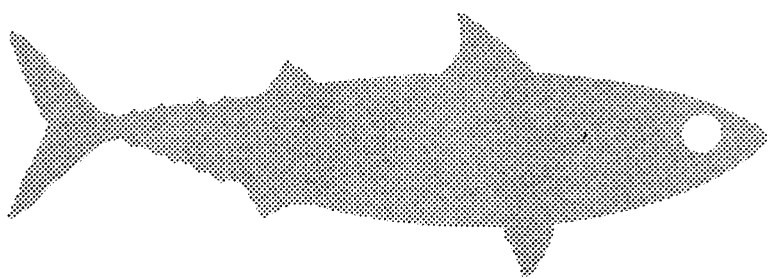
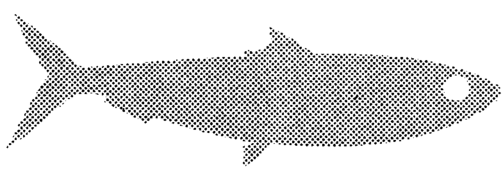
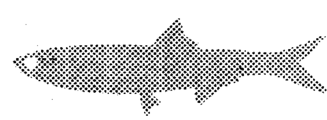




# *california cooperative oceanic fisheries investigations*

**1 July 1952 • 30 June 1953**



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The cover shows in outline and correct proportionate size the four species of food fishes now being investigated under the California Cooperative Oceanic Fisheries Investigations:

- Pacific sardine, *Sardinops caerulea* (center left)
- Pacific mackerel, *Pneumatophorus diego* (top)
- Jack mackerel, *Trachurus symmetricus* (far left)
- Anchovy, *Engraulis mordax* (bottom)

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

# CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

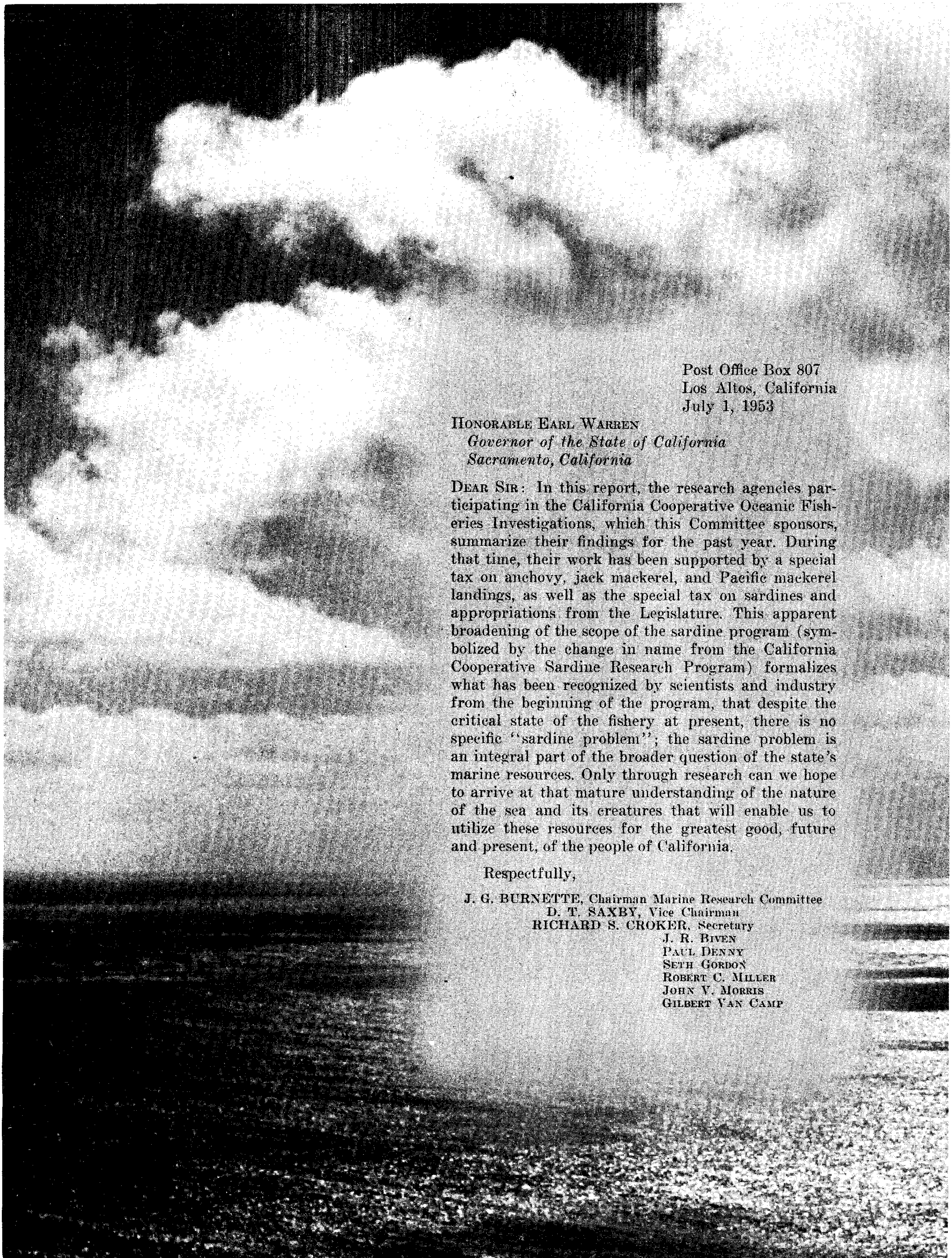
## *Progress Report*

*1 July 1952 to 30 June 1953*

*Cooperating Agencies:*

CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
U. S. FISH AND WILDLIFE SERVICE, SOUTH PACIFIC FISHERY INVESTIGATIONS
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY

1 July 1953



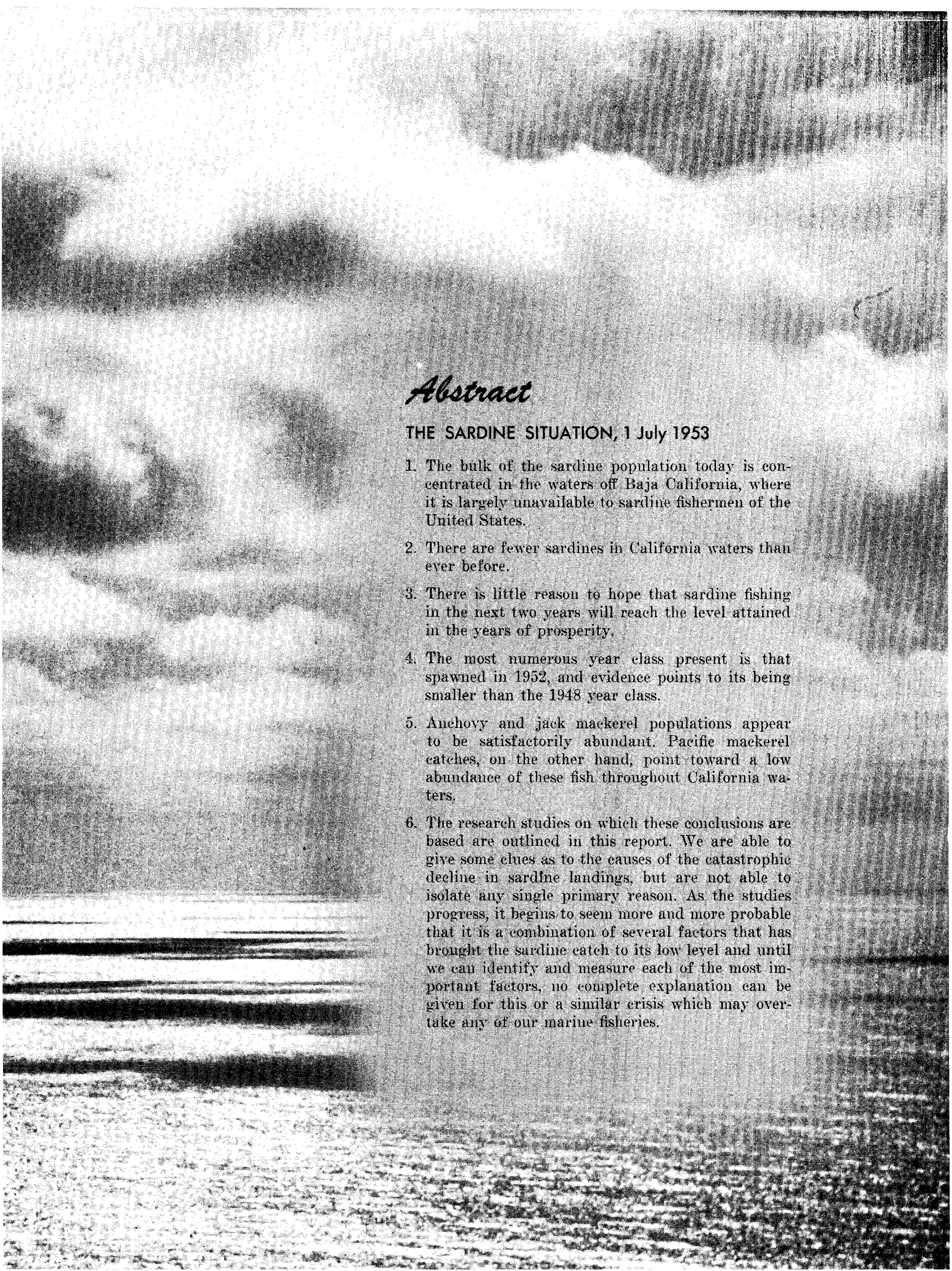
Post Office Box 807
Los Altos, California
July 1, 1953

HONORABLE EARL WARREN
*Governor of the State of California*
*Sacramento, California*

DEAR SIR: In this report, the research agencies participating in the California Cooperative Oceanic Fisheries Investigations, which this Committee sponsors, summarize their findings for the past year. During that time, their work has been supported by a special tax on anchovy, jack mackerel, and Pacific mackerel landings, as well as the special tax on sardines and appropriations from the Legislature. This apparent broadening of the scope of the sardine program (symbolized by the change in name from the California Cooperative Sardine Research Program) formalizes what has been recognized by scientists and industry from the beginning of the program, that despite the critical state of the fishery at present, there is no specific "sardine problem"; the sardine problem is an integral part of the broader question of the state's marine resources. Only through research can we hope to arrive at that mature understanding of the nature of the sea and its creatures that will enable us to utilize these resources for the greatest good, future and present, of the people of California.

Respectfully,

J. G. BURNETTE, Chairman Marine Research Committee
D. T. SAXBY, Vice Chairman
RICHARD S. CROKER, Secretary
J. R. BIVEN
PAUL DENNY
SETH GORDON
ROBERT C. MILLER
JOHN V. MORRIS
GILBERT VAN CAMP




# Abstract

## THE SARDINE SITUATION, 1 July 1953

1. The bulk of the sardine population today is concentrated in the waters off Baja California, where it is largely unavailable to sardine fishermen of the United States.

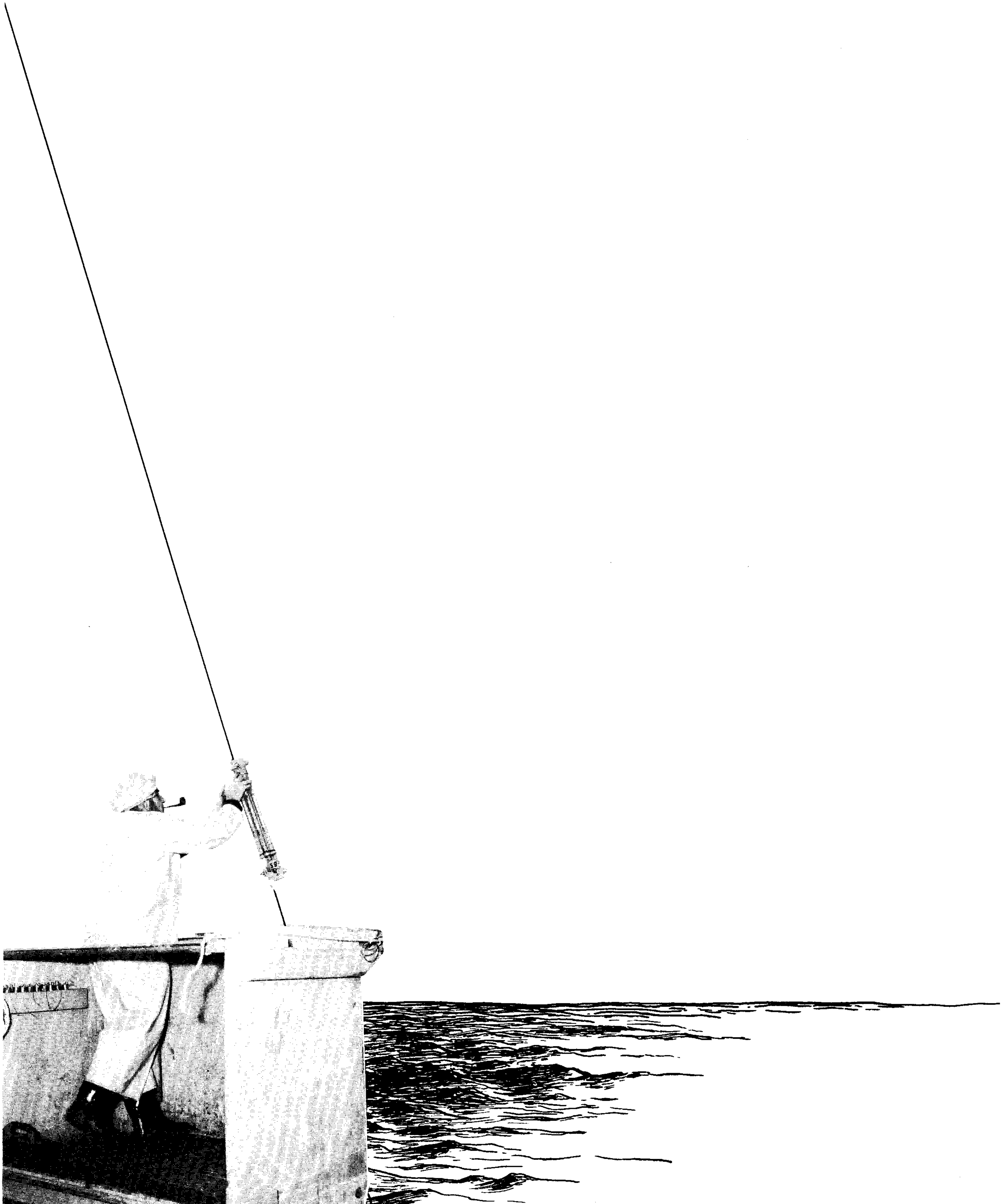
2. There are fewer sardines in California waters than ever before.

3. There is little reason to hope that sardine fishing in the next two years will reach the level attained in the years of prosperity.

4. The most numerous year class present is that spawned in 1952, and evidence points to its being smaller than the 1948 year class.

5. Anchovy and jack mackerel populations appear to be satisfactorily abundant. Pacific mackerel catches, on the other hand, point toward a low abundance of these fish throughout California waters.

6. The research studies on which these conclusions are based are outlined in this report. We are able to give some clues as to the causes of the catastrophic decline in sardine landings, but are not able to isolate any single primary reason. As the studies progress, it begins to seem more and more probable that it is a combination of several factors that has brought the sardine catch to its low level and until we can identify and measure each of the most important factors, no complete explanation can be given for this or a similar crisis which may overtake any of our marine fisheries.



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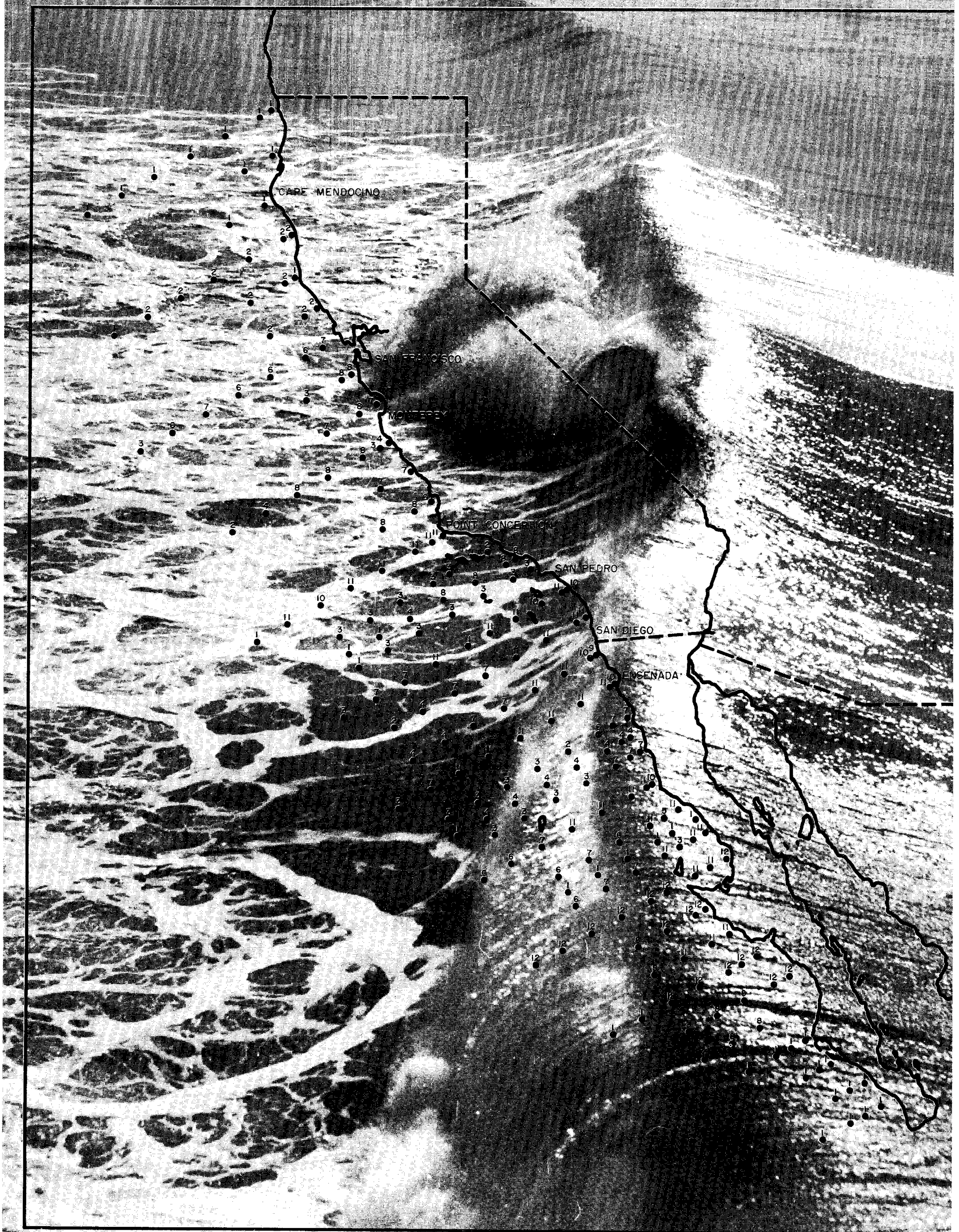


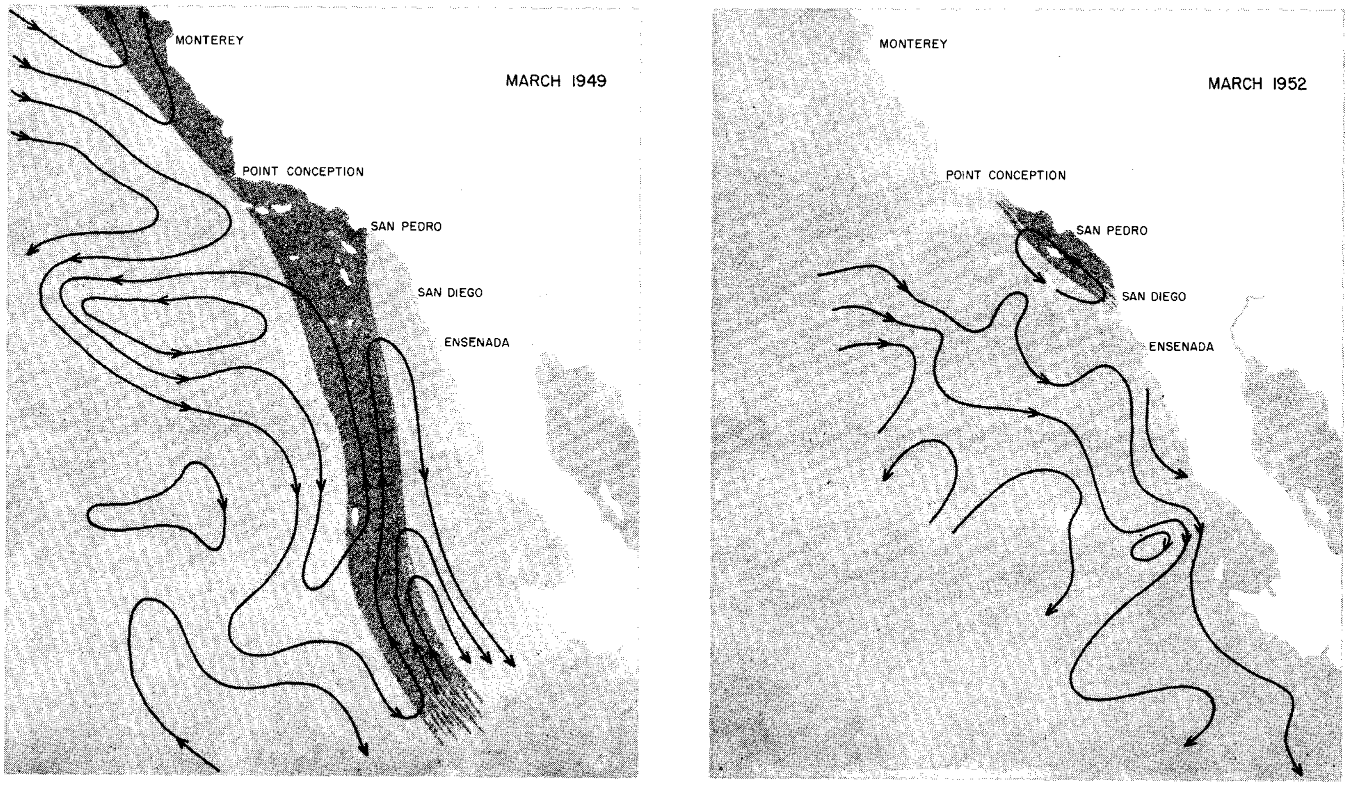
CAPE MENDOCINO
SAN FRANCISCO
MONTEREY
POINT CONCEPTION
SAN PEDRO
SAN DIEGO
ENSENADA

# Introduction

The California Cooperative Sardine Research Program began its routine oceanographic cruises in 1949. Since then the program has expanded to include work on other food fishes and in June, 1953, this expansion was recognized by changing the name of the program to the California Cooperative Oceanic Fisheries Investigations. In the four years 1949 to 1953 sardine and Pacific mackerel fishing off California have grown progresssively worse, and the industry has turned to jack mackerel and anchovies as substitutes. In this progress report we have attempted to summarize the information collected during the four-year interval, to compare these data with facts known prior to 1949, to relate all to the sardine, and to explain as far as possible why the sardine supply has continued to decline on the California fishing grounds.

