 meters for Stations 80.60, 80.90, and 90.45. The salinity for the two inshore stations was little changed. At Station 80.90, offshore, the salinity increased an average of 0.35 parts per mille from the surface to 100 meters, and 0.15 parts per mille from 100 to 150 meters. At 200 meters the salinity decreased over the other years by an average of 0.1 parts per mille. The oxygen values at Station 80.90 at 200 meters was much higher than usual, 4.0 milliliters per liter. The depth of the mixed layer was the same as in past years.

### October

By October a very noticeable change had occurred from Pt. Conception to Pt. Eugenia. The average

temperature from the surface to 200 meters indicated warming over the whole region. Offshore 150 miles and beyond there was warming of more than  $2^{\circ}\text{C}$ .

The temperatures at the four stations increased as deep as 400 meters with Station 80.90 having the largest increase. At 50 meters, the depth of the mixed layer, the temperature was over  $2^{\circ}\text{C}$  higher than the average, and at 150 meters it was  $1.8^{\circ}\text{C}$  higher. The salinity also increased for all stations except 90.45, where it was slightly less than in former years. The increase in salinity was the greatest at Station 80.90, averaging 0.4 parts per mille to 125 meters. Again at this station the salinity was less at 200 meters, by an average of 0.2 parts per mille. The oxygen value at Station 80.90 was 4.6 milliliters per liter. The mixed layer was the same as in previous years at all stations.

The geostrophic wind taken from monthly average pressure charts indicates that there was less northern component to the wind than the mean for the years 1949-56 (Fig. 4). In February the pressure charts indicate that the geostrophic wind had a southern component rather than the usual northern component.

There appears to have been upwelling during the period in which upwelling normally occurs. The amount of upwelling has not yet been determined. The higher surface temperatures indicate that the

upwelled water did not come from as deep or that the water in the lower layers was warmer than usual.

At present, clues to the currents during the year come only from the drift bottle experiments, as the hydrographic data must be processed before the standard current computations can be made. Other clues will come from the further analysis of the plankton.

The drift bottle experiments indicate that the eddy often found off southern California was in existence during November and December 1956, and during June, July, October, and November 1957. The eddy was not observed during February, March, April, and May. There are no data for January, August, and September.

The Davidson countercurrent, which sweeps along the central California coast during some months, usually in the winter, was apparently active during November and December 1956 and February, March, July, October, and November 1957. This is indicated by the fact that drift bottles released off Pt. Conception were found to the north. The two previous years of drift bottle experiments had shown the presence of the countercurrent only in November and December.

Though warming began in the south and shifted northward in time, there is no indication that southern water moved northward. Study of the zooplankton shows no species from other areas. The northerly winds were greatly reduced in the first part of the year. This may have retarded the normal transport of water along the coast, allowing advection of warmer offshore water into the region off southern California and Baja California. The slight increase in salinity at Station 80.90 in April and the larger increase at Station 100.70 indicate that water from farther west than usual was in fact present. By July, Station 80.90 more clearly shows the presence of a different water mass. The higher temperature and salinity and the higher oxygen at 200 meters indicate that this water mass was not from the south; it must have come from the west or northwest. Indeed, the shape of the T-S (temperature-salinity) curve and the values of higher temperature and salinity at Station 80.90 strongly resemble those of water that was found along a line from 40° N-145° W to 35° N-125° W during the NORPAC expedition in August and September 1955. By October the water mass had affected the inshore Station 80.60 and appears to have been present at a station one mile offshore from Scripps Institution.

We may summarize our conclusions to date by saying that the water was warmer, the northerly winds reduced, and that the warm water did not seem to come from the south, but at present we do not have

sufficient data analyzed for 1957 to understand the combination of the oceanographic and meteorological mechanisms by which these changes took place.

The major effort of the Scripps Institution in the CCOFI goes into investigations of the physics and the chemistry of the waters off our coast. That work is reported briefly above for 1957, in detail for earlier years in the scientific paper, "Studies of the California Current System," by Joseph L. Reid, Jr., Gunnar I. Roden, and John G. Wyllie, which makes up the body of this report.

