CALIFORNIA COOPERATIVE SARDINE RESEARCH PROGRAM

Progress Report

**1 January 1951
to 30 June 1952**

Cooperating Agencies

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

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE
1 July 1952

THE COVER of this report shows observed schooling patterns of sardines in an aquarium tank. All these patterns and several more were observed within a period of 15 minutes. Original drawings by California Academy of Sciences

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
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1 July 1952

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CHAIRMAN

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Department of Natural Resources
MARINE RESEARCH COMMITTEE

Post Office Box 807
Los Altos, California
July 1, 1952

Honorable Earl Warren
Governor of the State of California
Sacramento, California

Sir:

In this paper is presented a review of eighteen months of work under the California Cooperative Sardine Research Program. The work has been undertaken by five scientific agencies under the direction of this committee. The picture that emerges from the findings of the agencies is not encouraging. The catch in the 1951-52 season fell below profitable levels and some of our research people feel that the next two seasons may be even worse. The urgency of the situation, the import of the research findings, warrant the close study and reflection of everyone interested in California's marine resources.

Respectfully,

J. G. Burnette
J. G. Burnette, Chairman

D. T. Saxby
D. T. Saxby, Vice-Chairman

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Richard S. Croker, Secretary

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Abstract

THE SARDINE SITUATION, 1 JULY 1952

Today, that portion of the adult sardine population that is available to the California industry is almost totally confined to the waters off Southern California.

Unless the factor of availability should so operate as to increase the catch of older fish, the industry for the next few years will be dependent for any significant improvement in the catch on the sardines that have been spawned off Southern California and Baja California (chiefly the latter) since 1948.

The 1948 year class: This year class accounted for 65 percent of the 1951-52 catch. There is some evidence that indicates it may be a year class of major proportions, though it has so far not made an outstanding contribution (in numbers) to the catch.

The 1949 year class: This year class is about one-sixth the size of the 1948 year class.

The 1950 year class: This year class seems only slightly greater than the 1949 year class.

The 1951 year class: It is too early to say much about this year class, though it seems only slightly better than the 1949 year class at present.

The outlook for the industry in the next two seasons: Very bleak; it appears that unless the factor of availability operates so as to increase the catch of older fish, the industry, if it depends upon the sardine alone, must for the next two seasons subsist upon the smallest catches in a generation.

The long-term outlook: We are just beginning to be able to understand some of the major aspects of the fluctuations of the sardine population. More work will be needed before we can confidently predict variations in the catch at long range.

Contents

	Page
INTRODUCTION	7
PART 1: THE SARDINE AND ITS ENVIRONMENT, YESTERDAY AND TODAY	9
Distribution of Sardines	9
Eggs and Larvae	9
Young Fish	9
Adult Sardines	9
Subgroups	10
Numbers of Sardines	12
Adult Sardines	12
The Total Population	12
Variations in Mortality Rates	13
Age Composition of the Catch	14
Size of Older Year Classes	14
Eggs, Larvae, and Young Fish	14
Spawning Surveys	14
Young Fish	16
Habits and Behavior	22
Olfactory Sense	22
School Patterns	22
Behavior in an Electrical Field	22
Food of the Sardine	23
Food of the Larvae	23
Food of the Adult	23
The Environment	24
Oceanographic Conditions	24
Relation of Oceanographic Conditions to Other Factors	33
Population Size	33
Year-Class Size	33
Mortality Rates	33
Fishing Success	33
The Food Supply	37
Predators and Competitors	37
Bacteria	37
Other Fishes	38
Future Studies	44
PART 2: THE OUTLOOK FOR THE FISHERY	45
APPENDIX: TABULAR MATERIAL	47

ILLUSTRATIONS

Figure		Page
1.	Station plan, California Cooperative Sardine Research Program, 1951	6
2.	Relative abundance of young sardines, 1938-40 and 1950-51, in each of several localities	8
3.	Percentage of the sardine catch taken in the four major fishing areas during 11 seasons	8
4.	Fish growth and scale growth	10
5.	Means of averages of observed lengths of sardines taken in four areas from 1941-42 through 1951-52 seasons	10
6.	Deviations of one-year-old sardines in San Pedro fishery from average growth curve, 1941-42 through 1951-52 seasons	11
7.	Size distribution of 1948 year-class sardines sampled at Monterey, San Pedro, and Ensenada in 1951-52 season	11
8.	Catch and population estimates, 1932-33 through 1951-52 seasons	12
9.	Total mortality rate and fishing intensity, 1932-33 through 1950-51 seasons	13
10.	Percentage age composition based on numbers of sardines in California fishery for three time intervals	14
11.	Relative year-class size of sardines as measured by number of three-year-old fish caught per boat month in California	14
12.	Cedros Island area, Baja California	15
13.	Sardine spawning, January, 1951	16
14.	Sardine spawning, February, 1951	16
15.	Sardine spawning, March, 1951	17
16.	Sardine spawning, April, 1951	17
17.	Sardine spawning, May, 1951	18
18.	Sardine spawning, June, 1951	18
19.	Sardine spawning, July, 1951	19
20.	Sardine spawning, August, 1951	19
21.	Sardine spawning, September, 1951	19
22.	Sardine spawning, October, 1951	20
23.	Sardine spawning, November, 1951	20
24.	Sardine spawning, December, 1951	20
25.	Sardine spawning, January, 1952	20
26.	Sardine spawning, February, 1952	21
27.	Sardine spawning, March, 1952	21
28.	Comparison of abundance of 1948, 1949, 1950, and 1951 year classes of sardines at various ages	22
29.	Diagram illustrating behavior of sardines in the absence and in the presence of an electrical field	23
30.	Diagram illustrating behavior of sardines in an electrical field	23
31.	Food items in stomachs of 273 adult sardines as compared with plankton content of water samples	25
32.	Current patterns off the California coast, 1939, 1949, 1950	26
33.	Upwelling along the California coast	27
34.	Indicators of upwelling, central California, 1938-40 and 1949-51	28
35.	Indicators of upwelling, off Point Conception, 1938-40 and 1949-51	29
36.	Temperature survey, Monterey Bay, 2 October 1951	30
37.	Temperature survey, Monterey Bay, 13 December 1951	31
38.	Upwelling along the coast south of Monterey, late 1951 and early 1952	32
39.	Sardine catch and surface temperatures, August, 1949	34
40.	Sardine catch and surface temperatures, August, 1950	34
41.	Sardine catch and surface temperatures, September, 1949	34
42.	Sardine catch and surface temperatures, September, 1950	34
43.	Sardine catch and surface temperatures, October, 1949. (Inset, November, 1950)	35
44.	Sardine catch and surface temperatures, January, 1951	36
45.	Sardine catch (1949-50 and 1950-51) and schools of sardines located during the surveys (1949, 1950, and 1951) as related to surface temperatures	37
46.	Average volumes of plankton taken in California Cooperative Sardine Research Program cruises, March, 1949, to December, 1951	38
47.	Sardine larvae, 1951	39
48.	Anchovy larvae, 1951	40
49.	Hake larvae, 1951	41
50.	Jack mackerel larvae, 1951	42
51.	Rockfish larvae, 1951	43

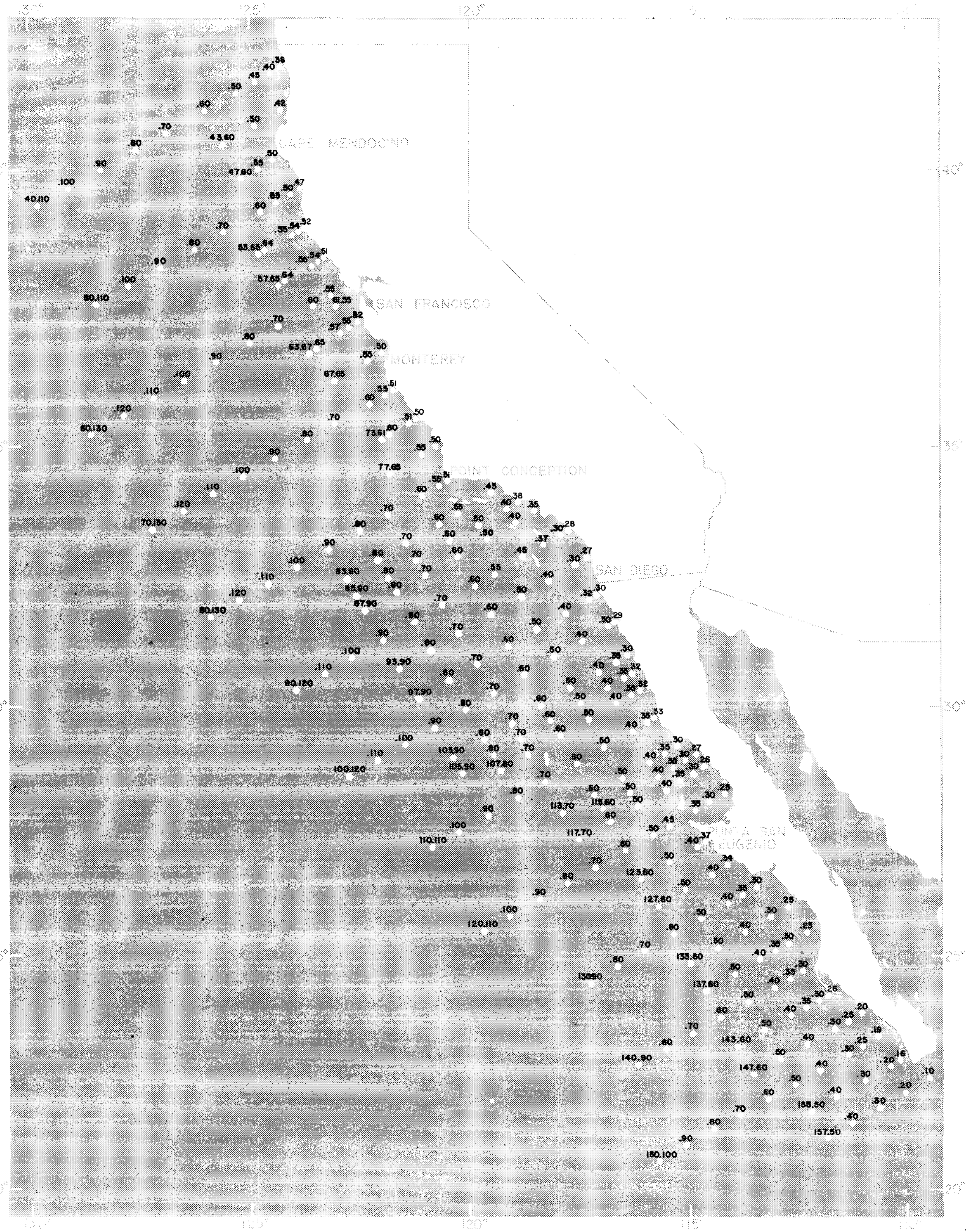


FIGURE 1. Station plan, California Cooperative Sardine Research Program, 1951. More intense coverage was made of the inshore areas and the southern Baja California region than in previous years.

Introduction

Where are California's sardines?

How many are there?

Is it likely that enough can be caught in the next few seasons to maintain the industry?

These are the questions that this report, which reviews 18 months of work (1 January 1951 to 30 June 1952) under the California Cooperative Sardine Research Program, is designed to answer as fully as is now possible.