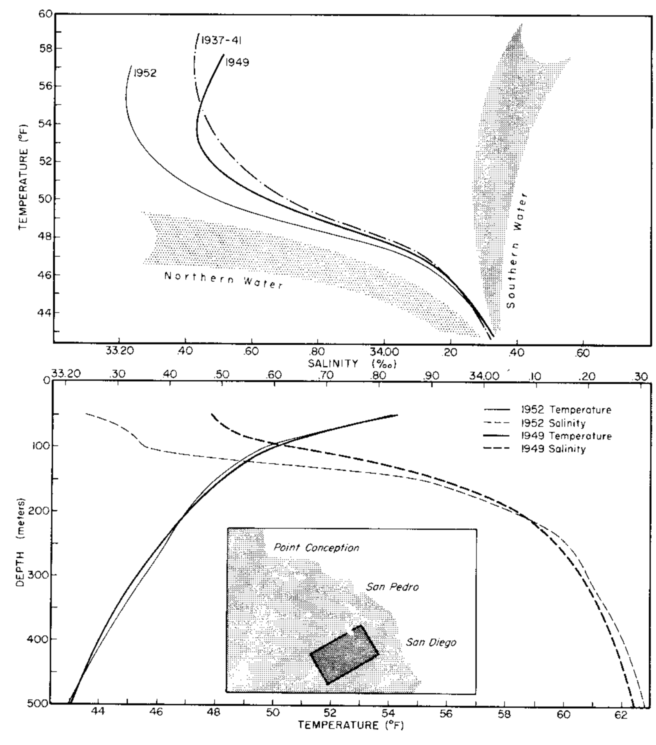
From the research standpoint, the year has been a productive one. Often a year's toilsome, expensive research eventuates in merely one more line of numbers in a table or one more point on a graph. It is only when a great deal of material has accumulated that we can set to work seeking out the relationships of the various individual projects and getting at the *whys* of the puzzles nature sets for us. But with each year's accretion of data, we move closer to the specific goal of our program, which is the ability to tell within reasonable limits where the sardines are, how many there are, and how large they are.

FIGURE 1. During 1952, 1,252 hydrographic stations were occupied by vessels engaged in fisheries research cruises. The dots in the accompanying chart show the locations of these stations; the numbers tell how many times we visited each location during the year. At each station we collected information on the temperature, salinity, and other properties of the water. We collected samples of the plants and small animals living in the upper layers. When the program first began, we occupied stations from the mouth of the Columbia River to central Baja California. But as we have learned more about the area, the station pattern has steadily changed. Since we have discovered that most sardine spawning now occurs off Baja California, we have intensified our coverage of that region and have decreased the visits to the north. However, we run cruises up the coast often enough to feel sure that we will not overlook significant developments there. Representing though it does several thousands of man-hours spent at sea, this station chart still does not include all the sea-going work on the California Cooperative Oceanic Fisheries Investigations; several times each year we send out what are in effect miniature scientific "task forces" to investigate a single problem, such as current measurements in a limited area for a specific period of time, or the numbers of young sardines off the coast. Keeping our vessels at sea takes slightly more than half of all the money that is being spent on the research program, yet it remains the only method we know for gathering the sort of detailed factual information we need in the study of the environment and spawning of sardines and other fishes.




▲

FIGURE 2. Here we show current patterns off the coast for comparable months in 1949 and 1952. Generally sardines are found in only a small part of the area we study. They seem to disperse well offshore in the spring to spawn but appear to spend the rest of the year inshore. But to understand the movement of the inshore waters, it is necessary to know a great deal about the offshore waters, for the circulation patterns of the latter determine the currents inshore. The years 1949 and 1952 ended with sardine seasons that were respectively fairly successful and the worst in history. Here we show current charts from the March cruises of each of those years. The arrows in these charts represent the direction of flow. The distances between the lines indicate the speed of flow; when the lines are close together, the currents are moving faster than when the lines are farther apart. The charts show that in 1949 the southward-flowing California Current meandered, that is, curved, much more than in 1952; that in the offshore area it was narrower and stronger in 1949 than in 1952; that the eddies, "whirlpools" set up by the action of the Current, were more pronounced in 1949 than in 1952. The charts also tell us that the Countercurrent, which here is heavily shaded, was stronger in 1949 than 1952. This is interesting, for it is very possible that the Countercurrent may immediately affect the sardine population in a number of ways.



# Sardines and the Ocean

## THE OCEAN CLIMATE, 1949-52

During 1952, 1,252 hydrographic stations were occupied by vessels engaged in fisheries research cruises (Fig. 1). Several shorter cruises were also undertaken to investigate specific aspects of the program.

Slightly more than half the money spent on sardine research in California goes toward keeping the vessels at sea. (This sum represents approximately one-fourth of the amount spent for all the State's marine fisheries research.) Expensive though it is, such work is indispensable if we hope to learn how the sardine is linked to its environment, and in this complex relationship must lie the answer to such startling fluctuations in sardine landings as were evidenced by the 1952-53 catch.

We seek to know how the environment affects the sardine—for example by physical or chemical changes so sharp that the fish cannot cope with them and so seek another area or depth or by controlling the amount and kind of food available at any time and place.

The best relation we have found between a physical property and any stage of the sardine's life is that between temperature and spawning. The bulk of the spawning we have studied in the past four years occurred in waters between 56.3° and 60.8°F.

We have been unable to determine any simple relation between temperature and the sardine population at other stages of the fish's life. Temperature, however, is only one of the several physical properties of the ocean that we measure, and we continue to search for relationships.

The fall months of 1949 and 1952 seem to offer a made-to-order case for seeking to discover direct effects of the environment on the sardine, for in 1949 there were enough adult sardines off California to provide a moderately good catch, while in 1952 there were almost none at all. How did the environment vary in those years? An illustration of the way we are studying such problems can be given by a comparison of our data for 1949 and 1952. The material on hand points up one immediate difference between the two years: The California Current, the broad, southward-flowing current that dominates the oceanic circulation off our coast, meandered more in 1949, was narrower and stronger in the offshore area, and set up more intense eddies than in 1952. As a corollary, the Countercurrent, which flows northward along the coast inshore, was stronger in 1949 than in 1952 (see Fig. 2).

The stronger Countercurrent of 1949 brought more water of southern origin into the area. This is shown by Figure 3, wherein average curves are drawn for points of temperature plotted against salinity for a group of stations off Southern California. These T-S (Temperature-Salinity) curves are our means of identifying different water masses. Water of southern origin is characterized primarily by higher salinity than water of northern origin, and usually though not always by higher temperature. When we replot our T-S curves into their component parts, we find that the water temperatures for 1949 and 1952 were, depth for depth, almost identical, whereas the salinities varied greatly, particularly in the upper layers. Vertical movement of the water, upwelling, results in increased

◀ FIGURE 3. When the Countercurrent is strong it brings to our coast water that differs markedly in nature from that which makes up the California Current. This southern water is characterized by higher temperature and salinity values. Here we show how we distinguish the different types of water. We have averaged the temperature and salinity values for two stations off the Southern California coast (see inset for location) and have plotted temperature against salinity for three periods. We use the years 1937-1941, which were marked by successful sardine fishing, as a reference curve. When the data for the years 1949 and 1952 are entered on the chart, it is obvious that the water in 1952 more nearly approached the northern type of water than that of 1949. In the lower part of Figure 3, we compare the two properties, temperature and salinity, for the years 1949 and 1952 depth for depth. It becomes apparent that the chief difference was in salinity, the water in 1949 being much more saline in the upper layers than that in 1952. Increased salinity is one of the indicators of upwelling, the slow vertical movement of water from mid-depths to the surface, but the higher salinity values of 1949 cannot be attributed to that cause, for upwelling also brings lower temperatures. Thus we can feel fairly sure that the increased salinity values of 1949 can be laid to increased activity of the Countercurrent. The Countercurrent may directly affect the sardines in two ways: since it moves northward, it may make it easier for the fish to migrate north during the spring and early summer and will oppose their southward migration in the fall. It may also affect the sardines indirectly, for since it causes the inshore temperatures to remain comparatively high, it may defer the cooling of the water and thus delay the southward migration of sardines. A pronounced Countercurrent with its accompanying higher inshore temperatures thus would mean that fish might delay their start to the south and hence be unable to reach Baja California waters before the onset of the California fishing season.

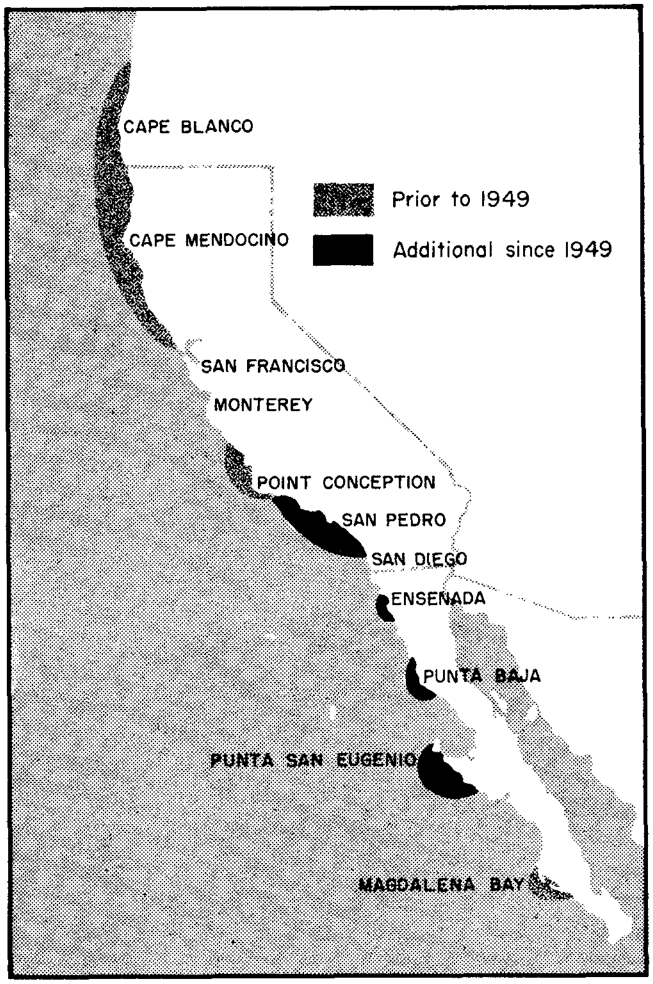



FIGURE 4. Upwelling is an oceanographic factor that has long been acknowledged as a possible key to sardine fluctuations because it enriches the surface water and thus leads to intensified plant and animal growth. Upwelling was studied long before the expanded sardine program began. The known areas of intense upwelling, as of 1948, are shown in this figure. Since starting the survey cruises in 1949 we have found that upwelling is more general both in time and space than had been previously thought. In the figure we have plotted the localities where upwelled water has been found since the survey cruises began. As has been mentioned, two of the characteristics of upwelled water are high salinity and low temperature. A third indicator is lowered oxygen content, since upwelled water comes up from the depths. Only where all three of these changes are present can we feel absolutely certain that upwelling has occurred, for there are other physical processes which can cause any one of the three factors to change.

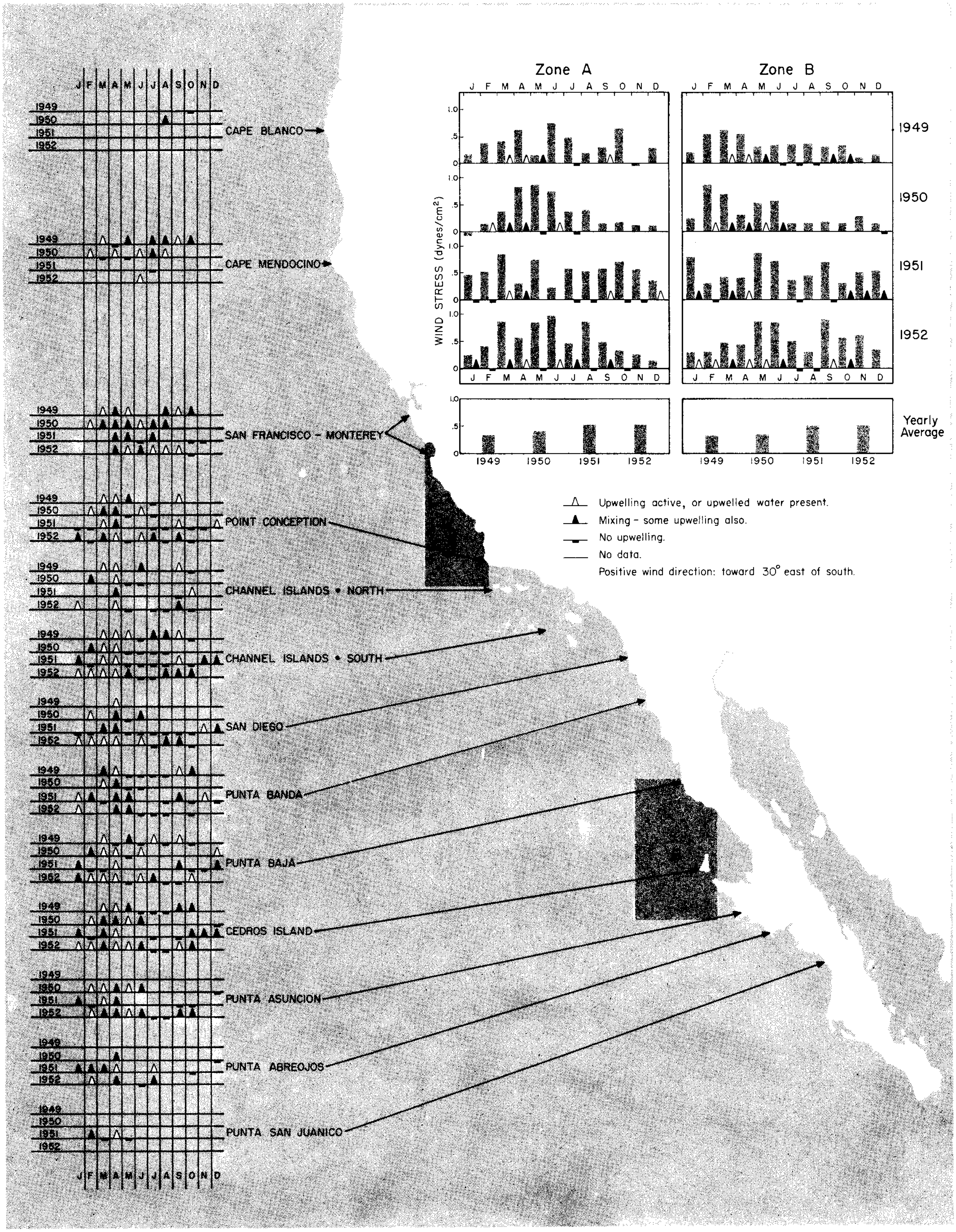
FIGURE 5. One of the interesting things that we have discovered is that upwelling not only appears in areas not known about before (this is not surprising, since the region had been little surveyed), but that it also occurs at different times and far more frequently than had been suspected. In this figure, we chart the times and places that we have found upwelled water since 1949. The chart shows that the period March through October, 1952, shows the most upwelling, 1949 next, then 1950, and least of all 1951. Though upwelling is caused by the winds, and there is much wind data available, the relationship is very complex, and it is as yet impossible to predict upwelling from wind conditions. Yet the inset figure, which shows wind stress values and incidence of upwelling off Point Conception and Cedros Island, indicates that upwelling has usually been found after a period of increased wind stress and has not been found when the winds have decreased.

salinity values, but the 1949 values cannot be entirely ascribed to upwelling, for had only that process been at work, temperature values would have been lower than those observed.

If we assume that the major patterns of sardine behavior along the coast have remained unchanged in the past few decades, we can immediately see how the Countercurrent might have far-reaching effects on the California catch. It will be remembered that studies have shown that many of the sardines migrated northward from the spawning grounds during spring and early summer and returned to the south in the winter. A strong Countercurrent in the spring and early summer would lend support to the northward migration by physical transport of the fish. But if the Countercurrent remained strong throughout the year, the southward return, against the current, would be impeded; in a strong north-flowing current the sardines might reach the fishing grounds later in the year. Unable to move to the south of the waters fished by the California industry by the time of the opening of the season, they would be more available to the sardine fleet.

The Countercurrent causes temperatures in the inshore areas to be higher than average. Thus, if it is the cooling in the water due to the onset of winter that causes the sardines to migrate southward, the beginning of the migration would be delayed. In 1949, for example, the sardines would have started south later than in 1952.

These are ideas about the possible effects of the environment on sardine behavior and illustrate one of the hypotheses that we are trying to test.


J F M A M J J A S O N D
1949
1950
1951
1952
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO - MONTEREY
POINT CONCEPTION
CHANNEL ISLANDS • NORTH
CHANNEL ISLANDS • SOUTH
SAN DIEGO
PUNTA BANDA
PUNTA BAJA
CEDROS ISLAND
PUNTA ASUNCION
PUNTA ABREOJOS
PUNTA SAN JUANICO
Zone A
Zone B
WIND STRESS (dynes/cm²)
Yearly Average
Upwelling active, or upwelled water present.
Mixing - some upwelling also.
No upwelling.
No data.
Positive wind direction: toward 30° east of south.