However, other research studies connected with the Investigations are under way. Studies of the marine zooplankton, the floating animals of the sea of which the sardine is one in its earlier stages, are being conducted.

Significant studies are being conducted of the role that ocean currents can play in the life history of such floating or feebly swimming creatures. One of these projects concerns itself with the pelagic phyllosoma larval stages of the California spiny lobster, *Panulirus interruptus*. Plankton collections from the CCOFI area have been utilized in this study. The project required the complete description of all the hitherto unknown developmental stages—there were eleven. The last stage metamorphoses into the puerulus stage. At this time the animal deserts the planktonic existence to assume the morphological features and benthic habit of the adult. As an essential part of this study the phyllosoma larval stages of the pinto spiny lobster, *Panulirus gracilis*, have also been identified since the range of that species overlaps that of *Panulirus interruptus*.

With this information at hand the plankton samples for six years (1949 to 1954) have been sorted and the developmental stages recorded with a view to determining the duration of the pelagic life, the major areas of larval concentration, and the pattern of dispersal and drift in the water currents off the coast. The seasonal distribution of the successive larval stages points to a pelagic life of several months' duration. The major larval concentrations occur off Baja California. Evidence is accumulating that there may be cross-current transport of larvae.

Another project is concerned with the search for compounds in the sea which encourage or inhibit growth. The identification of such compounds would be the first step towards actual "farming" of the sea.

The concept of a particular nutrient limiting the growth of a population dates back to 1840. The obviousness and simplicity of the idea, as well as its repeated experimental verification, have given it strong intellectual appeal, and have led to its acceptance as a basic ecological concept. As a result many attempts have been made to interpret the abundance of natural populations whose food requirements pri-

marily consist of simple and/or soluble substances in terms of growth-limiting nutrients. Particular emphasis has been placed on this concept in relation to the dynamics of marine plankton populations.

However, studies with cultures of certain bacteria have shown that the growth-limiting nutrient is not necessarily the same as the nutrient that determines the rate at which a population grows, *i.e.*, the rate-limiting nutrient.

If this applies to bacteria in the sea, then there is a possibility that the distributions and abundances of phytoplankton and other populations are primarily controlled by rate-limiting nutrients.

Additional results from this study show that a population in a given environment may respond differently to different rate-limiting nutrients. Thus whether a certain nutrient is rate-limiting is not obvious from its concentration. Further, different species can respond differently to the same nutrient. As a result, in a specific environment the abundances of different species may not be determined by the same nutrient.

Studies are now being made to elucidate further the role of rate-limiting nutrients in the population dynamics of microorganisms and to ascertain the effects of such environmental factors as temperature and salinity on the growth response of various species to selected nutrients. If successful, these studies should not only give us further understanding of factors controlling the development of microbial populations in the sea, but they should give us increased insight into the population dynamics of other organisms as well.

Two studies in marine genetics at the Scripps Institution bear on the program of CCOFI:

In one of these studies, one of the marine bacteria is subjected to ultraviolet irradiation to produce mutants which are unable to synthesize some item from their natural diet. As must human victims of diabetes, they must obtain the substance from external sources. The organism is *Serratia marinorubrum*, a bright red pigmented bacterium which normally grows when supplied solely with inorganic salts and glycerol (a simple carbohydrate). Irradiation of this organism by ultraviolet light has produced three mutant strains thus far. These differ from the normal parent strain in that one biosynthetic process has been eliminated in each, thus leading to requirements for certain specific growth factors, to-wit, Biotin, Uracil, and a non-specific Purine requirement.

The vitamin mutant will respond to concentrations of Biotin as small as 0.002 ug/ml (two one-millionths gram per liter, supporting 10 billion cells) while both the Purine and the Pyrimidine mutants require about tenfold more of their specific supplement. The reason for emphasizing the minute amounts of these biochemical substances which are required to produce a

response in the bacterial mutants is to indicate the value of these biochemically deficient cells for a bioassay.