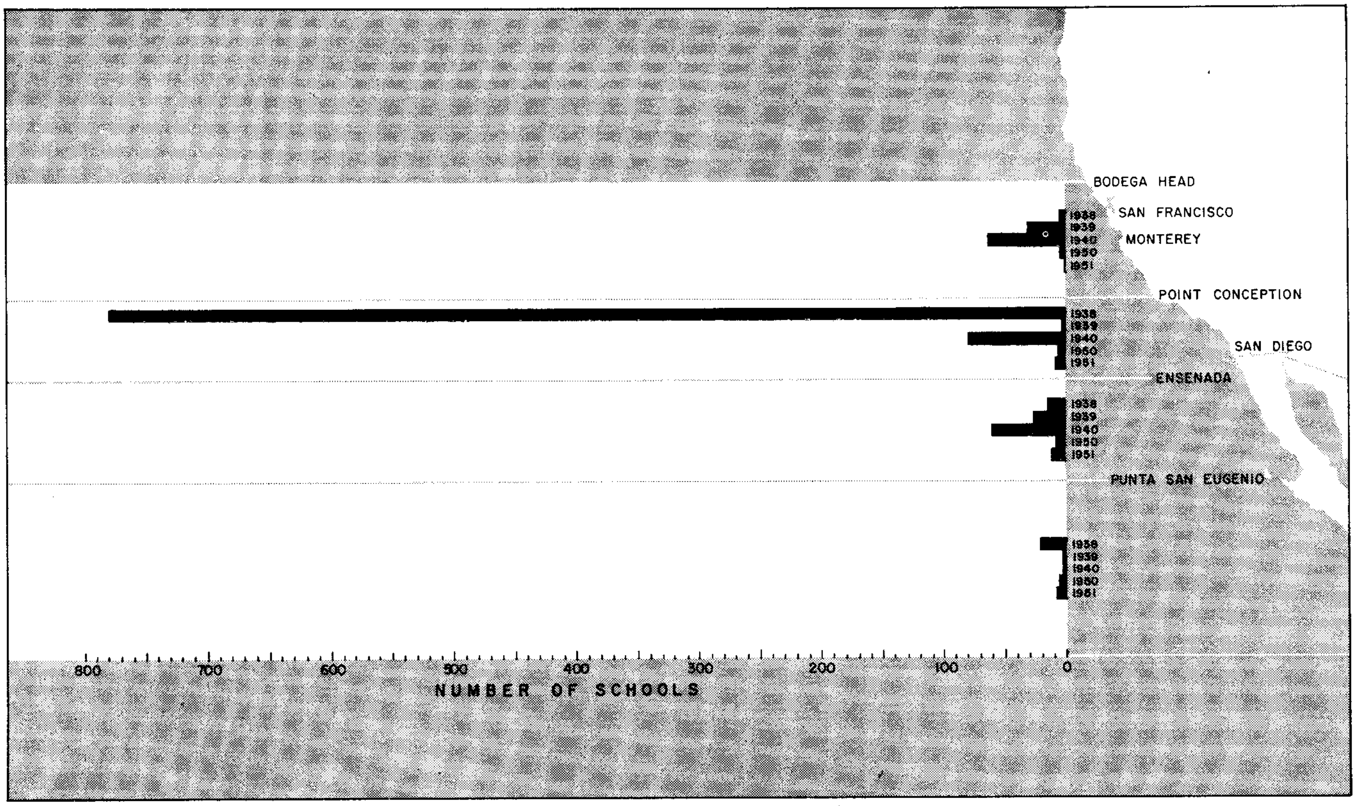
At its November 1951 meeting, the Marine Research Committee put into the record these objectives for the research agencies participating in the program:

1) to seek out all possible facts concerning and factors influencing the distribution, numbers, habits, and behavior of the sardine at each stage of its life;
2) on the basis of these facts to make the best possible estimates of the fluctuations in the abundance and availability of the sardine and to predict the outlook for the fishery;
3) to make these facts and estimates promptly known to the appropriate management agencies, to the industry, and to the public at large.

In this report, we seek to meet the first objective in Part 1: The Sardine and Its Environment, Yesterday and Today, in which is briefly summarized what we have learned in the past 18 months and the findings are compared with those of earlier, more prosperous periods; the second objective is met in Part 2: The Outlook for the Fishery; and it is hoped that the report as a whole, will satisfy the third objective.

Five agencies are now engaged in research on the sardine—the California Academy of Sciences; the California Department of Fish and Game; Hopkins Marine Station of Stanford University; the U. S. Fish and Wildlife Service; the University of California, Scripps Institution of Oceanography. The work is supported in part by funds from the industry itself (in the form of a tax on sardine landings) and in part from the Federal Government, but the largest portion of the research funds comes from the State of California as a whole, through the Legislature. (Next year, further moneys will be available from a tax on processed mackerel and anchovies. According to present plans, these fisheries are to be subject to the special tax for one year only.)

None of the five agencies pretends to have come up with an easy answer to "the sardine problem." What they here present, through the Marine Research Committee, to the people who support their work—the industry and the public at large—is a series of comparisons of the status of the sardine population today with that of several years ago, with the feeling that from this picture of a very critical period as contrasted with a relatively prosperous one, there will emerge the best answers they can at present give to those three important practical questions—Where are the sardines? How many are there? Can they be caught?



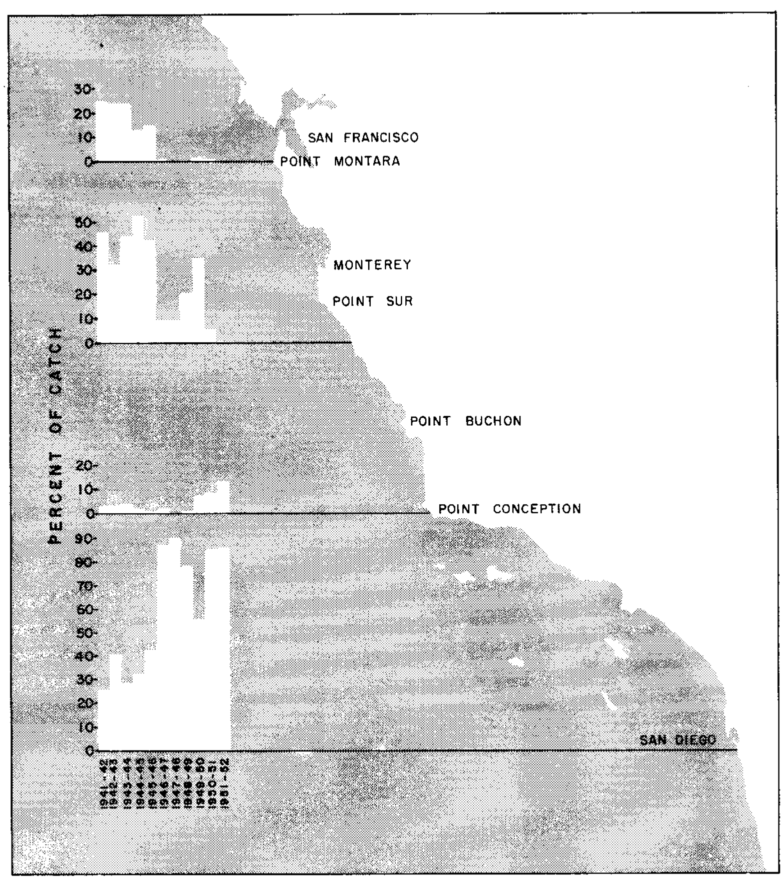


FIGURE 2. Number of schools of young sardines, 1938-40 and 1950-51, in each of several localities. Note extreme abundance of 1938 year class off Southern California. (Data, Table 2, Appendix.)

FIGURE 3. Percentage of the sardine catch taken in the four major areas during 11 seasons. (Data, Table 3, Apendix.)

Part 1: The Sardine and Its Environment, Yesterday and Today

1) to seek out all possible facts concerning and factors influencing the distribution, numbers, habits, and behavior of the sardine at each stage in its life;

DISTRIBUTION OF SARDINES

It is common knowledge that most of the adult sardines that are available to the fishermen are now in Southern California waters. This area's portion of the catch has risen steeply in the past few years. Not nearly so well known is the fact that changes have also taken place in the distribution of eggs and larvae and young fish.

Eggs and Larvae

Prior to 1949, surveys of the distribution of sardine eggs and larvae were sketchy except off Southern California. But within that area, past and current data show large variations: in 1950 sardine larvae were less than one-half as abundant there as they were in 1940 and 1941, and in 1951 one-sixth (see Table 1, Appendix).

Yet as has been proven by the survey cruises of the California Cooperative Sardine Research Program, the waters off Southern California constitute one of the two major centers of spawning on our coast. The other major center of spawning lies off central Baja California, and it now is far more productive, at least in number of eggs spawned, than the Southern California region. Whether this relationship held true in the past is unknown; we have no data as to the relative productivity of Baja California spawning prior to the inception of the present program.

In addition to the decrease in spawning off Southern California, the seasonal pattern of spawning has changed. In the early years spawning off Southern California, abundant as early as March, reached its peak in April. In 1950 and 1951, the peak was reached during May and June. Water temperature in the area is now colder in March and April than in the 1940 and 1941 period; this change in oceanographic conditions may account in part for the change in time of spawning; whether it also may account for the decrease in amount of spawning, we do not know.

Young Fish

Even though precise details are obscured by changes in methods of observation, our data show that the distribution of young sardines (about six months old) has changed considerably between the two periods, 1938-40 and 1950-51. Figure 2 compares the relative abundance of the specific year classes when they are a few months old in each of several general localities. (A year class comprises all sardines spawned in a certain year.) The 1938 year class, it will be seen, was extremely abundant in Southern California, the 1939 year class exceptionally scarce there, being most abundant in Central California. The surveys on which these data were accumulated extended only as far north as Northern California; other sources of information show us that spawning of the 1939 year class extended northward to the Pacific Northwest and resulted in an outstandingly abundant year class. The 1940 year class was evenly distributed along the coast from Central California through central Baja California.

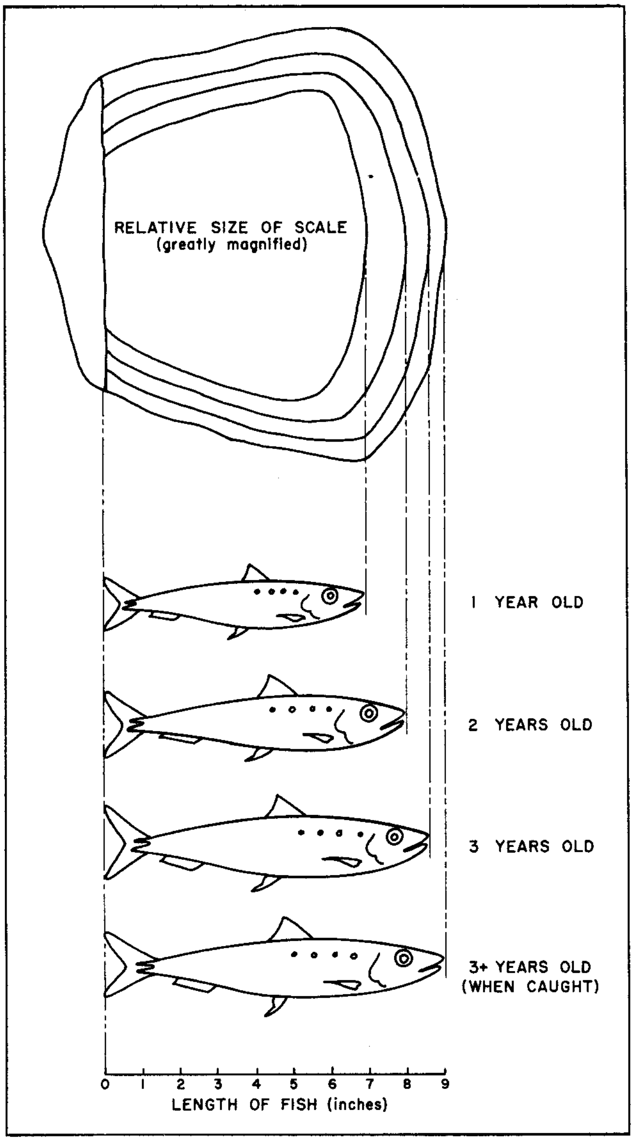
Three year classes the young of which were found in considerable numbers off California and northward were above average in abundance: the 1938 year class, 1.7 times the average, the 1939 year class, 2.5 times, the 1940 year class, 1.2 times. The 1950 and 1951 year classes, the young of which were found chiefly south of Point Conception, appear to be much below average in abundance.

