Probably the most significant result of this research to date is the very close correspondence between the contents of the sardine stomachs and the water samples (Fig. 31). Where items appeared in a large percentage of the stomachs, they usually appeared in a large percentage of the water samples. Discrepancies easily can be explained by normal sampling errors or by the nature of the animals involved. Thus the sardine itself samples the water much better than our nets do, for it can collect the smaller animals, such as the very young stages of copepods, that pass through the nets. And soft-bodied animals that are found in abundance in the water, are often lacking or occur in small numbers in the stomachs, presumably because digestion has occurred.

The conclusion is almost inescapable that the sardine is primarily a filter feeder, gathering its food by straining quantities of water through its gills. It does not seem to be exclusively a filter feeder, however, for sardines have been caught with hooks baited with red beads and in the aquarium they can be seen to swerve from their swimming path to snap up some particular morsel.

Physically the largest items in the diet of these sardines were the salps, soft-bodied creatures that reach two inches or so in length, but in total bulk it seems likely that the microplankton (made up of animals and plants 0.002 to 0.040 inch long) constitutes the major item.

The microplankton tends to be concentrated at the shallower stations. We find the fish being caught in the areas where the microplankton is most abundant, but to what degree the distribution of microplankton influences the distribution of the sardine is not known.

THE ENVIRONMENT

Oceanographic Conditions

Along our coast flows the California Current, a slow-moving water body about 350 miles wide and generally no more than 1,000 feet deep. It moves sluggishly but steadily southward over a great thickness of almost motionless, colder and more saline water beneath it. Compared to land streams, the California Current is tremendous; the amount of water it annually carries to the south is 200 to 300 times that discharged each year at the mouth of the Mississippi, one the earth's mightiest streams. Yet the annual transport of the California Current is only about one-tenth that of the narrow, fast, and deep Gulf Stream in the Atlantic. Sweeping southeastward along the coast from the Gulf of Alaska to central Baja California, where it turns westward to lose its identity and join in the northern equatorial current, the California Current is the dominant feature in the ocean geography of the Eastern Pacific.

Between the California Current and the coast, the region in which the sardine spawns and is fished, appear complex systems of countercurrents and eddies, changing with the changing seasons. Winter ordinarily finds a strong, narrow countercurrent flowing northward along the entire coast. When the countercurrent is absent at the surface, as it usually is during the summer, oceanic eddies, great lazily revolving masses of ocean water, form in the inshore region. Such eddies usually form near Central California, near the Channel Islands of Southern California, and near Punta San Eugenio in central Baja California.

The most persistent of the eddies is located near the Channel Islands. This giant wheel of water, some 100 miles or more across, rotates slowly counterclockwise. Its center is characterized by the "enriched" water that has ascended to the surface from a depth of 700 to 800 feet ("upwelling"). To the seaward side of this eddy, it will be remembered, lies one of the known centers of sardine spawning.

The waters on the south side of this eddy are flowing eastward, that is, toward the shore. This area off northern Baja California is devoid of sardine eggs and larvae. A desert of the sea, it is marked by "downwelling," the sinking of surface waters to considerable depth.

South of the desert area, off central Baja California, where the California Current begins to turn westward to join the equatorial current system, lies the predominant center of present-day spawning.

The persistence of these general current features is strikingly shown by comparing a current chart from the period 10 May-10 July 1939, one of the very few times before the initiation of the California Cooperative Sardine Research Program from which we have ample oceanographic data, with charts from Cruises 4 and 14, made at approximately the same months in the years 1949 and 1950 (Fig. 32).

The region off central Baja California where the California Current turns westward is marked by surface waters that have the proper characteristics of freshly upwelled water (low temperature, low oxygen content, high salinity, high phosphate content).

Upwelling (see Fig. 33) brings fresh nutrients to the zone in which they can be used by the tiny rootless plants that grow in the layers of the sea reached by sunlight. These plants are eaten by the small animals in the waters. Such animals comprise the major item in the diet of most marine fishes, including, as has been shown by the food studies, the Pacific sardine.

Large-scale upwelling is closely related to the wind. Means are being studied to forecast the amount of upwelling from meteorological information. Ultimately the success of sardine spawning and recruitment, in a generalized sense, might be predicted on the basis of weather maps.

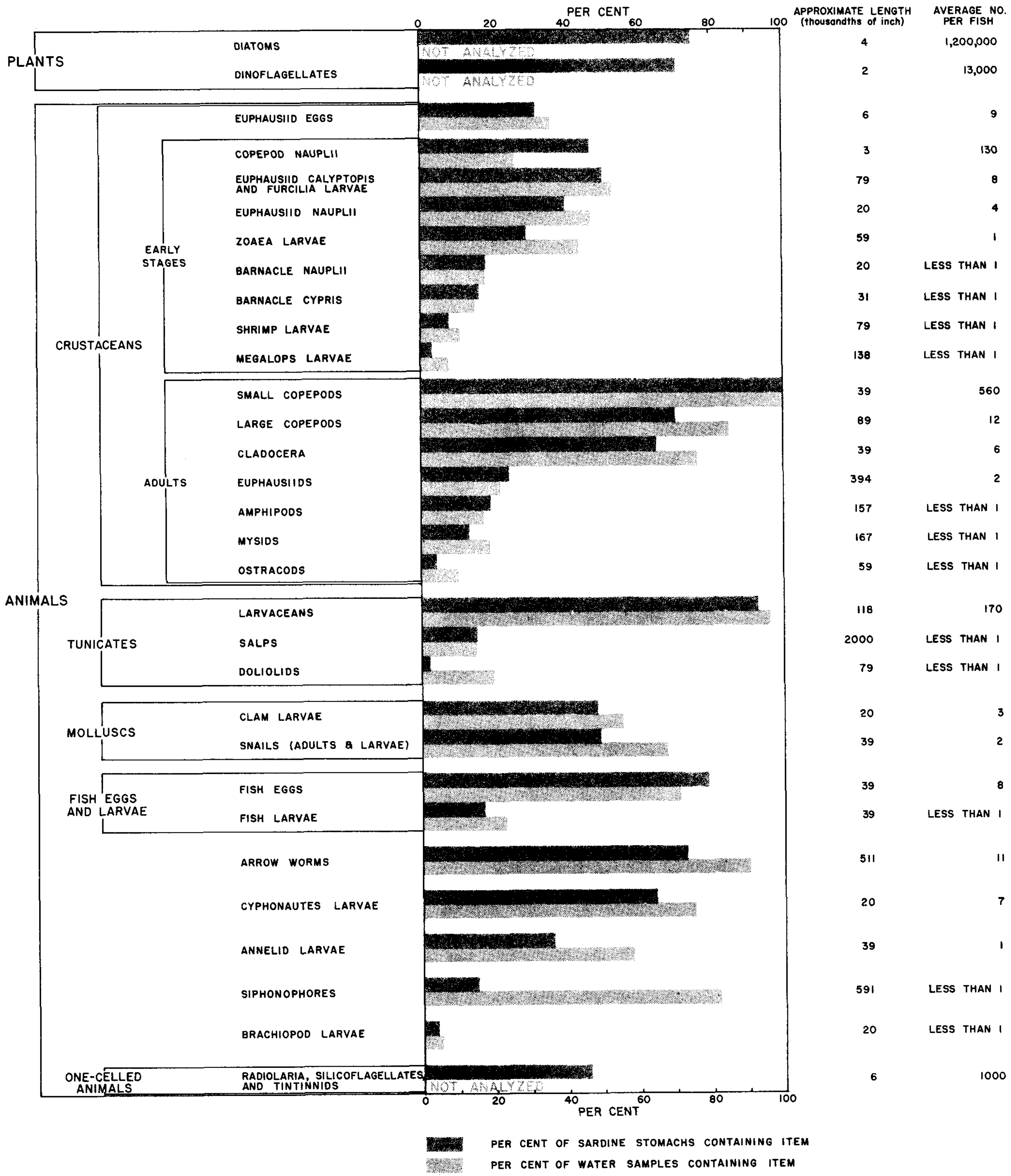
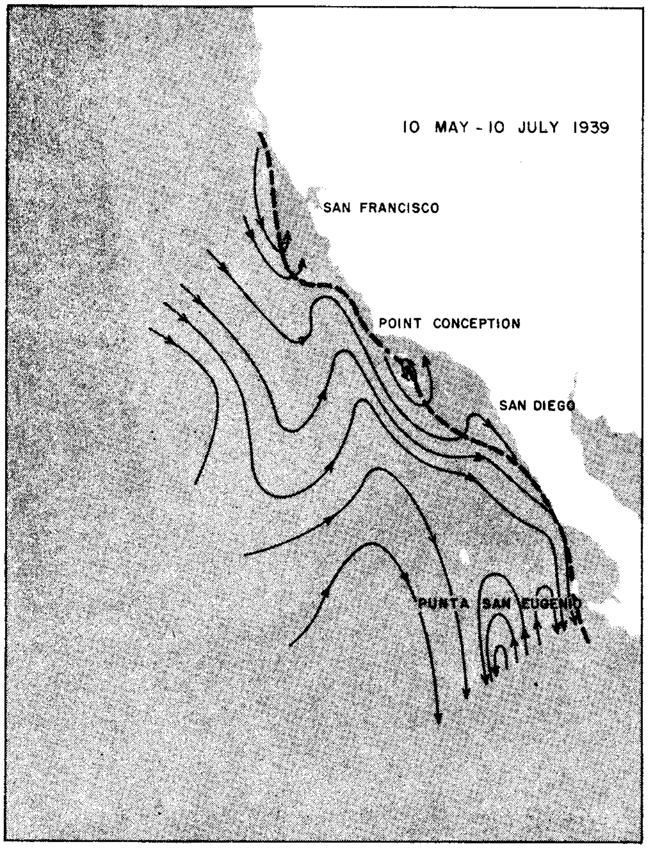
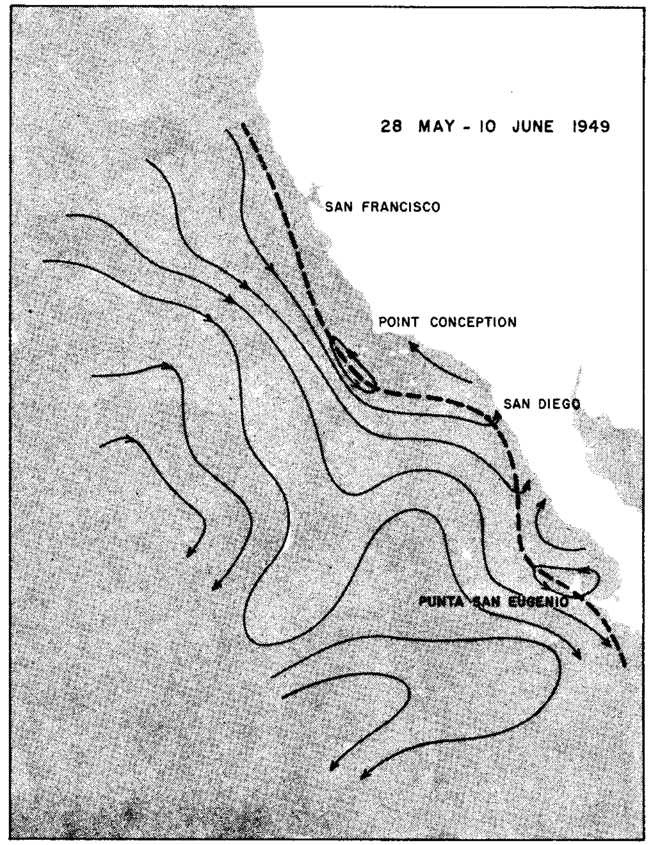


FIGURE 31. Food items in stomachs of 273 adult sardines as compared with plankton content of water samples taken along with the sardines. A variety of crustaceans—shrimps and crabs and their relatives—are found. A two-inch salp (one of the tunicates, a group of soft-bodied, watery creatures) was the largest item found. (Data, Table 9, Appendix. Average number of food items per sardine per month is given in Table 10.)