The utilization of biochemical mutants for the bioassay of sea water for its content of various growth factors has been prompted by the suggestion that these growth factors might be partially responsible for the discontinuous distribution and the high degree of localization of some marine flora and fauna. This theory gains support from an increasing number of reports concerning growth factor requirements in marine algae and the effect of external metabolites on feeding and on other responses.

In a preliminary test of the validity of the bioassay system, some 29 samples of sea water were taken. These were tested with the mutant organisms (ability to grow indicates presence of specific biochemical supplement; amount of growth indicates concentration). Biotin was found in 55 percent of the samples, Uracil in 21 percent, and Purine at only one location (less than 5 percent). These results emphasize the utility of the technique as well as the desirability of expanding both testing facility and the scope of the tests.

The search continues for more mutants with diverse biochemical requirements. Ultimately it is hoped that a broad spectrum of mutants will be available so that the bioassay will become even more meaningful.

The character of the non-specific Purine requirement has posed the question of the mechanism of biosynthesis of Purines—the bases of which nucleic acids are composed. This pathway is being examined by the use of enzyme chemistry, chromatography, and spectroscopic analysis. It seems likely that other biosynthetic pathways will prove amenable to test as future mutant strains are isolated.

The second project in the field of marine genetics is concerned with *Tigriopus*, a tiny tide-pool crustacean. These creatures are hardy, reproduce rapidly, and are easily handled in the laboratory. One problem studied is that of sex determination. Contrary to the common concept of numerical equality of the two sexes at the time of conception, *Tigriopus* showed a very marked deviation in favor of the males. Analysis of the situation, both cytological and experimental, suggested a relatively primitive mechanism where a number of genes are involved in determining the sex of the organism in a manner analogous to other quantitative characters, such as crop yield or weight in cattle. Apparently this mechanism is not triggered by a sex chromosome (as in human beings, for example) which would basically assure a 1:1 ratio of the two sexes. It has thus been possible to select and maintain families, at will, with as high as 80 percent or as low as 0.5 percent females.

Additional work with *Tigriopus* includes a cytogenetic study on British, Japanese, and California

species, and an intensive morphological study on samples from all over the world.

How rich in plant and animal life are the waters off southern California? The determination of this has been the aim of another project at the Scripps Institution of Oceanography.

This past spring an attempt was initiated to relate phytoplankton (plant) abundance, as reflected by chlorophyll "a" concentration, to zooplankton abundance and to the physical and chemical regime in the waters between Pt. Conception and Ensenada. The analysis of the data has not been completed as yet, but several generalizations may be made from a consideration of the data thus far analyzed.

The area encompassed by this study may be divided into two regions on the basis of the amount of chlorophyll "a" present at the surface: stations located on or inshore of the .60 stations (*e.g.* 80.60, 83.60, 87.60, etc.) exhibit relatively high but variable concentrations, while those offshore are generally lower and less variable. Within both regions there occurs a gradual decrease in chlorophyll "a" in the southerly

direction. An additional difference between the two regions is the manner in which chlorophyll "a" is distributed vertically. In the mixed layer, the offshore stations show very little in the way of gradients, being essentially homogeneous, while the inshore stations show a marked increase in chlorophyll "a" at about 20-30 meters.

The concentrations of chlorophyll "a" observed in this area compare favorably with those observed in the waters off Central America and Mexico, which are known to support a large tuna fishery.

The relationship between chlorophyll "a" and zooplankton volume is difficult to understand at present. Generally speaking the maximum zooplankton concentration is observed in the regions of low chlorophyll concentration. It has been suggested that this may result from the general southern drift of zooplankton from the rich waters north of Pt. Conception. If the zooplankton is not produced locally, then the suggestion is probably correct and accounts for the anomaly. This possibility is currently being examined.