Unlike the egg and larvae surveys, the early young-fish surveys did extend into Baja California waters. As many if not more young fish were found there in the earlier period as in 1950 and 1951. In other words, the decrease in numbers of young sardines in California waters does not seem to have been compensated by an increase in abundance off Central and Southern Baja California.

Adult Sardines

Catch statistics tell the story of the changing distribution of the adult sardines. The record shows that even prior to the collapse of the fishery in the 1947-48 season and the subsequent contraction of profitable fishing to Southern California, there had been a gradual increase in the proportion of the sardine catch taken on the more southern fishing grounds (Fig. 3). It was not until the almost total failure of the 1951-52 season that the catch in Southern California declined below 100,000 tons; and in 1950-51, the ports there registered the largest catch in their history.

Thus the data indicate that at present the waters north of Point Conception are marked by not only a great paucity of adult sardines but also by almost complete absence of sardine eggs, larvae, and young fish.



In Southern California, which is furnishing 75 percent or more of the commercial catch, the number of sardines caught has fluctuated widely in the past two seasons; the number of sardine eggs, larvae, and young fish collected has declined greatly as compared with the pre-World War II years.

Subgroups

There is evidence which strongly suggests that the California sardine fishery depends not upon a single homogeneous population of sardines, but upon two or more subgroups within the population which differ to some degree.

We know that sardines are found all along the Pacific coast from southeastern Alaska to the tip of Baja California, and in the Gulf of California; off the Pacific coast of South America; and off South Africa, Australia, New Zealand, Japan, and Korea. All these populations are referred to the same genus, *Sardinops,* but to different species. Our sardine belongs to the species *Sardinops caerulea* (the blue sardine).

Within a species there can exist subgroups of fishes, closely akin but differing slightly. We have observed differences in the sardine population, but we do not know yet if these differences are of genetic significance. Tagging experiments conducted several years ago demonstrated an intermingling of sardines throughout the fishing grounds from British Columbia at least as far south as Sebastian Vizcaino Bay, Baja California. A general migratory pattern emerged: northward to the Pacific Northwest during the summer months, southward to the California fishing grounds in the fall and winter. The experiments suggested many minor

FIGURE 4. Fish growth and scale growth. The growth of the fish and the growth of individual scales proceed at about the same rate. A distinguishable ring is added to each scale each year. By a study of the scales, it is possible to calculate the size of a sardine at a former time interval of its life.

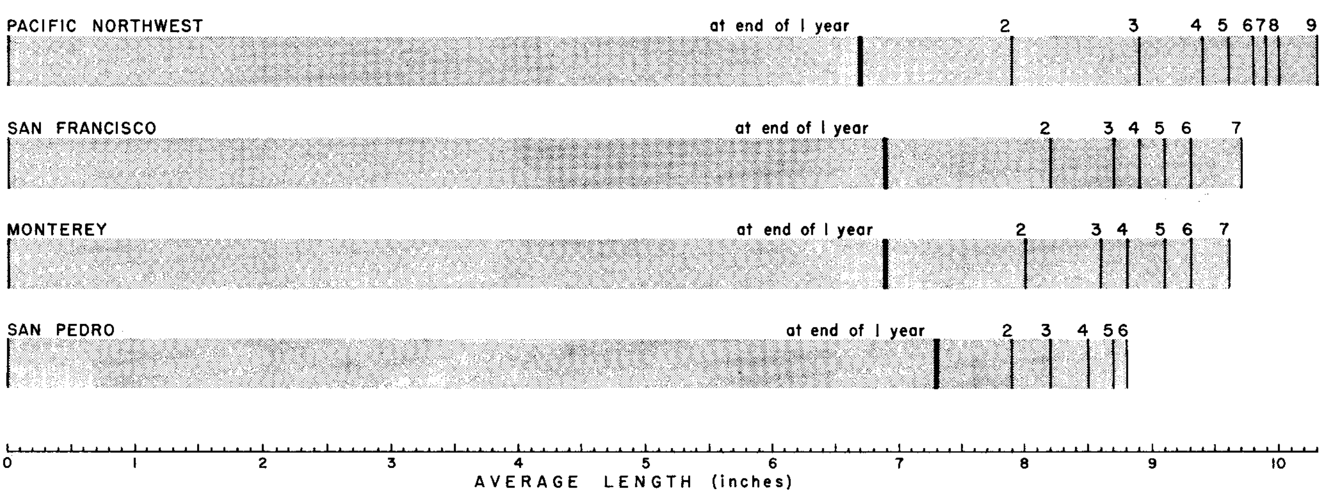


FIGURE 5. Means of averages of observed lengths of sardines taken in four areas from 1941-42 through 1951-52 seasons. Fish caught at San Pedro are longer at end of first year, shorter thereafter.

movements of subgroups within this broad general pattern. What these movements were it was not possible to define from the tag returns. Now other studies are beginning to unravel these complexities. It appears that in the California population there may be at least two subgroups, one spawned off central Baja California and migrating to the north to mingle in varying proportions with fish of the second group, which are spawned off Southern California. Presumably the Southern California group bulks larger in the northern fishery. The "southern" fish, to give those spawned off central Baja California a manageable name, are as a rule shorter and stubbier than the "northern" fish, growing at a slower rate after their first year of life.

The existence of these two individualized subgroups cannot as yet be proved completely. The situation is unfortunate, for differential movements on to the fishing grounds of year classes with different origins may play an important role in the location of the fishery from season to season and in the magnitude of the catch. Because of its import, the evidence for the existence of subgroups will be briefly summarized.

By the study of scales one can calculate the size of a sardine at former time intervals in its life, for the growth of the fish and the growth of individual scales proceed at about the same rate (see Fig. 4). A distinguishable ring is added to each scale each year. From information on the sizes of the fish in the catch it is possible to construct growth charts which show the increase in fish length with increase in age. Such observed data for sardines are shown in Figure 5. From these charts it is apparent that the fish taken in each major

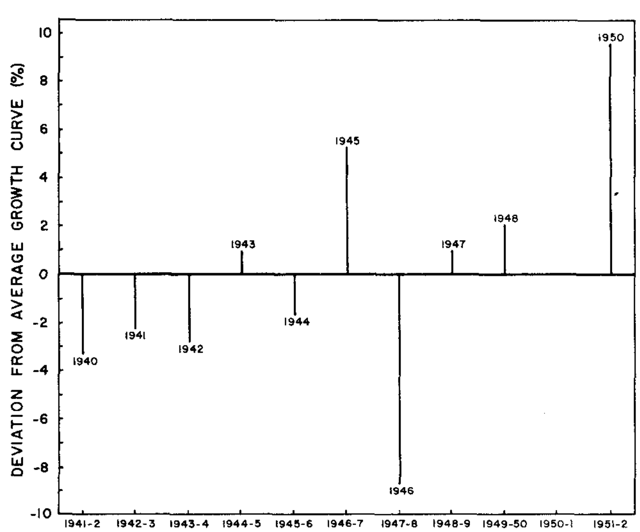


FIGURE 6. Deviations of one-year-old sardines in San Pedro fishery from average growth curve, 1941-42 through 1951-52 seasons. The 1945 and 1950 year classes, which at one year were longer than average, are tentatively assumed largely to have originated on the Baja California spawning grounds; the 1946 year class, which was shorter than average, off Southern California. The 1949 year class was not sampled at one year of age.

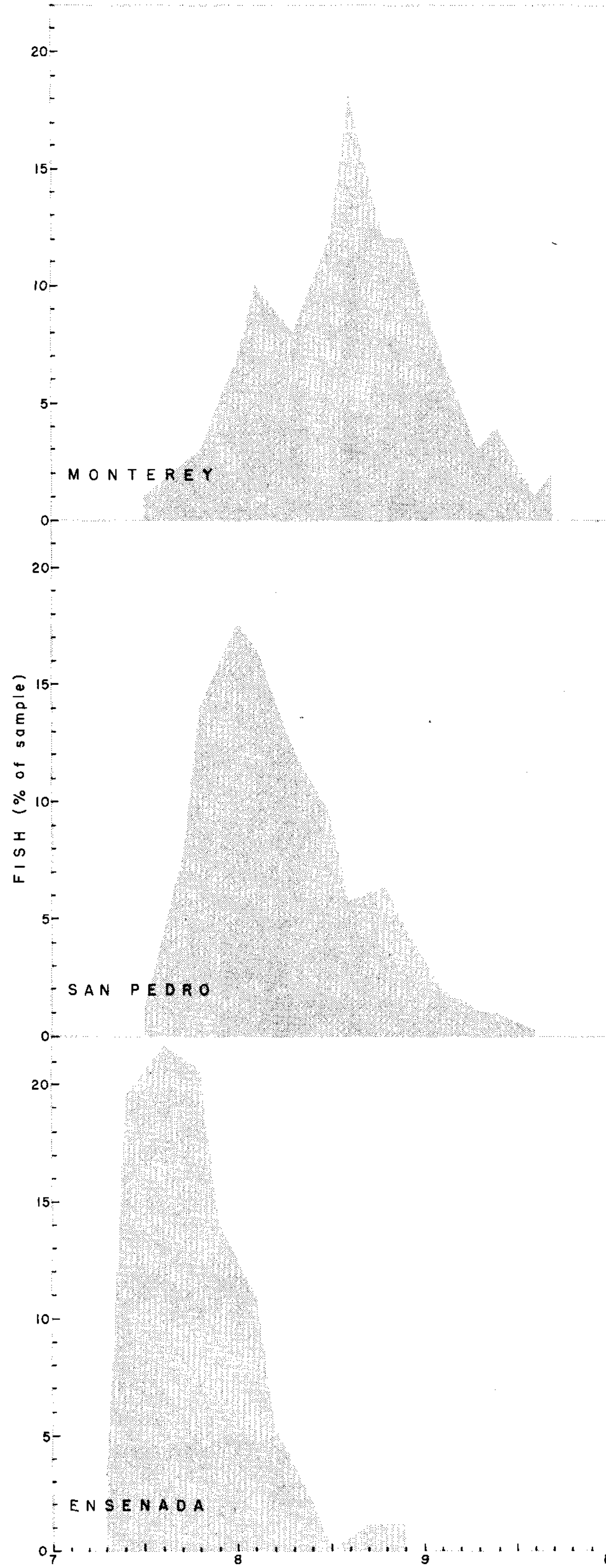


FIGURE 7. Size distribution of 1948 year-class sardines sampled at Monterey, San Pedro, and Ensenada in the 1951-52 season. Three-year-old sardines of southern origin would be shorter than those of northern origin. Very few southern fish were at Monterey, very few northern fish at Ensenada. (Data, Table 4, Appendix.)

region of the fishery show a distinctive growth pattern, with the fish taken at San Pedro growing on the average (and after their first year) at a less rapid rate than those taken farther north.