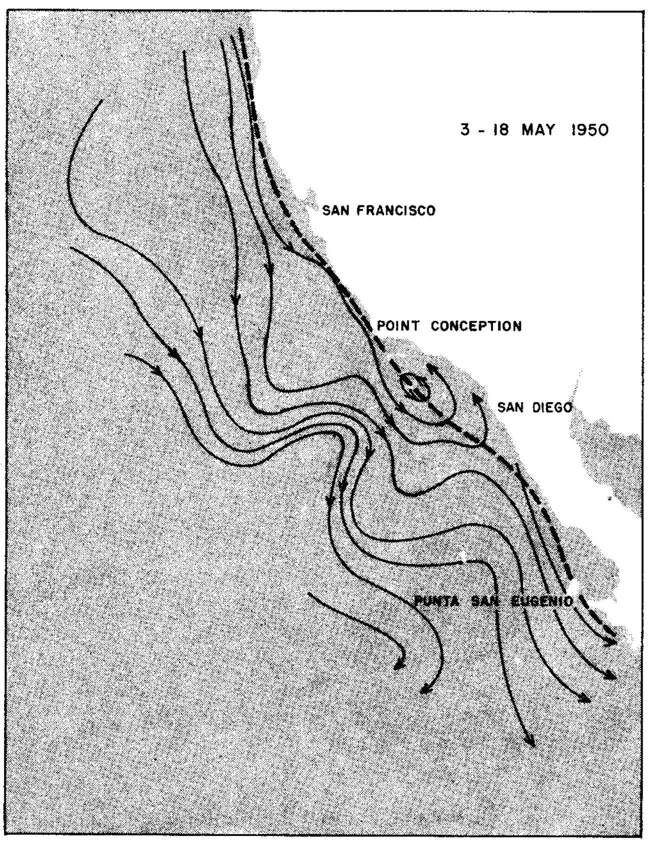


FIGURE 32. Current patterns off the California coast, 10 May-10 July 1939, 28 May-10 June 1949, 3-18 May 1950. The dashed line delineates the eastern edge of the south-flowing California current. Note the eddy off Point Conception on each chart.

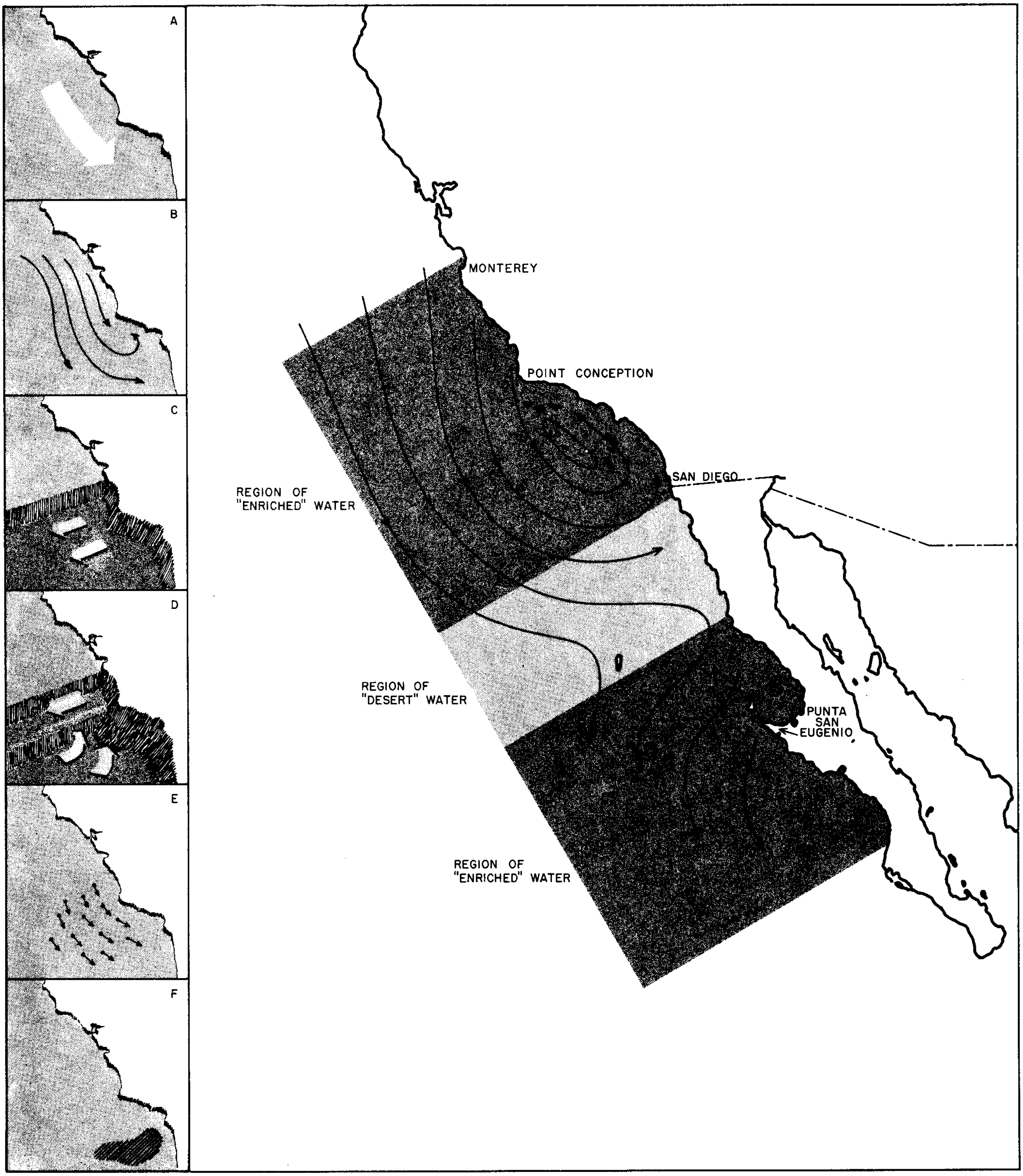


FIGURE 33. Upwelling along the California coast. A, Strong winds parallel to the coast favor upwelling. B, A counterclockwise eddy begins to form off Point Conception. C, The surface waters begin to move off shore. D, The colder, richer, and more saline waters rise from depth to replace the surface waters. E, The enriched waters of the surface are carried down the coastline as part of the California current. F, Spawning area off Southern California. The large map shows a generalized picture of the current system off the coast, with a large eddy near the Channel Islands and offshore flow off Punta San Eugenio. Between these two regions lies a "desert" region which is poor in marine life.

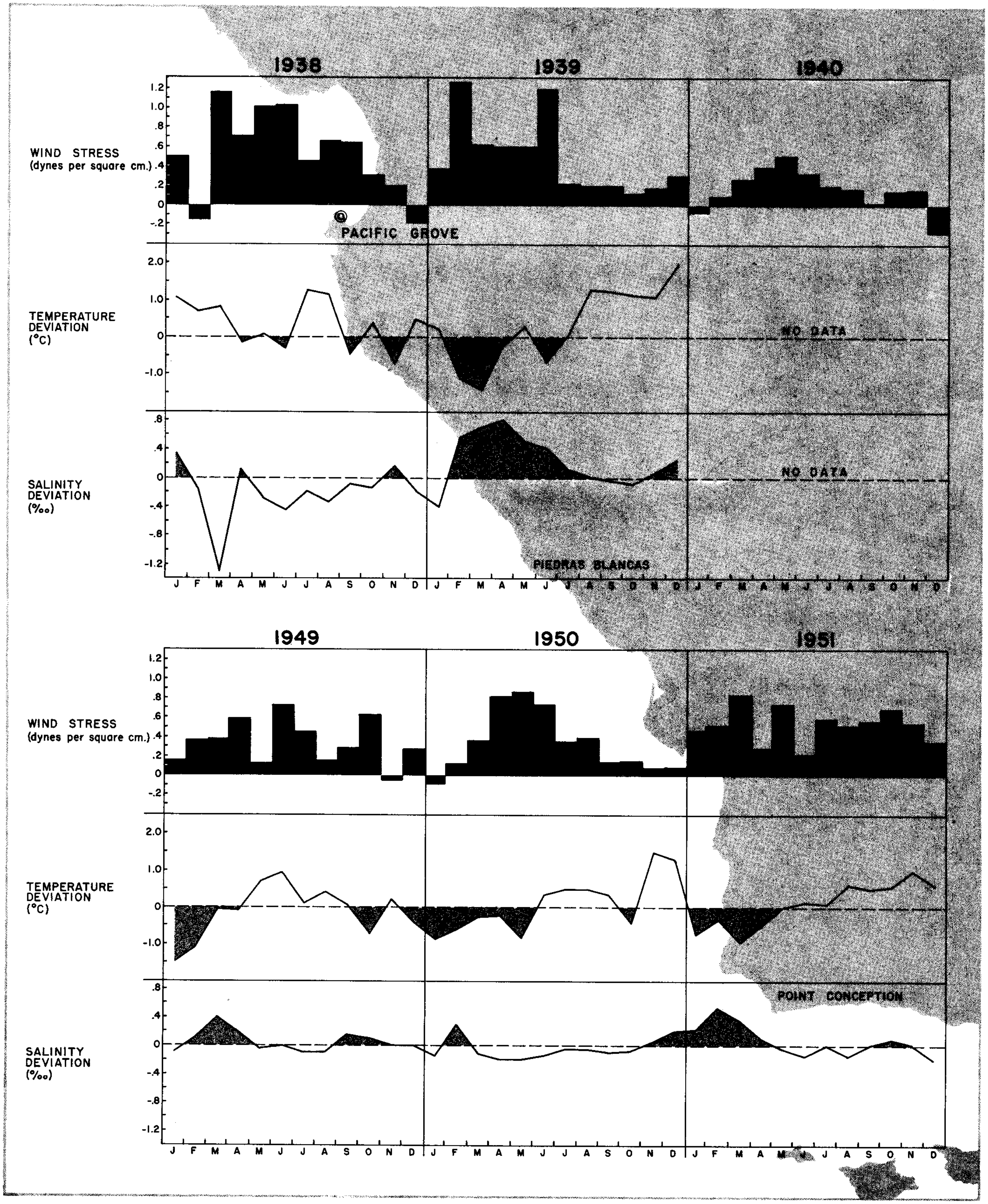


FIGURE 34. Indicators of upwelling, central California, 1938-40 and 1949-51. Wind stress has been computed for the entire area. Temperature and salinity deviations are from records collected at Pacific Grove. Only components of wind stress parallel to the coast have been measured. High wind stress parallel to coast favors upwelling. Low temperatures and high salinity values indicate upwelling. The early spring months of 1939 offer an example of a period when all of these factors are notably present.

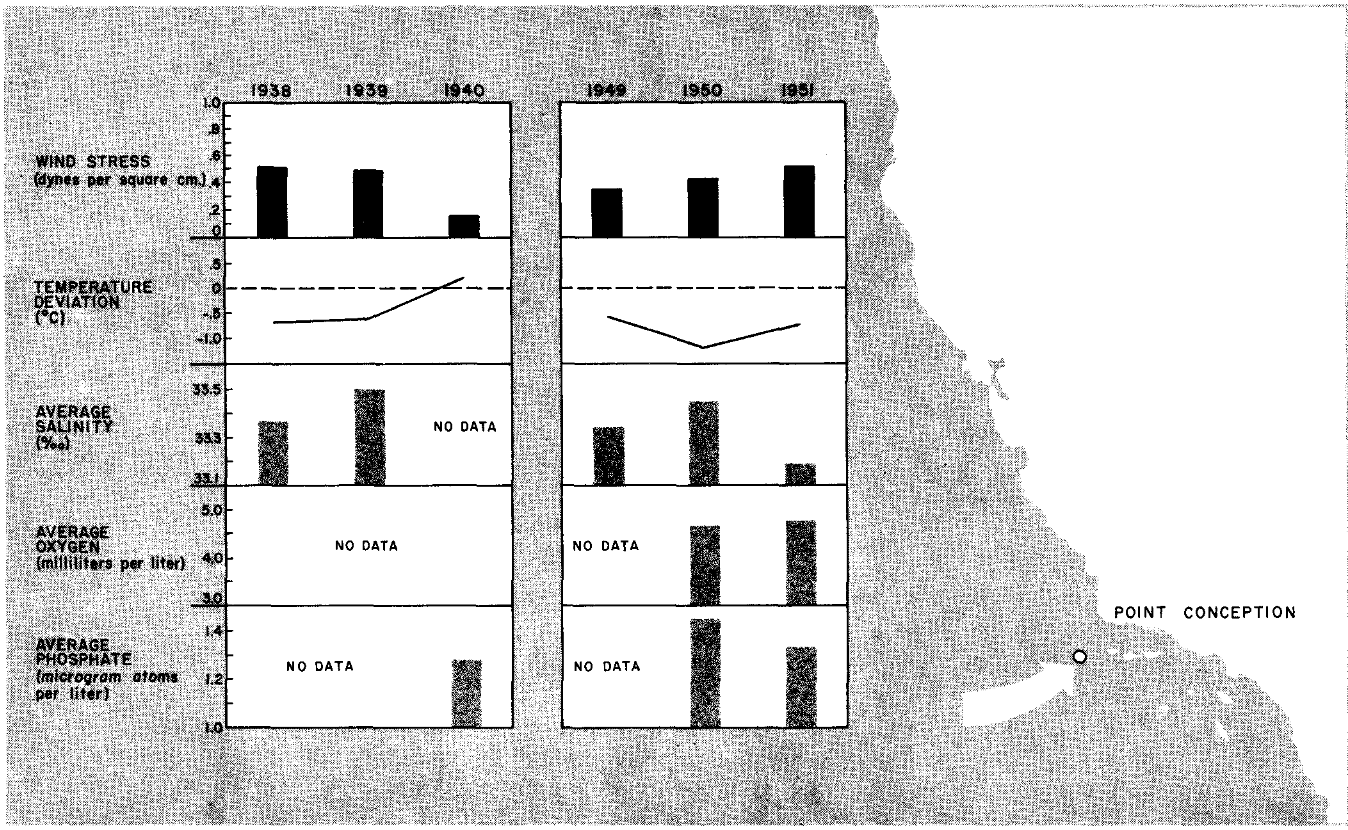


FIGURE 35. Indicators of upwelling, off Point Conception, 1938-40 and 1949-51. Wind stress was computed from weather maps. Temperature, salinity, oxygen, and phosphate data were collected at the station marked. The data indicate that 1940 was a very poor year for upwelling.

