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.

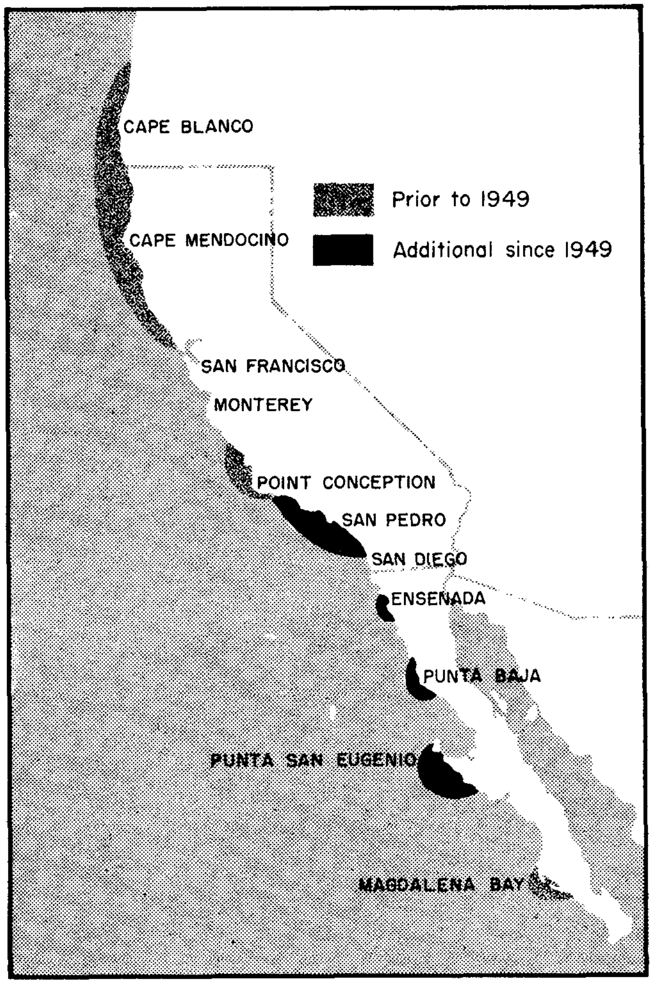

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FIGURE 4. Upwelling is an oceanographic factor that has long been acknowledged as a possible key to sardine fluctuations because it enriches the surface water and thus leads to intensified plant and animal growth. Upwelling was studied long before 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.

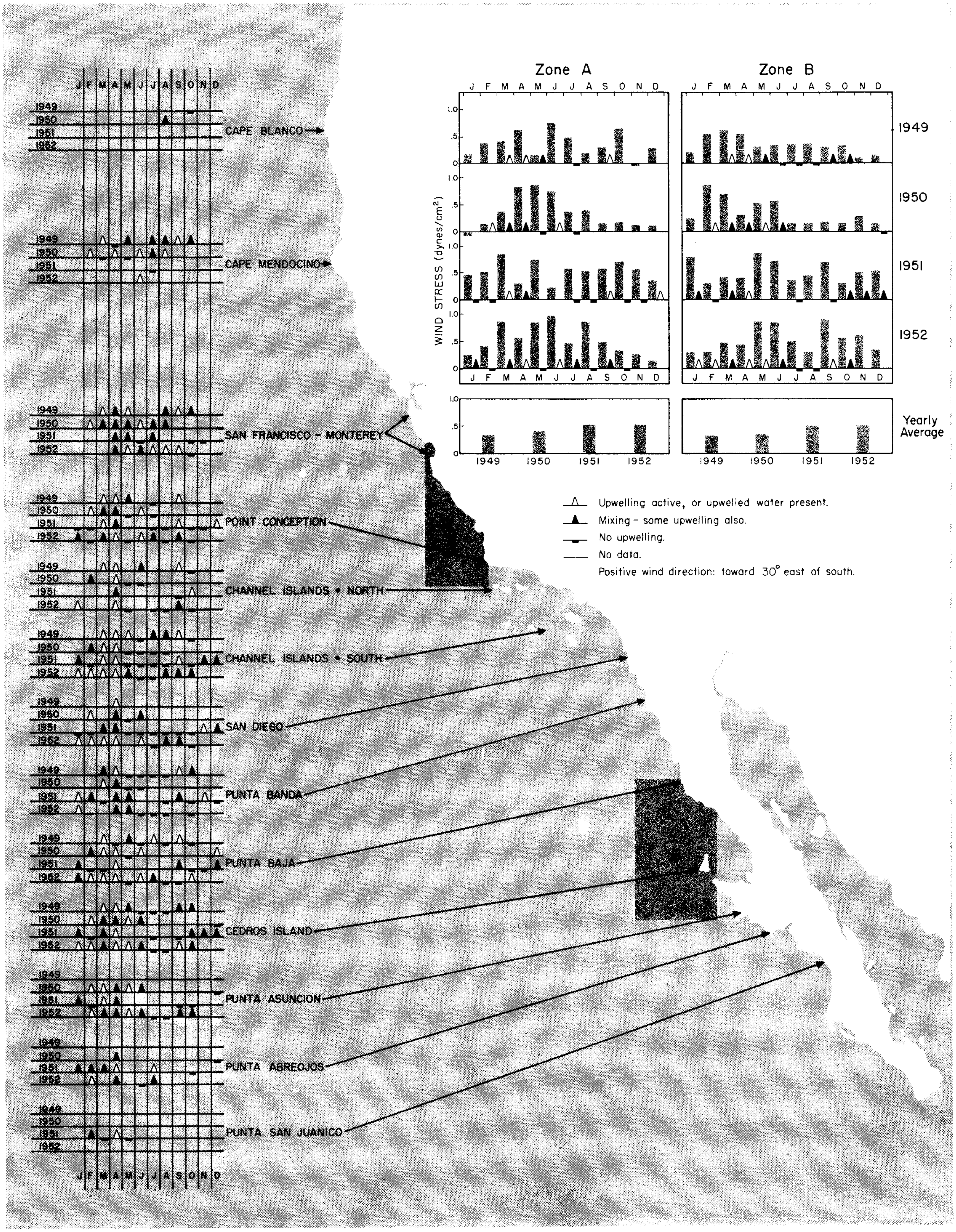
FIGURE 5. One of the interesting things that we have discovered is that upwelling not only appears in areas not known about before (this is not surprising, since the region had been little surveyed), but that it also occurs at different times and far more frequently than had been suspected. In this figure, 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. ►