Other evidence that suggests the existence of subgroups is a comparison of the rates of growth of the various year classes. In Figure 6 the growth differences among year classes have been demonstrated in the San Pedro fishery by calculating the deviations of the one-year-old fish of each year class from the average growth curve (shown in the figure as a straight line). The one-year-old fish of three recent year classes (1945, 1946, 1950) depart considerably from the average. The 1945 and 1950 year classes, which at one year were longer than the average, are tentatively assumed to have originated largely on the Baja California grounds; fish of the 1946 year class, shorter than average, off Southern California.

Further evidence for this difference in growth rates is indicated by Figure 7, which shows the size distribution of the fish of the 1948 year class sampled at Ensenada, San Pedro, and Monterey during the 1951-52 season. At three years, typically southern fish would be shorter than typically northern fish; the data show that the Ensenada fish were on the average shorter than the others. The San Pedro sardines, intermediate in length between those at Ensenada and Monterey, could be a mixture of the slow-growing southern fish and the faster-growing northern fish at Ensenada. Very few southern fish were at Monterey, very few northern fish at Ensenada.

Thus the studies continue to suggest subgroups in the sardine population, with complex intermingling, sometimes only partial, perhaps sometimes complete.

The knotty problem of subgroups, rapidly summarized here, is being attacked with a variety of scientific techniques and should be much nearer solution within a year or so.

NUMBERS OF SARDINES

Adult Sardines

THE TOTAL POPULATION

We have seen that at present the population of adult sardines available to the commercial fishery seems to be confined to the waters off Southern California. How many of these fish are there?

There are several ways to estimate the number of adult sardines, and some of these ways are independent of each other, so that the results of one method can be checked against the results of another.

The calculations upon which such estimates are based involve complicated mathematics which cannot be presented here. They indicate that the minimum

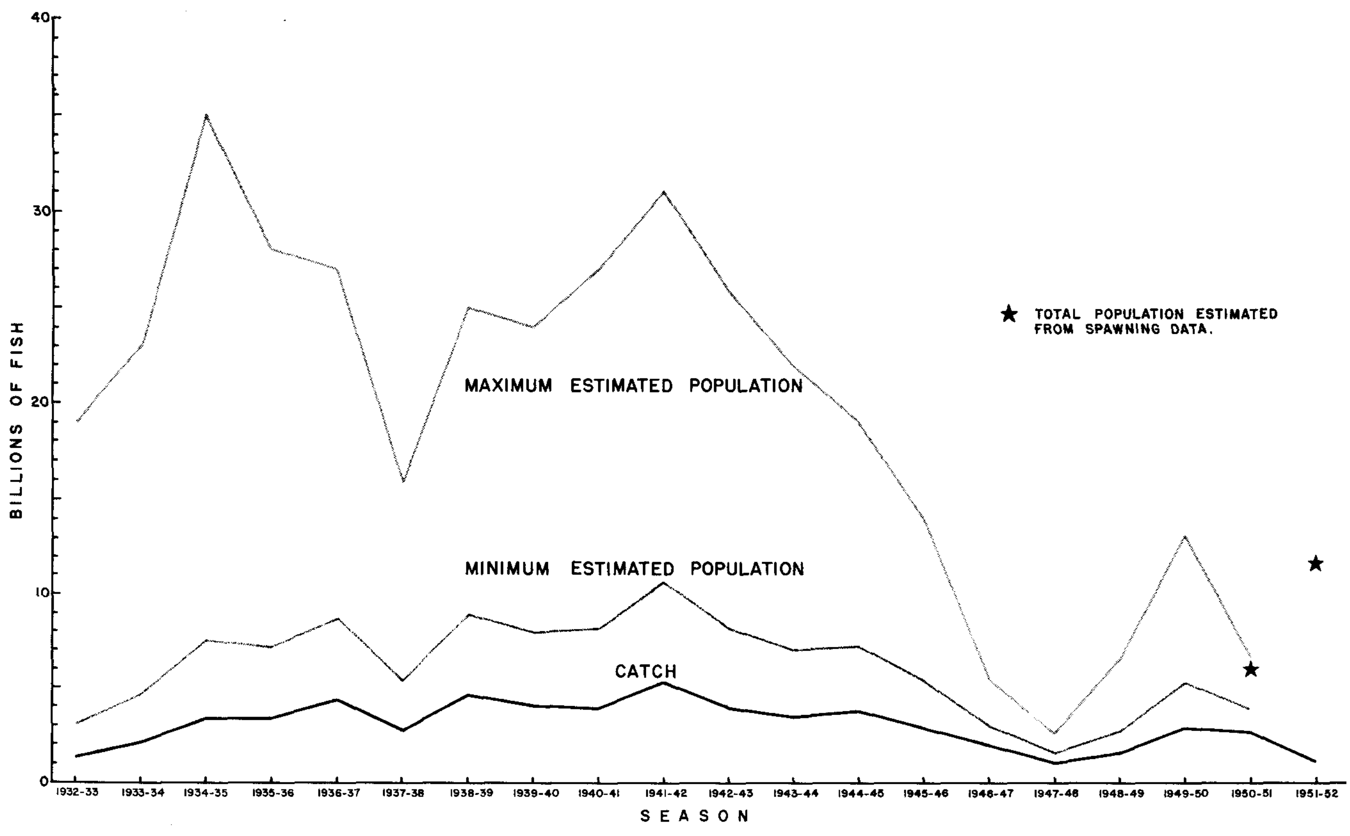


FIGURE 8. Catch and population estimates, 1932-33 through 1951-52 seasons. The minimum estimated population is designated by the second curve, the maximum estimated population by the top curve. The last two points on this curve were obtained from data on spawning. (Data, Table 5, Appendix.)

population size over the seasons 1932-33 to 1950-51 corresponds to the second line in Figure 8. The maximum might have been as great as the top line indicates. The true value probably lies somewhere between. The proportion of this population available to the fishery varies from season to season.

Another estimate has been reached by a method which we have been able to use for only two seasons. That is to determine the total number of eggs spawned during a year, divide by the number spawned per female to obtain an estimate of the number of females, and multiply by two to include the males (the sardine population is about evenly divided between males and females), thus obtaining an estimate of the spawning population. Such estimates have been obtained:

ESTIMATED POPULATION SIZE
(billions of fish)

Year	*California*	*Baja California*	*Total*
1940	4.0	no data	
1941	3.0	no data	
1950	0.7	5.4	6.1
1951	0.3	11.3	11.6

Work is in progress to determine what reliance can be placed upon all the estimates of population size. At present at least four methods are being used.

VARIATIONS IN MORTALITY RATES

The term "total mortality" is used to denote the death rate of fish. Total mortality has two components, fishing mortality and natural mortality.

Some fish are caught, and that is fishing mortality.

Some fish are eaten by other creatures of the sea, some die of disease or of old age, some starve to death; that is natural mortality.

Rather satisfactory estimates of the two elements of total mortality can be arrived at. But mortality rates alone cannot tell us if fish can be caught.

Fishermen often report "wild schools," fish that cannot be caught. These fish would be called unavailable. The fish may have moved to other areas; they may be schooling at greater depth; or they may have both moved to other areas and schooled at greater depth. All these possibilities are expressed in the term "availability."

The role of availability in the catch is one of the most controversial issues of fishery biology. Its existence is not denied; like many other intangibles—like the good will of a business, for example—it is acknowledged to exist and operate. But like good will, it is difficult to measure quantitatively. Availability varies unpredictably.

Records are kept of the ages of the fish in the catch. As the number of fish from a certain year class declines, we draw a curve descending toward zero, which marks the extinction of that year class. If these curves were an absolute measure of the year-class strength one would expect them to decline steadily, since no new fish of a previous year class can be added to a population, but occasionally they do not decline. They turn upward. This upturn is expressed, in another way, as a negative total mortality rate. The 1948-49 sardine season offers an example. In that season, the total mortality rate was minus 40 percent. A negative death rate would at first thought appear ridiculous, yet so far as the fishery is concerned, this is just what happened. The fish in that season became more available than previously. This increase in the catch could be

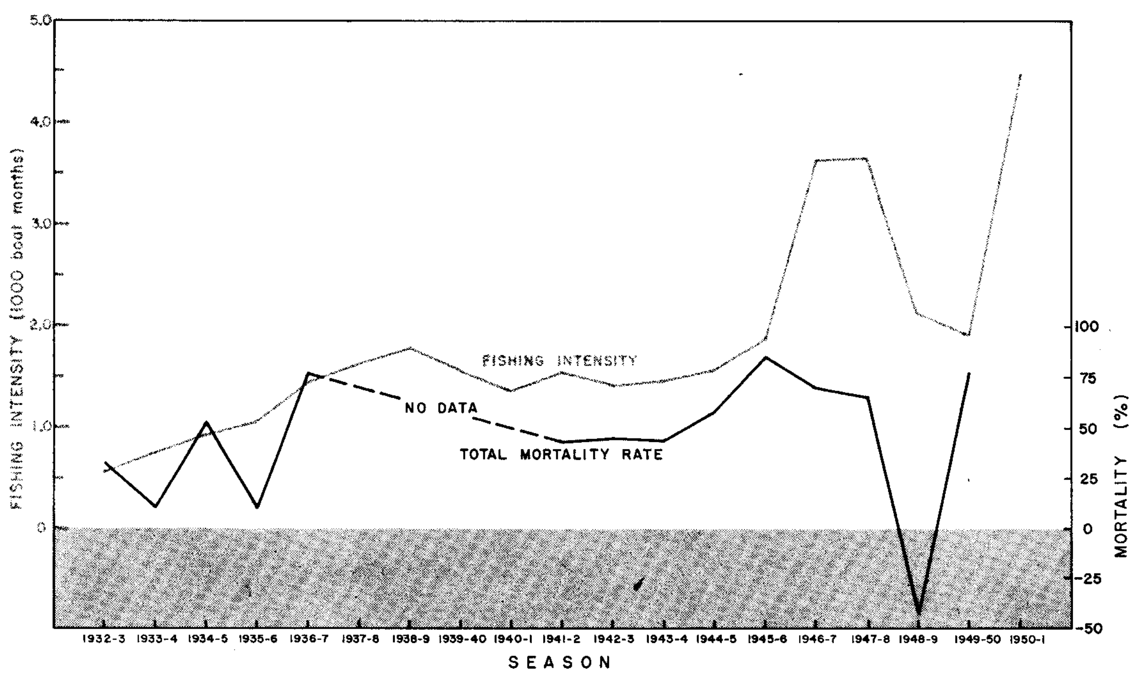


FIGURE 9. Total mortality rate and fishing intensity, 1932-33 through 1950-51 seasons. A negative mortality rate indicates that the fish became more available to the fishermen during the season.

due to both a decrease in natural mortality, and an increase in availability, but not to natural mortality alone. Yet how much of the increase in catch is due to availability, is at present impossible to determine.

Figure 9, which is based on the age composition of the catch, gives the best data we have on the total mortality rate for the seasons 1932-33 through 1936-37 and 1941-42 through 1950-51.

AGE COMPOSITION OF THE CATCH

The fish that are available to the fishermen are the only ones that appear in the catch, or course. The records show significant changes in the composition of this population during the past years. Young fish play a far bigger part in the catch than they did several years ago. The fact has important implications for the industry; the success of the catch is now more directly tied in with the success of the previous few years' spawning than it was before. There is no backlog of older fish as there was in the past.