Northwest winds, which usually occur during the spring and summer, favor upwelling. It is possible to give estimates of the comparative intensity of upwelling from values of the component of wind stress (traction exerted by the wind on the sea) parallel to the coast in an upwelling region. Figure 34 shows an example. Here are given the monthly wind-stress values in a single region in two periods, 1938-40, 1949-51. The region is an important one for the sardine fishery because the rich water which upwells there is transported southward by the currents to join the eddy flow near the Channel Islands, a proven spawning area.

Looking at the charts in Figure 34, we find that winds favorable for upwelling were most intense in 1938 and the first half of 1939. Values for June through December 1939 were extremely low. Winds favorable for upwelling occurred at least a month earlier in 1939 than in any of the other years. Values for 1940 favored only a small amount of upwelling. The year 1949 seems a fairly normal year except for the occurrence of relatively light winds in May, sandwiched between favorable upwelling conditions in April and June. It would appear that in 1950, little if any upwelling occurred until in March. The graph for 1951 shows favorable winds almost throughout the year, without the very pronounced concentration of such winds in what may be the critical spring and summer months. In Figure 34 we have shown how temperatures and salinities at Pacific Grove varied from the climatological mean temperatures and salinities for this period. These deviations emphasize fluctuations that have occurred in environmental conditions.

Figure 34 shows us at once that the early spring of 1939 was marked by at least three factors indicative of upwelling: strong winds parallel to the shore, low temperatures, high salinity. (The year 1939, it will be remembered, produced a phenomenally successful year class of sardines.) The combination of factors shown for that period has not been repeated so markedly since then.

Upwelling is also characterized by pronounced changes in the chemical constituents of the water. Since this water comes from the depths and so has not been in contact with the air for some time, the oxygen content is low. Phosphate content, which is a rough measure of the richness of the water, is high. In Figure 35 are combined several forms of data: wind stress favorable for upwelling, deviation of offshore temperatures from climatological means, and absolute measures of salinity, oxygen, and phosphate. Some of these data are for but a short period of months within the year; consequently they give only an approximation of ac-

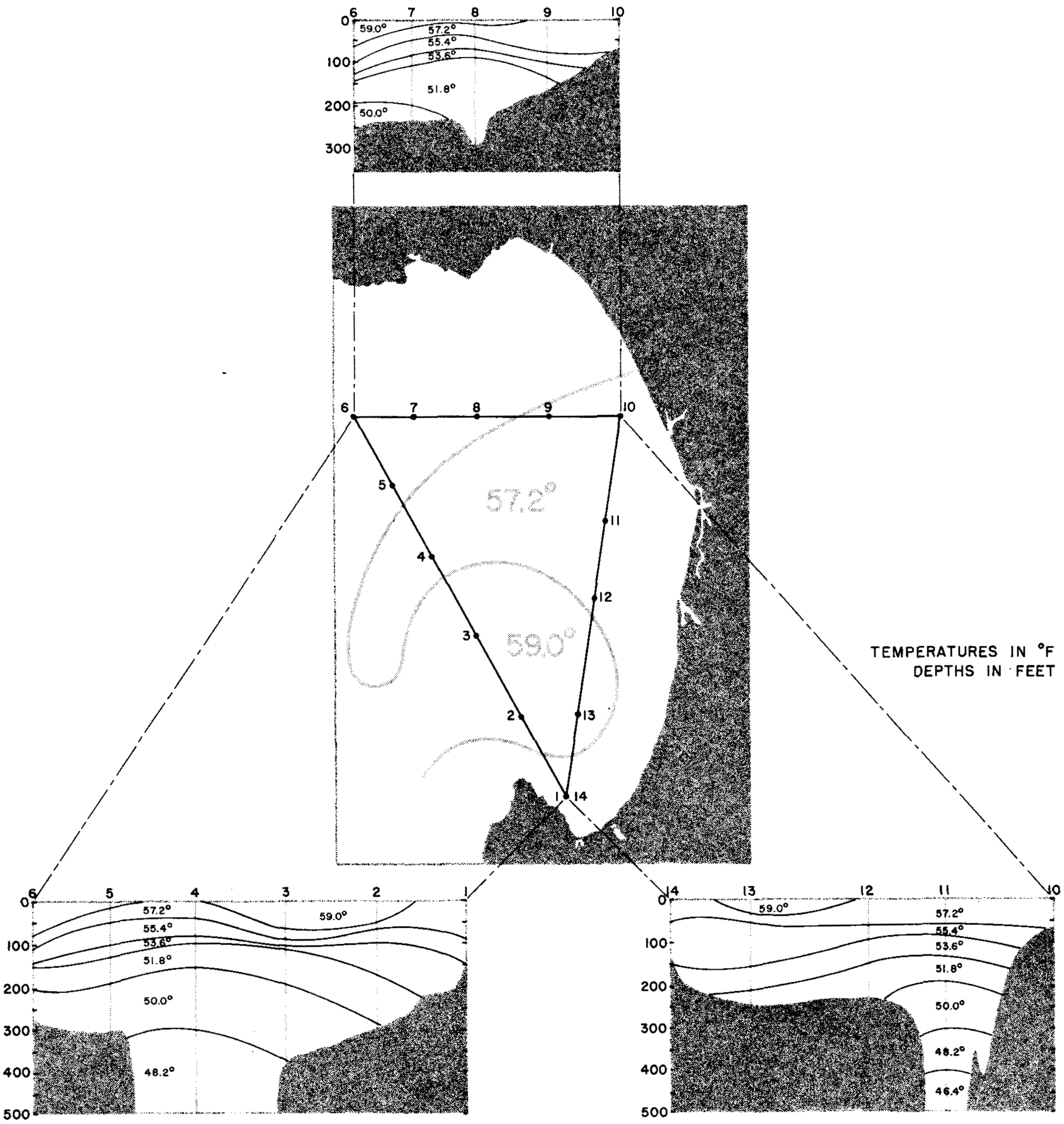


FIGURE 36. Temperature survey, Monterey Bay, 2 October 1951. The center chart gives course followed and the distribution of surface temperature. Stations 4 and 11 lie over Monterey Submarine Canyon. The smaller charts give cross-sections of temperature along each leg of course.

tual conditions. Yet they show several interesting things:

Wind Stress. The winds, it will be seen, favored the most intense upwelling during 1938, 1939, and 1951. The year 1940 was the poorest. However, from these annual averages we cannot determine if the winds were most favorable during the important spring and early summer months.

Temperature Deviations. The section studied lies at approximately the outer edge of the continental shelf and approximately coincides with the outer limits of the fishing region. In general, temperatures were higher off Central and Northern California in the early years of good year classes and prosperous catches than they have been during the past few years.

Salinities. Salinities varied more in the early period than in the later. In general, 1939 stands out as having high salinity values at the surface, which is in accordance with the supposition of strong upwelling that year. It is not possible to explain the abnormally low values of 1951 by the absence of upwelling; some other factor must have been at work.

Oxygen. Oxygen values for the early years are lacking. They were slightly higher in 1951 than in 1950.

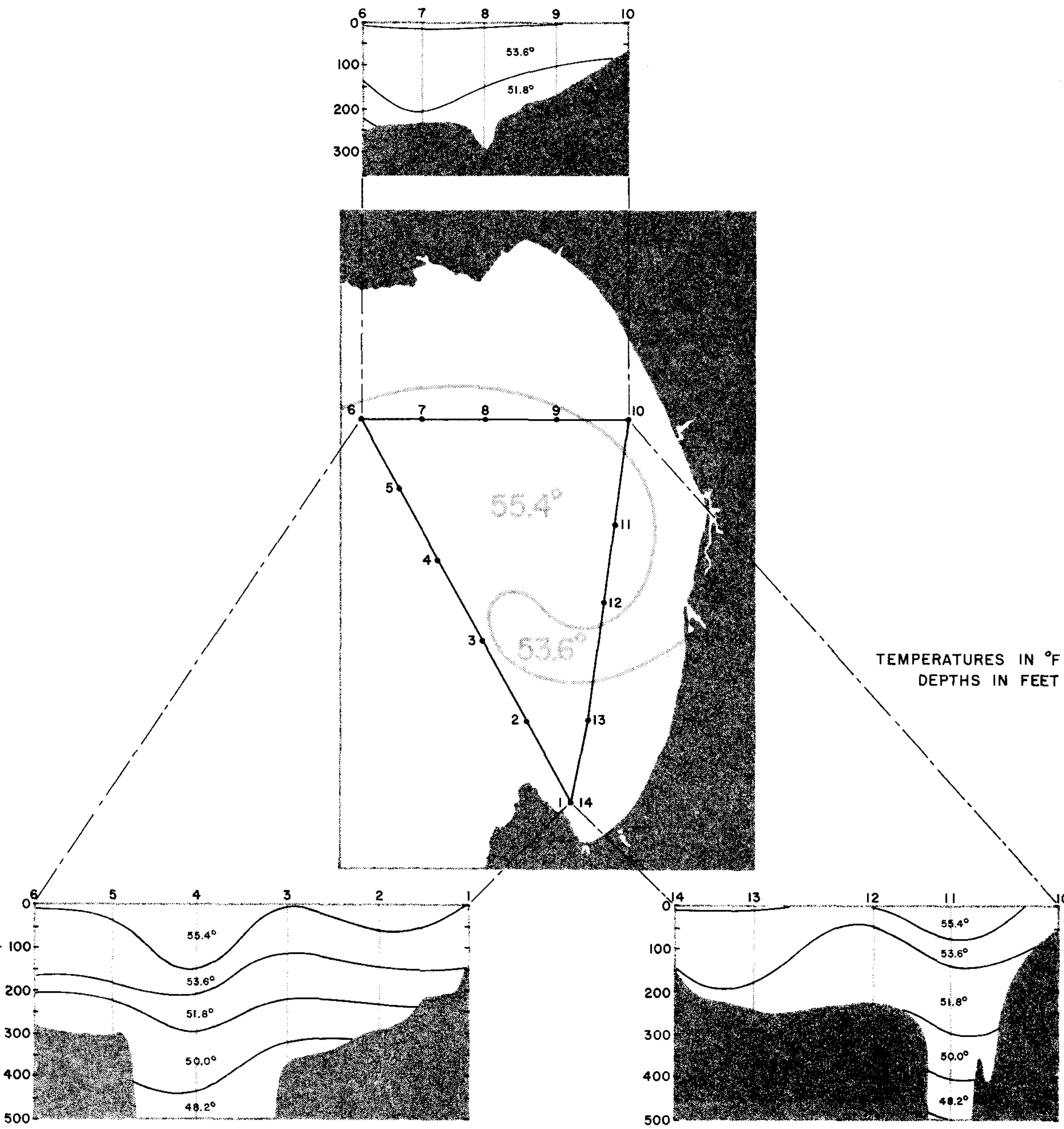


FIGURE 37. Temperature survey, Monterey Bay, 13 December 1951. The center chart gives the course followed and the distribution of surface temperature. Stations 4 and 11 lie over Monterey Submarine Canyon. The smaller charts give cross-sections of temperatures along each leg of course.