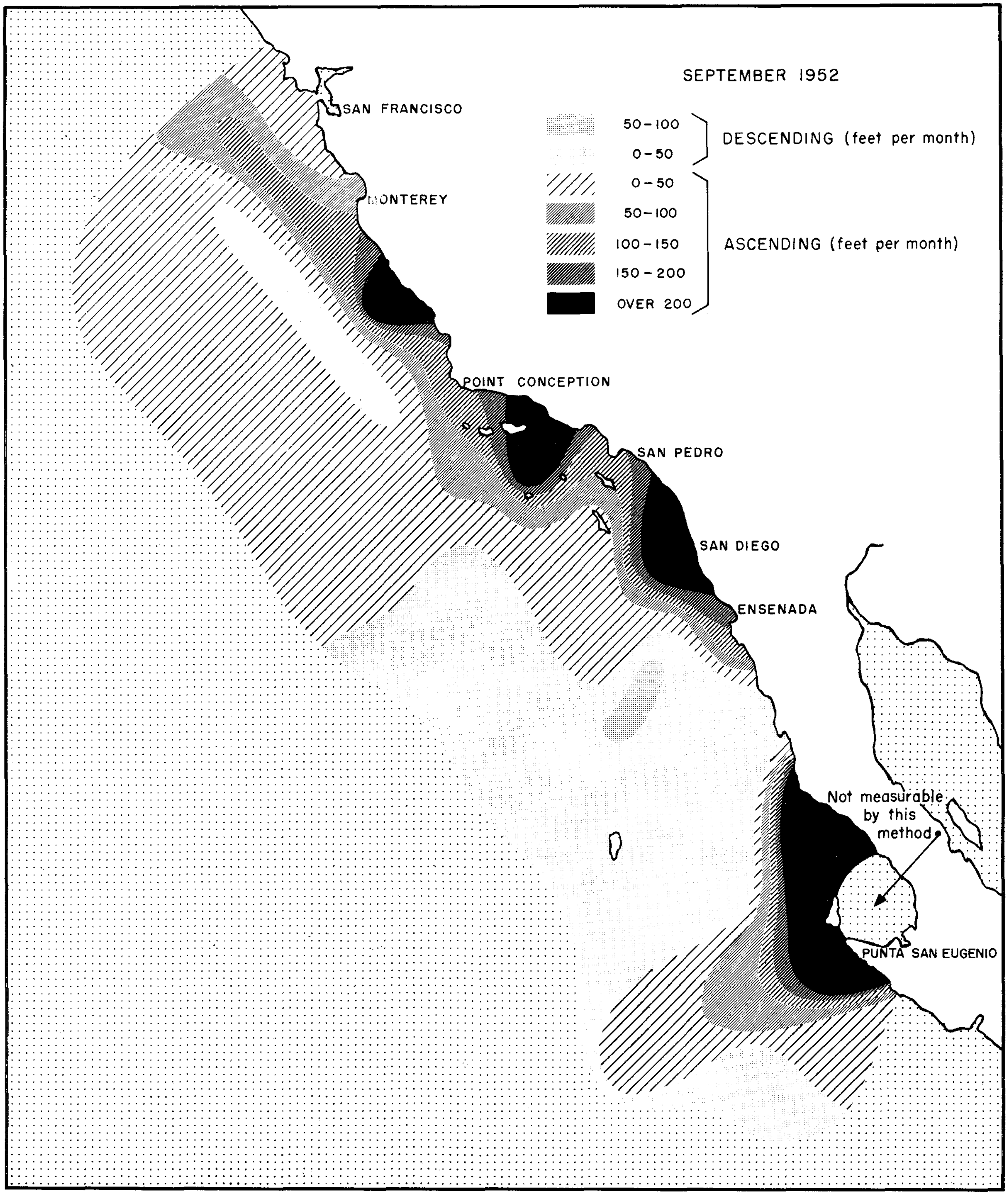

SEPTEMBER 1952
50-100
0-50
DESCENDING (feet per month)
0-50
50-100
100-150
150-200
OVER 200
ASCENDING (feet per month)
SAN FRANCISCO
MONTEREY
POINT CONCEPTION
SAN PEDRO
SAN DIEGO
ENSENADA
Not measurable by this method
PUNTA SAN EUGENIO

FIGURE 6. It has been only in the past few months that we have been able to assign what we think are reliable numerical values to upwelling. Working with data collected on our survey cruises, a Japanese oceanographer who has recently joined the program has devised a measure of upwelling. The results are expressed in the vertical transport of a unit volume of water in a unit period of time. We here present one of the first charts to be worked out by this method. The data from Cruise 41, September, 1952, indicate that intense upwelling (water ascending at a rate of well over six feet a day) had been occurring south of Monterey and Point Conception, near San Diego, and—the largest area—near Cedros Island. It is instructive to compare this figure with Figure 5, which shows that upwelling had occurred or upwelled water appeared at all these areas between the August and September cruises. The new method of measuring upwelling will require refinement and testing, but values so far achieved thus seem to agree well with what we have learned of upwelling by other techniques.

The Countercurrent thus may affect the sardine directly; a physical process which is not likely to have a direct influence on the sardine but indirectly affects the fish by regulating its food supply is upwelling. The phenomenon of upwelling has long been known and studied, but until a few months ago we had not been able to assign more than approximate numerical values to the process. By noting changes in temperature, salinity, and oxygen between cruises, we have been able to delineate the areas in which upwelled water has been found, for such water bears its own "signature" in the form of lower temperature, lower oxygen content, and higher salinities. In the four years of survey cruises, we have greatly extended our knowledge of the area of upwelling (see Fig. 4), and the times at which it occurs (Fig. 5). The area chart (Fig. 4) shows that intense upwelling occurs not only off Point Conception and along the Northern California coast, as was known, but also from Point Conception almost to San Diego, and at several locations along the Baja California coast. Figure 5 shows that upwelling is not restricted to a few months of the year, but can occur at almost any season, depending on wind conditions.

Comparing the March through October periods, for which all four years (1949 through 1952) were measured, we find that 1952 shows the most upwelling, 1949 the next (though the difference was slight), then 1950, with 1951 showing the least upwelling. Data we took from January to March show no important upwelling then, so we must regard 1951 as a year of less than normal upwelling. The January through March data for 1952, on the other hand, reinforce 1952's position as the year with most intense upwelling.

Only a few months ago, one of the oceanographers working on the program devised a method which will allow us to give at least approximate numerical values to upwelling. We present as Figure 6 one of the first charts prepared by this method. One of the interesting things about this chart is its close agreement with the material presented in Figure 5, in which it was indicated that between September and October, 1952, upwelled water was found along the inshore boundary of almost the whole survey area. In Figure 6, upwelling is presented in units of feet of vertical motion per month, the most intense shading representing the regions where water has upwelled at a rate of more than 200 feet a month, or more than six feet a day. Immediately apparent in the figure is the "desert area" of water we have found so often off the northern Baja California coast.

This new method of measuring upwelling will allow us to prepare comparative charts for each cruise we have made, and offers a potentially useful tool, though results of course must always be checked with information gained by other means.

In Monterey Bay, which is well exposed to the ocean, temperature appears to be largely controlled by the oceanographic conditions off coastal California. If a trusted relationship can be found, we may be able to reduce our observations.

During the late fall and early winter, surface temperatures in the Monterey Bay area average 11° or 12°C. These are fairly constant for several months along long stretches of the coast (see curve for 17 December 1952, Fig. 7). No distinct thermocline is present during this period; the temperature decreases evenly and very gradually with increasing depth, water of 9° or 10°C being characteristic at a depth of 300 feet (see map and profiles, Fig. 8).

From early March until August upwelled water appears and is particularly prominent in certain areas as, for example, along the open coast in the region of Soberanes Point on 13-15 May (Fig. 7). During this period the temperature of the surface waters varies considerably from week to week and even from day to day. With the advance of the summer, the surface layers are slowly warmed until temperatures of 15° or 16°C or even higher are common over shallow areas, and a marked thermocline develops. The prevailing temperature at 300 feet during the time of upwelling is 8°C (see map and profiles, Fig. 9).

Rarely as early as April, but usually in July, warm water appears at the surface in the bay. At first its presence is detected in only the most superficial layers. As the season progresses, the effects are felt in the deeper waters as well. Often in September, and even in August and October, warm water is replaced for short periods of time by colder water. During times when warm-water conditions are best developed, any temperature depressions that do occur are of minor magnitude (see curve for 5 September 1952, Fig. 7). However, the variations appear over very short distances, especially on sides of headlands where small patches of the previously predominant water exist as unflushed residues. The non-upwelling period is normally characterized by temperatures of 14° to 15°C at the surface and 10°C at a depth of 300 feet (see map and profiles, Fig. 10). The thermocline is usually not strongly developed, except early in the season.

Although many more data are required in order to establish any definite correlation between water masses in the bay and particular organisms, a few indications that some of the commercial fishes may respond to the water movements have been noted. Thus, Pacific and jack mackerel were taken in 1952 only during periods of warm surface water, while all of the very few catches of sardines in Monterey Bay during the past year have been made during or immediately following appearance of upwelled water. On other occasions the appearance or disappearance of anchovies and herrings has coincided with a fairly abrupt temperature change, although it must be mentioned that frequently these fishes were not available

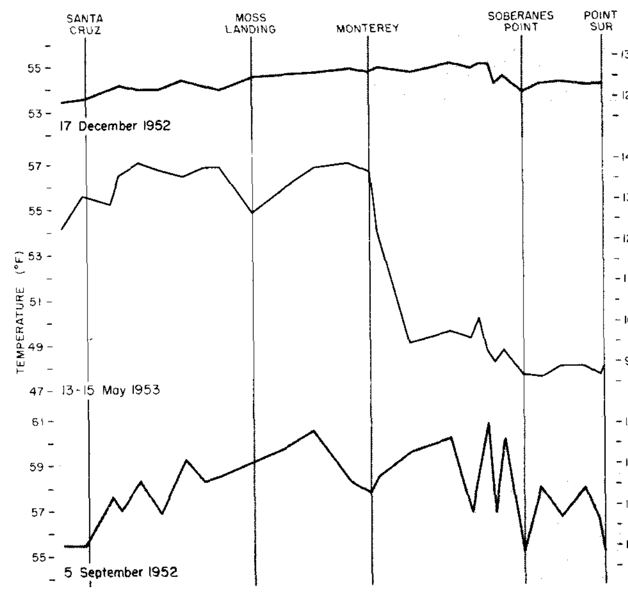



**FIGURE 7. Surface ocean water temperatures in the vicinity of Monterey at three seasons of the year. Note the sharp decrease during May to the south of Monterey.**

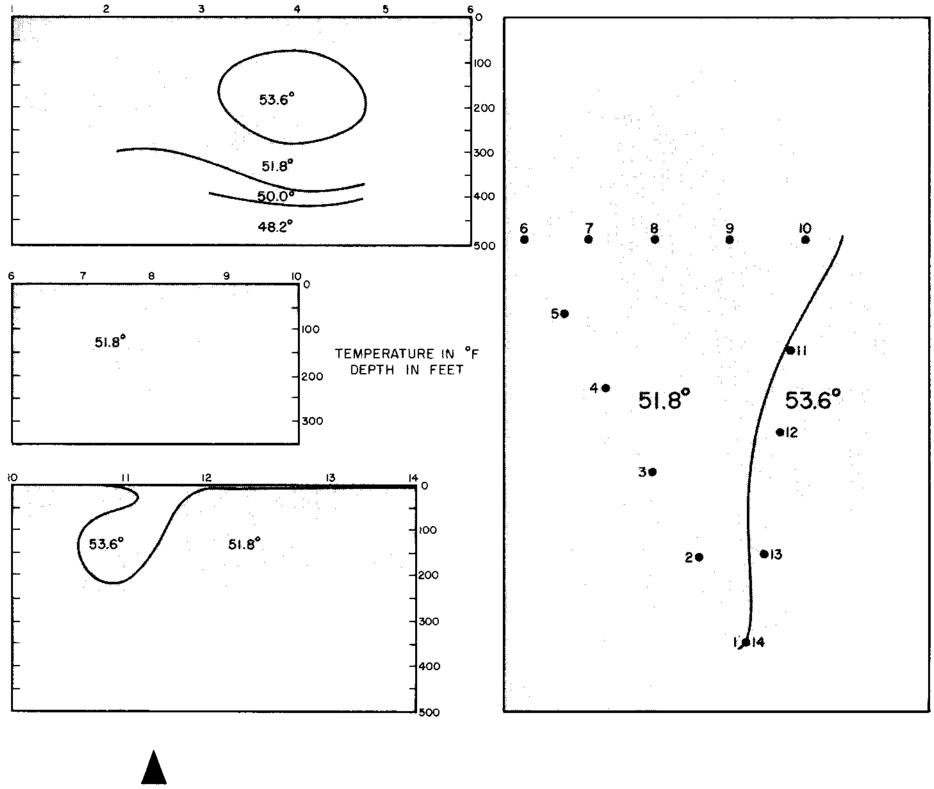



FIGURE 8. During the late fall and early winter, there is no distinct thermocline present in Monterey Bay. Water of 9° or 10°C (approximately 51°F) is characteristic at a depth of 300 feet.

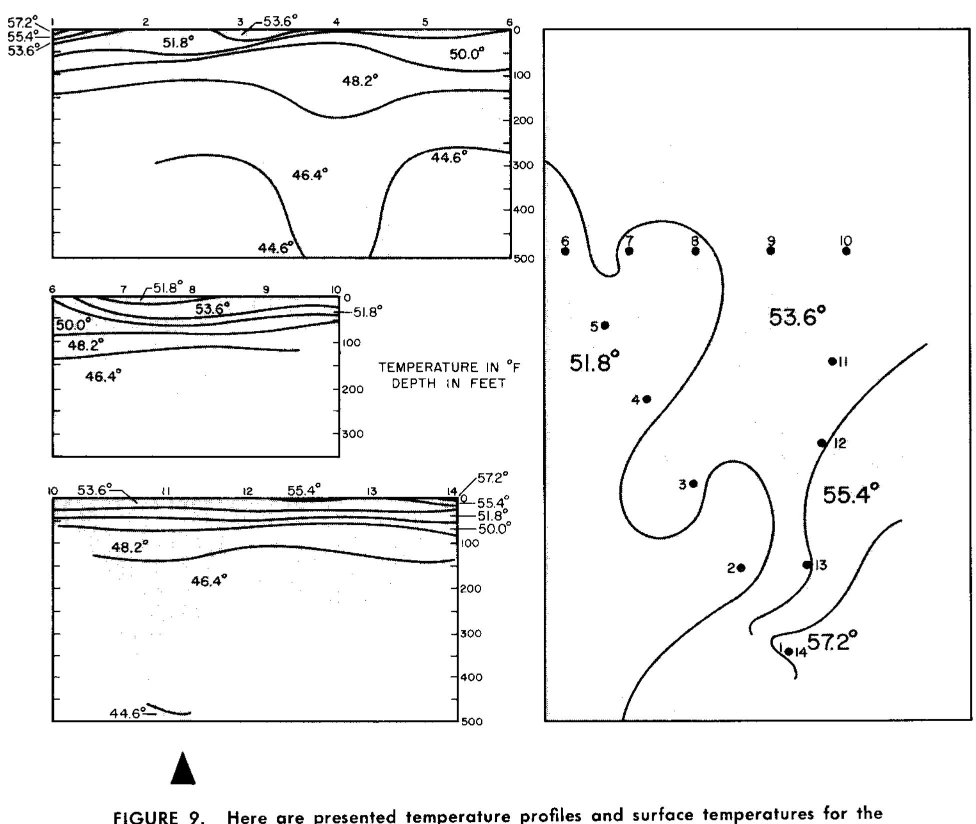



FIGURE 9. Here are presented temperature profiles and surface temperatures for the summer period in Monterey Bay. The prevailing temperature at 300 feet during this time is lower than during the late fall and early winter (Fig. 8).

when temperature conditions appeared to be favorable. Further attempts to establish correlations of this nature will be made.

Upwelling is worthy of close study because it brings to the surface rich waters in which phytoplankton, the basic foodstuff of the ocean, thrives. If we exclude the coastal seaweeds, the whole productivity of organic matter in the sea ultimately depends on the chlorophyll-containing phytoplankton (floating plants). Measurement of the productivity of the sea by sampling this crop of plant food presents knotty technical problems, some of which have not been solved. Comparing counts made of samples collected off the Scripps pier, we have been unable to discover any significant trend in phytoplankton production in the years 1950-1952 (Fig. 11). The method utilized may be faulty, however, and must be supplemented by other ways of getting information. Among these are laboratory investigations as well as field studies. The object of such work is to determine the growth factors in sea waters and subsequently to measure the concentrations of these factors in different parts of the ocean to determine those that limit productivity. Laboratory work has already shown us that small iron and vitamin $B_{12}$ concentrations may so operate.

The abundance of floating plants has little direct bearing on sardine studies, for the creature as a larva selects its food from other members of the zooplankton (floating animals) and as an adult mainly filters the water, ingesting whatever is present there. We are more interested in phytoplankton productivity as a key to understanding fluctuations of the zooplankton population, of which the sardine as an egg and larva is a member.

An omnivorous, filter-feeding fish, whose eggs and larvae are themselves planktonic, the sardine is intimately connected with and dependent upon the plankton, the floating plants and animals of the sea, throughout its whole life history. In its early stages it must run the risks of being eaten by many potential predators; later as it begins to feed it must find its food among the many plankters, and still later must spend most of its life in waters rich enough in plankton to support it. In its first few months of existence, it runs the risk of attack from many planktonic predators. Disease may strike a sudden blow, *and always the danger* exists that some other organism may replace or displace the sardine. The fish then is related to the plankton in three primary ways, first for its food, second through the danger of predation,

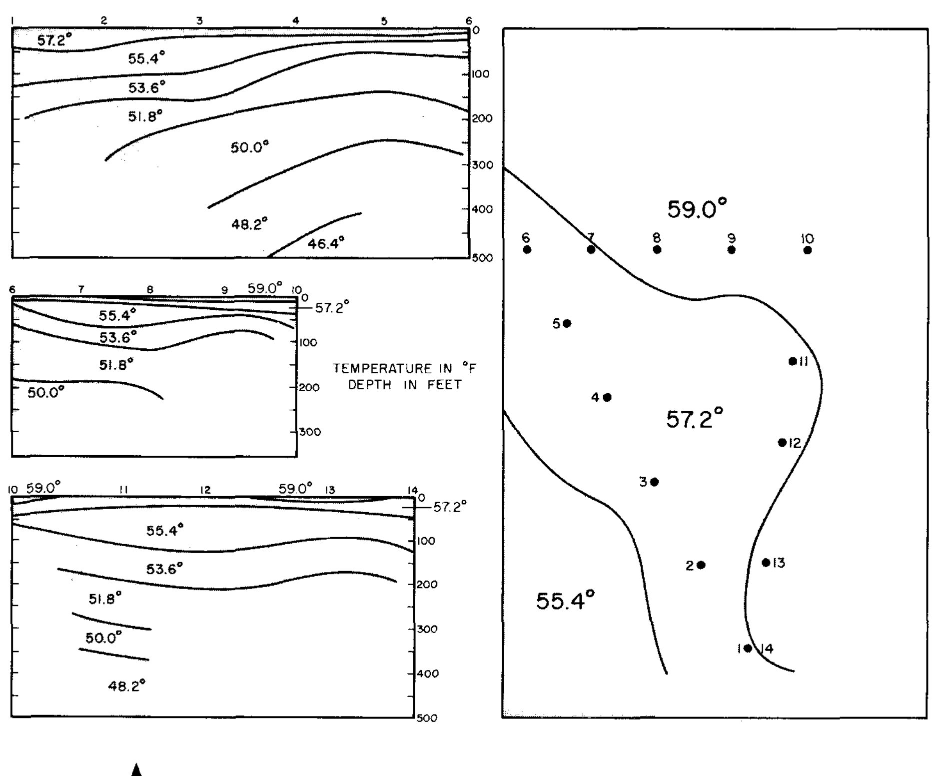
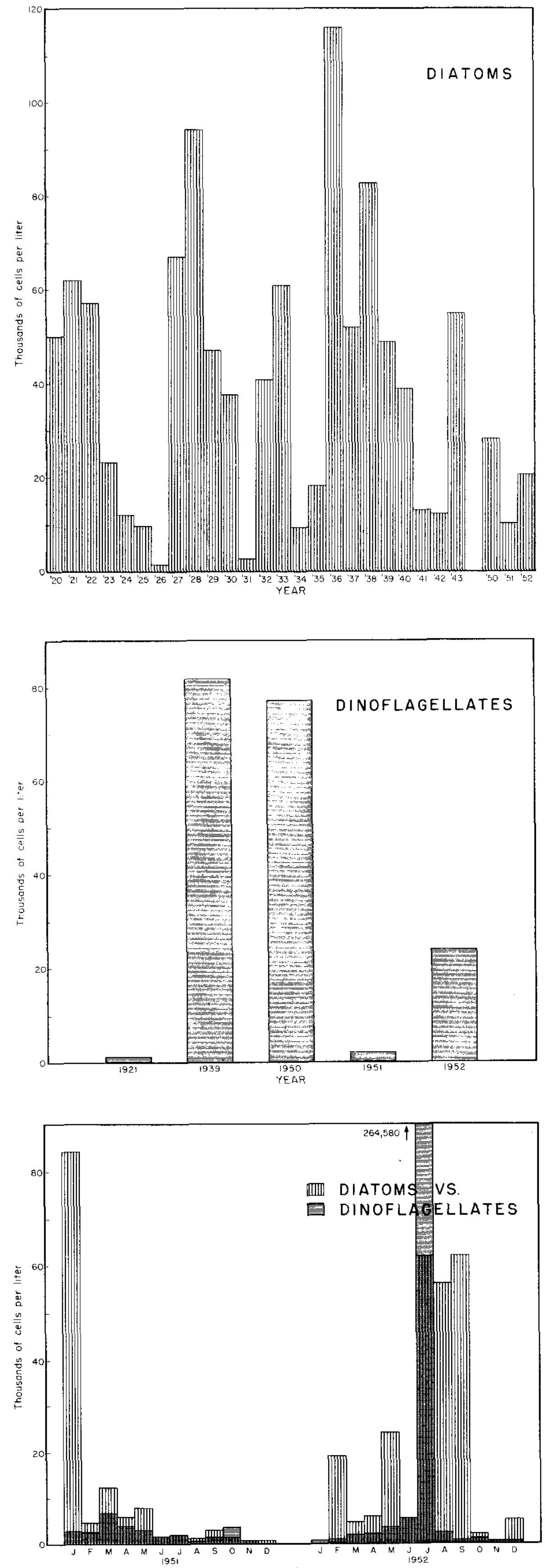



FIGURE 10. Summer non-upwelling periods are normally characterized by comparatively warm waters both at the surface and at depth.