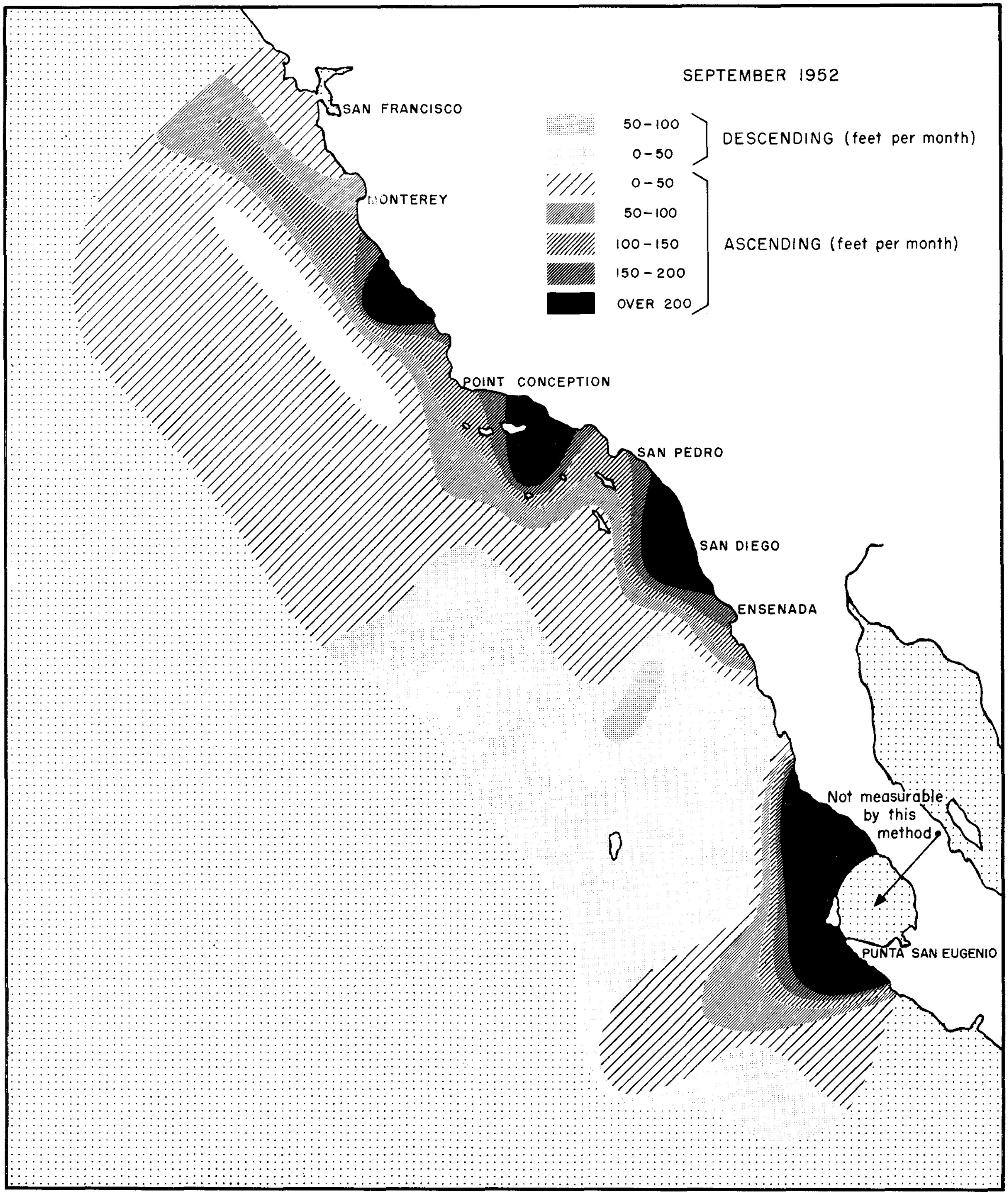
salinity values, but the 1949 values cannot be entirely ascribed to upwelling, for had only that process been at work, temperature values would have been lower than those observed.