Phosphate. Phosphate values indicate that 1950 and 1951 were better years for upwelling than 1940, the only year of the period for which data are available.

The evidence shows that on the whole 1940 was a very poor year for upwelling. Estimates of year-class strength based on the catch of three-year-old fish indicate that the 1940 year class was only 54 percent as large as the 1939 year class, although still above average in abundance. This decline in year-class strength coincided with a change toward a physical environment less favorable for replenishment of nutrients in the surface layers of the sea.

It has been known for some time that when north winds are blowing, the water on the south sides of points in Baja California becomes much colder than that on the north sides. The reason is that the warmed surface water, pushed by the winds, piles up on the north sides of points and colder water rises to replace it on the south sides.

During each month of the past year, shore temperatures have been taken along the coast from central Baja California to San Francisco, a straightline distance of more than 700 miles. Particular emphasis has been placed on getting temperatures from both the north and south sides of points.

Another study in progress is that of oceanographic conditions in Monterey Bay. Surface isotherms, plotted on the basis of data collected on weekly cruises over a triangular course, frequently show rather complex swirl patterns (see Figs. 36 and 37).

Upwelling is suggested by the fact that these swirls of cooler water apparently originate over the head of Monterey submarine canyon. Further evidence of this origin is shown by plotting subsurface temperatures on profiles along the legs of the cruise course. This is particularly noticeable during periods of northerly and westerly winds at Stations 4 and 11, which lie over the main canyon itself, but it is also frequently detectable at Station 8, at the head of Soquel Canyon. At other times, warm water centered in the bay seems to be sinking and the isotherms over the canyon are depressed (see chart for 13 December 1951, Fig. 37).

South of the Monterey Peninsula the coastal temperatures increase some 3.6° F. in a distance of about 100 miles, the differential being somewhat greater during the summer than during the winter. However, the relationship between temperature and latitude does not usually approximate a straight line. A massive cold-water patch, centering in the area of Soberanes Point, is very characteristic of the summer and early fall (see curve for 8 September 1951, Fig. 38). This water mass has repeatedly yielded specimens of fishes characteristic of areas far to the north and entirely unknown from the adjacent coast line. That the water is derived from upwelling is clear. The abrupt change in temperature at the northern border of the area, and the much more gradual change toward the south, suggest that the origin of this cold, upwelled water lies to the north, probably in Monterey Canyon and particularly in its side branch, Carmel Canyon. The effects of this upwelled mass of water, so striking along shore, must influence thousands of square miles of offshore waters. Another area of cold water, smaller, less sharply defined, and much less stable, washes the coast south of Point Piedras Blancas. This probably stems from Lucia Canyon which, since its head is well out from the coast, does not make its influence felt along shore until the water has drifted far southward.

In late October the coastal temperature gradient flattens rapidly and upwelling remains at a minimum

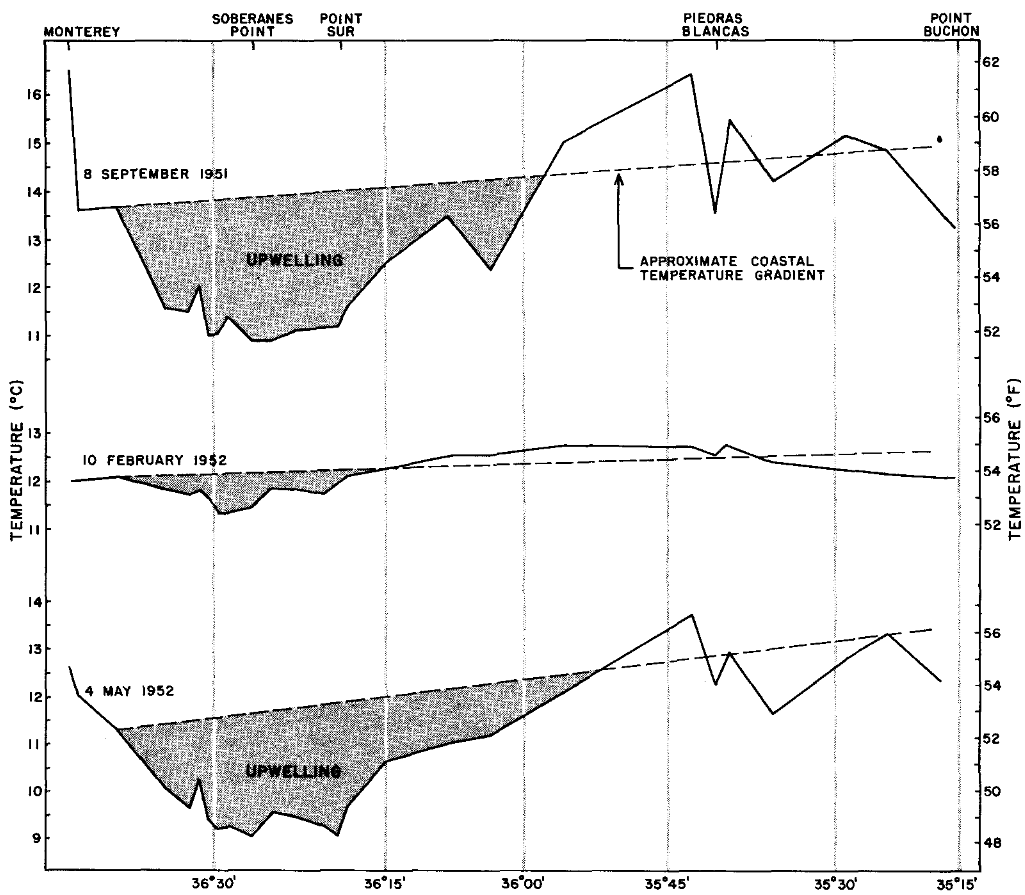


FIGURE 38. Upwelling along the coast south of Monterey, late 1951 and early 1952. The shaded areas indicate marked departures of temperature from approximate coastal temperature gradient.

until early March (see curve of 10 February 1952, Fig. 38). During those months the average temperature decreases about 3.6° F.

After an unstable transition period of almost two months, the upwelling mass of water again becomes firmly established (see curve of 4 May 1952), and the enrichment of the surface waters is once more in full swing.

Relation of Oceanographic Conditions to Other Factors

In seeking to isolate the oceanographic conditions that directly influence spawning, survival, and the catch, or to identify the particular combinations of those conditions that favor or harm the fishery, we are embarking on a relatively new line of research. The scope and complexity of the subject have made progress necessarily slow. Below is given a brief résumé of what has been learned to date on the relation of oceanographic conditions to other factors, with full knowledge that some of it is fragmentary or of only a negative value.

POPULATION SIZE

Population size is of course a function of the number of births and the number of deaths. These are discussed under Year-Class Size and Mortality Rates, respectively.

YEAR-CLASS SIZE

We know that sardines usually spawn in waters between 55.4° F. and 61.7° F. Evidence suggests that the best year classes have resulted when spawning has extended far north along the California coast and when weather and oceanographic conditions have been favorable for upwelling. As yet we cannot directly correlate any of these conditions with the success of spawning in such a way that a reliable numerical estimate of year-class strength can be made from oceanographic data alone, and possibly we shall never be able to do so. The information being gained on the program, however, is telling us more than we have ever known before about general conditions that are favorable for spawning, so that it may be possible to issue a qualitative if not a quantitative estimate.

MORTALITY RATES

At present the only connections between mortality rates and oceanographic conditions must be considered as speculation. It is easy to list the various causes of mortality (starvation, predation, disease, etc.), but the relation of oceanographic conditions to variations in these rates is at present unknown.

These causes of mortality are what determine the year-class size (in numbers) at early ages and may seriously alter the adult population (as by an epidemic). Possibly because of difficulties inherent in such a study, this field has been relatively neglected in all fishery work. A profitable beginning could be made by experiments to determine the range of variation in environmental conditions that can be tolerated by sardines. Studies of this nature will be possible (for the early stages) when methods of raising marine fishes in aquaria are perfected. Work on this is in progress.

FISHING SUCCESS

Previously it has been shown that the catch per boat week in the Oregon-Washington sardine fishery was higher when temperatures were low (say, 56° F.) and lower when temperatures were high (say, 62° F.). More recent experiments have shown that sardines tend to school more closely from temperatures of about 54° F. down to 43° F. and, conversely, this tendency was reduced at temperatures from 54° F. up to 77° F.

A study now nearing completion investigates the relationship between the sardine catch and seasonal variations in average sea-surface temperature in the area between 35° N. (just north of Point Conception) and 40° N. (just south of Cape Mendocino) and between the coast and 125° W. The temperature averages were for the months August through February. These data extended over a nine-season period, 1935-36 through 1943-44. A relationship similar to those described above was observed. The best catches tended to be made at lower temperatures (about 55.5° F.) and the smaller catches at higher temperatures (about 58.0° F.).

The temperatures used in this study were obtained from U. S. Navy Hydrographic Office punch card data. They include observations from merchant ships and navy ships, observations which as a rule are less reliable than those taken on the sardine research program. Also, most of the data are scarce outside of the relatively narrow shipping lanes. It is possible that the temperatures here given may not be entirely accurate but the trend toward better catches at lower temperatures seems unmistakable.

A second study investigates the distribution of sardine catches in relation to the sea-surface temperature distribution in the 1949-50 and 1950-51 seasons. Comparisons are shown in Figures 39 through 44.

No clearcut relationship between the catch and the surface temperatures is evident. The maps do suggest that more fish may be taken at temperatures between 57.5° F. and 62.6° F., but fishing can be and was carried on at temperatures as low as 51.8° F. This relationship is somewhat further clarified in Figure 45, which gives the average number of tons per 10-mile-square at each degree Centigrade for the seasons 1949-50 and 1950-51. Also shown are the numbers of sardine schools located during the 1949, 1950, and 1951 young-fish surveys.

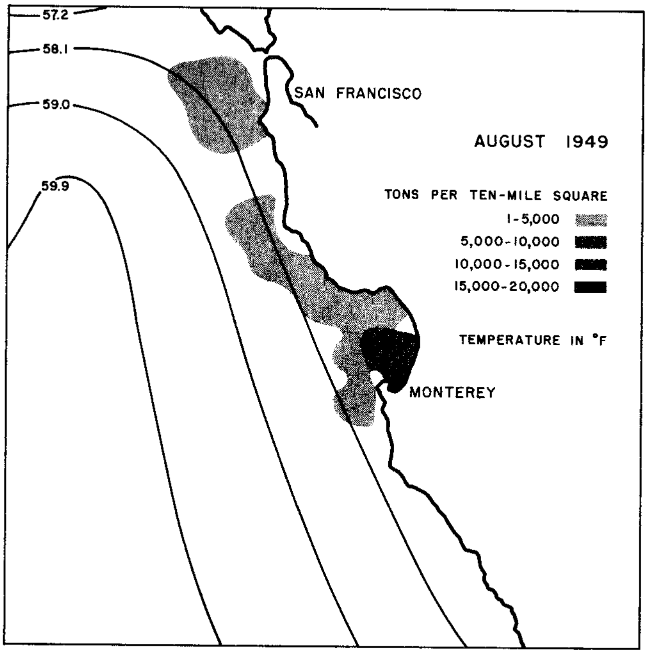


FIGURE 39. Sardine catch and surface temperatures, August, 1949.