FIGURE 11. Upwelling brings to the surface of the sea waters in which marine plants and animals thrive. If we exclude the coastal rocks with their covering of seaweeds, the whole productivity of organic matter in the sea ultimately depends on the chlorophyll-containing phytoplankton (minute floating plants). Changes in the nutrient content of sea water and hence in the plant populations are thus of the greatest importance to all life in the sea. We have a series of measurements of the phytoplankton from 1920 to 1943. In the past few years we have taken similar collections from the same spot, hoping to determine if there had occurred any large-scale changes which might affect the sardine population. The results, as shown in the accompanying figure, are negative. Although the diatom populations for the last three years have been smaller than the average for the 24 years studied earlier, they are not exceptionally low as compared with a number of years in the earlier period. Nor is there a trend toward decline in dinoflagellate (another common marine plant) population in the past three years. The methods used in this study are subject to some criticism on the grounds that collections were made off a pier and are not representative of conditions in the open sea. We are planning work at sea to test the validity of this criticism and if possible devise other and better means to measure the true productivity of the ocean.



and third through the necessity for successful competition.

The chief result of the food studies, which for the larvae consist of examination of the stomach contents and for the adult of comparing the stomach contents with the plankton samples, has been the accumulation of evidence that the larva feeds selectively, the adult indiscriminately. Other interesting information has come from these studies. Later in this report, we will compare the feeding habits of sardines with those of other species. At the moment, we wish to draw attention to two findings from the studies of the food of adult sardines:

(1) Several samples have been taken in spawning condition and from water containing sardine eggs. These fish were found to have empty stomachs. In other instances where samples contained a few fish ready to spawn but where no eggs were found, nearly normal amounts of food were in the stomachs. Thus sardines in the act of spawning or in the presence of spawning fish seem to stop feeding, although feeding apparently goes on up to the time of spawning and is resumed shortly thereafter.

(2) A few samples of fish taken during daylight hours were among those examined in the food studies. These fish contained essentially the same amounts and kinds of food found in the sardines caught at night.

Many detailed studies are now in progress which are yielding information concerning the organic environment of the sardine. Individual groups of plankton organisms are being analyzed and the gross composition of plankton samples is being determined. In this way we are obtaining quantitative data on the amounts of food available to the sardine and on the numbers and distribution in the plankton of individual food items, predators, and competitors of the sardine.

While essentially all planktonic organisms enter the diet of the sardine, the single most significant group of food animals are the copepods, minute marine shellfish. It is indicative of the complexity of the problem we are attacking that although the greatest concentrations of copepods occur to the north of San Francisco, these great food resources at present remain unused by the sardine.

Certain copepods represent potential predators of the sardine, at least during its early development. A notable example is represented by the genus *Candacia* of which at least 11 species occur throughout the waters inhabited by the sardine.

Other predators upon sardine eggs and larvae are represented by such groups as arrow-worms, jellyfish, comb-jellies, and certain amphipods and pelagic mollusks. Recent work on arrow-worms indicates a thousandfold increase in maximum numbers of one inshore species since the 1904-1909 period. The effect of this large predatory population on the nearshore spawning of the sardine could be very large.

The distribution of such predators as jellyfish and comb-jellies tends to be fairly uniform through the area of study, but high concentrations are not uncommon. The presence of large populations of these predators on the spawning grounds could account for a great diminution of the year class of fish from that area. Among the pelagic mollusks, such genera as *Carinaria* and *Pterotrachea* are known carnivores; although usually only a few of these animals occur in a given area, their presence on the spawning grounds in large number could have serious effects.

Detailed study of another group, the euphausiids (shrimplike crustaceans), is yielding much information. By 1950, 17 species had been discovered in the survey area; continuing work has shown that more than twice that many species are present. Since euphausiids are found in 20 to 25 percent of the sardine stomachs examined in the study of the food of the adults, knowledge of this group is pertinent to a complete understanding of the food of the fish.

Many of the animals of the plankton in addition to serving as food of the sardine or as predators also compete directly and indirectly with the sardine for food. One such large and common group are the salps. These animals are now being intensively studied. The salps, which themselves are filter-feeders, eat many of the same food items as the sardines and also eat many items which, though too small for the sardine to catch, represent the food of the food items of the sardine. The salps therefore not only compete directly with the sardine but also indirectly. At times concentrations of more than 300 salps per cubic meter of water occur on the fishing and spawning grounds, if we list as salps both these animals themselves and their relatives, the doliolids. It is immediately obvious that these animals will markedly deplete the environment of food. In 1950 the volumes of whole plankton samples were more than three times those of the 1949 samples. Although this suggests a much increased food supply, it now appears in many of the samples that this increase in volume was the result of large numbers of salps being present and probably worsened rather than bettered the environment for the sardine.

The material here presented indicates how studies of the plankton are yielding information relative to the sardine. It should be pointed out that these studies apply in the same fashion to other pelagic fishes such as jack mackerel, Pacific mackerel, and anchovies. Moreover much of the detailed distributional data obtained concerning single plankters has direct application to studies of currents, water masses, and the dispersal of fish eggs and larvae. Study of the plankton is essential not only to an understanding of one species of fish or of several species, but is of primary importance to an understanding of the environment as a whole.

## SUMMARY: THE ENVIRONMENT OF THE SARDINE, 1 JULY 1953

1. During 1952, 1,252 hydrographic stations were occupied by vessels engaged in sardine research studies. The most intense coverage was off Southern California and Baja California, where we have found almost all spawning to occur.
2. Several special cruises were made to study sardines in the nearshore areas.
3. The year 1949 ended with a fairly good fishing season; the year 1952 ended with the worst season in history. We have found that the California Current meandered more in 1949 than in 1952, causing the appearance of the Countercurrent nearshore.
4. The Countercurrent brought warmer waters along the immediate coast during the 1949 fishing season than during 1952. We do not know that this fact bears on the spectacular failure of the fishery in 1952; it is a possibility that we intend to investigate further.
5. In four years of survey cruises, we have tremendously enlarged our knowledge of upwelling, the physical factor that results in enriched water and and consequent plant and animal growth. We have found upwelling to occur at more places and times than had been known before.
6. Recently we have developed a theory that allows us to give a numerical value to upwelling, expressing the amount in distance upward traveled in a unit of time. This potentially very useful method checks well with our other upwelling studies, and may point a way for relating upwelling more closely to other quantities measured on the program, such as food production, amount of spawning, and the catch.
7. Using past studies as our basis for comparison, we have not been able to demonstrate that the plant population of the ocean has changed significantly during the past few years. This negative result by no means closes the door on further investigation of the productivity problem; it is useful in that it indicates our method may be faulty and suggests better ways to get the information.
8. Studies of adult sardines have shown them to be primarily filter-feeders, straining out any organisms present in the surrounding water.
9. Larval sardines are unable to strain food; they seize it with their mouths. Larval sardines show a definite preference for copepods, which are minute shrimplike marine creatures.

In sum,

(1) we have found interesting and possibly significant differences in current patterns between 1949 and 1952, years strikingly different so far as the catch was concerned;

(2) we have developed a potentially very useful tool for the quantitative measurement of upwelling;

(3) we are learning enough about sardine feeding habits and the patterns of plankton distribution in the sea to be able to plan studies that if continued should eventually tell us finally if the "sardine problem" is basically a "food problem."

## THE POTENTIAL FISHERY

Since the expanded sardine research program was undertaken in 1949, there has been a continual lessening of both the amount and extent of sardine spawning off California. During 1949 there was evidence of considerable sardine spawning to the north of Point Conception, and in 1950 there was rather widespread but light spawning in this area. In 1951, however, only a single sardine egg and a single larva occurred in collections made to the north of Point Conception, and during 1952 (Figs. 12 and 13) neither eggs nor larvae were taken north of Santa Barbara.

Sardine spawning has been found to occur mostly in two centers, one off Southern California and adjacent Baja California, the other off central Baja California. The northern center has decreased in importance year by year. In 1950, approximately 17 percent of the sardine eggs were taken off Southern California and adjacent Baja California, in 1951 only 6 percent, and in 1952 only 3 percent. There has been no noticeable decline in abundance of either eggs or larvae in the area off central Baja California, however.

In former years, as the older sardines disappeared from the fishery, new year classes entered the fishing grounds and thus maintained the fishery. In the past four seasons no adequate replacement has occurred. During the late summer and fall months of 1950, 1951, and 1952, inshore surveys were made of the relative abundance of all age groups in the sardine population. These surveys covered the entire coast from Northern California south to Magdalena Bay, Baja California. The results (Fig. 14) indicate that no great numbers of sardines have survived from spawnings since 1948. In 1950, when the 1948 year class was two years old, and again in 1951, when these fish were three years old, this year class outnumbered each of the younger groups, 1949, 1950, and 1951. By 1952 all age groups except the 1952 year class, only six months old, were reduced to a low level. At six months the 1952 year class was not as abundant, however, as was the 1948 year class at two years of age. No great contribution to the California fishery can be anticipated, therefore, from this age group in the coming years.

## SUMMARY: THE POTENTIAL FISHERY, 1 JULY 1953

1. Since 1949, sardine spawning has progressively lessened both in amount and extent off California.
2. There has been no noticeable decline in the abundance of either eggs or larvae off central Baja California.
3. Young-fish surveys indicate that no great numbers of sardines have survived from spawnings since 1948.
4. By 1952 all age groups of sardines were reduced to a low level except the six-month-old 1952 year class; these fish are too young to contribute a large tonnage to the California fishery in the 1953-54 season.

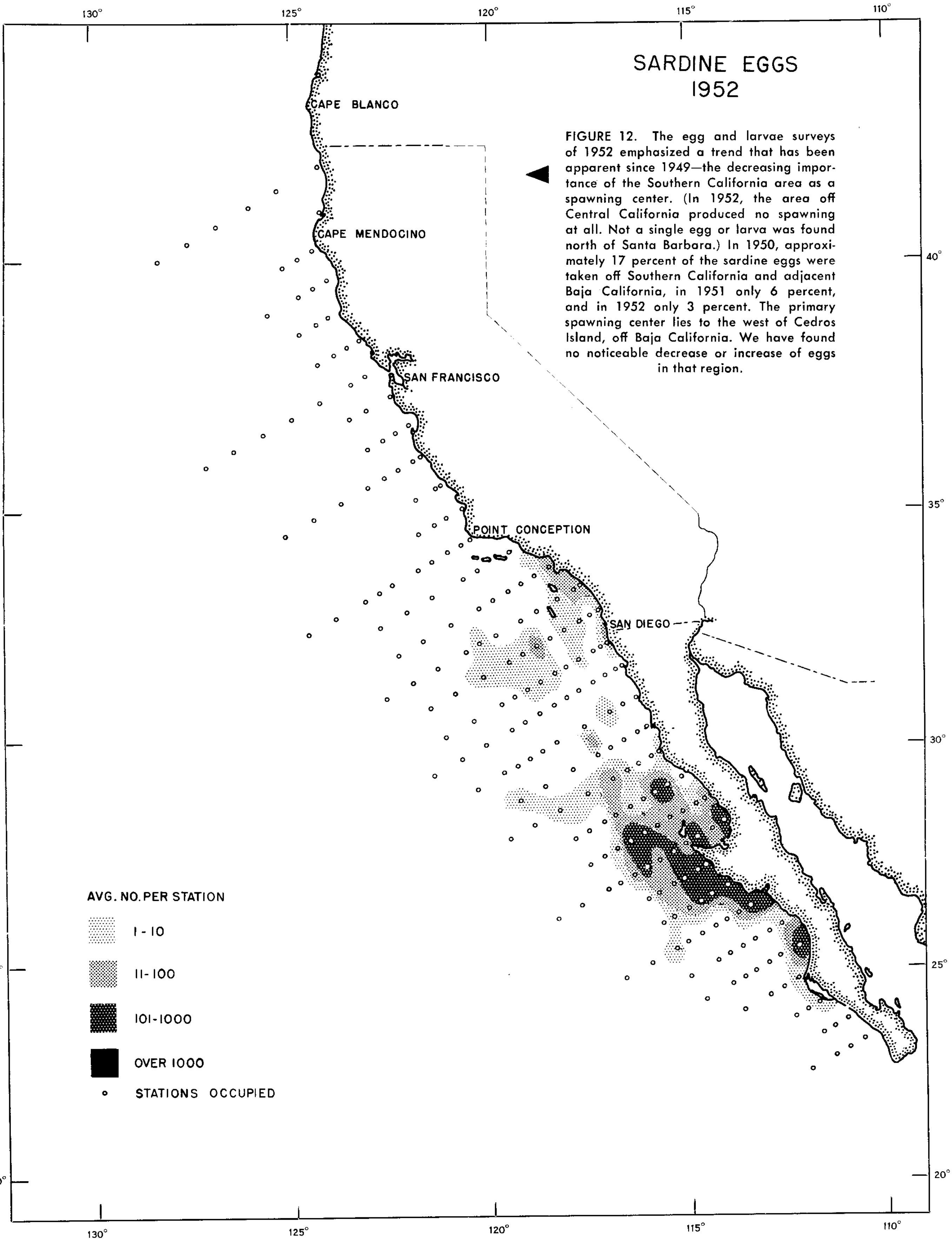



FIGURE 12. The egg and larvae surveys of 1952 emphasized a trend that has been apparent since 1949—the decreasing importance of the Southern California area as a spawning center. (In 1952, the area off Central California produced no spawning at all. Not a single egg or larva was found north of Santa Barbara.) In 1950, approximately 17 percent of the sardine eggs were taken off Southern California and adjacent Baja California, in 1951 only 6 percent, and in 1952 only 3 percent. The primary spawning center lies to the west of Cedros Island, off Baja California. We have found no noticeable decrease or increase of eggs in that region.

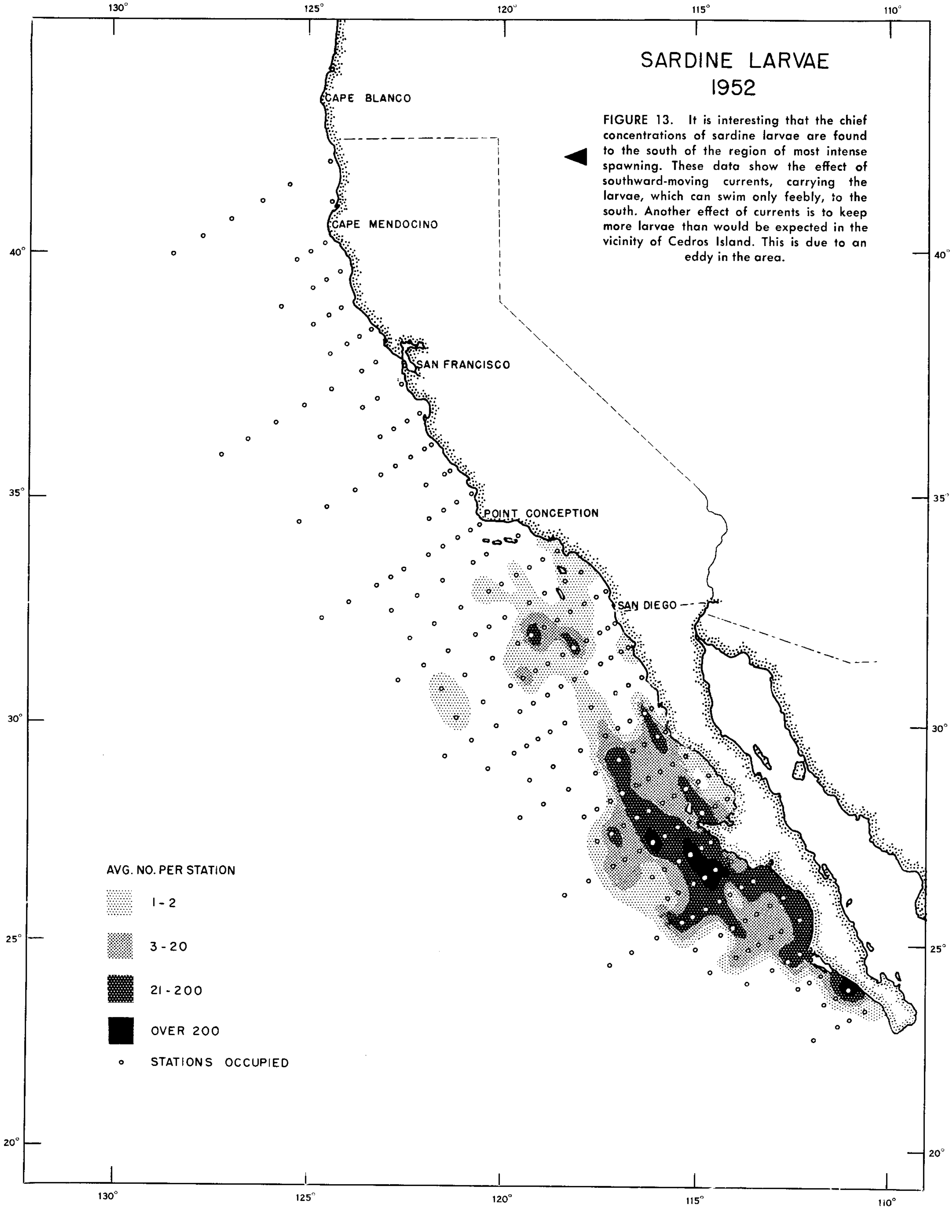



FIGURE 13. It is interesting that the chief concentrations of sardine larvae are found to the south of the region of most intense spawning. These data show the effect of southward-moving currents, carrying the larvae, which can swim only feebly, to the south. Another effect of currents is to keep more larvae than would be expected in the vicinity of Cedros Island. This is due to an eddy in the area.