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.


Zone A
Zone B
J F M A M J J A S O N D
WIND STRESS (dynes/cm²)
1.0
.5
0
1949
1950
1951
1952
Yearly Average
Upwelling active, or upwelled water present.
Mixing - some upwelling also.
No upwelling.
No data.
Positive wind direction: toward 30° east of south.
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


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

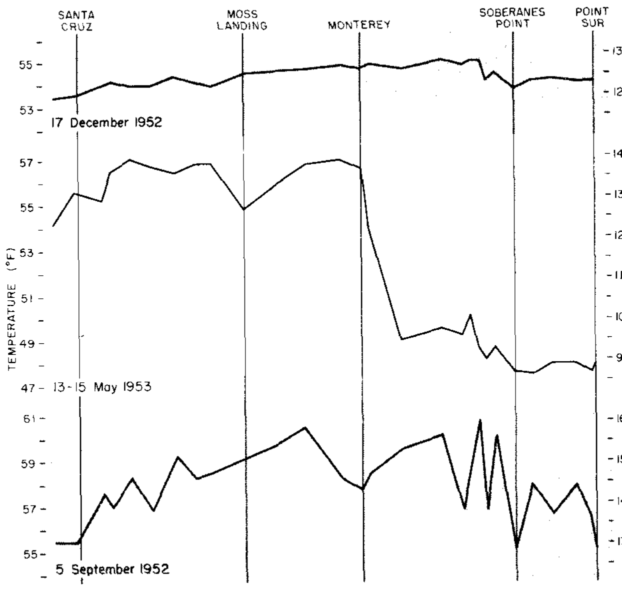


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FIGURE 7. Surface ocean water temperatures in the vicinity of Monterey at three seasons of the year. Note the sharp decrease during May to the south of Monterey.

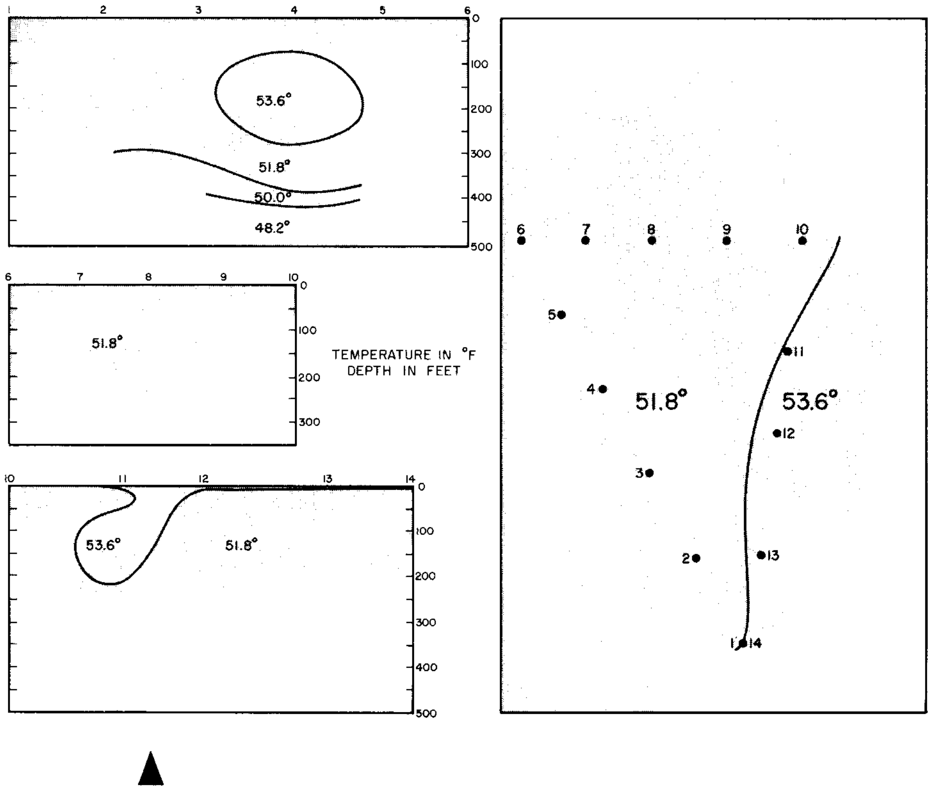


FIGURE 8. During the late fall and early winter, there is no distinct thermocline present in Monterey Bay. Water of 9° or 10°C (approximately 51°F) is characteristic at a depth of 300 feet.