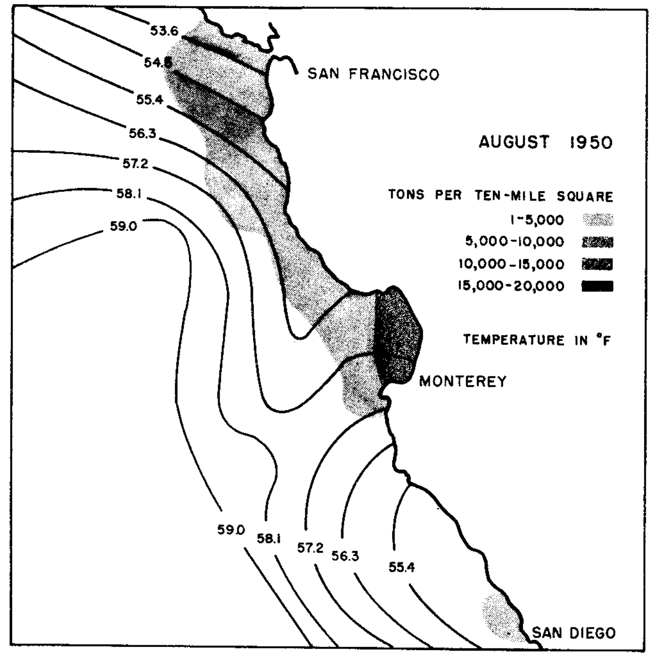


FIGURE 40. Sardine catch and surface temperatures, August, 1950.

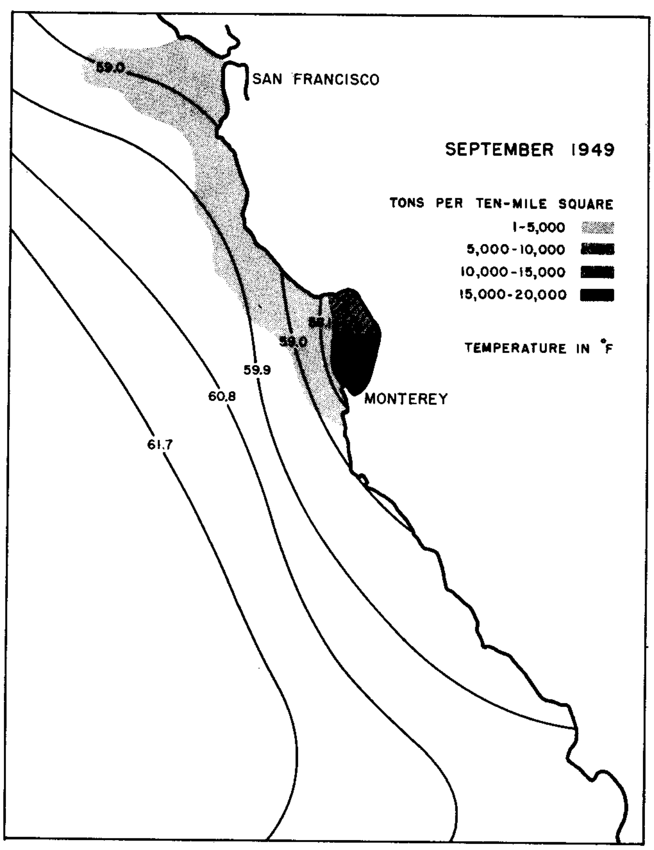


FIGURE 41. Sardine catch and surface temperatures, September, 1949.

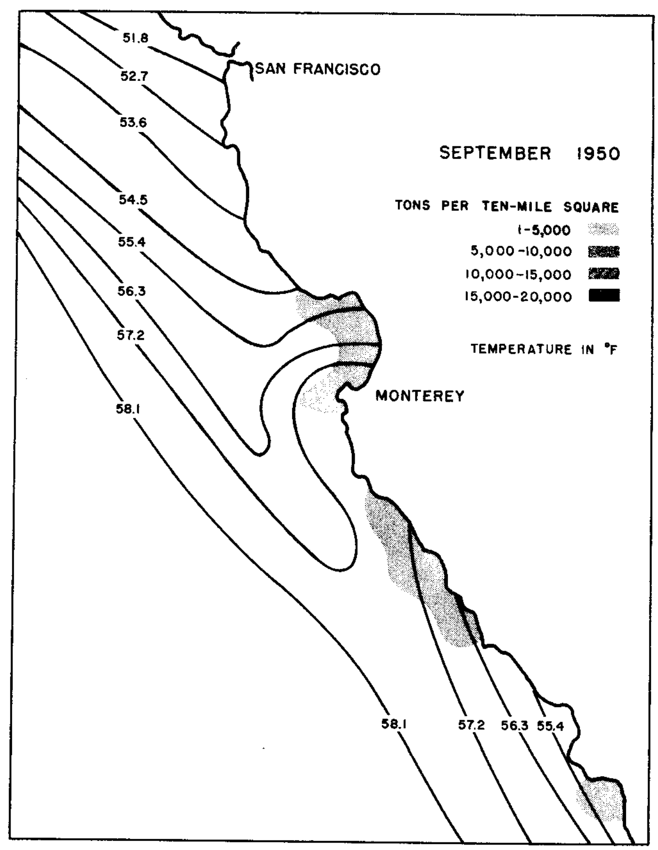


FIGURE 42. Sardine catch and surface temperatures, September, 1950.

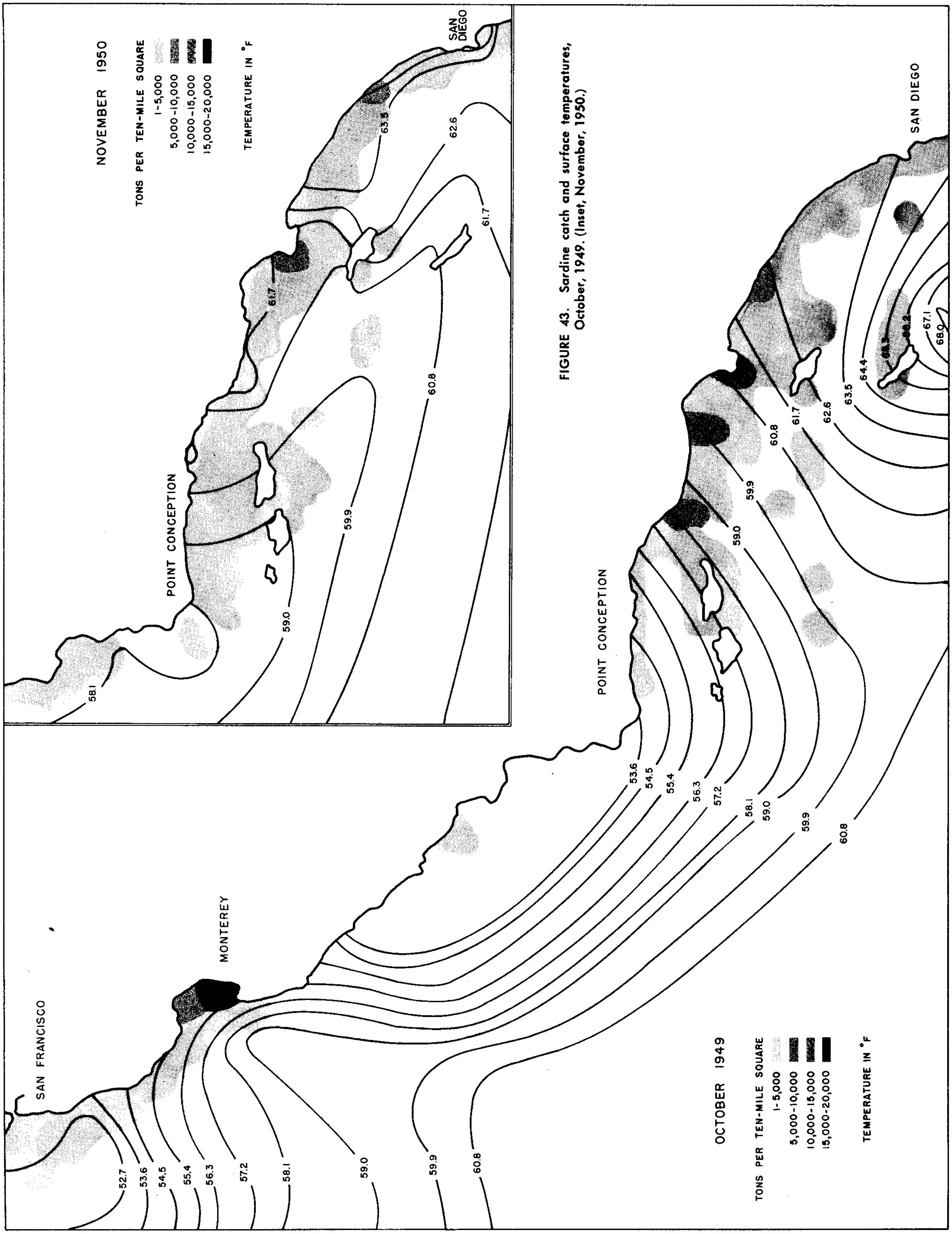


FIGURE 43. Sardine catch and surface temperatures, October, 1949. (Inset, November, 1950.)

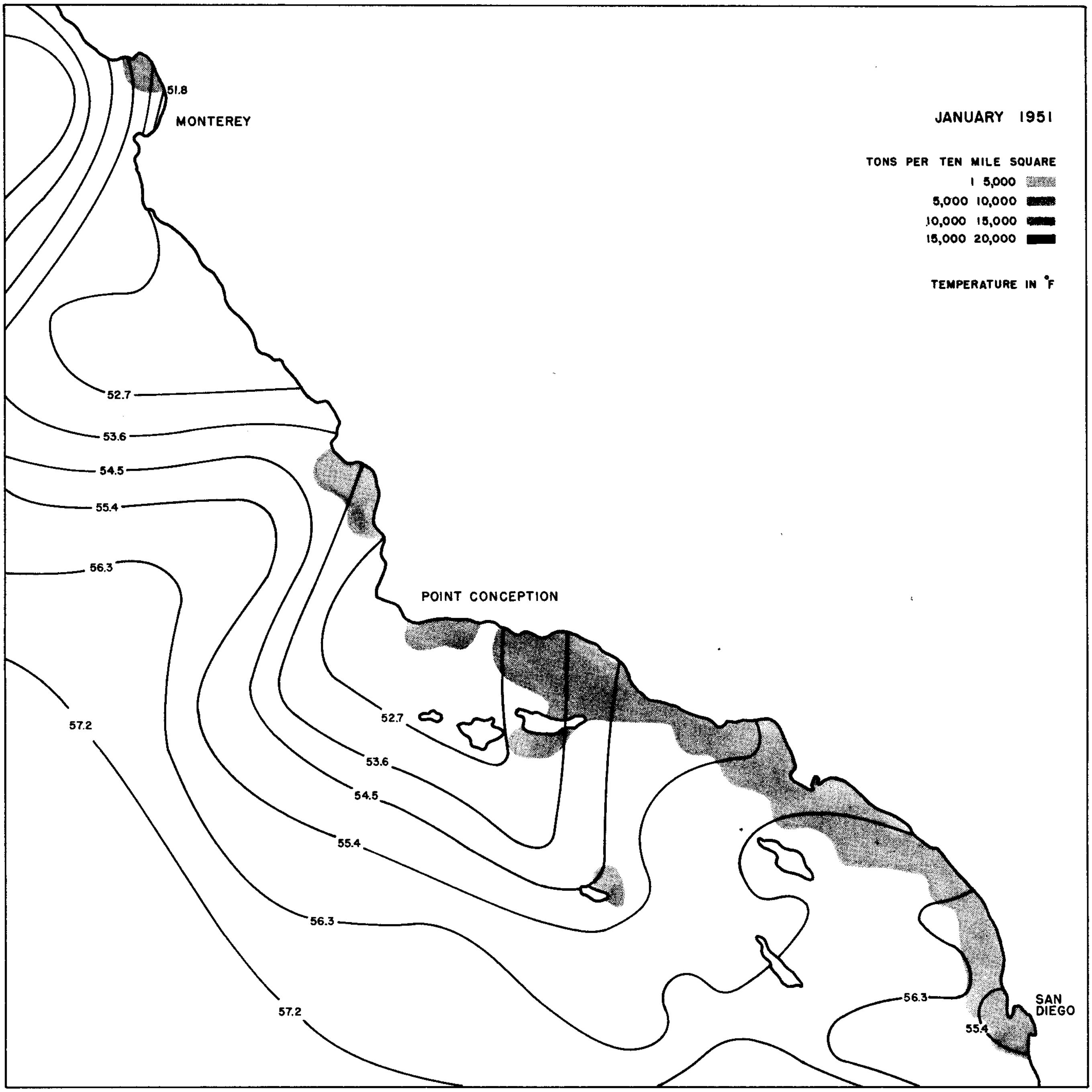


FIGURE 44. Sardine catch and surface temperatures, January, 1951.