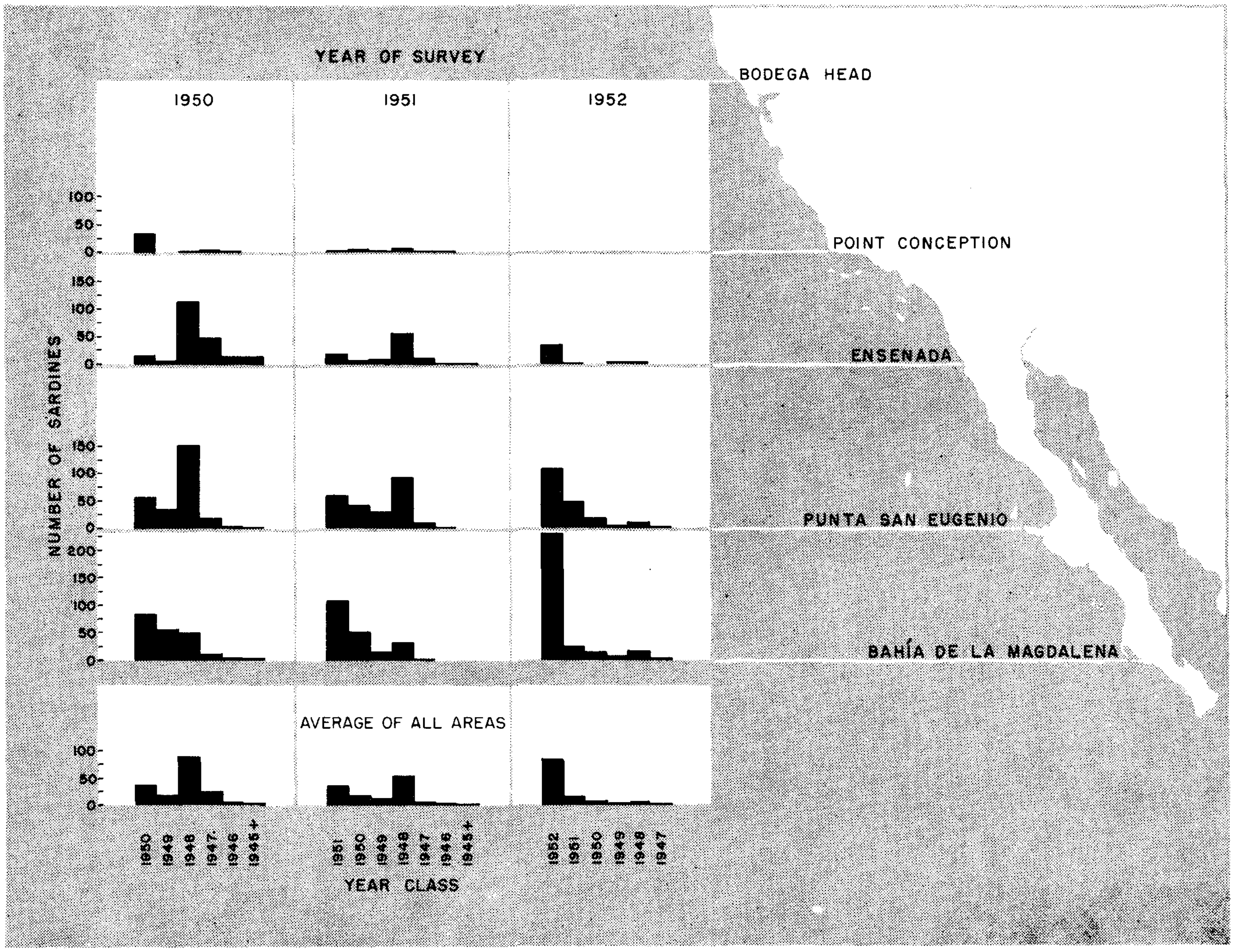



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FIGURE 14. Each year since 1950, we have sent out cruises which survey the coastal waters to observe the numbers and locations of schools of sardines. These are called young-fish surveys because their primary purpose is to assess the number of sardines six months or so old that are present. Here we present the results of the young-fish surveys, so far as they relate to sardines, for the years 1950 through 1952. The figures are standardized to the numbers of sardines of each year class sampled per night of scouting so that the figures will be comparable. It is apparent that the 1952 year class (sardines spawned in 1952) was found most abundantly off southern Baja California. Off Southern California and adjacent Baja California it was the most abundant year class yet sampled at this age, but none at all were found north of Point Conception, whereas the 1950 and 1951 year classes had been found there at the same age. Note in the combined averages (at the bottom of the figure) that the number of 1952 year-class sardines found during the 1952 surveys did not quite equal the number of 1948 year-class sardines found in the 1950 surveys. Since year classes steadily decrease in size, this would indicate that next year, at two years of age, the 1952 year class will be unlikely to equal the not particularly outstanding contribution of the 1948 year class to the catch.

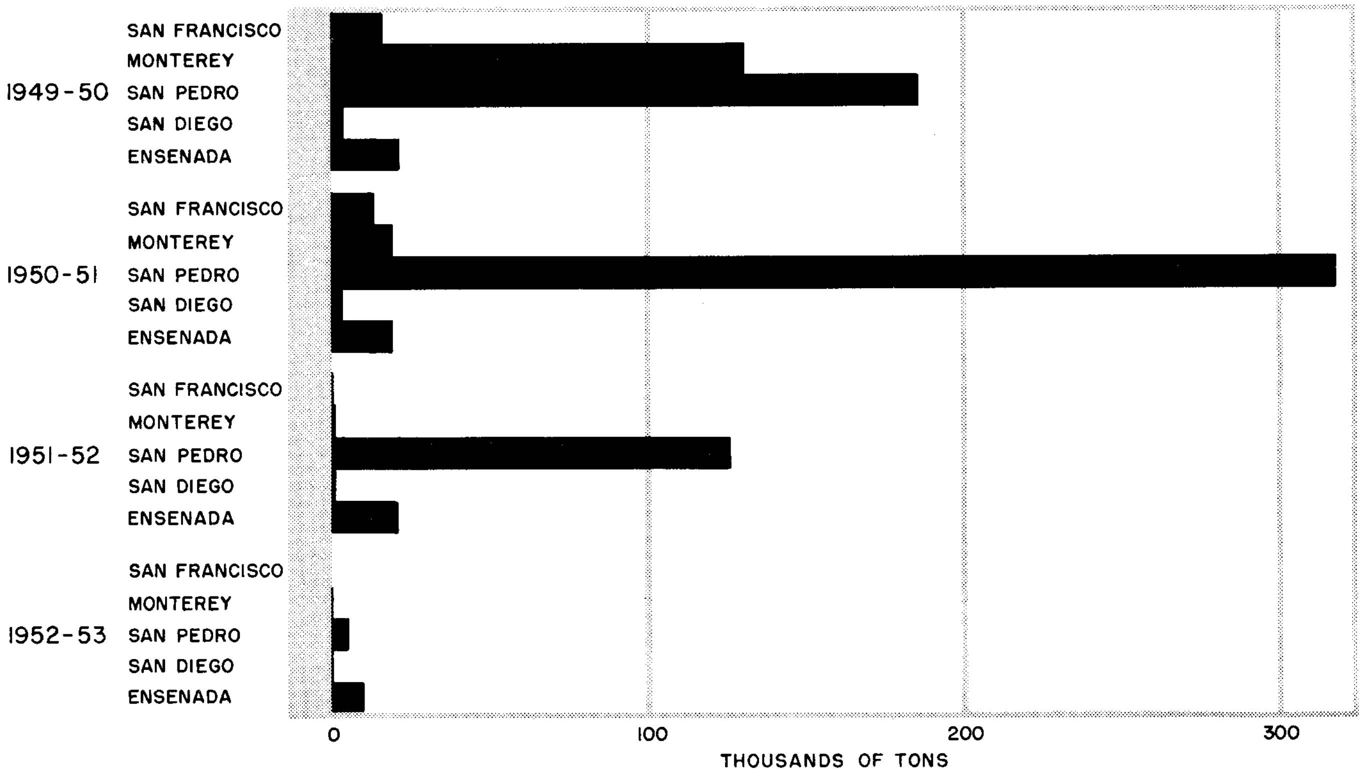


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FIGURE 15. The total California sardine catch for the 1952-53 season was 5,420 tons. Only 70 tons of the total came from ports north of Point Conception. The Baja California port of Ensenada accounted for more tonnage than all California ports even though the catch there (9,630 tons) amounted to less than half that for the previous year. The Ensenada totals are for the calendar year in which the California season starts (1949-50 = 1949, etc.). The tonnages for Ensenada were obtained through the courtesy of the processing plant operators; we much appreciate their wholehearted cooperation.

# Sardines and Man

## THE 1952-53 CATCH

In the last progress report, we forecast that the 1952-53 sardine season would be "very bleak." A better description would have been "catastrophic." The total sardine catch for the entire Pacific coast in the 1952-53 season fell to 15,000 tons, just one-tenth of the previous season's poor catch (see Fig. 15).

Most of the sardines were caught off Ensenada. Through the courtesy of processors canning sardines there, tonnages received at this port have been obtained for the calendar years 1949 through 1952. In this time interval the Mexican landings exceeded those of San Francisco and after 1950 those of Monterey also. Between 1951 and 1952 the Ensenada sardine catch declined from 21,330 tons to 9,620 tons. Yet in spite of a scarcity of sardines on the Mexican fishing grounds during the spring and early summer of 1952, the total catch for the year exceeded that for all California in the 1952-53 season.

The total catch for the four seasons during which the expanded research program has been in operation has shown great fluctuations. The tonnage landed in the 1949-50 season at California ports was about twice that of the previous season, the increase being most evident at San Francisco and Monterey. In the next season, 1950-51, the total landings again showed a slight increase, as a phenomenally successful catch off Southern California offset a serious decrease to the north. In 1951-52 practically no fish were taken on the Central California fishing grounds and the Southern California fishery showed a marked decline. Finally the entire fishery failed in 1952-53.

## AGE COMPOSITION OF THE CATCH AND MORTALITY RATES

The presence or absence of sardines on the California fishing grounds depends on the history of each individual year class comprising the population: its abundance, its availability, and its rate of decline. During the seasons 1949-50 through 1952-53 the catch was made up almost entirely of fish two, three, and four years old (Fig. 16). For this time interval these age groups represent year classes spawned in 1946, 1947, and 1948. By 1951-52 the 1946 year class had almost disappeared from the catch, there were few of the 1947 year class left, and the 1948 year class had declined in numbers. By 1952-53 too few sardines of any age group were caught on the California grounds to support a fishery.

The contraction in the distribution of sardine is indicated in Figure 17, which shows the percentage of each year class from 1937 through 1948 caught in each of four areas along the coast. This figure shows how the fishing area has contracted: it does not show another factor of great importance that also is visible in the catch—a decrease in actual numbers arising by reason of a series of small year classes being present on the fishing grounds. As the figure indicates there is considerable variation with time not only in the spatial distribution of a given year class, but also between year classes. Differences in year-class origin as well as variations in behavior account for this.

What has been happening to the sardines is shown by data collected in the course of our young-fish surveys. Though, as the name indicates, these cruises are directed primarily toward an assessment of the status of the young-fish population, information on adult fish is also gathered. For each of the year classes now in the fishery mortality rates between the years 1950 and 1951 and again between 1951 and 1952 may be estimated from the survey data. These rates appear to have been extremely high.

TABLE 1
TOTAL MORTALITY RATES ESTIMATED FROM SURVEYS ALONG THE CALIFORNIA AND BAJA CALIFORNIA COASTS

| *Year class* | *Percentage decline between 1950 and 1951* | *Percentage decline between 1951 and 1952* |
|---|---|---|
| 1945 and older | 90 | 100 |
| 1946 | 75 | 100 |
| 1947 | 70 | 90 |
| 1948 | 40 | 85 |
| 1949 | 25 | 80 |
| 1950 | 45 | 60 |
| 1951 | -- | 50 |

Mortalities were higher during both time intervals among the older age groups subject to fishing as well as natural mortalities. All rates were higher between 1951 and 1952 than between 1950 and 1951 but this increase was most marked among the younger year classes reaching sizes suitable to the fishery.

At the present time (1953) sardines older than 1948 year class have all but disappeared from the California fishing grounds. Nor are these older fish present in Baja California waters. They may have originated from spawnings off California and never have been abundant in the southern waters or the southern representatives of these year classes may have moved northward and been caught in the California fishery. On the other hand, fish of the 1948 year class and younger age groups are now more abundant off Baja California than off California. These groups probably resulted largely from southern spawnings. The 1948 year class has made a material contribution to the California fishing grounds but no great numbers of the 1949 and 1950 groups have been caught. The success or failure of the fishery in the immediate future will be largely determined by the number of sardines that may move from the Baja California waters onto the California fishing grounds.

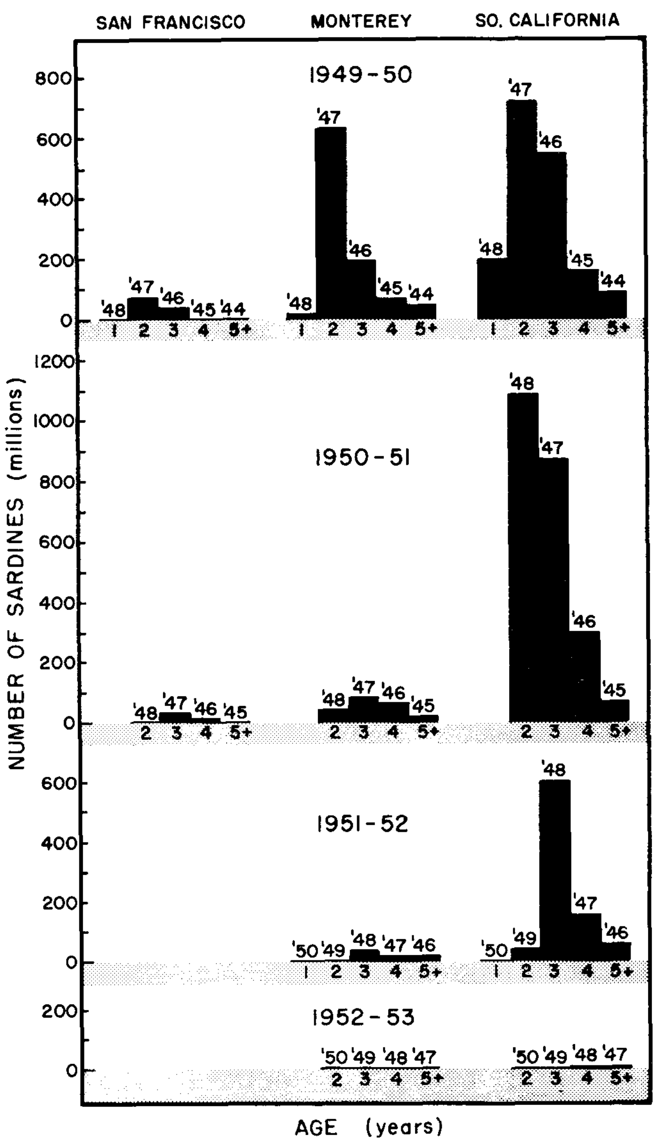
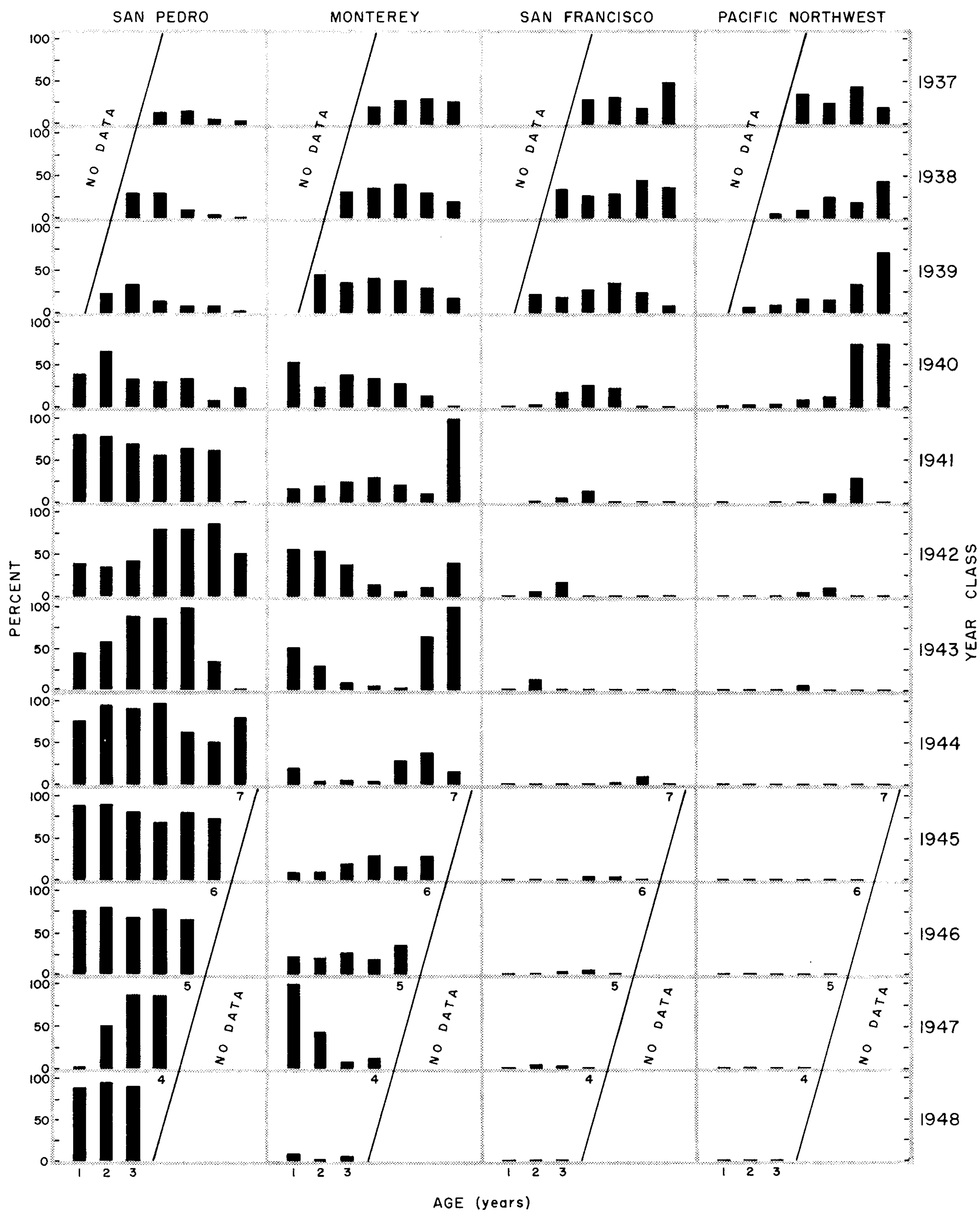



FIGURE 16. In this figure we show a breakdown of the California catch for the past four seasons for each of three areas according to the age groups taken in the commercial catch. (We have no similar figures for the Mexican fishery.) As can be seen, the fishery for the first three seasons depended primarily on the two- and three-year-old fish. The insignificant 1952-53 catch came from the four- and five-year-old fish. For four seasons the California fishery has depended on fish spawned in 1948 and previously. There has been no significant contribution from the younger year classes, nor, as has been indicated in Figure 14, can we expect one from any year class in the fishery at the present time.

FIGURE 17. This rather complex graph documents an important aspect of the sardine situation. There has been a great contraction of the sardine population. For purposes of comparison, we assume that all the year classes from 1937 to 1948 were of the same numerical strength. Each bar in the graph represents the percentage of the total fish of a particular year class at a specific age that were caught at a single port. Thus, for example, if we add the percentages for the 1940 year class at three years of age for each of the four areas, we arrive at 100 percent. By eliminating variations in year-class strength, we emphasize the strong southward contraction of the fishery.


SAN PEDRO
MONTEREY
SAN FRANCISCO
PACIFIC NORTHWEST
PERCENT
YEAR CLASS
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
NO DATA
AGE (years)

## AVAILABILITY ON THE FISHING GROUNDS

The data that we collect on the catch and the amount of effort spent to take the catch may be used to derive information on how much changes in fish distribution and behavior may affect the availability of the fish to the fisherman. They will not, of course, tell us why such changes take place, but they do constitute a record of those changes.

One method of estimating total population size also yields estimates of the fraction, or percentage, of the total population that is available to the California fishermen each season. The changes in this availability fraction from one season to the next are given in Figure 18. It is important to note that the availability fraction pertains not to the absolute *numbers* of fish on the fishing grounds, but rather to that *fraction* of the total number of fish which are on the fishing grounds, regardless of what the total number may be. The figures thus refer to the changes in that fraction from one season to the next.

So far no one can say exactly why some fish are unavailable, where they are when they are unavailable, or why the degree of availability varies with time. Several explanations can be suggested: differences in schooling behavior in any given area (recent results of the young-fish surveys indicate that there may actually be a size or age difference in schooling behavior and that this explains why the small, young fish are ordinarily not represented in the catch in proportion to their true abundance in the ocean); inshore and offshore movements; north and south movements (for which there is considerable evidence from tagging); up and down movements; and so on.