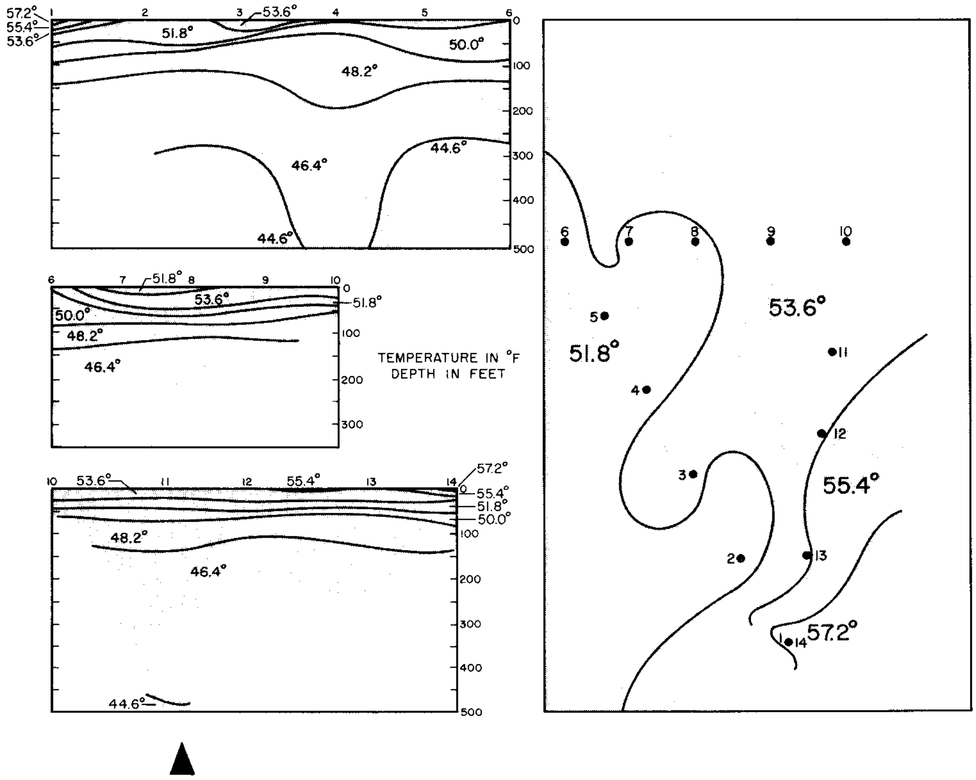


FIGURE 9. Here are presented temperature profiles and surface temperatures for the summer period in Monterey Bay. The prevailing temperature at 300 feet during this time is lower than during the late fall and early winter (Fig. 8).