The greatest tonnages of sardines in central California (Point Reyes to Point Conception) were taken in areas where the surface temperature ranged from 55.4° F. to 59.0° F. In southern California (Point Conception to the U. S.-Mexican Boundary) catches between 60.8° F. and 66.2° F. exceeded the tonnages in colder temperatures. The number of sardine schools located in the surveys indicate a greater abundance from 60.8° F. to 66.2° F. There is, therefore, a suggestion that the most favorable surface temperature for sardines falls between 57.2° F. and 66.2° F., but sardines can and do occur at temperatures as low as 51.8° F. and as high as 77.0° F., and these do not necessarily mark the maximum and minimum ranges.

The temperatures used in this study, again, cannot be accepted as completely applicable. The sardine research program temperatures are taken in the course of the routine cruises, which may not always correspond with the time of the fishing darks. And the region fished is a small one when compared with the extent of the area surveyed. More detailed studies, similar to that mentioned earlier of Monterey Bay, are needed.

The Food Supply

There are hundreds of species of plankton, plant and animal, in the waters off the coast. Found in concentrations that vary seasonally and annually, some of these have been studied for years. The amount of data accumulated on the sardine cruises, though, has been almost overwhelming; the collections so made have revealed many new species and told much that is absolutely new about the distribution of the plants and animals that are available for the sardine to eat. Since the publication of the first sardine progress report in 1950, there have been discovered no less than 19 additional species, hitherto unreported for the area, of one type of animal plankton, the euphausiids, tiny shrimp-like creatures on which many fishes, including sardines, are known to feed.

Two types of plankton data are sought. One is the total volume of plankton per unit volume of water ("wet plankton"), the other the precise knowledge of the species involved. The first is the undifferentiated food material. Figure 46 shows the average wet plankton volume per station per cruise from March 1949 through December 1951. Perhaps the most striking feature is the tremendous increase in volume in February through May of 1950. In view of these great and abrupt differences, it appears that we cannot do much more than present the data; in order to make a realistic analysis, we shall need to investigate further the organic composition of the volumes and factors such as diurnal vertical migrations and regional differences that are smoothed out in the averages. The one generalization we can make is that on the whole there seems to be more plankton found at the inshore stations and in the northern part of the survey area.

The other type of plankton data recorded is the careful listing of relative amounts of all species in each sample. The sorting of the plankton is an exacting task. Each animal in the sample must be identified and counted. And though the samples are small ones, there are literally thousands of them. Consequently, the detailed plankton studies are progressing rather more slowly than some other investigations in the program, and we have not reached a stage when we can say with some confidence that any one year was better or worse than another.

Predators and Competitors

BACTERIA

Bacteria have been found in the highest reaches of the atmosphere and (very recently) in the deepest parts of the ocean. They attach themselves to every living organism. Some are beneficial to the organism and some actively attack it.

How bacteria affect sardines has never been extensively studied. Recently investigations of sardine eggs have shown that bacteria are present in large numbers, occasionally in such strength that the egg cell wall is almost invisible. These observations suggest that bacteria may be partly responsible for the high rate of abnormal and dead eggs in the routine egg collections. Laboratory experiments were attempted by which the presence of bacteria during the maturation of sardine eggs could be controlled. For these experiments, early-stage eggs were collected and returned to the laboratory as soon as possible. Using antibiotics, bacteria were eliminated from half the eggs. Results showed that 95 percent of the eggs free from bacteria hatched. Only 50 percent of the untreated eggs hatched.

Adult fish were also observed for evidence of bacterial attack. This study was performed on a group of

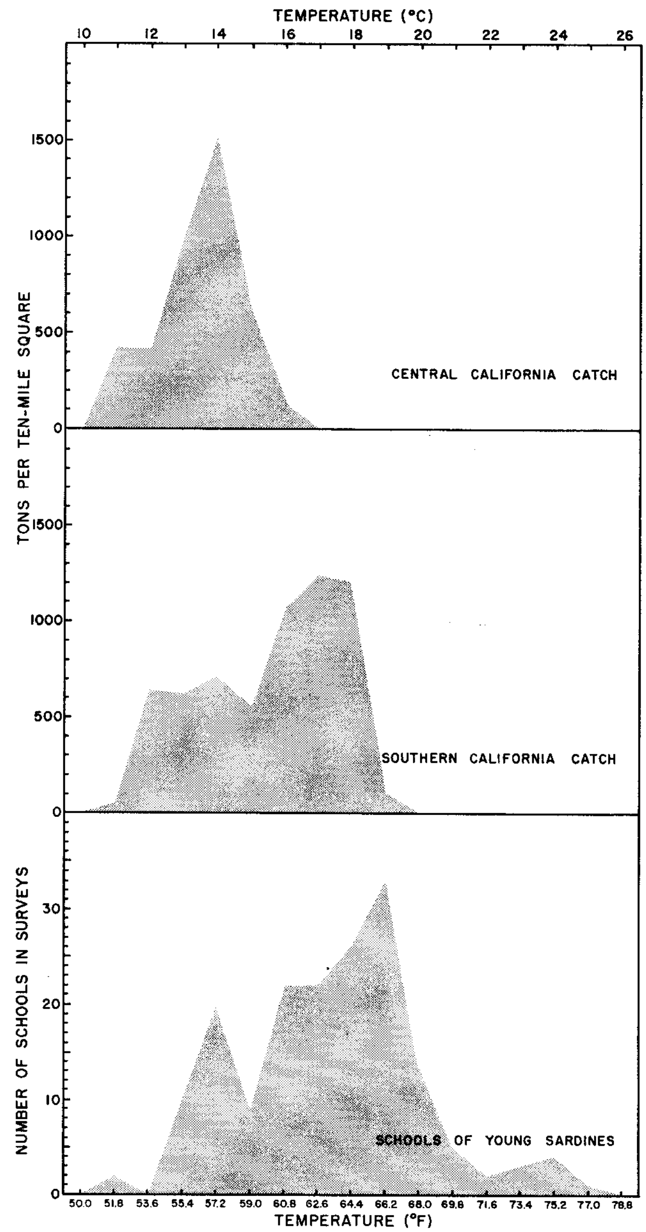


FIGURE 45. Sardine catch (1949-50 and 1950-51) and schools of sardines located during the surveys (1949, 1950, and 1951) as related to surface temperature.

adult fish which were maintained in an aquarium for five months. It was noted that death often occurred following a characteristic bleeding at the base of the scales, fins, and tail. The bleeding began about two to three days before death occurred and suggested that small blood capillaries had ruptured. Presumably death was the result of bleeding or some toxic product of a disease agent.

These observations and experiments emphasize that further investigation of the relation of bacteria to the sardine would probably be profitable both from a scientific standpoint and to the industry. Methods for making field investigations are being improved and new apparatus that would expedite the study is being designed.

OTHER FISHES

Since the sardine lives in an ocean crowded with other fishes with which it must compete for food, when we study the sardine and its environment, we inevitably study a number of other fishes. Plankton hauls taken for sardine eggs and larvae contain eggs and larvae of other fishes spawning in the same area at the same time. Observations on the kinds of fish that gather under the work lights while hydrographic stations are being occupied at night have yielded information on many fishes in addition to the sardine. Trolling lines are kept out while traveling between stations; in this way a considerable amount of data has been accumulated on the distribution and abundance of albacore, yellowtail, and other species. On the young-fish surveys, records are kept of other kinds of fishes that are observed and collected.

The Young of Other Fishes. Information on the eggs and larvae of other species is important because many of these compete with the sardine larvae for available food or actually prey upon the eggs and young of the sardine, and because some of these fishes are being exploited commercially, while others constitute fishery resources of considerable potential value.

The larvae of several fishes, including the northern anchovy, hake, jack mackerel, and rockfish, were collected in greater abundance than the larvae of the sardine during 1951. (Figs. 47 through 51. The chart of the sardine larvae is included for reference.)

The role these species could play either as competitors or as food for the sardine may be shown by the frequency of their occurrence in hauls containing sardine eggs or larvae. Rockfish appeared in 75 percent of the hauls containing sardine eggs or larvae during the period of widespread sardine spawning (January through July, 1951), hake larvae in 67.5 percent, northern anchovy in 65.0 percent, and jack mackerel in 50.0 percent of the hauls (see Table 12, Appendix).

Saury eggs were taken in nearly twice as many plankton hauls as were sardine eggs during 1951. The spawning season is a fairly extended one, for saury eggs were commonly taken during the six-month period February through July and a few eggs were taken even during the off-season.

The newly hatched saury larva is much larger than individuals of this stage in the sardine and anchovy and is much better able to fend for itself. Even the smallest of the saury larvae is an active swimmer. This is probably the reason why saury larvae are seldom taken in plankton hauls, a fact which puzzled us for some time.

Other Food Fishes. The young of many other food fishes (in addition to the anchovy, jack mackerel, hake, and rockfish) of present or potential importance to the commercial fishery, occur in the collections being made for the study of the sardine. Pacific mackerel larvae have been taken in moderate abundance, particularly in inshore hauls off central Baja California.

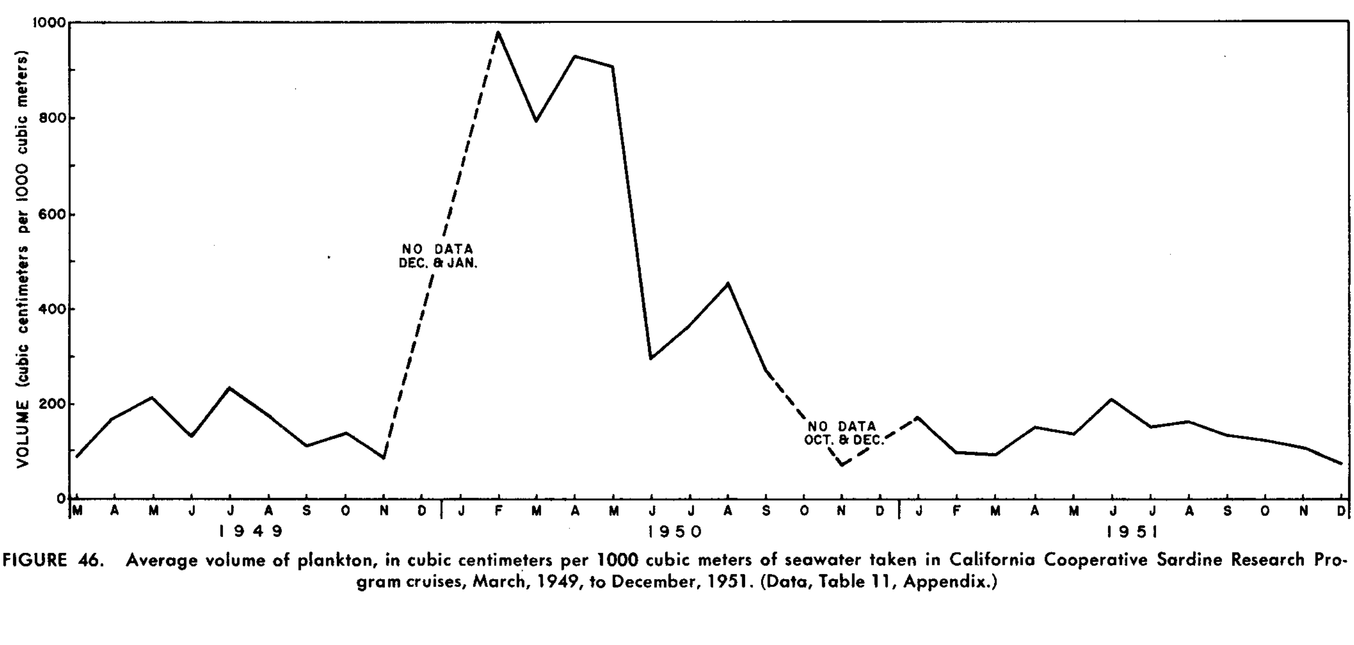


FIGURE 46. Average volume of plankton, in cubic centimeters per 1000 cubic meters of seawater taken in California Cooperative Sardine Research Program cruises, March, 1949, to December, 1951. (Data, Table 11, Appendix.)