Some data have been collected within the last few years which will yield information on north and south movements. In this case we may consider fish which are south of the International Boundary as unavailable to the California fishermen. Of course, any particular fish may move so that it is at one time north of the Boundary, then south of it, then north, etc. But while it is south of the Boundary, it is unavailable to the California fishermen. It was suggested in the last progress report that one source of variation in the San Pedro catch could be the existence of a "southern" group of sardines which moved onto the California grounds in varying amounts in different seasons. The data mentioned bear on this.

Collections of sardine eggs can also be used to estimate the total number of spawning fish and, also, the geographic distribution of these fish during the spawning season. The young-fish surveys yield information as well on the distribution of adults within the time and place of the survey. Comparison of these two independent sources of information shows a net northward movement of fish between spring and fall (Fig. 19). (Our data are so arranged that it has been easier to show the percentages north and south of

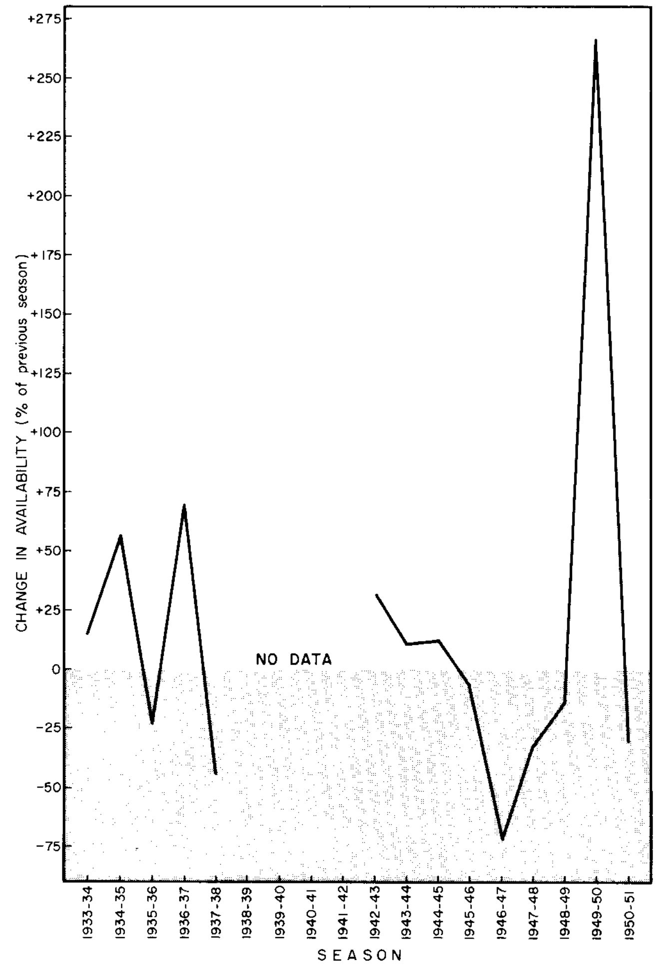



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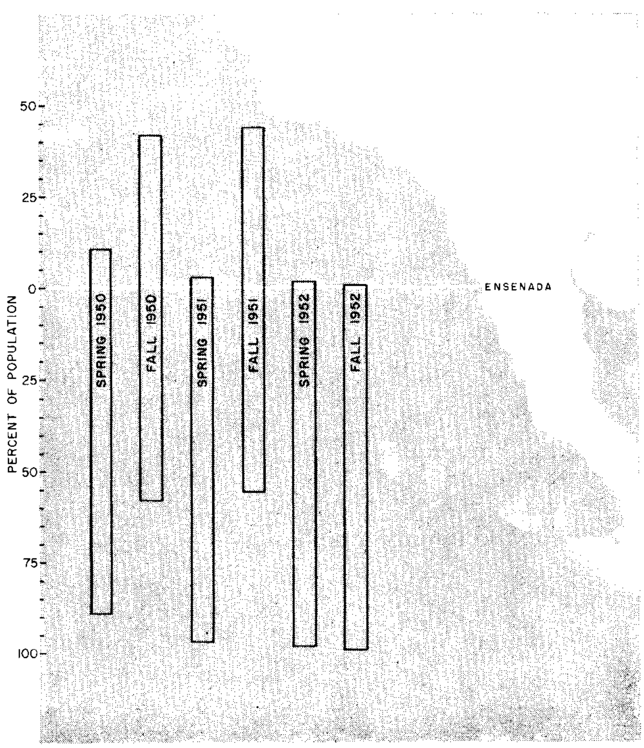
**FIGURE 18.** The factor of availability varies from season to season, sometimes operating to increase the expected catch, sometimes to decrease it. In this figure we have charted estimates of the changes in availability from one season to the next for two periods. The table shows, for example, that the fraction of the population available to the fishermen in 1934-35 was 56 percent greater than in 1933-34; that in 1935-36 it was 23 percent less than in 1934-35; and so on. It is important to note that these estimates do not pertain to the absolute numbers of fish on the fishing grounds, but rather to that portion of the total number on the fishing grounds regardless of what the total may be. So far, no one can say exactly why some fish are unavailable, where they are when they are unavailable, or why the degree of availability varies with time.

FIGURE 19. California sardine fishing stops at the International Border between the United States and Mexico. Information from two separate sources locates the bulk of the adult sardine population south of the border at all times of the year. (In this chart we have arbitrarily displaced the border to Ensenada to avoid some complex and rather unproductive reworking of the data.) Each bar represents the entire population, regardless of its numerical size. The egg surveys show that during the spring and early summer months, most of the spawning fish are south of Ensenada. The young-fish surveys, which also yield information on the distribution of adult sardines, also locate the majority of the sardines south of Ensenada, though the proportions have sharply changed, indicating a net northward movement in the summer and early fall months. A possible explanation lies in the existence of separate, but mingling, subgroups in the sardine population, with one centered off Baja California (the "southern fish" of last year's progress report), another off Southern California.




Ensenada, rather than the International Boundary. The few miles between the Boundary and Ensenada are unlikely to cause any major distortion of the information.)

In 1950, only 11 percent of the spawning fish were north of Ensenada in the spring, but by fall 39 percent of all adults were north of Ensenada, a net northward movement of about 28 percent of the adult population. In 1951 the net northward movement was about 25 percent and 1952 there was a slight net southward movement.

The reasons for movements of sardines, such as that demonstrated above, are not known. This is unfortunate, for they would be of great value in the understanding of the behavior and distribution of the population and their effects on the catch.

## A NEW METHOD OF ATTACKING THE PROBLEM OF SUBGROUPS

Much of our evidence leads us to believe that the sardine population along the coast consists of several local populations that may mingle to a small or large extent. Last year we described some of the evidence for this theory. This year we can say a little more about a new technique, borrowed from geneticists, that may eventually clear up this matter.

The technique is paper partition chromatography. The genetic constitution of an organism is known to affect its biochemical makeup. The technique requires that one treat a bit of tissue (we are using muscle) with chemical solvents. The tissue is placed on a sheet of filter paper and allowed to dry. The edge of the paper is immersed in a solvent; with the paper acting as if it were a wick, the solvent dissolves out various components of the muscle tissue and carries them along the sheet. When the process is stopped it is found, by application of ultra-violet light or special indicators, that the substances are distributed in a linear series of spots, each spot being a definite chemical compound (see Fig. 20). The pattern of spots formed is characteristic of the species. It is hoped that further research will yield patterns representative of subgroups.

Obviously if sardines carry such a "built-in" tag, a number of interesting questions can be answered, but wholly reliable and significant information is unlikely to emerge from the use of this technique until we have had time to determine its limitations.

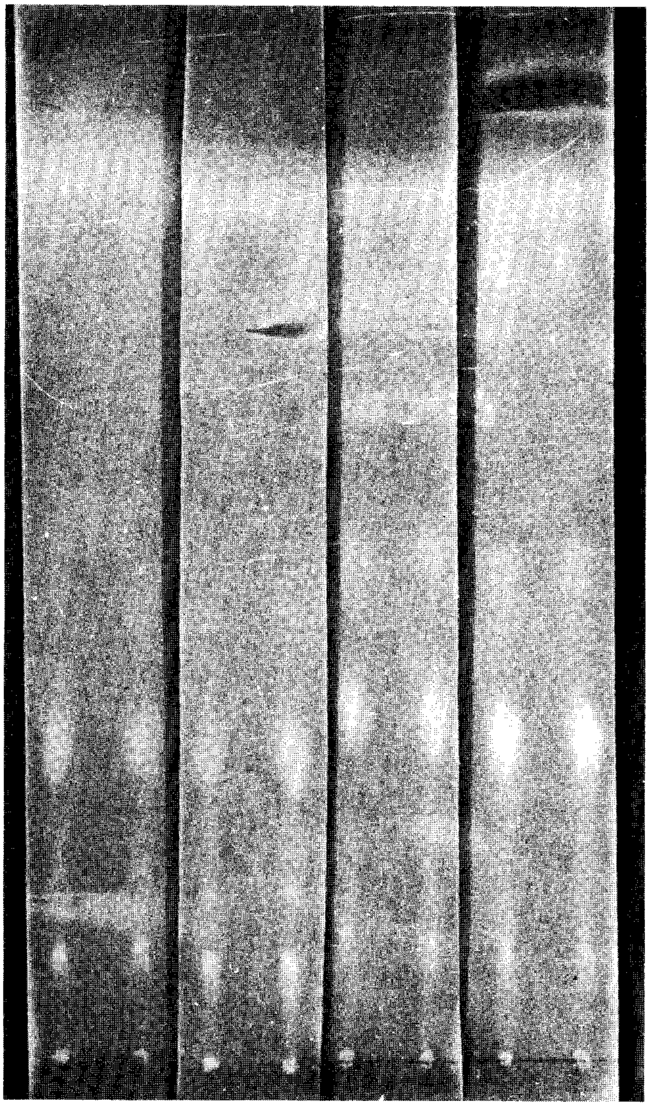


FIGURE 20. Recent experiments indicate that sardines, like other living creatures, may carry a "built-in" tag. The technique of paper partition chromatography is being tried on an experimental basis on Pacific sardines to see if it offers a means for the study of such problems as migration and subgroups. A bit of dried muscle tissue on a sheet of filter paper is treated with chemical solvents, which dissolve out various components of the tissue and carry them along the sheet. When the process is stopped it is found, by application of ultra-violet light or special indicators, that the substances are distributed in a linear series of spots, each spot being a definite chemical compound. The pattern of spots formed is characteristic of the species. Here we show two chromatograms each from sardines from (left to right) Punta Blanca, Lagoon Head, Morro Hermoso, and Punta Abreojos. Variations in the patterns may point to slight but significant differences between sardines from different environments.

## SUMMARY: THE STATUS OF THE ADULT SARDINE POPULATION, 1 JULY 1953

1. In the past four years we have witnessed a decrease in numbers of sardines of all sizes on the California fishing grounds, and a maintenance, but no marked increase, in the numbers in Baja California waters south of Ensenada.
2. By 1952-53, too few sardines of any age group remained on the California grounds to support a fishery.
3. A contraction of the area in which the sardines are caught has been paralleled by a series of poor year classes.
4. Between 1951 and 1952, estimated mortality rates increased greatly over the preceding year's estimate.
5. The success or failure of the fishery in the immediate future will be largely determined by the number of sardines that may move from the Baja California waters onto the fishing grounds.
6. There is evidence for a vastly increased availability in the 1949-50 season, with a declining availability since then.
7. Estimates of population size have yielded information that indicates a variable net northward movement from Baja California to Southern California of sardines in the fall, and this variability accounted in part for the failure of the 1952-53 season.
8. A new technique has been introduced for the study of the problem of subgroups.

# Sardines and "Substitute Sardines"

With a declining catch, the sardine industry has been forced to seek and use more of those species which are usually mixed in with sardine schools, the anchovy, the jack mackerel, the Pacific mackerel. We call these fish "substitute sardines" because being less profitable to can or process than sardines, they are being fished extensively at present only in lieu of the sardine. These fish have always been taken in some numbers, but only recently have they played much of a part in the total California catch. For the 26 years preceding the 1946-47 season, in fact, the sardine dominated all California marine fisheries in numbers caught (Fig. 21), and in dollar value amounted at times to 40 percent of the total value of California landings (Fig. 22).

During the 1952-53 fiscal year, the work of the Marine Research Committee was supported by a special tax on anchovy, jack mackerel, and Pacific mackerel, as well as sardine landings. The additional tax support did not require extensive reorientation of the research program, for inevitably in the study of sardines we have collected much information on those fish which are competitors and sometimes predators of the sardine. It was not until 1952 that the catch of these "substitute sardines" exceeded the sardine catch itself (Fig. 23).

The "substitute sardines" are collected as eggs and larvae (Figs. 24 through 26) and are sampled during the young-fish surveys. Comparative data on the feeding habits of larval sardines, jack mackerel, and anchovy have been collected (Fig. 27). Figure 28 shows observations made on all four species during the young-fish surveys.

In the following sections, we shall summarize in turn what we have learned of each of the "substitute sardine" species.

## ANCHOVY

### *The Catch*

Anchovies taken in the California fishery have two major uses, bait and canning. Formerly bait, both live and dead, exceeded canning in importance and still does in Southern California. In this region the live-bait fishery used 7,000 tons in 1952, and the Central California canneries brought the total anchovy catch to 34,500 tons.

### *Age Composition*

Preliminary analyses of the 1952 catch indicate that in Central California the 1950 and 1949 year classes each contributed about 30 percent of the fish and the 1948 year class about 25 percent. The remaining 15 percent came from older age groups. In the Southern California fishery the 1951 and 1952 year classes were taken in considerable numbers and the catch in general consisted of anchovies one or two years younger than in the Central California catch. Anchovies in the Southern California fishery ranged in length from 2.5 to 7.5 inches and in Central California from 4.5 to 8.0 inches.

### *Distribution*

Anchovies are found along the Pacific coast of North America from British Columbia south to the lower tip of Baja California. Off California and Baja California the 1950-52 surveys indicate that greatest abundance is reached in Southern California waters (Fig. 28). Throughout California they exceeded the abundance of the sardine during these three years but off Baja California in the young-fish surveys the anchovies were considerably less abundant than the sardine.

## JACK MACKEREL

### *The Catch*

Jack mackerel did not become of great importance in the California fishery until the 1947-48 season when slightly over 71,000 tons were caught. In the succeeding seasons the catch has fluctuated between 25,000 and 65,000 tons. The landings have varied in general with the successes and failures of the sardine and Pacific mackerel fisheries. Jack mackerel serve as a substitute canning fish when the latter two species are not obtainable in sufficient quantities to meet the canned fish demand. Over three-fourths of the catch has been taken in Southern California waters and landed in the Los Angeles region.

### *Age Composition*

Preliminary studies of the ear bones of the jack mackerel have shown that these fish attain an age of over 25 years. Most of the fish in the commercial catch have been less than six years old with the majority either two, three, or four years. On rare occasions catches have been made of extremely large individuals ranging in age from 10 to over 25 years. These largest fish are between two and two and one-half feet long and weigh over four pounds. The majority of the jack mackerel in the catch were from 8 to 15 inches in total length.

### *Distribution*

Only one species of jack mackerel occurs along the Pacific coast of North America. It ranges from Acapulco, Mexico, northward to British Columbia and offshore over 500 miles. A superficially similar fish, the Mexican scad, which is rather abundant off Baja California and has been taken off San Clemente Island, California, could be confused with the jack mackerel.

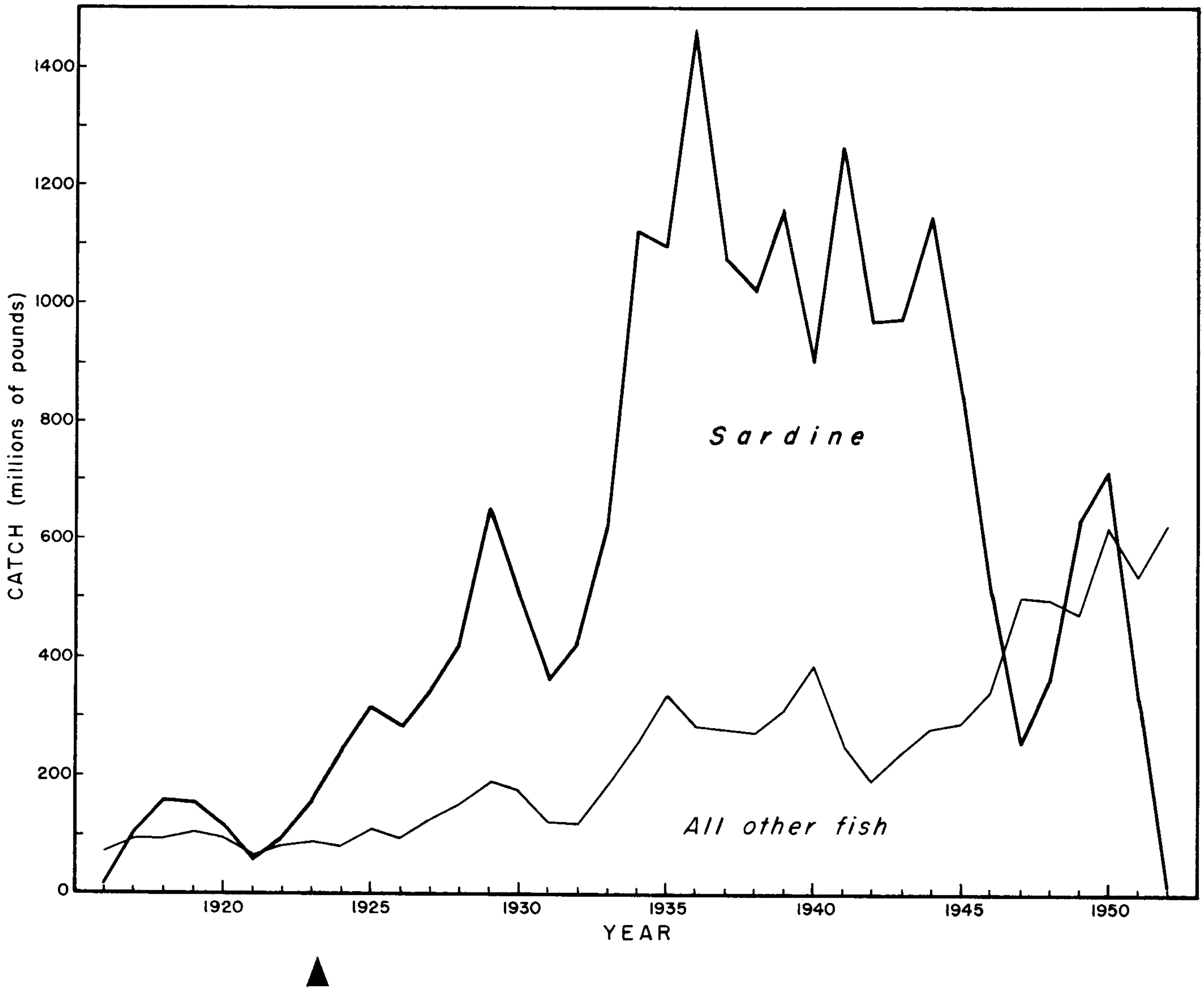



FIGURE 21. From 1922 to 1946, the catch of Pacific sardines exceeded in weight that of all other California fisheries combined, particularly so during the 1930's.