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,

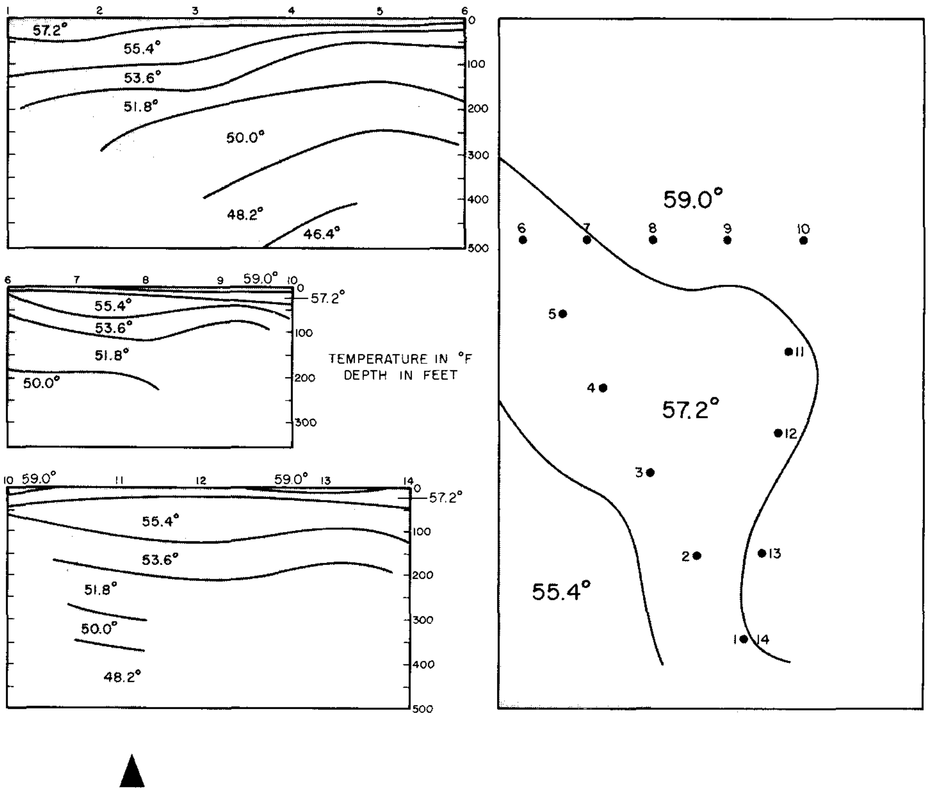


FIGURE 10. Summer non-upwelling periods are normally characterized by comparatively warm waters both at the surface and at depth.

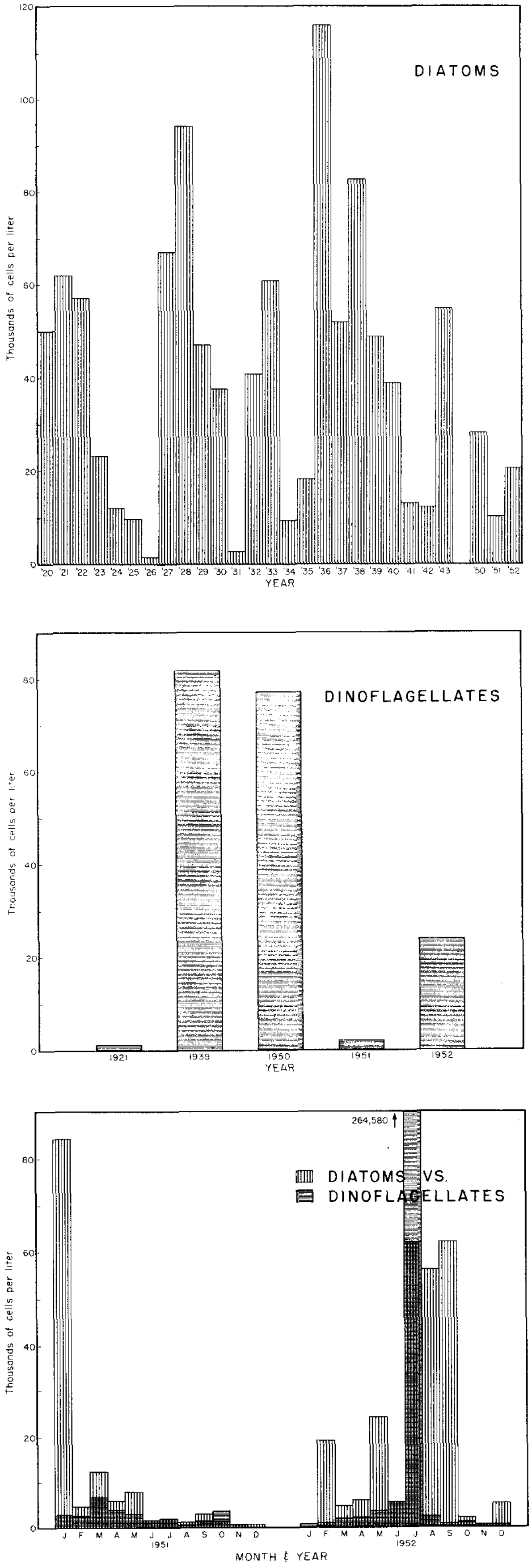


FIGURE 11. Upwelling brings to the surface of the sea waters in which marine plants and animals thrive. If we exclude the coastal rocks with their covering of seaweeds, the whole productivity of organic matter in the sea ultimately depends on the chlorophyll-containing phytoplankton (minute floating 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.