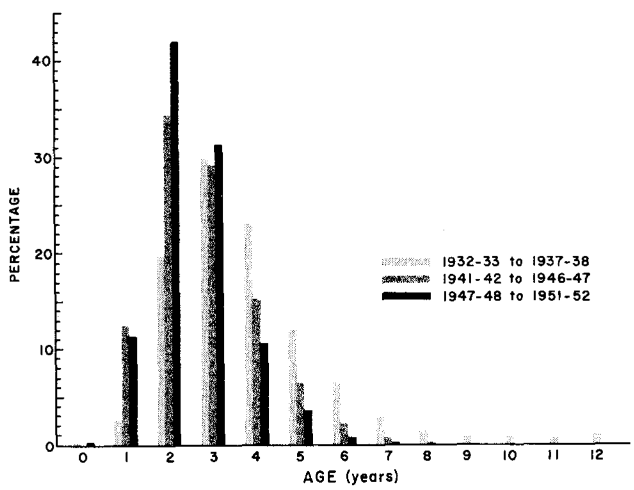


FIGURE 10. Percentage age composition based on numbers of sardines in the California fishery for three time intervals, 1932-33 to 1937-38, 1941-42 to 1946-47, 1947-48 to 1951-52. The latter period has seen very small percentages of older fish in the catch. (Data, Table 6, Appendix.)

Figure 10 shows the percentage of sardines taken from each age group for three periods between 1932 and 1952. In all three time intervals, the three-year-olds supplied almost a third of the catch in numbers. In the midthirties, however, almost half (48 percent) of the catch was made up of sardines four years and older and only 20 percent of sardines two years old. During the forties these percentages began to change. In the past five seasons the two-year-olds have comprised 42 percent of the total.

SIZE OF OLDER YEAR CLASSES

When a year class has been on the fishing grounds long enough to be fully available to the fishery, one can measure its relative abundance. This full recruitment usually occurs by age three and measurements of relative abundance are based on numbers caught per boat month during the season when a year class is between three and four years old.

Such relative measurements have now been completed for year classes 1929 through 1934 and 1938 through 1947 (Fig. 11). Among these year classes, three were outstanding: 1931, 1932, 1939. The largest group, 1932, was 16 times greater than the smallest, 1944. Over this same period, the largest total catch (in numbers of fish) was about 5.7 times the smallest, and the largest catch per boat month 7.2 times the smallest.

Unless availability so operates as to increase the catch of older fish, the California sardine industry for the next few years will be dependent for any significant improvement in the catch on the sardines that have been spawned off Southern California and Baja California since 1948.

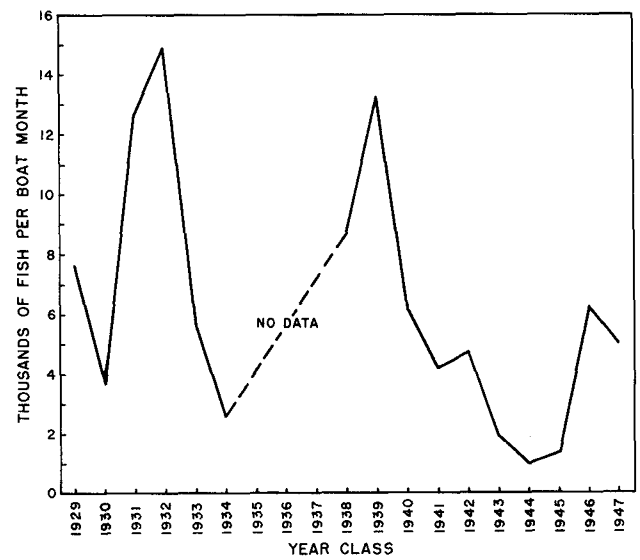


FIGURE 11. Relative year-class size of sardines as measured by the number of three-year-old fish caught per boat month in California. (Data, Table 7, Appendix.)

For four of those years, we have had ships working in the spawning area almost every month. Eggs and larvae have been counted, the occurrence of schools of young sardines regularly noted. In the following section, we shall deal in considerable detail with what has been happening in the spawning centers in the past year or so. (The 1950 data can be found in the Progress Report, 1950.) The immediate future not only of the industry but of the California sardine resource itself is perhaps being determined just off the coast from Point Conception to central Baja California, since it is in this region that sardine spawning is largely concentrated today.

Eggs, Larvae, and Young Fish

SPAWNING SURVEYS

About halfway down the lean peninsula that is Baja California, lies fish-hook shaped Sebastion Vizcaino

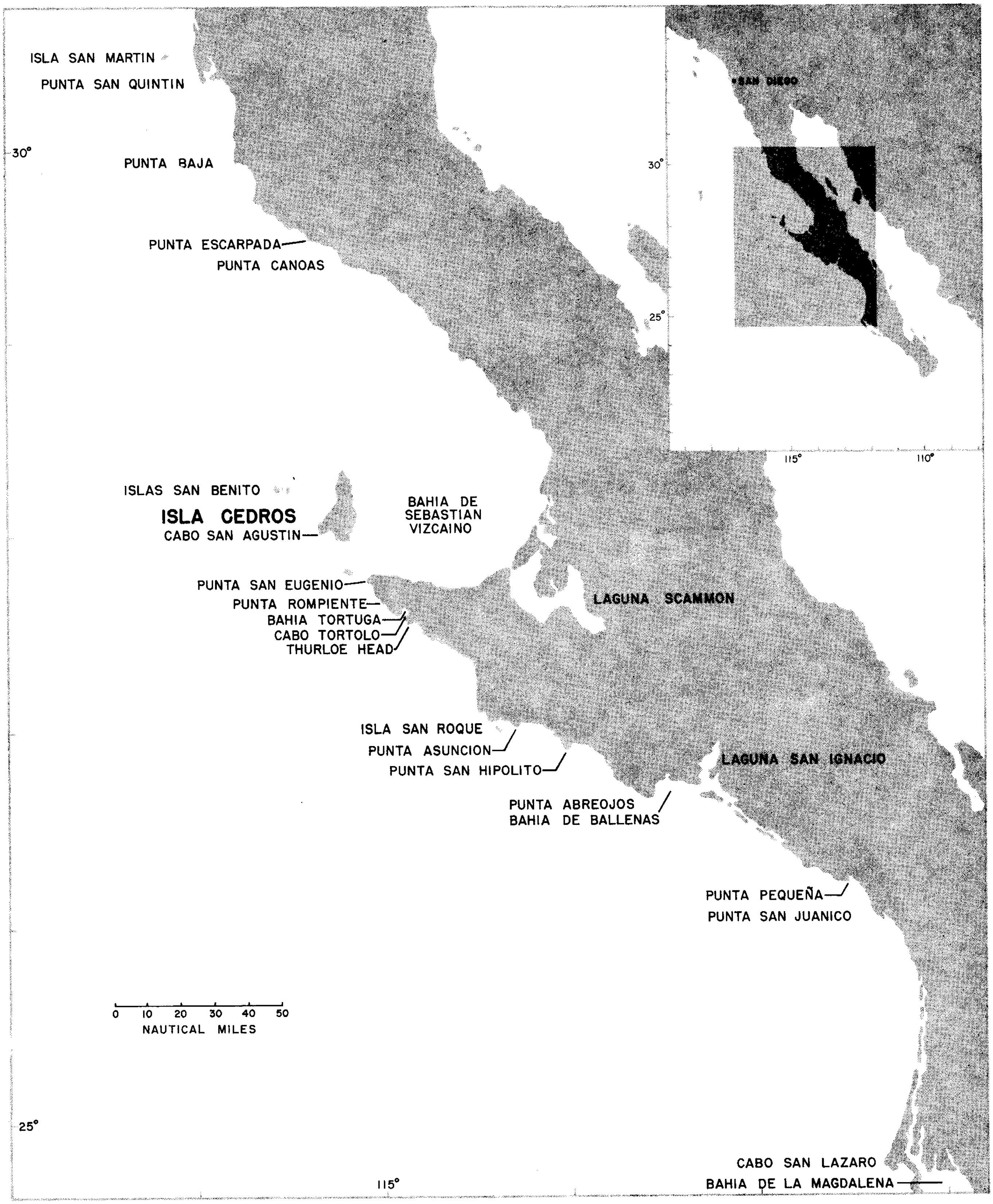


FIGURE 12. Cedros Island area, Baja California. Survey cruises have proved this region to be the major center of sardine spawning today. (See Figs. 13 through 27, and Fig. 47.)

Bay (Fig. 12). At the very bottom of the hook, big, shallow Scammon's Lagoon runs inland for several miles. Here in the winter the resurgent population of the California gray whales gathers to bear young and breed. Just off the tip of the fish-hook lies Cedros Island, a barren, steep-sided island that is the largest on the west coast of Baja California.

One of the real achievements of the California Cooperative Sardine Research Program to date has been the discovery of the important part the Cedros Island area now plays as a spawning ground. First indication of its present importance came in February 1948, when a survey concentrating on the region between Punta San Eugenio and Punta Abreojos revealed there was abundant spawning in a coastal strip about 50 miles wide. Large-scale oceanographic-fishery survey cruises began in 1949. They indicated that there were two centers of spawning, one off Southern California (as had long been known), the other in the Cedros Island area. Separating the two centers was a relatively barren stretch of water.

In the succeeding seasons, the work within the spawning centers has been intensified, and a sufficiently wide coverage has been maintained, especially during the summer, to sample adequately any spawning occurring to the north of Point Conception. Also, at intervals the

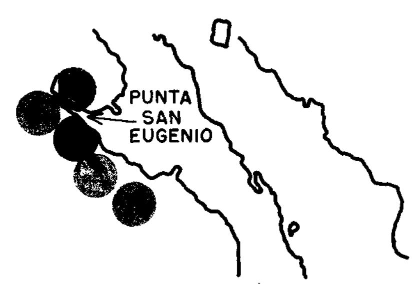


FIGURE 13. January, 1951—Sardine spawning confined to a coastal strip off central Baja California. Moderate in amount. Area covered: San Francisco to Cabo San Lazaro.

coverage has been extended as far south as the tip of the peninsula to determine the relative importance of sardine spawning off southern Baja California.

The distribution of sardine spawning during 15 months (January, 1951, through March, 1952) is shown in Figures 13 through 27. There are no charts as detailed as these for the earlier years, since spawning surveys then were limited to Southern California. The only directly comparable data we have indicate a considerable decrease in the number of larvae in that area. In 1941, the average number of sardine larvae per station during the period March through August was 30.20. In 1950, this figure had fallen to 12.30, in 1951 to 5.23.

The picture these charts draw is similar to that for the 1949 and 1950 surveys, though in part because the coverage of the spawning area was intensified, far more eggs and larvae were found on the 1951 surveys than in 1949 and 1950. Again we have two centers of spawning, located in approximately the same places each year. Again the major amount of the spawning is off central Baja California. In 1951, more than 90 percent of all sardine eggs and larvae obtained on the cruises were collected in the general vicinity of Cedros Island. This figure represents a gain over 1950, when the Baja California grounds furnished only about 75 percent of the eggs and larvae.

YOUNG FISH

The young-fish surveys are designed to provide a census of young sardines in approximately the sixth month of their lives.