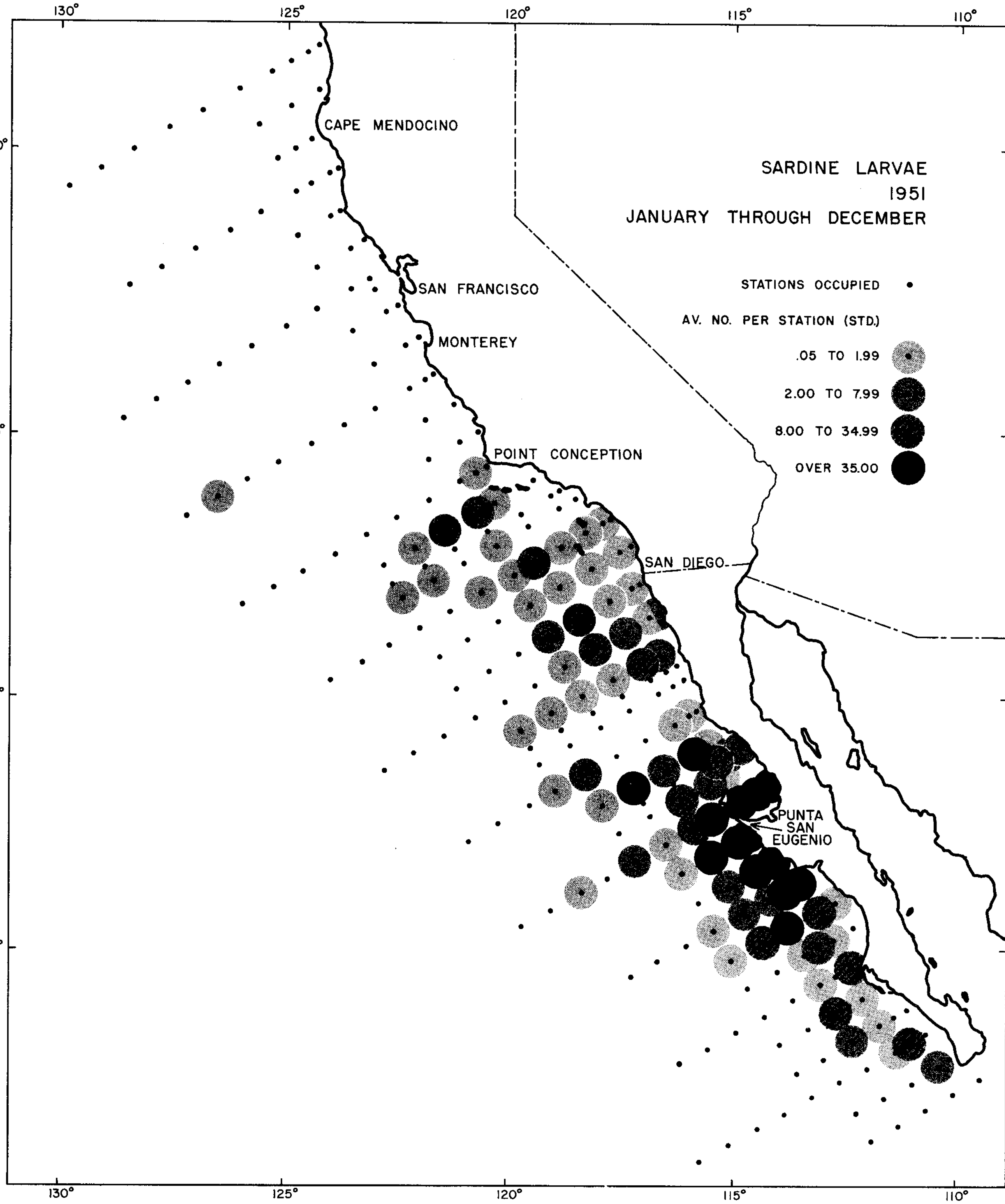


FIGURE 47. Sardine larvae, January through December, 1951.

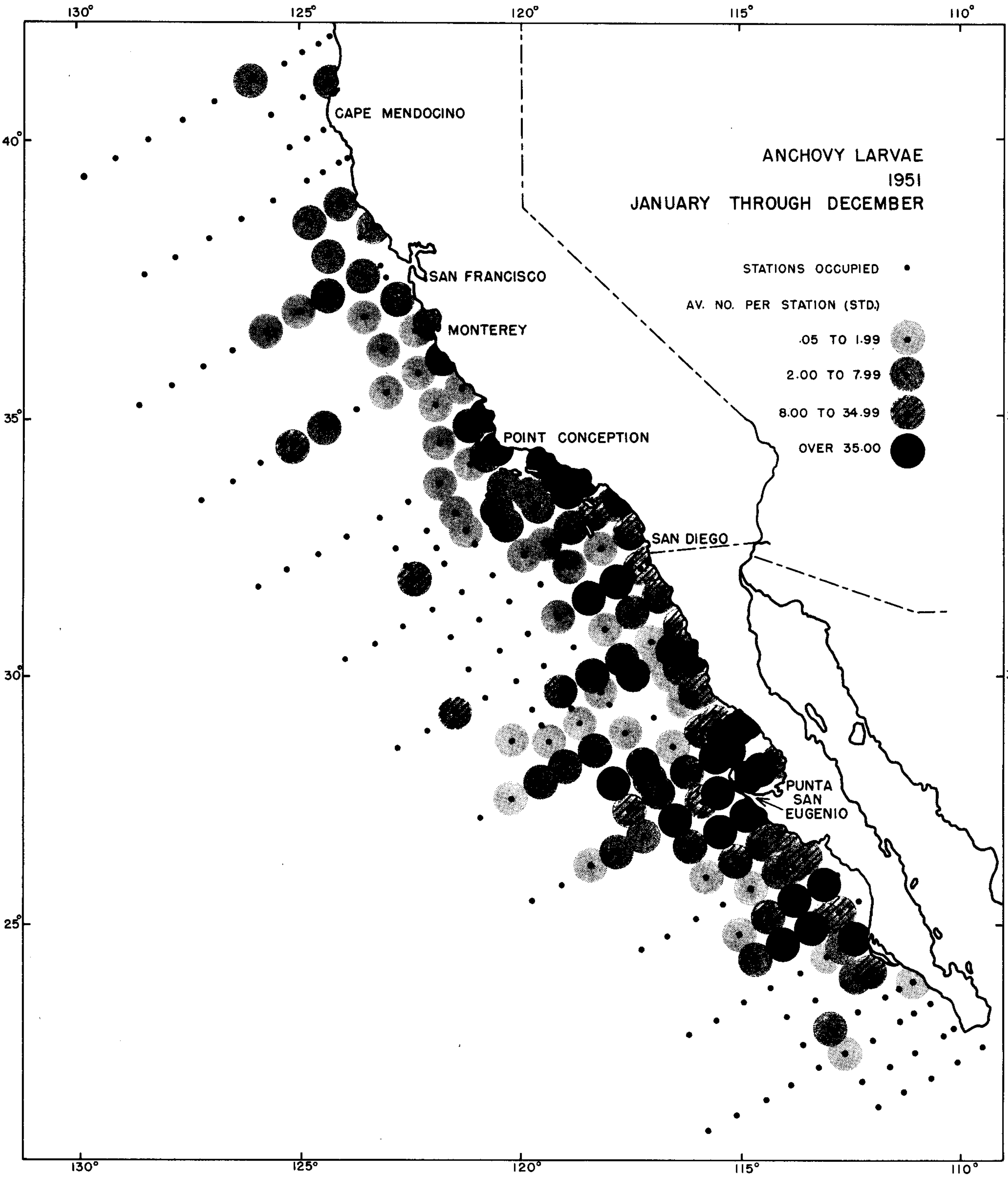


FIGURE 48. The northern anchovy spawns along the whole extent of the area being surveyed, and for an undetermined distance to the north of the area. During 1951 the largest concentrations of anchovy eggs and larvae were taken off central Baja California: an area of especially heavy concentration was found to the south of Punta Abreojos. Although anchovies spawn during every month of the year, spawning was most abundant off central Baja California during February through May, and off Southern California during April, May, and June. At the height of anchovy spawning, the eggs and larvae may be collected as far seaward as 250 to 300 miles. Off-season spawning, however, is mostly confined to a coastal strip.

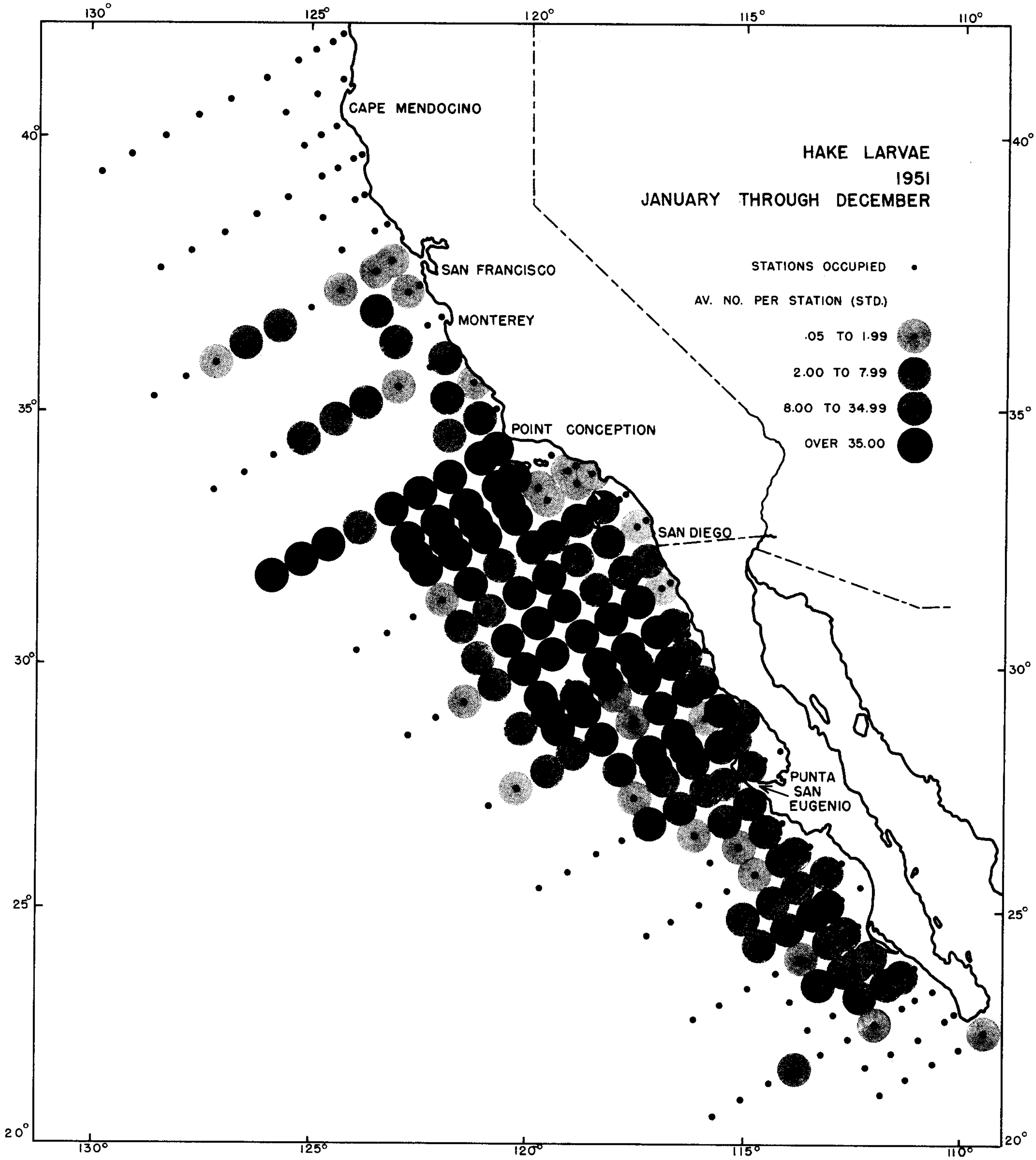


FIGURE 49. The hake was the most abundant larval fish taken in our hauls during 1951. The larvae were widely distributed, with the center of abundance occurring off Southern California and adjacent northern Baja California. The hake has a relatively short spawning season; in 1951 most hake larvae were collected during the three-month period, February through April, with a marked peak in abundance during March. Of all our latent fishery resources, the hake is almost certainly the largest.