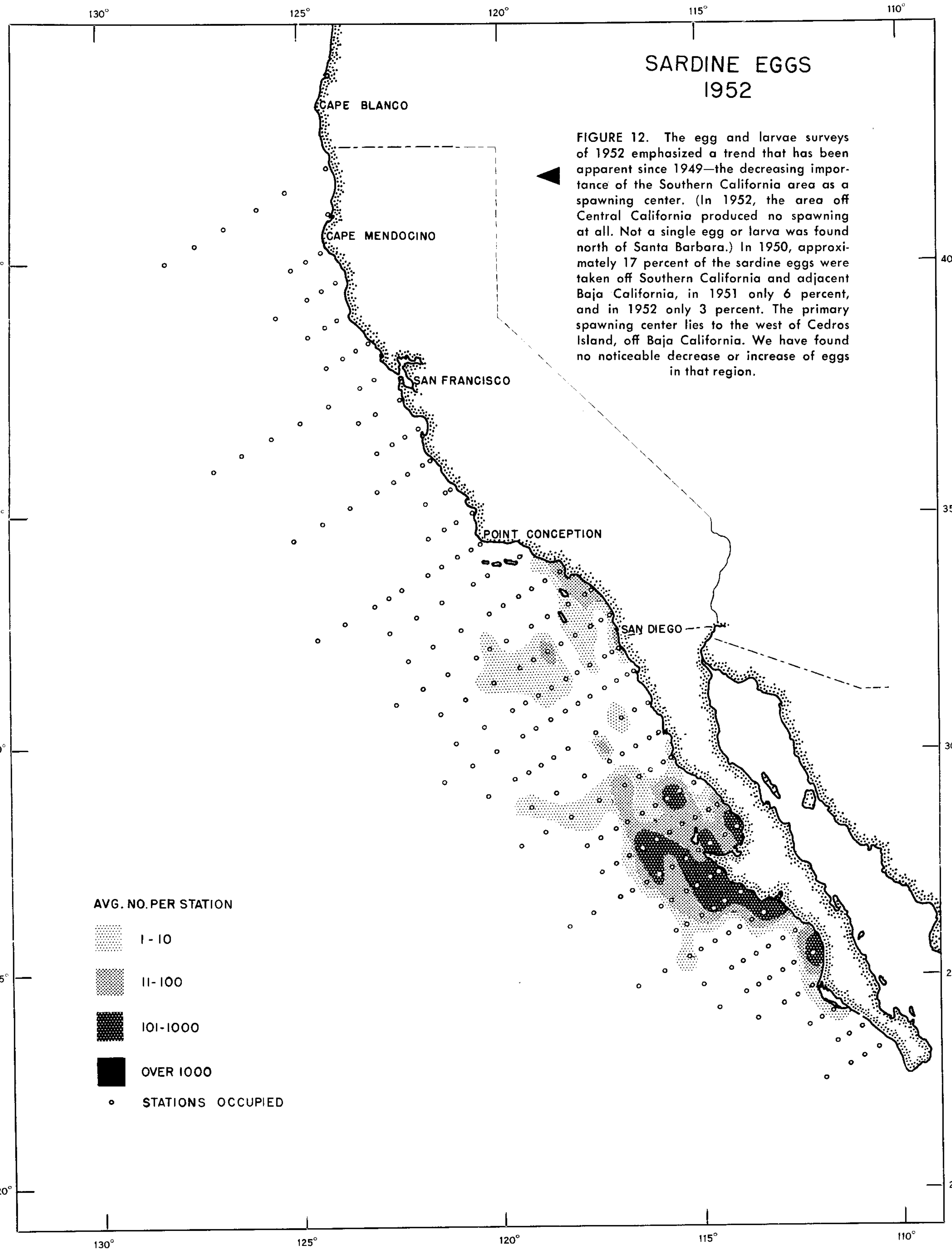
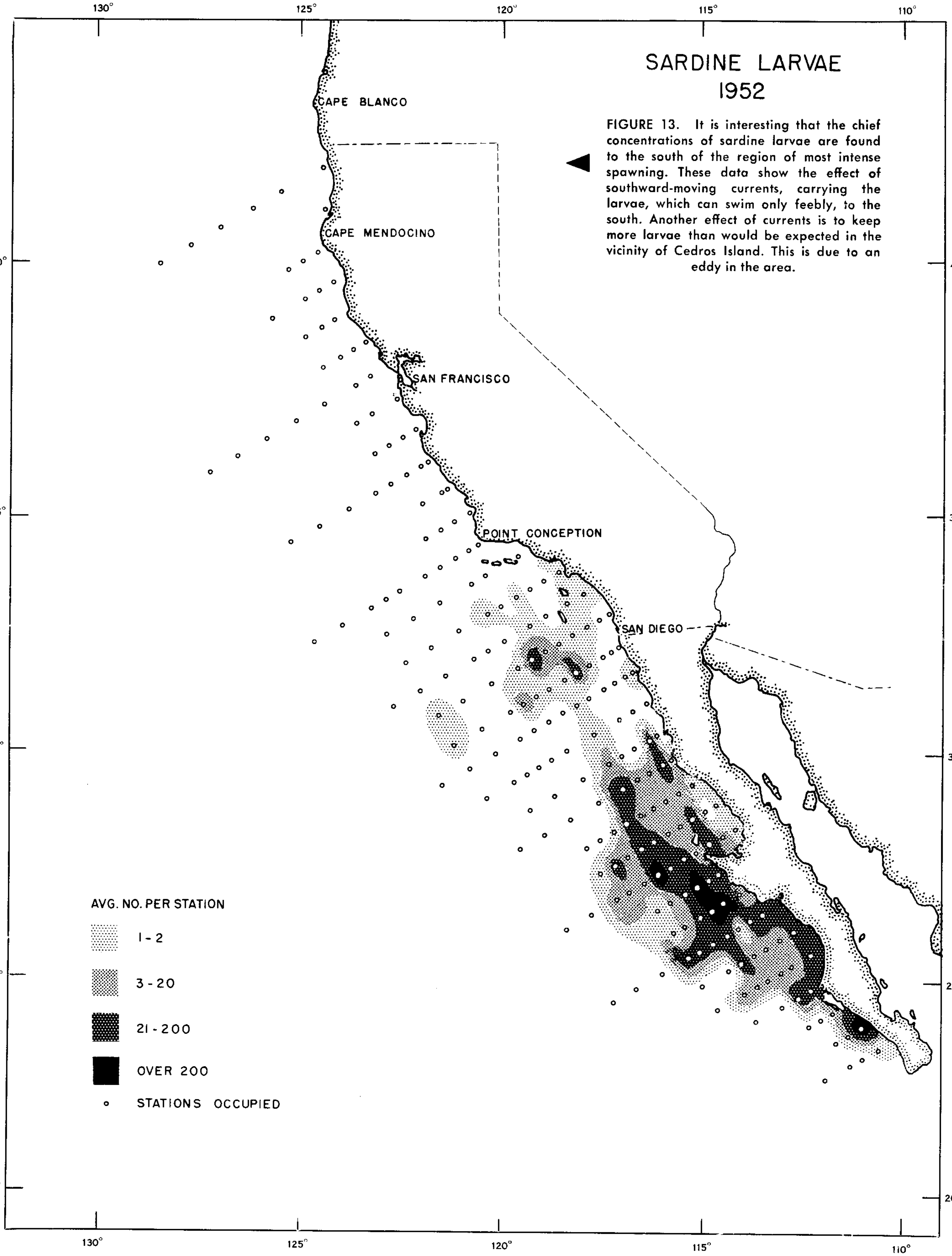