The 1950 and 1951 young-fish surveys have shown a scarcity of young sardines (Fig. 28). Table 8, Appendix, gives the numbers of schools of sardines by year

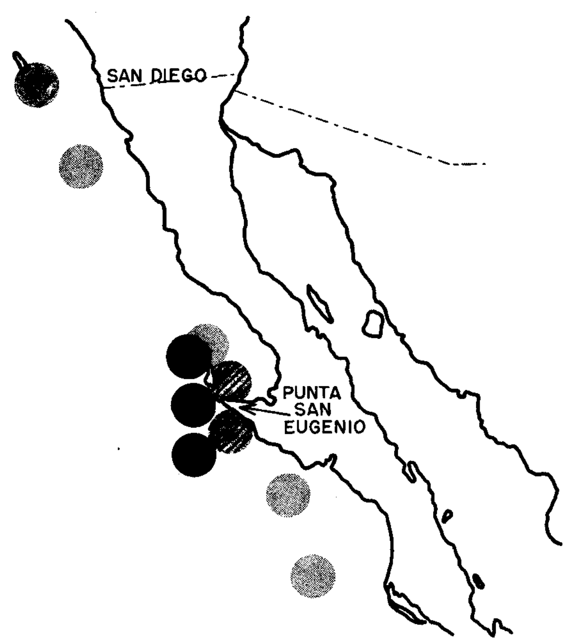


FIGURE 14. February, 1951—Spawning off central Baja California heavier than during January. Light spawning at a few stations off southern California. Area covered: Point Conception to Cabo San Lazaro.

LIGHT MODERATE MEDIUM HEAVY HEAVY

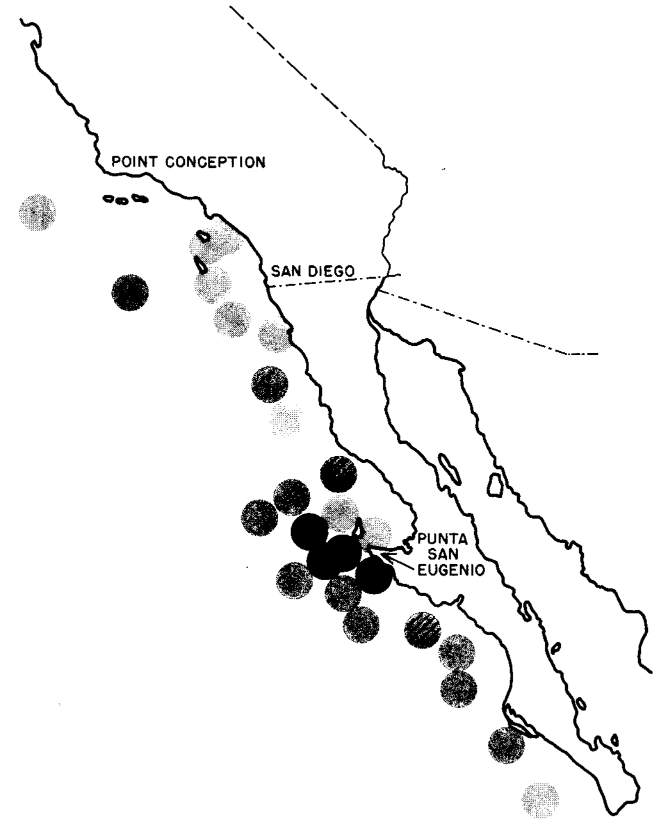


FIGURE 15. March, 1951—Very heavy spawning off central Baja California, more widespread than during January or February. Light spawning at several stations in the Southern California area. Area covered: Point Conception to Cabo San Lucas.

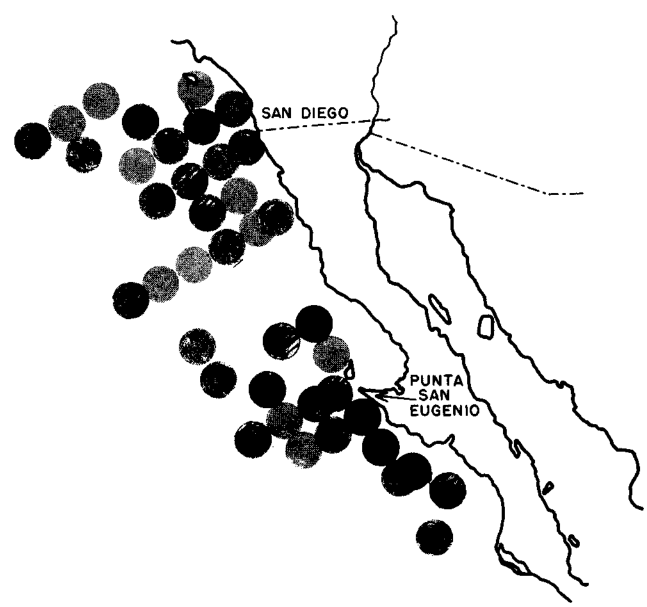


FIGURE 16. April, 1951—Heavy and fairly widespread spawning continuing off central Baja California. Light to moderate spawning widespread off Southern California and adjacent Baja California. Area covered: San Francisco to Cabo San Lazaro.

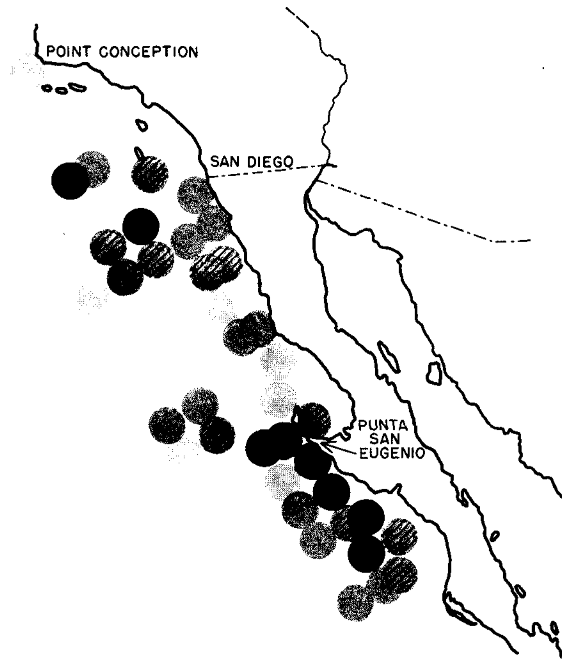


FIGURE 17. May, 1951—The peak month in the Southern California area. Off central Baja California, heavy spawning continuing. Sardine larvae were at their peak abundance in both spawning centers. Area covered: San Francisco to Cabo San Lazaro.

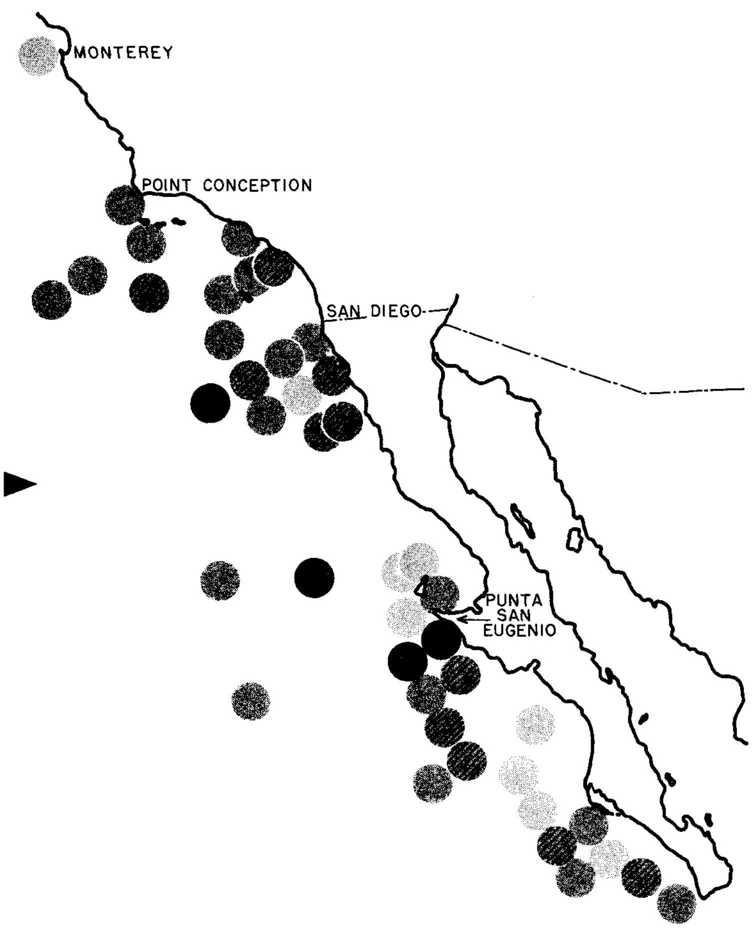
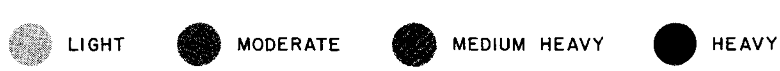


FIGURE 18. June, 1951—Spawning more widespread than during any other month. Marked decrease in abundance of eggs in collections from off central Baja California, but sardine larvae still taken in fairly large numbers in this area. In the Southern California area, collections of eggs and larvae nearly as heavy as during May. Area covered: San Francisco to Cabo San Lucas.



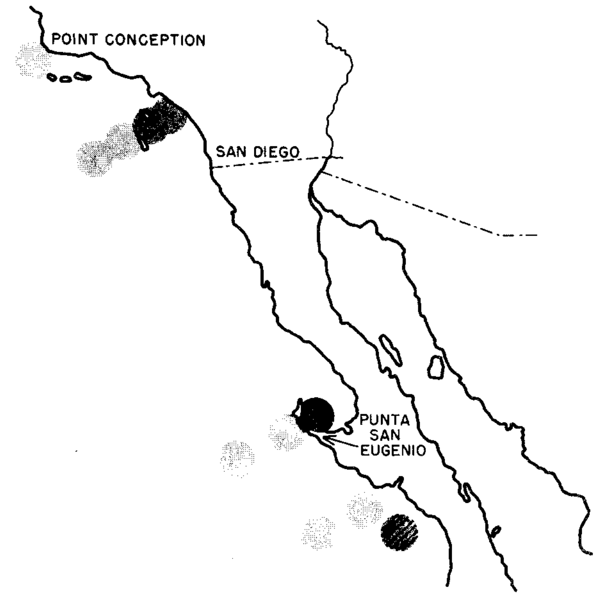


FIGURE 19. July, 1951—Spawning markedly decreased in amount and extent. Light in both spawning centers. Area covered: Cape Blanco to Cabo San Lazaro.

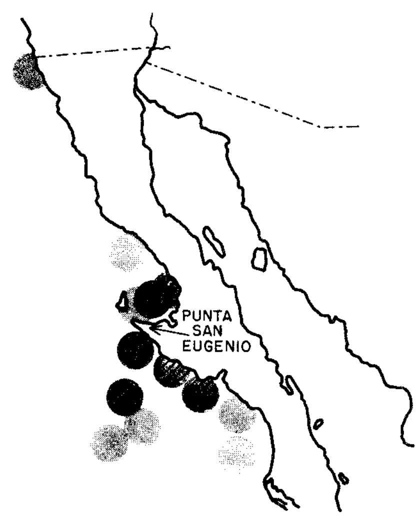


FIGURE 20. August, 1951—Spawning mostly confined to central Baja California, heaviest in Sebastian Vizcaino Bay. Area covered: Cape Blanco to Cabo San Lazaro.

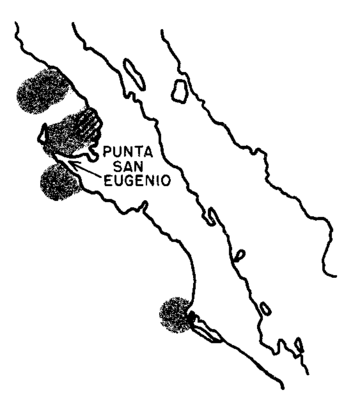


FIGURE 21. September, 1951—Mostly confined to Sebastian Vizcaino Bay. Area covered: San Francisco to Cabo San Lucas.