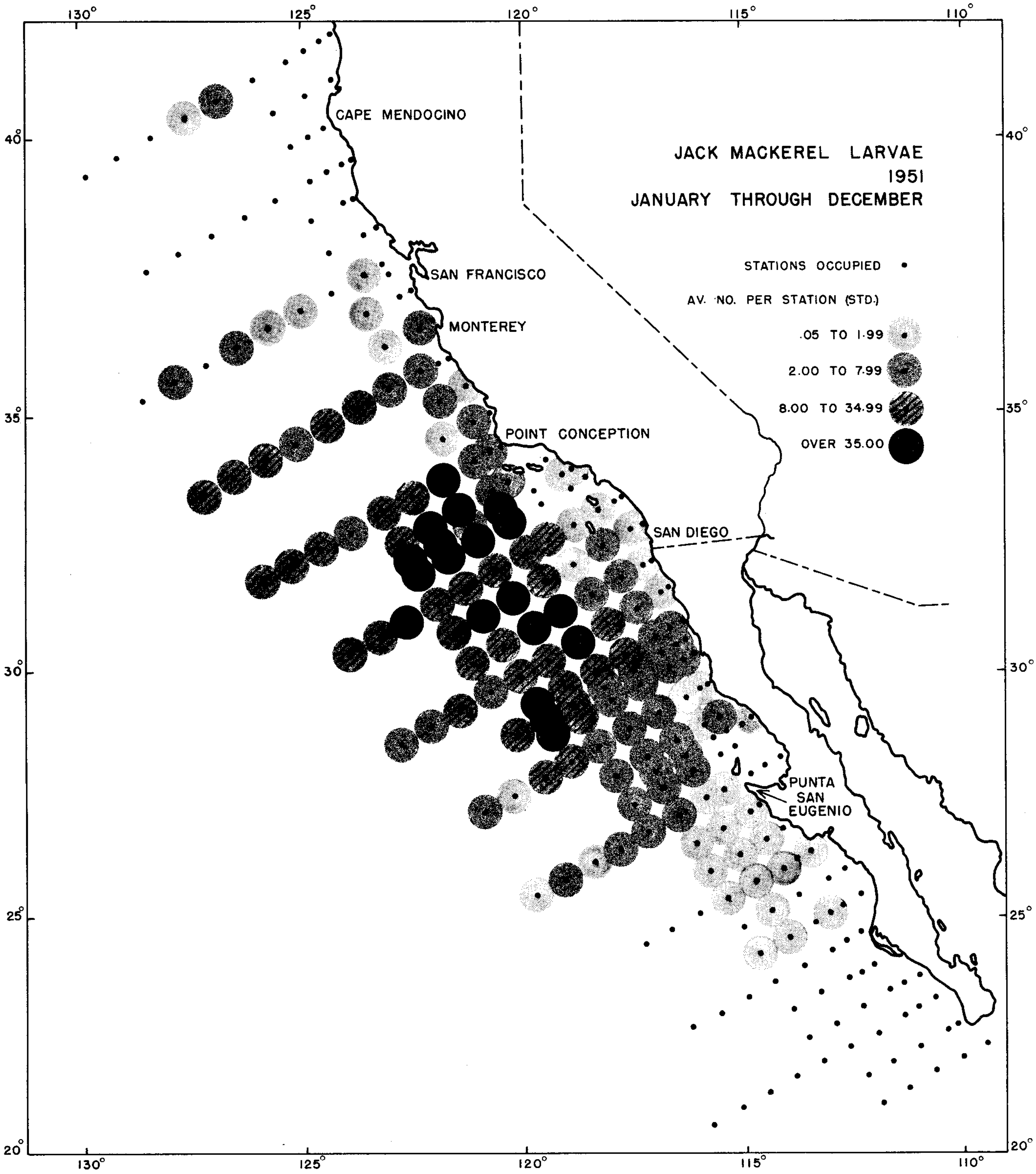


FIGURE 50. Information on the distribution and abundance of jack mackerel larvae is another of the incidental by-products resulting from the sardine spawning surveys. The larvae have been found to be very widely distributed with the center of abundance occurring well offshore off Southern California. The larvae occur as far seaward as we go on our survey cruises, hence we have not been able to delimit the offshore extent of jack mackerel spawning. During 1951, most of the jack mackerel larvae were collected during the four-month period, March through June, with the peak month being April.

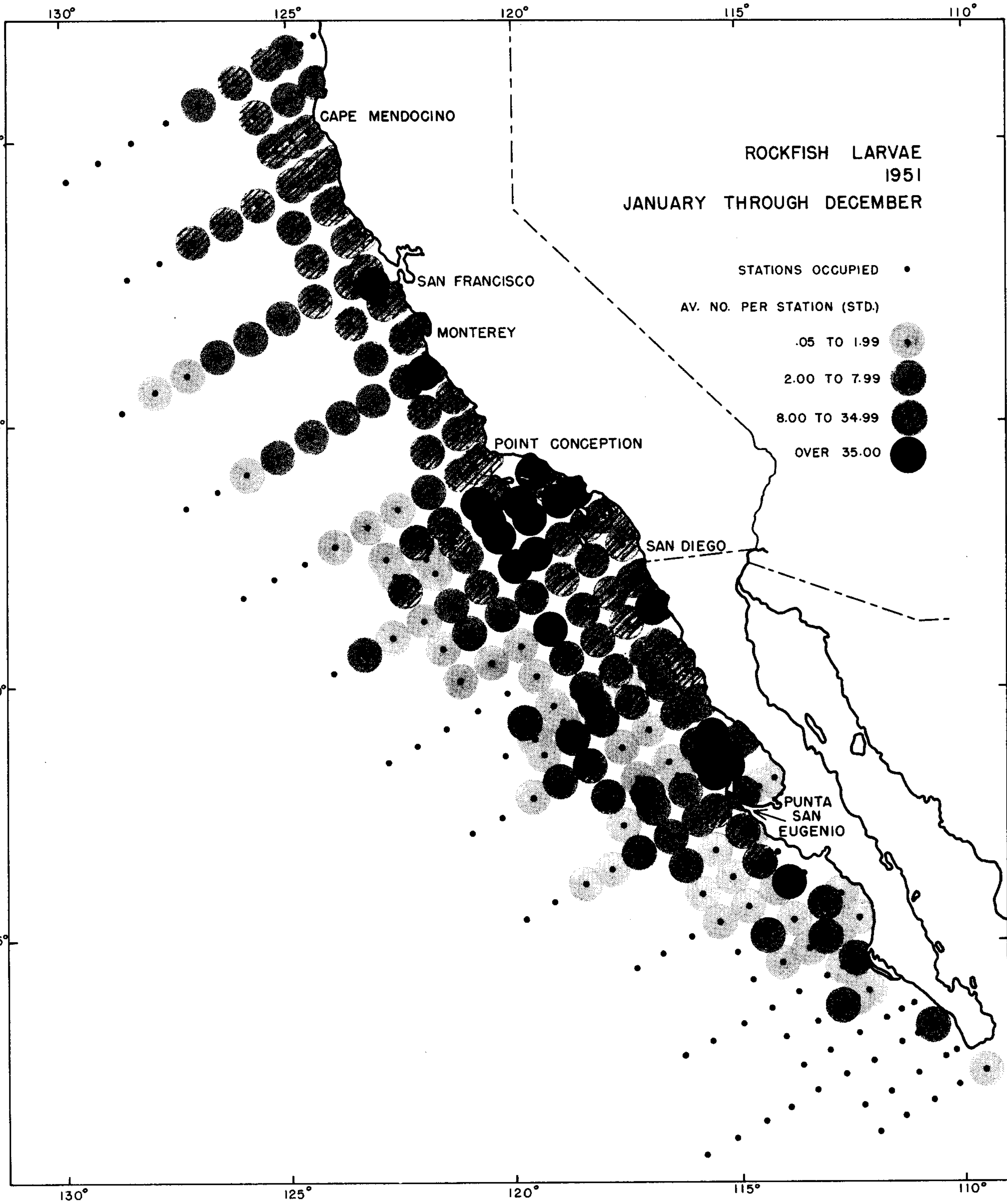


FIGURE 51. Rockfish larvae include several species of Sebastodes. The larvae are widely distributed during every month of the year. The persistent occurrence of rockfish larvae well offshore (up to 300 miles) suggests that some species of rockfish may lead a pelagic existence. As noted above, rockfish larvae occurred in more hauls containing sardine eggs and larvae than any other kind of larval fish.

Many flatfish larvae are taken, including the larvae of rex sole, dover sole, slender sole, English sole, petrale sole, sand dabs (several species), turbots (several species), and California halibut. The most abundant and widely distributed of the flatfish larvae are those of the several species of sand dabs.

A few of the other food fishes represented in the material include the larvae of barracuda, bonito, cabezone, flying fish, pompano, round herring, sablefish, sculpin, and sea bass.

Other Fishes Sampled on Young-Fish Surveys. The species other than the sardine most often found in the young-fish surveys were the jack mackerel, the Pacific mackerel, and northern anchovy (data summarized in Table 13, Appendix). In both 1950 and 1951 the largest concentration of jack mackerel occurred off Southern California and adjacent northern Baja California. Pacific mackerel were sampled in greater abundance off Southern California during 1950 and in the vicinity of Punta San Eugenio during 1951.

For the entire coast, anchovies and sardines differed little in abundance. Anchovies tended to be slightly more abundant than sardines in California and northern Baja California waters; in Sebastian Vizcaino Bay, sardines exceeded the anchovies in abundance, while farther south the anchovies were again more numerous.

Adults of Other Fishes. *Albacore.* There are few diversions offered from the monotonous and strenuous routine of work on the survey vessels, and none is so eagerly anticipated as meeting up with a school of albacore. During the summer and fall months albacore have been taken on jiglines trolled from the research vessels when traveling between stations. When albacore start hitting the bone-and-feather jigs the vessels usually are slowed to half speed without altering course. As no attempt is made to stay with a school, the catches represent only a fraction of what could be taken.

Rather complete records have been kept during a three-year period on the vessel which usually operated north of Point Conception. A few albacore were taken within 100 miles of the coast, but most were taken between 235 and 275 miles offshore. The area about 150 miles off Cape Mendocino has consistently had albacore in August and September during the past three years.

Saury. During the past year, we have systematized our observations of the saury. The saury is readily attracted to a light hung over the side of the vessel at night, and so a visual estimate of its abundance may be made at stations occupied during the dark hours. When sauries are at all abundant, a considerable size range is usually represented, often including fish from about one or two inches to a foot or so long. The small fish dart along the surface of the water with a rapid, snake-like motion, often breaking the surface. The larger fish swim about as individuals or in small schools, usually staying a few feet below the surface, but at times leaping completely out of the water. (From this habit the saury has acquired the vernacular name of "skipper.")

Since we began our systematic recording of saury abundance, this species has been observed at about half of the night stations occupied. It has been observed at one time or another in every part of the area being surveyed, but our records indicate that the largest numbers are encountered within about 80 miles of the coast. Occasionally, very large schools of sauries are seen.

Because the saury is so obtrusively evident, there may be a tendency to overestimate its abundance. However, we have obtained from another source evidence on the abundance of the species and this also points to a large population. The saury has been found to be the most important item of food of the albacore caught by the research vessels, comprising almost 50 percent of the total food volume. A recent study of the stomach contents of 29 marlin showed that sauries comprised about 77 percent of the total contents.

FUTURE STUDIES

The results of these studies, and the new problems revealed by them point up the type of work yet to be done under the California Cooperative Sardine Research Program. The measures of relative abundance of different year classes in the catch, on the nursery grounds, and on the spawning grounds, will be continued. Methods for calculating measures of absolute abundance are being studied and improved. Analysis of the mass of data on the physical and chemical conditions in the ocean has proved complicated and difficult; as a result it has not yet been possible to isolate the environmental factors which may determine successful survival of young sardines from any season's spawning, or to indicate clearly how environmental conditions may affect availability. The collection of physical and chemical data must continue and satisfactory methods of analysis be developed.

The expanded program has also indicated the need for a more accurate measurement of the contribution to the California fishery from the spawning and nursery grounds off central and southern Baja California. Presumably the most direct approach to this would be an extensive tagging program, which at present is beyond the physical and financial resources of the cooperating agencies. Since the support of the program has now been expanded to include moneys from processed mackerel and anchovies, consideration must also be given to these fisheries. This will necessitate a more thorough coverage of inshore waters to determine better the Pacific mackerel spawning grounds, perhaps greater coverage farther offshore to delimit the jack mackerel spawning area, and an expansion of analyses of the anchovy catch. Analyses of the Pacific and jack mackerel catches are now being carried on.