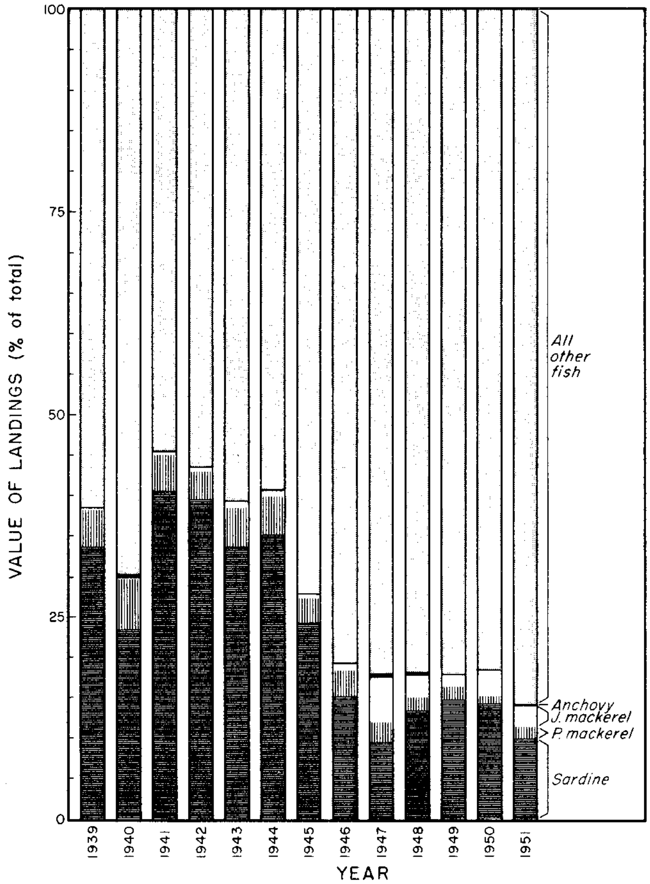
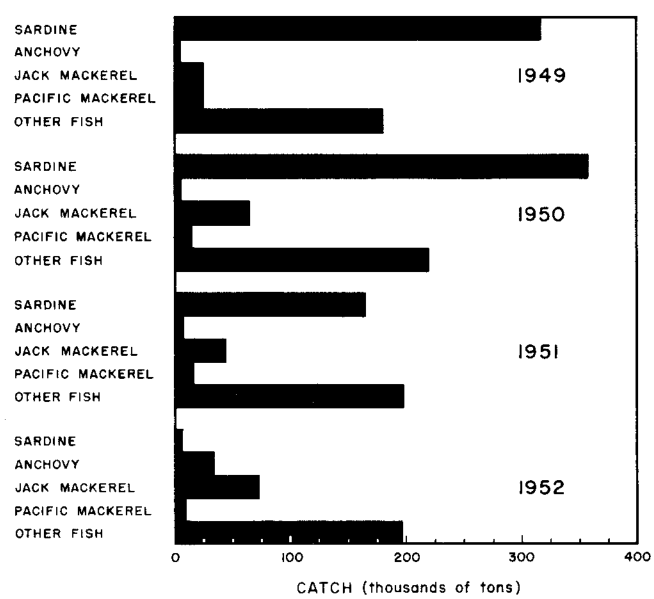
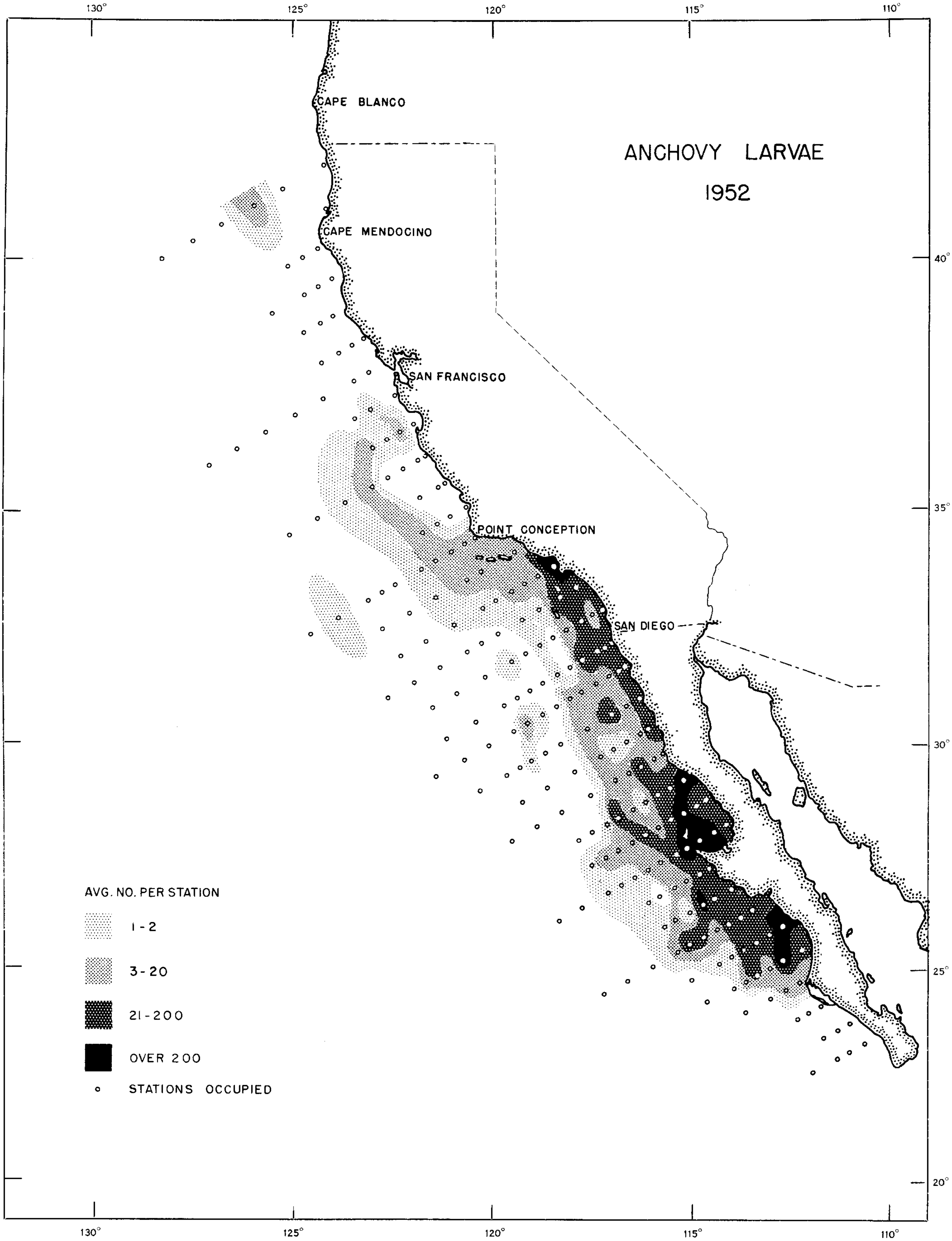



FIGURE 22. In the 13 years, 1939 through 1951, the sardine accounted at times for almost half the total dollar value of all California landings and shipments of fish, mollusks, and crustaceans. But recent years have shown sharp decreases in the sardine percentages, sharp increases in those of the "substitute sardines," Pacific mackerel, jack mackerel, and anchovy. There has been an increasing dependence on jack mackerel and anchovy as the sardine catch has declined.

FIGURE 23. Catches of sardines and Pacific mackerel have shown a downward trend since 1949. Landings of anchovy, jack mackerel, and other species have increased.





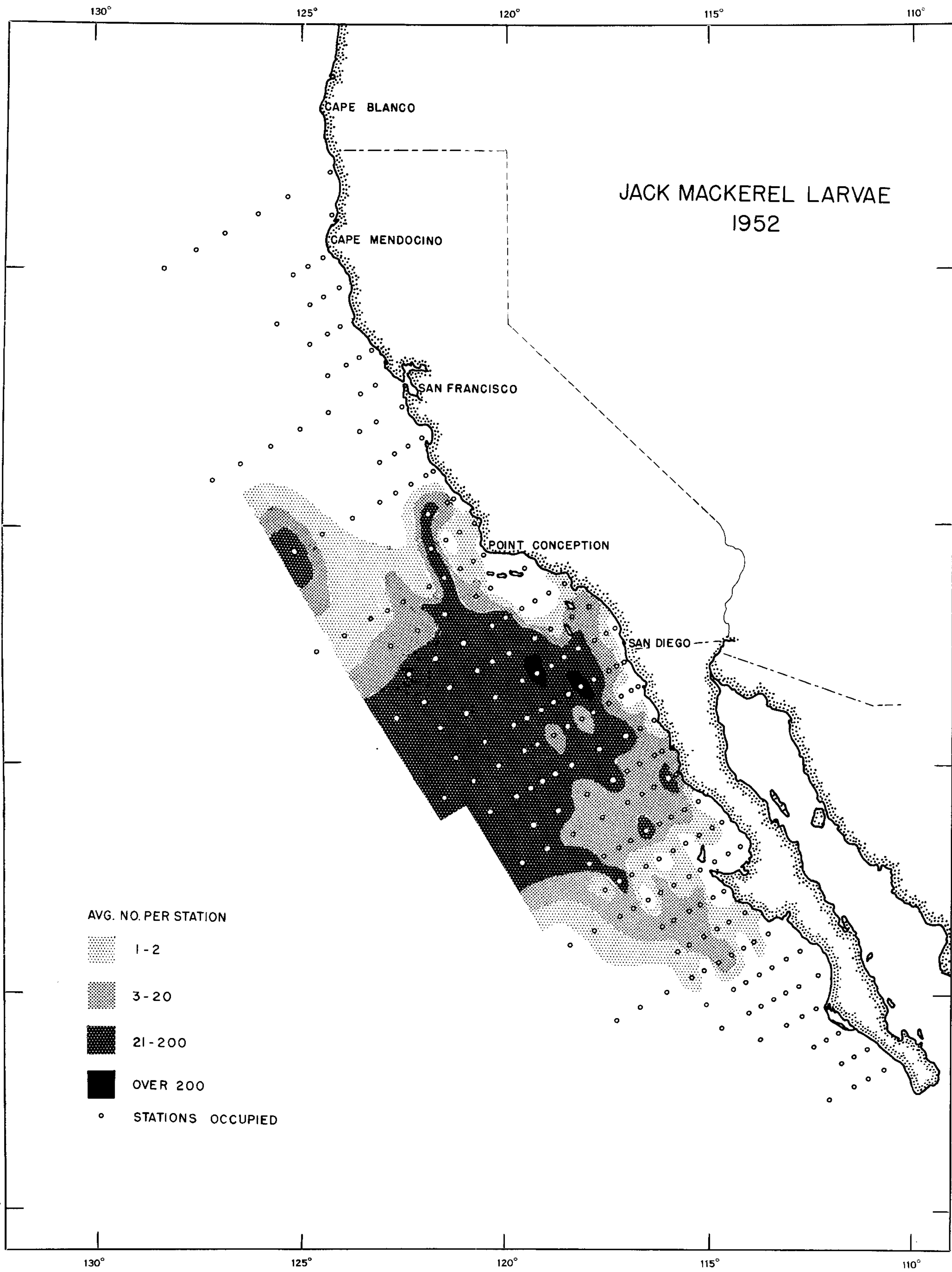
ANCHOVY LARVAE
1952
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
AVG. NO. PER STATION
1-2
3-20
21-200
OVER 200
STATIONS OCCUPIED

FIGURE 24. During both 1951 and 1952, we have found anchovy larvae second in abundance in our collections, being exceeded only by hake larvae. (The hake is not fished commercially on this coast.) Although anchovies are known to spawn from British Columbia to Cape San Lucas, the larvae are taken in greatest abundance to the south of Point Conception. The larger concentrations of anchovy larvae occurred in a coastal band seldom more than 100 miles wide and usually much narrower, but some larvae were taken as far as 200 miles offshore during 1952. However, a noticeable difference between the distribution of anchovy larvae in 1952 as compared to the preceding year was the concentration of the larvae closer to shore.

To the north of Point Conception, anchovy larvae were obtained during a three-month period, July through September, though never in large numbers. Off Southern California and adjacent Baja California, on the other hand, anchovy larvae were taken on every cruise.

Anchovy larvae were approximately four times as abundant off central Baja California as off Southern California and adjacent northern Baja California. The largest concentration of larvae—over 200 per haul on the average—was obtained in Sebastian Vizcaino Bay. Collections made within 50 miles of the coast in other areas off central Baja California averaged approximately 140 larvae per haul, as compared to approximately 35 larvae per haul off Southern California.

Approximately 60 percent of the larvae taken off Southern California were collected within 25 miles of shore, and 83 percent within 50 miles of the coast. In the central Baja California area, larvae were equally abundant out to 50 miles from shore, 77 percent being contained in this zone. Only about 1 percent were taken farther offshore than 100 miles in Southern California waters, while nearly 7 percent occurred at distances greater than 100 miles off central Baja California.


JACK MACKEREL LARVAE
1952
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
AVG. NO. PER STATION
1-2
3-20
21-200
OVER 200
STATIONS OCCUPIED
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°

◄ FIGURE 25. We have found the center of abundance of jack mackerel larvae is off Southern California and adjacent Baja California, between Point Conception and Cape San Quintin. The season of greatest abundance is during the five-month period, March through July.

Jack mackerel larvae are taken farther offshore than either sardine or anchovy larvae, the largest concentrations occurring between 50 and 200 miles to sea. During 1952, the larvae were found farther offshore (160-240 miles from the coast) during the early months of the year and closer inshore (50-125 miles from the coast) during the months July through September. We are not delimiting the offshore distribution of jack mackerel larvae. This is especially true of the 1952 cruises, when offshore coverage was less extensive than during either 1950 or 1951. The distribution of jack mackerel during 1952 was rather similar to that found during 1950. Both seasons differed from 1951 in two respects: (1) the peak of abundance occurred a month later than during 1951 and (2) the larvae were not distributed as far northward. During 1952 only 2 percent of the larvae were taken to the north of Point Conception, while during 1951 nearly 15 percent of the larvae were found in this area.

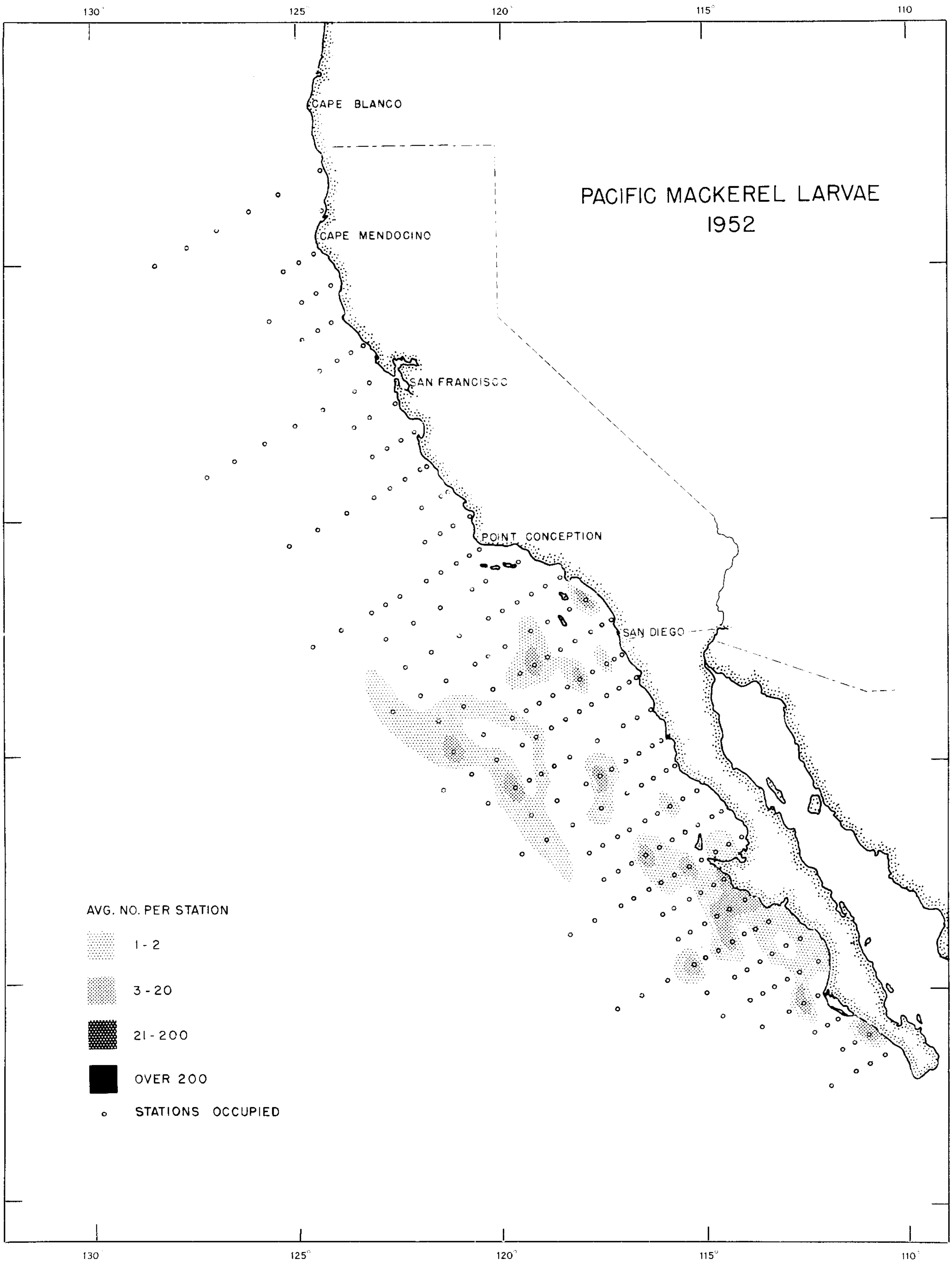
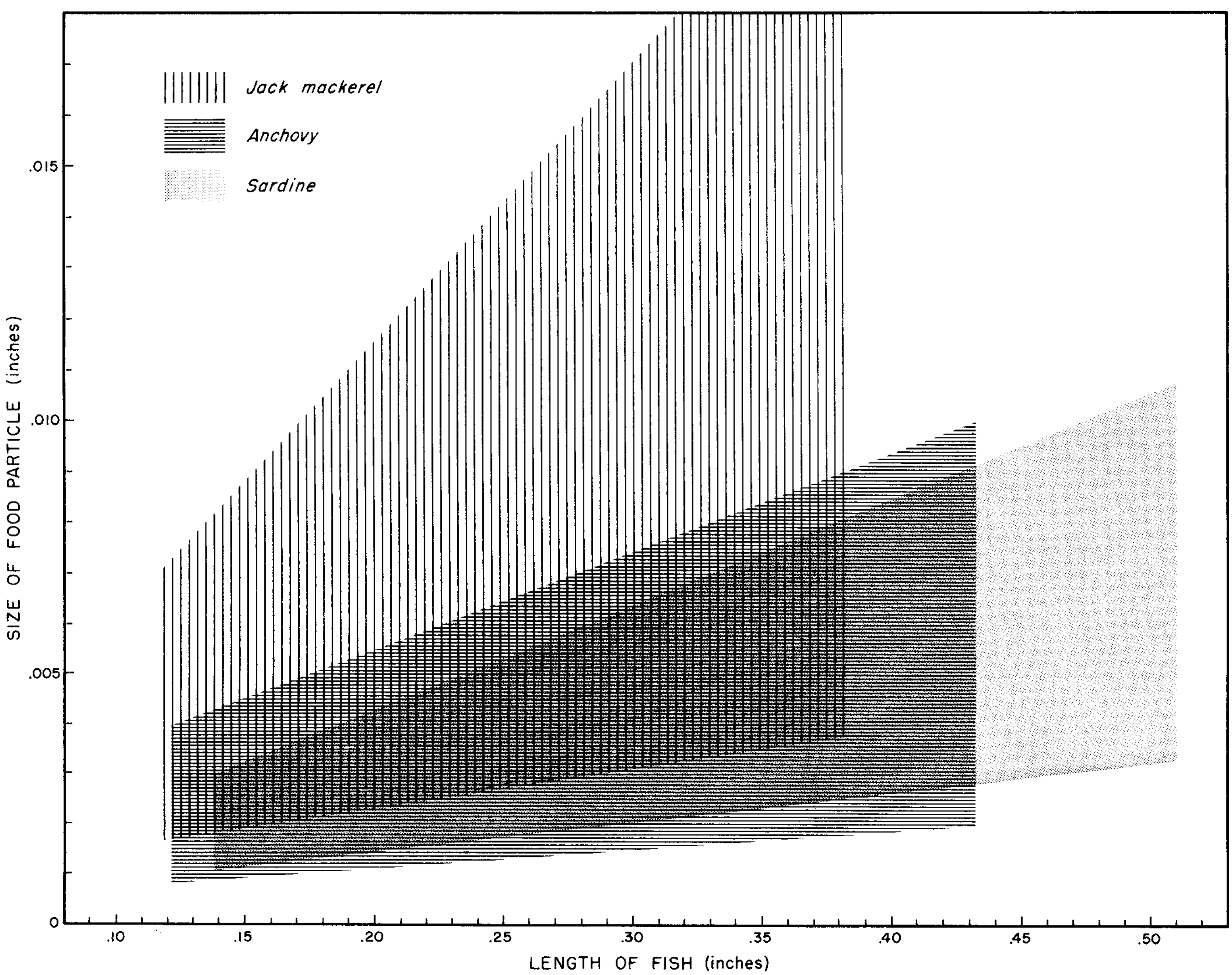

PACIFIC MACKEREL LARVAE
1952
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
130°
125°
120°
115°
110°
40°
35°
30°
25°
20°
AVG. NO. PER STATION
1 - 2
3 - 20
21 - 200
OVER 200
STATIONS OCCUPIED

FIGURE 26. Pacific mackerel larvae occur off Southern California and along the length of Baja California. The larvae have a fairly widespread distribution, especially off Southern California, occurring as far seaward as 300 miles. During the 1952 season approximately 20 percent of the Pacific mackerel larvae were obtained off Southern California and adjacent Baja California, and 80 percent off central Baja California. The period of maximum occurrence off Southern California during 1952 was May through July. The season was a month later than during 1951, when the largest numbers were taken during April, May, and June. Off central Baja California the larvae have been taken during every month of the year. During 1952, the largest numbers were obtained during April and May. In many respects the distribution of Pacific mackerel larvae is similar to the distribution of sardine larvae (Fig. 9). There are two major centers of abundance, one off Southern California and adjacent Baja California, the other off central Baja California. The largest numbers of larvae of both species are taken in the southern spawning center. Even the seasons of spawning of the two species are similar, being mostly limited to April through June (or July) off Southern California, while occurring during most of the year off central Baja California. In the latter center the larvae of both species are taken farther offshore during the spring months than during the late summer or fall, when most occurrences are within 25 miles of the coast.