FIGURE 22. October, 1951—Again spawning mostly confined to Sebastian Vizcaino Bay. Area covered: San Francisco to Cabo San Lazaro.

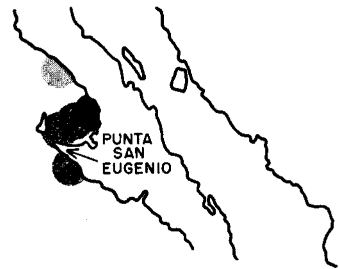


FIGURE 23. November, 1951—Distribution similar to October. Area covered: San Francisco to Cabo San Lazaro.

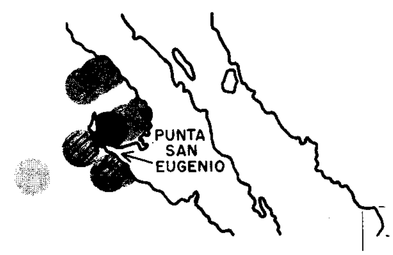


FIGURE 24. December, 1951—Confined to central Baja California, mostly in Sebastian Vizcaino Bay. Area covered: San Francisco to Punta Abreojos.

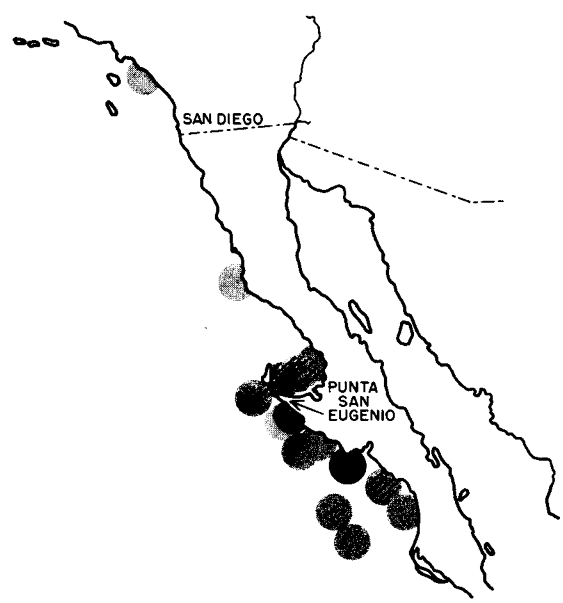


FIGURE 25. January, 1952—Confined to central Baja California, heaviest off Punta Abreojos. Area covered: Point Conception to Cabo San Lazaro.

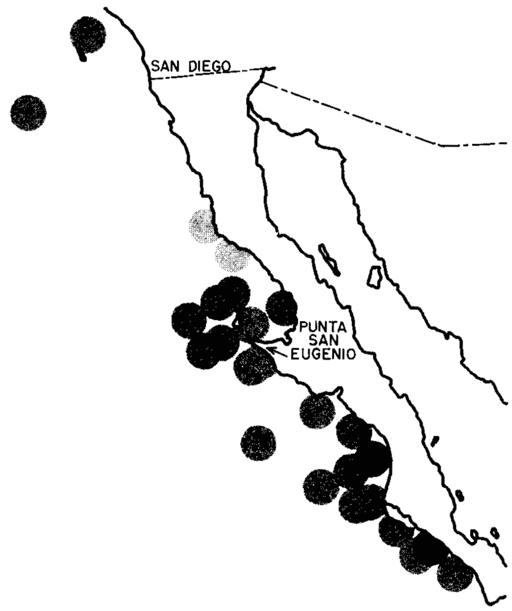


FIGURE 26. February, 1952—Spawning around Cedros Island and inshore southern Baja California. Some spawning off Southern California. Area covered: Point Conception to Cabo San Lucas.

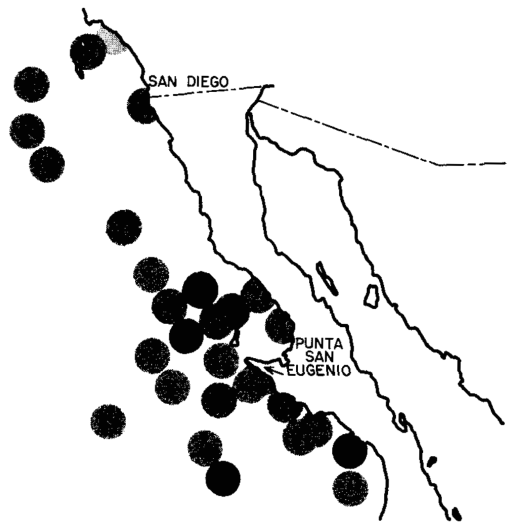


FIGURE 27. March, 1952—Spawning more plentiful and extending seaward. Area covered: Point Conception to Cabo San Lazaro.

LIGHT MODERATE MEDIUM HEAVY HEAVY

class and region per scouting night for the 1950 and 1951 surveys. Since the surveys, which were first conducted before World War II and then dropped, were not resumed until 1950, the 1948 group was measured only at two years of age. It was, however, much more abundant than the three following year classes, being more than five times the size of the 1949 year class when the latter was two years of age. The surveys do not indicate increased abundance of young fish off Baja California in 1950 and 1951 as compared to 1938, 1939, and 1940.

HABITS AND BEHAVIOR

We can guess, though we do not know, that in the bitterly competitive world of the sea, the sardine spends most of its life in an unremitting search for food, probably traveling northward toward the food-laden colder waters in the summer months and returning south in the fall and winter.

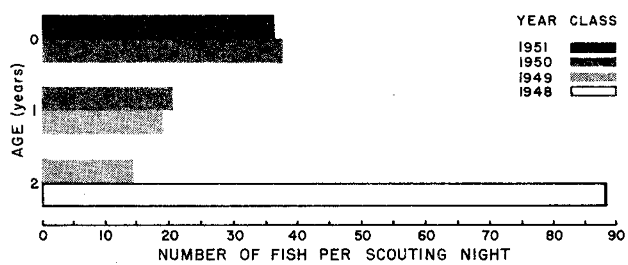


FIGURE 28. Comparison of abundance of 1948, 1949, 1950, and 1951 year classes of sardines at various ages, based on 1950 and 1951 young-fish surveys from Bodega Head, north of San Francisco, to Punta San Juanico, Baja California. These are average values; values for each of four localities are given in Table 8, Appendix.

It seems apparent that some of the really basic answers to the sardine problem can only emerge from studies of the fish itself—what kind of animal it is, how it behaves and why it behaves that way, what it eats. Some of these matters can be learned only from direct observation of living fish, and since sardines are difficult to maintain or raise in captivity research has had to start from the ground up, with experiments aimed at learning how to keep sardines alive in an aquarium.

We can report much progress along this line. Adult sardines have been kept for over 18 months in refrigerated tanks in which the water is held between 50.0° F. and 53.6° F. They are fed exclusively on adult brine shrimp. These are shellfish less than half an inch long. They are found in salt ponds. To collect them, one has to seek out a pond and seine for the shrimp; as a result, brine shrimp make a rather expensive food because of the time spent in collection. Ordinarily the sardines are allowed to eat about 200 brine shrimp each in 24 hours. Although they have remained healthy, there has been little growth on this diet. Recently an experiment was conducted in which the amount of food was stepped up, the sardines getting more brine shrimp in eight hours than they previously had in 24. It was estimated that each fish ate more than 300 brine shrimp per hour while feeding (about 36 times as much as usual). Owing to the expense involved, it has not been possible to continue to feed the sardines on this quantity of shrimp in order to obtain more rapid growth.

Olfactory Sense

When brine shrimp are thrown into a tank, sardines within a foot or so of them will respond immediately with feeding actions, rapid swimming, and mouth motions. Are the fish locating their food by sight or smell?

An extract of brine shrimp was prepared and poured into the tank at feeding time. The response was identical to that resulting from introduction of live brine shrimp: those sardines within approximately 12 inches of the colored extract cloud responded almost immediately to it by rapid swimming motions, though without mouth motions.

Next a suspension of fuller's earth in sea water, exactly the same color as the brine-shrimp extract, was thrown into the tank. The sardines showed no response at all. A repetition of the brine-shrimp extract immediately brought about feeding.

As a further test of the importance of the olfactory sense in feeding, yellow cornmeal was used for feeding the sardines. The appearance of the cornmeal, either dry or soaked in sea water, elicited no response at all, though in other experiments sardines have been known to respond to cornmeal. Then cornmeal that had been soaked for four hours in brine-shrimp extract was fed the fish. The mixture was the color of the brine-shrimp cloud. The sardines responded readily with seining type of feeding behavior.

Then cornmeal soaked in food coloring of a shade approximating that of the brine-shrimp cloud was introduced. The fish did not respond. A repetition of the flavored cornmeal resulted in active feeding.

Following several feedings on flavored cornmeal, the sardines did respond to the colored but unflavored mixture with active seining, indicating that conditioning had resulted.

On the basis of these tests, it appears evident that the olfactory sense does play an important role in the feeding behavior of the sardine, at least of the adults.

School Patterns

On the cover of this report are shown some of the patterns that sardines in an aquarium tank assumed during a 15-minute period. From these and other observations, it is evident that sardines in captivity may circle in either a clockwise or counterclockwise direction or both at the same time while in a school formation. At no time has it been determined that any individual sardine or group of sardines acts regularly as leader or leaders of the school pattern.

The strong schooling proclivity of sardines is accentuated by disturbing stimuli and is well expressed by the positive reaction of sardines to schools of other fishes sharing the same tank. Experiments indicate that the reflection of light against the silvery sides of sardines and other schooling fishes stimulates closer aggregation.

Behavior in an Electrical Field

That the actions of small fishes can be controlled by electricity has been known some 65 years. Applications have been worked out in fresh-water fisheries research.

Since World War II there have been stories that both the Germans and the Russians have managed to apply the principle to marine fisheries, but few specific details of the methods employed have been made available.

The work on the Pacific sardine has been confined to experiments in small aquarium tanks. Behavior of the fishes is diagramed in Figures 29 and 30. Of the many types of current tried, the most effective was one in which the density began at zero, increased to a maximum of 30 milliamperes per square inch of cross-sectional area of water for a duration of eight cycles, and then returned to zero for four cycles. These pulses were repeated five times per second.

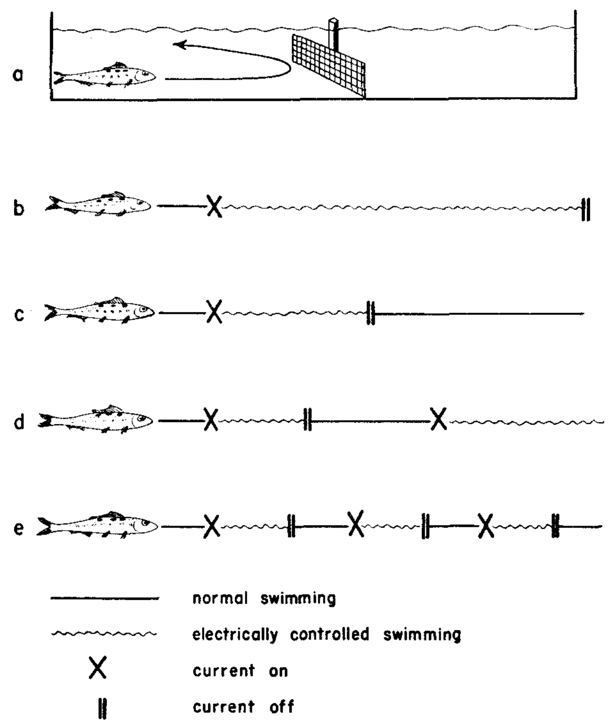


FIGURE 29. Diagram illustrating behavior of sardines in the absence and in the presence of an electrical field.