FIGURE 12. The egg and larvae surveys of 1952 emphasized a trend that has been apparent since 1949—the decreasing importance of the Southern California area as a spawning center. (In 1952, the area off Central California produced no spawning at all. Not a single egg or larva was found north of Santa 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.



SARDINE LARVAE
1952

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.

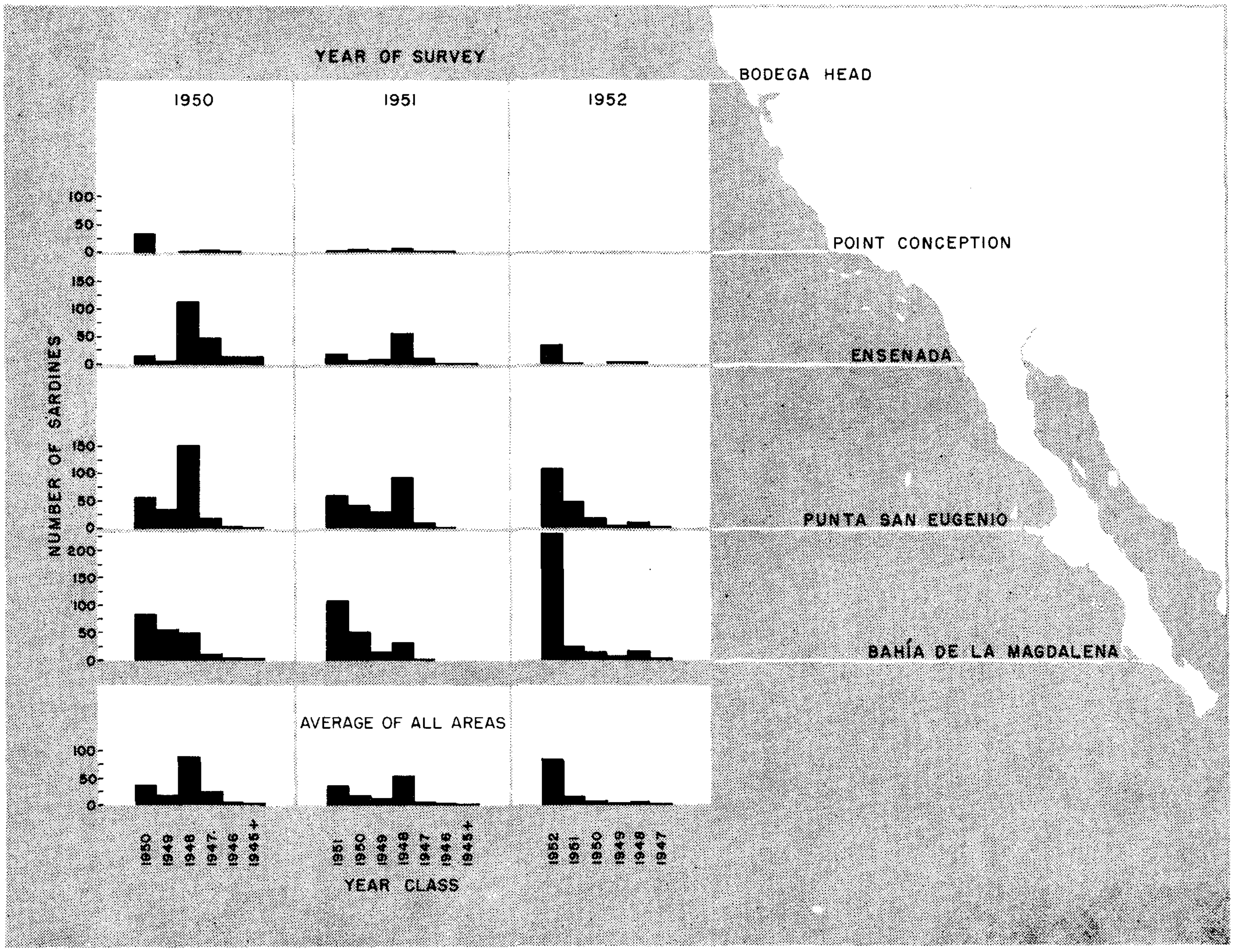


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FIGURE 14. Each year since 1950, we have sent out cruises which survey the coastal waters