FIGURE 27. Competition for food between the sardine and other species seems to be at its most intense during the larval stages when, our studies have revealed, the anchovy and sardine compete directly for microscopic food items. The jack mackerel larva, which is larger than either the anchovy or sardine larvae, also eats some particles of the same size, but feeds more on larger items which the anchovy and sardine larvae are unable to ingest. This information comes from studies of the food contents of several hundred larval sardines, anchovy, and jack mackerel.



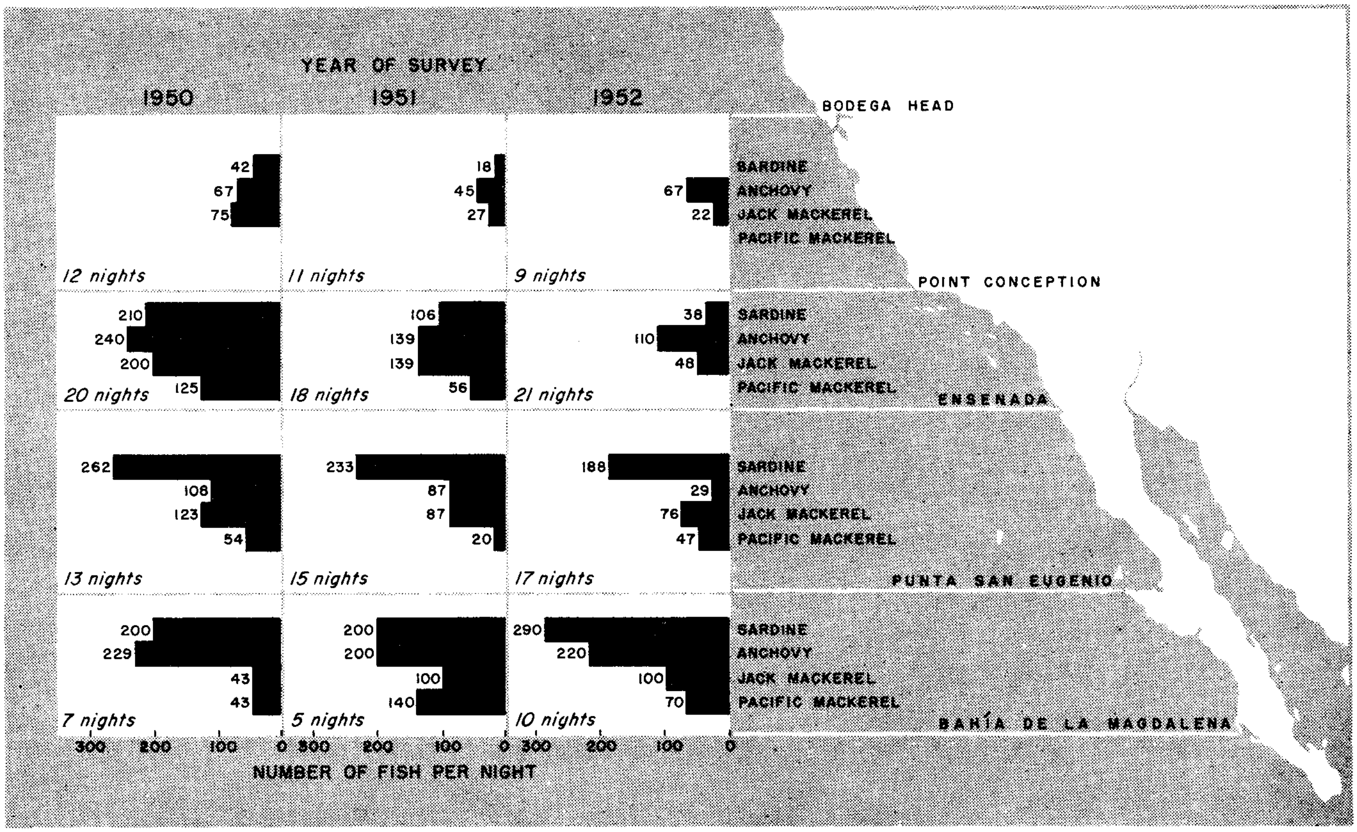



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FIGURE 28. The young-fish surveys collect specimens of all four species. Here we show the numbers of sardines, anchovies, jack mackerel, and Pacific mackerel collected per night at various areas along the coast during the surveys of 1950, 1951, and 1952. In 1952 only anchovy and jack mackerel were collected north of Point Conception. The largest numbers of all species were collected off southern Baja California.

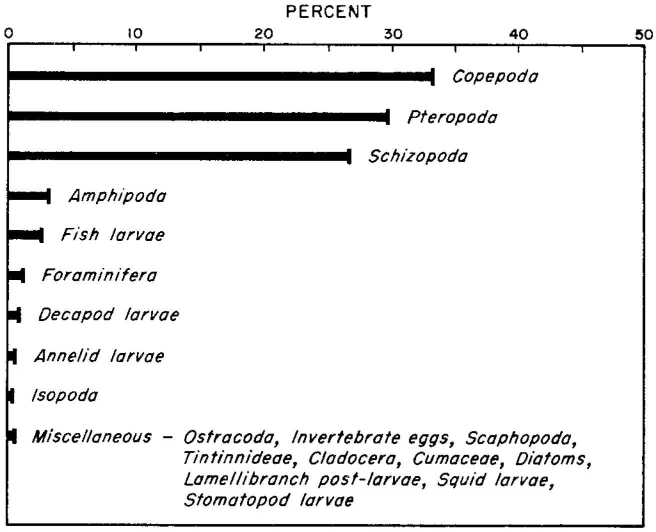


**FIGURE 29.** The jack mackerel feeds largely on small crustaceans, these creatures making up about 65 percent of the food items eaten by fish studied. Minute mollusks make up another large percentage of the food of the jack mackerel. Percentages are based on numbers.

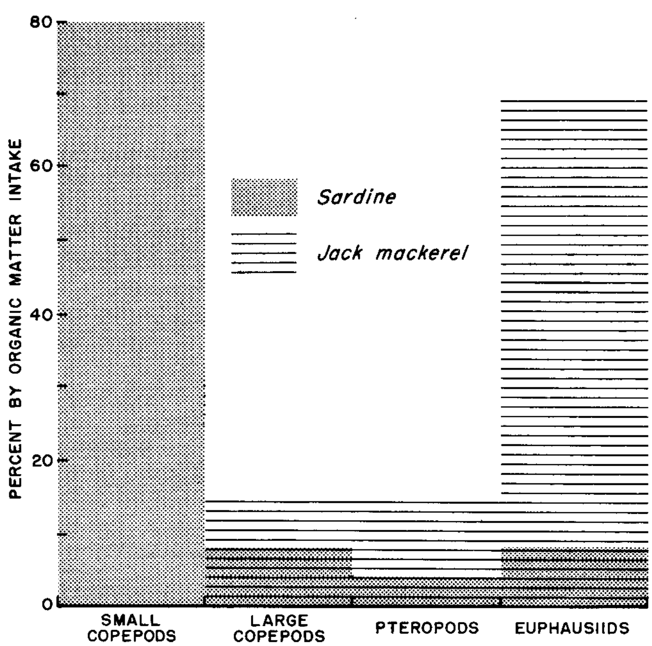


**FIGURE 30.** Competition for food hardly exists between the adult sardines and jack mackerel. Here we show the percentage by volume of organic matter intake of several food items important in the diet of both species. The overlap of the two shaded areas shows the amount of competition.

Jack mackerel occur farther offshore than other species and our surveys only reflect the relative abundance of these fish in the inshore waters.

The 1950 and 1951 surveys indicate that jack mackerel were most abundant off Southern California and northern Baja California but in 1952 a somewhat greater proportion was found in central Baja California. Off southern Baja California the numbers of jack mackerel declined in all surveys (Fig. 28).

### *Food*

Food studies of 150 juvenile and adult jack mackerel showed 51 percent with some identifiable food present. Over 90 percent by numbers of all food consisted of small crustaceans (copepods), larger shrimp-like crustaceans (euphausiids) and minute mollusks (pteropods) (see Fig. 29). Crustaceans alone made up 65 percent of all food eaten. Among the juvenile fish copepods were a more important food item than among the adults. These crustaceans and mollusks are among the most common animals in the plankton and it seems probable that food does not limit the distribution of jack mackerel to any particular area.

Samples of planktonic food taken from the waters where the jack mackerel were found indicate that most of the food utilized by the jack mackerel is taken by a definite act of capture. In any given stomach, only a few at most of all the different organisms present in the plankton were found. Were the jack mackerel, like the sardine, a filter-feeder, merely swimming about, mouth open, the gill rakers would strain out many more types of organisms than are ever found in the stomach analyses. In addition, many stomachs have certain organisms present in far greater proportion than in the plankton collected at the time the fish were caught. This is particularly noticeable for those fish in which the stomach was greatly distended by large quantities of euphausiids with no other food present. Jack mackerel frequently can be taken on feathered and other artificial lures, on strikers and on cut bait, which is further evidence of a particulate feeding habit.

Since the sardine and jack mackerel sometimes occur together in schools, spawn in part on the same grounds, and occupy in part the same waters off our coast, it is of interest to see how much competition there is between these species for food.

A comparison (Fig. 30) indicates that here too there may be competition, but perhaps even to a lesser extent than between their larvae. The sardine is an omnivorous filter-feeder which at times may exercise its ability to select particular items from the plankton, while the jack mackerel is entirely a selective particulate feeder eating the larger planktonic animals. Over 90 percent by numbers of the food of the jack mackerel consists of three types of animals, euphausiids, large copepods, and pteropods (small mollusks), whereas by numbers the minute phytoplankters make up more than 99 percent of the diet of the sardine. On a basis of the volume of the actual organic matter (nutritive material) the phytoplankters in the food of the sardine assume a relatively minor role, while copepods become the most important single item, they alone being accountable for at least 80 percent of the nutritive intake of the fish. It should be emphasized here that the copepods eaten by the sardine are for the most part small, while those eaten by the jack mackerel are large. If we consider the diet of the jack mackerel in terms of nutritive value we discover it has quite a different aspect than the presentation by numbers might suggest. On a basis of organic matter the euphausiids become the most significant single food item, accounting for approximately 70 percent, while the large copepods and pteropods together make up most of the remaining 30 percent. The euphausiids which appear to be so important to the jack mackerel account for only 3-4 percent of the total food of the sardine and therefore very little competition exists for this food item. Also, owing to the differences in sizes of copepods used by the two fish, little competition exists here, and the same is true for the pteropods, of which the sardine eats about one-eighth the amount of the jack mackerel. The percentages in Figure 30 are based on the assumption that the four food groups included make up 100 percent of each fish's diet. From the figure it appears obvious that very little direct competition for food exists between these fish and that they may better be spoken of as complementary feeders than as competitors.

## PACIFIC MACKEREL

### *The Catch*

For the 23 seasons 1930-31 through 1952-53 the catch of the Pacific mackerel totaled 713,570 tons. Of this 92 percent was landed in the Los Angeles region (Fig. 31). Since the peak season, 1935-36, the total catch has trended downward with a marked acceleration after 1944-45.

### *Age Composition*

Although Pacific mackerel may live to be at least 12 years old, fish over eight years are extremely uncommon in the commercial catch. Pacific mackerel attain a length of about 10 inches and a weight of a quarter of a pound during their first year. A 12-inch mackerel is nearly three years old and weighs three-fourths of a pound. The largest Pacific mackerel on record was 24.8 inches and weighed 6⅓ pounds. In general two- and three-year-old mackerel have made up the bulk of the catch. In the past few seasons, however, conditions have paralleled those of the

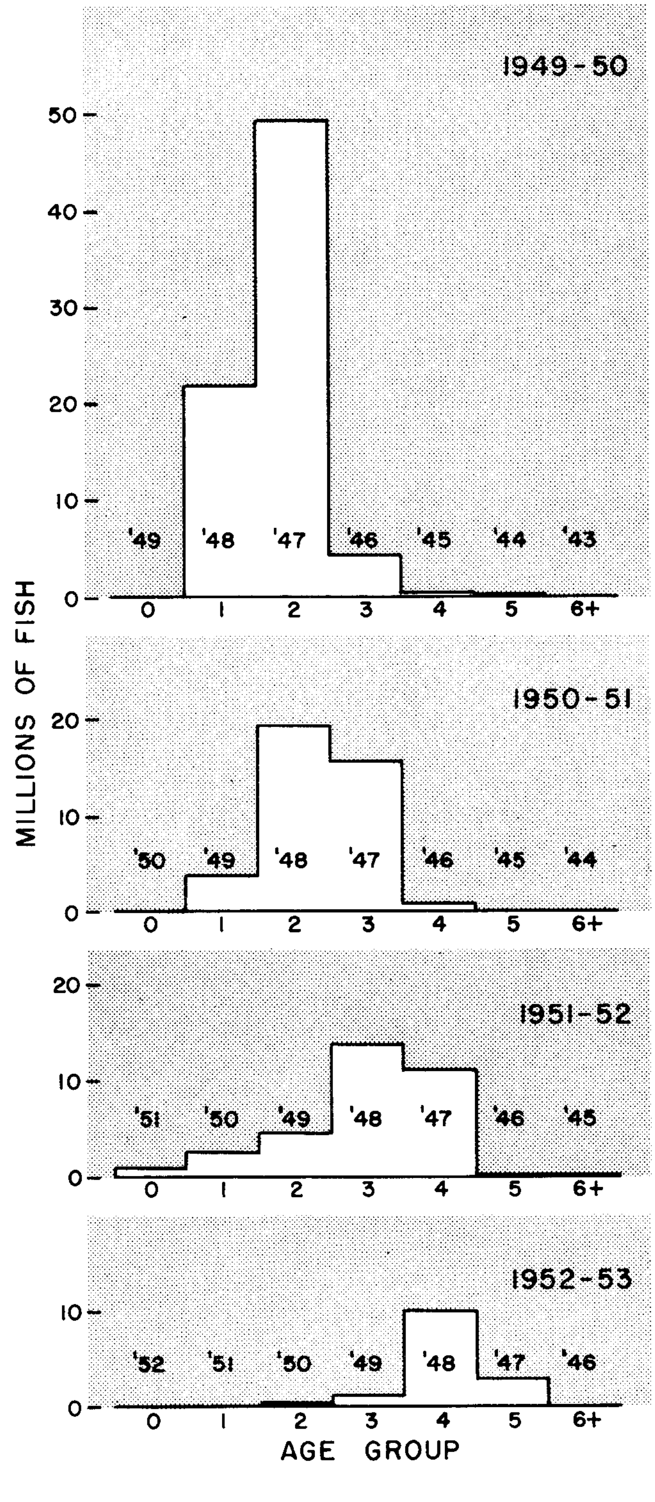


FIGURE 31. The Pacific mackerel catch in the past few years has consisted chiefly of fish from the 1947 and 1948 year classes. Total catch has declined.

sardine. Younger year classes have not appeared on the fishing grounds to replace the older mackerel as the latter disappear from the fishery. As a result the declining fishery has been supported by three-, four- and five-year olds, now few in number.

Three year classes, 1938, 1941, and 1947, have made outstanding contributions to the fishery. Over 125,000,000 fish were taken from each of these groups. The smallest contributions were made by the 1946 and 1949 classes, furnishing only about 10,000,000 fish each. Thus, as with the sardine, Pacific mackerel year-class sizes are variable, some being as much as 12.5 times as abundant as others. Preliminary estimates indicate that the 1950, 1951, and 1952 year classes may not supply even 5,000,000 fish before they are exhausted.

### *Distribution*

The range of the Pacific mackerel extends from the Gulf of Alaska southward into the Gulf of California and off the tip of Baja California at Socorro and San Benedicto Islands in the Revillagigedo group. Racial analyses indicate that within this range there might be as many as five reasonably distinct populations among which little mingling occurs. However, tagging experiments demonstrate that many of the fish from the northern and some from the central Baja California groups ultimately enter the California fishing grounds. San Roque Bay, 60 miles south of Punta San Eugenio, represents the southern point along the Baja California coast from which such recoveries were made.

Data from the surveys of 1950, 1951, and 1952 indicate that Pacific mackerel were the least abundant of the four principal species sampled (Fig. 24). In 1950 Pacific mackerel were most common off Southern California and northern Baja California. In 1951 they were in greatest abundance in the area between Punta San Eugenio and Punta Abreojos. In 1952 these fish were about equally distributed over the areas off central Baja California; none were found north of Ensenada.

### *Food*

The usual diet of the Pacific mackerel includes anything that can be swallowed, from fish, squid, and tunicates several inches long down to copepods smaller than fleas. Although as a rule mackerel are exceedingly voracious, there are times when they appear decidedly "choosy" about their food.

## SUMMARY: THE STATUS OF THE SUBSTITUTE FISH POPULATIONS, 1 JULY 1953

1. Landings of anchovies, especially in central California, would indicate that this population is satisfactorily abundant, although the appearance of the anchovies on the fishing grounds is somewhat sporadic and seasonal. The same seems to be true of the jack mackerel population in Southern California. Pacific mackerel catches, on the other hand, indicate a low abundance of these fish throughout all California waters.
2. Young-fish surveys, designed primarily to sample sardines, also sample anchovies, jack and Pacific mackerel. With the exception of jack mackerel these surveys give an estimate of the relative abundance of the four species and their distribution along the coast from Northern California to southern Baja California. Jack mackerel schools occur farther offshore than do the other species and the surveys only reflect the relative abundance of these fish in the inshore waters. This was evident in the 1952-53 season when jack mackerel were scarce on the Southern California fishing grounds but the fishermen were able to bring in good tonnages from the offshore banks. This offshore fishery, however, did not yield any appreciable tonnages of sardine or Pacific mackerel.
3. The lowest abundance of all species occurred off central California. The numbers of Pacific and jack mackerel declined steadily in the Southern California waters throughout the three years of the surveys but showed a slight increase off Baja California. Anchovies were more abundant off Southern California and Baja California than off central California. Off California their greatest abundance occurred in 1950. They were slightly more abundant in 1952 than in 1951.
4. From 1950 to 1952 the decline of sardines on California grounds was steady and rapid. Pacific mackerel, at a lower level at the beginning, disappeared almost completely by 1952. Anchovy and jack mackerel also declined but at a slower rate. Throughout the three years their abundance exceeded that of sardines.
5. In Baja California waters, jack mackerel decreased slightly and anchovies more markedly. Pacific mackerel did not decline and showed a minor increase in 1952. They were the least abundant of all species, however, on the Baja California grounds as well as off California.

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*printed in* CALIFORNIA STATE PRINTING OFFICE

***ABOUT THIS REPORT:***

Six thousand copies of this report have been printed for distribution to the fishing industry, research institutions, government agencies, and individuals in this country and abroad. Copies are available from California State Fisheries Laboratory, Terminal Island, Calif. The report was edited by Mr. Thomas A. Manar, Office of Oceanographic Publications, Scripps Institution of Oceanography. The report was designed by Mr. Robert W. Kirk of the Scripps Institution, who also prepared the illustrations, with the exception of Figures 12, 13, 24, 25, and 26, which were prepared by Mr. George Mattson and Mr. James Thrailkill of the U. S. Fish and Wildlife Service. The photographs were taken by Mr. John MacFall of the Scripps Institution.