to observe the numbers and locations of schools of sardines. These are called young-fish surveys because their primary purpose is to assess the number of sardines 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.

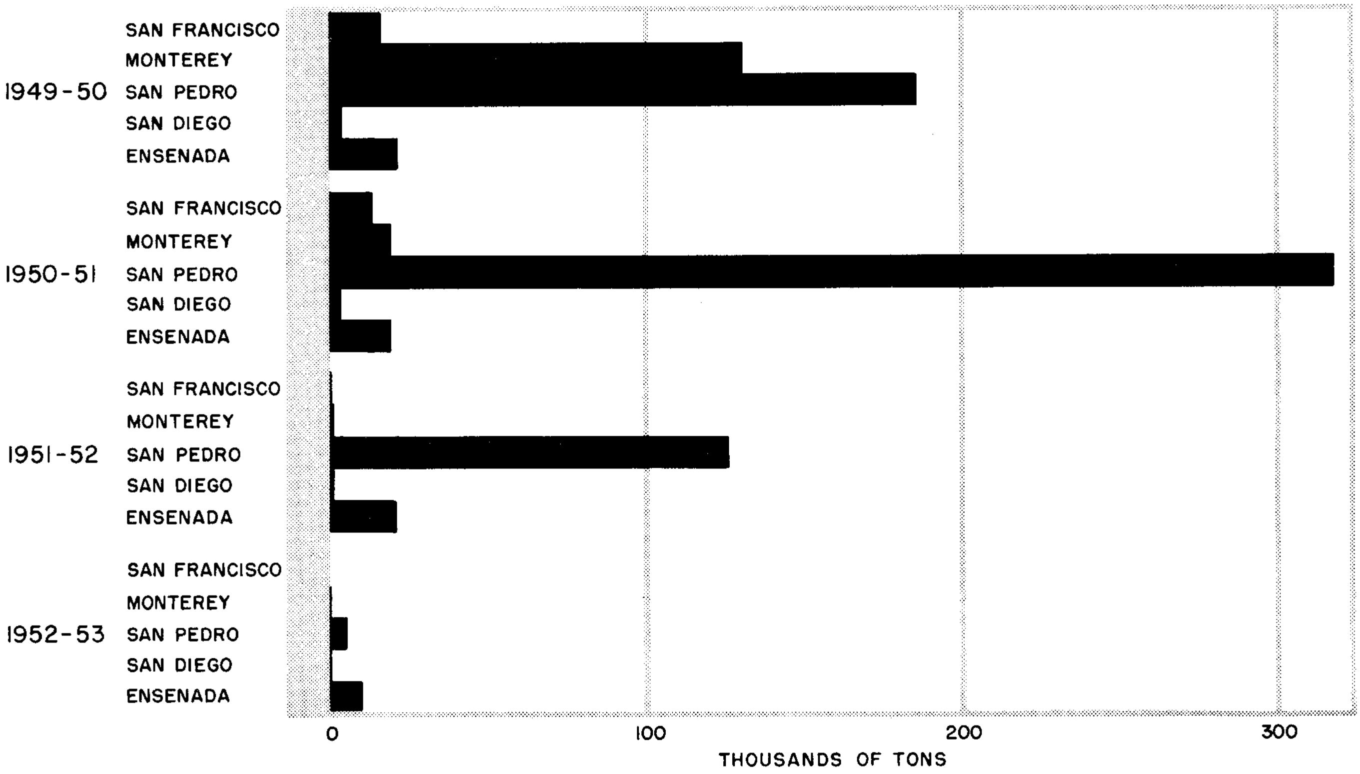

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FIGURE 15. The total California sardine catch for the 1952-53 season was 5,420 tons. Only 70 tons of the total came from ports north of Point Conception. The Baja California port of Ensenada accounted for more tonnage than all California ports even 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.