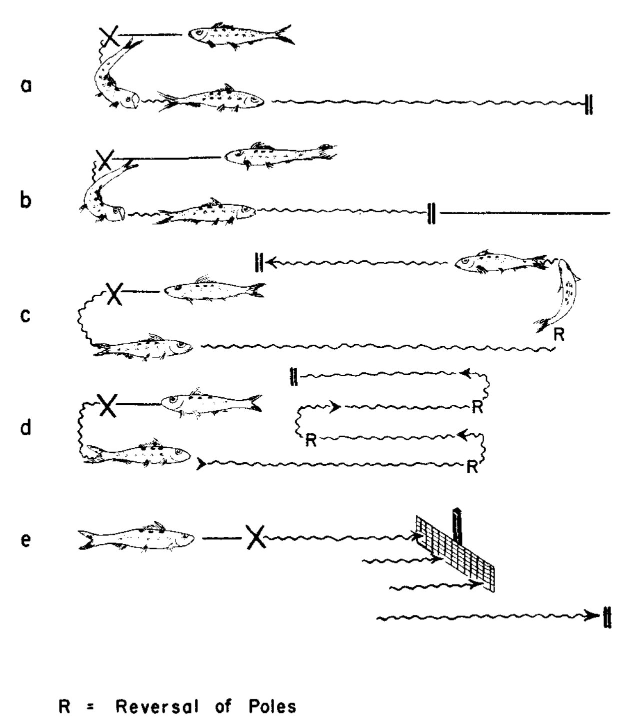


FIGURE 30. Diagram illustrating behavior of sardines in an electrical field.

Food of the Sardine

One of the sterling examples of the practical value of oceanographic research to the fisheries has been the use of a scientific device, the Hardy plankton recorder, in the British herring fishery. Scientists use the recorder to determine the kinds and amounts of minute plants and animals in the sea. The fishermen use a simpler version of the same instrument to tell if waters are good for fishing. They are able to do this because it has been discovered that the herring avoid waters where plant plankton is concentrated and seek out areas where the animal plankton predominate. Plant plankton shows up as a greenish smear on the recorder, animal plankton as a reddish smear. (Plans are being made, incidentally, for extensive tests of the Hardy recorder in California waters, though it is not known if it can be profitably used by the sardine industry.) The information that made the use of the recorder by the industry practicable was gained from long studies of the feeding habits of the herring. No such completed studies exist for the Pacific sardine, but at present two preliminary investigations are under way. One concerns the larvae, the other the adults.

FOOD OF THE LARVAE

The chief food of the sardine larvae are the very early stages of small copepods, which are microscopic crustaceans that are plentiful in all oceans. The smaller sardines, under one-fourth an inch long, feed as much at night as during the day. Larger ones, particularly those over about one-half an inch long, feed almost exclusively during the day. The recently hatched sardine larvae can ingest particles no more than 0.003 inch long. Less than 10 percent of the larvae in our collections contain food.

FOOD OF THE ADULT SARDINE

The contents of the stomachs of adult sardines are being compared with plankton collections taken at the same time and place as were the sardine samples. Phytoplankton (plants) was found in only 75 percent of the sardine stomachs; zooplankton (animals) in 100 percent. The phytoplankton content of the water samples under study has not been measured; zooplankton occurred in 100 percent of the water samples.

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

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

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

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

THE ENVIRONMENT

Oceanographic Conditions

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

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

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

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

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

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

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

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

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

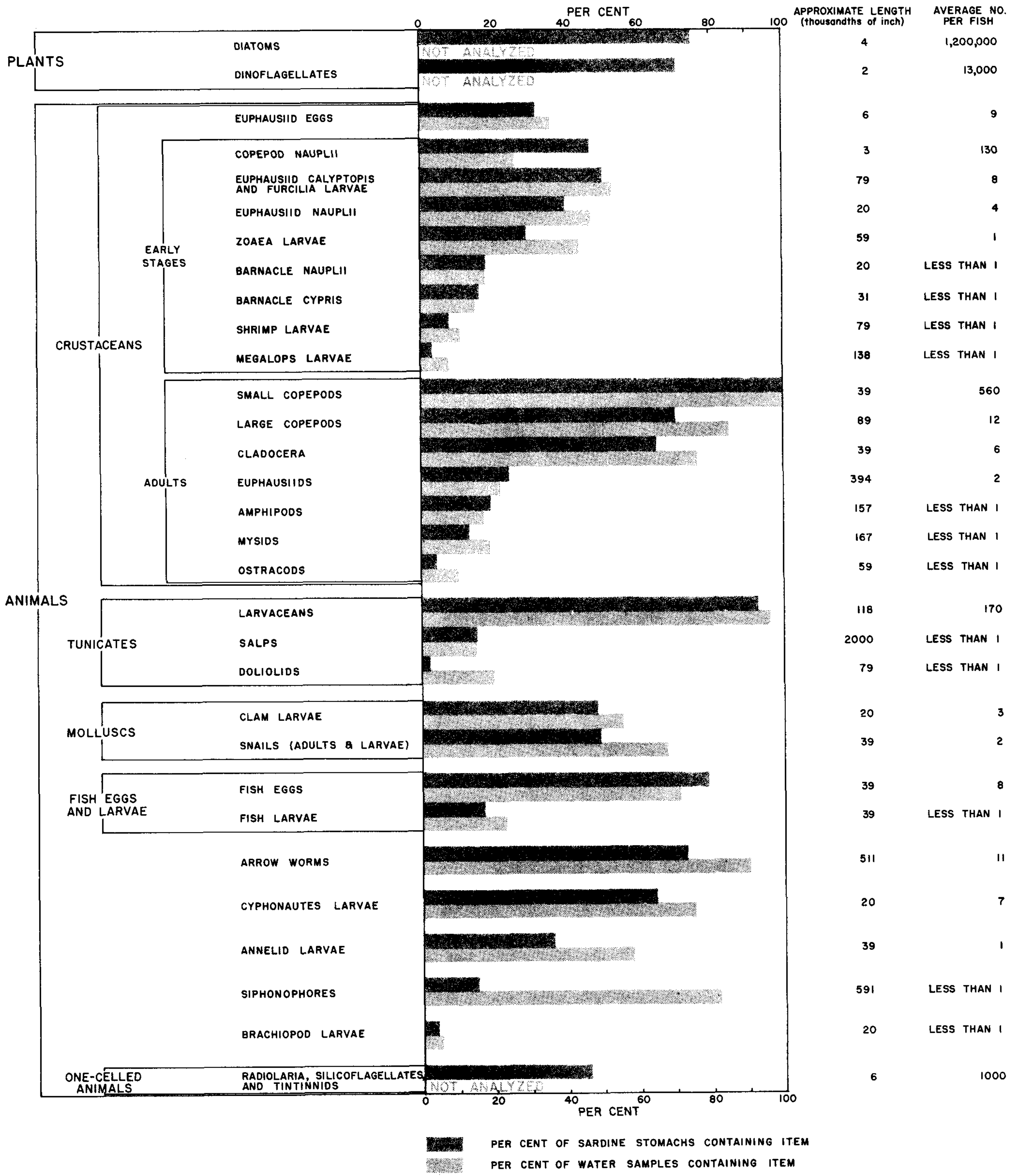
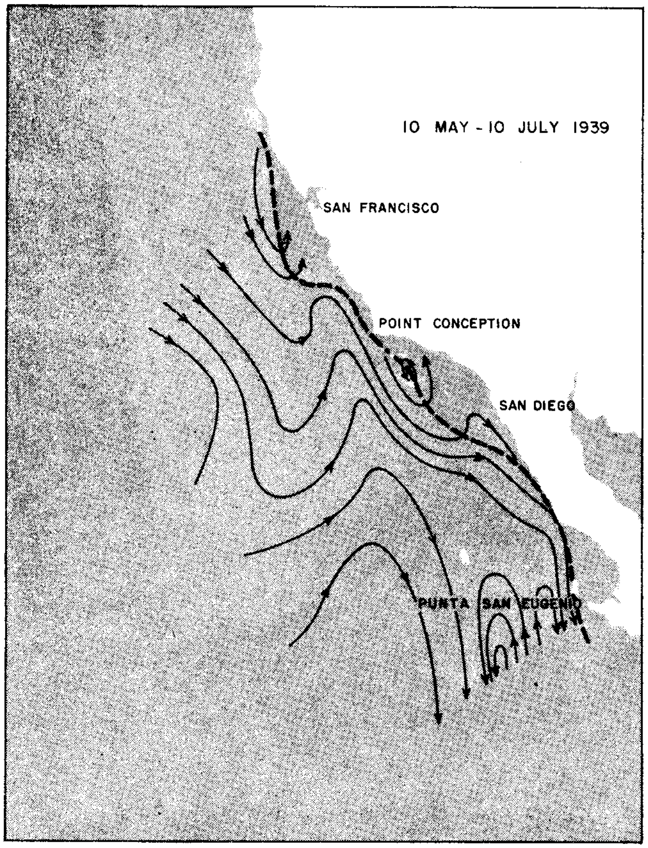
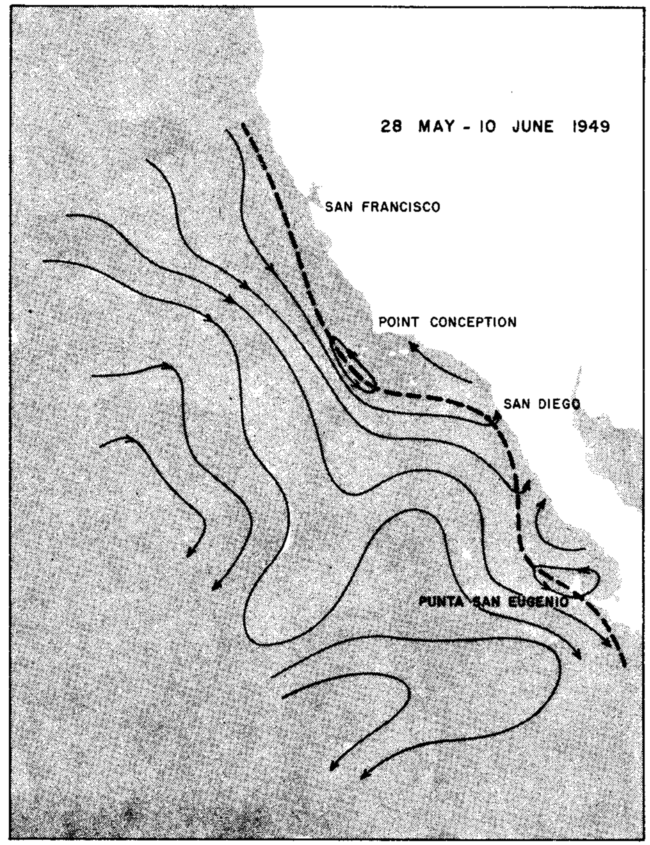


FIGURE 31. Food items in stomachs of 273 adult sardines as compared with plankton content of water samples taken along with the sardines. A variety of crustaceans—shrimps and crabs and their relatives—are found. A two-inch salp (one of the tunicates, a group of soft-bodied, watery creatures) was the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





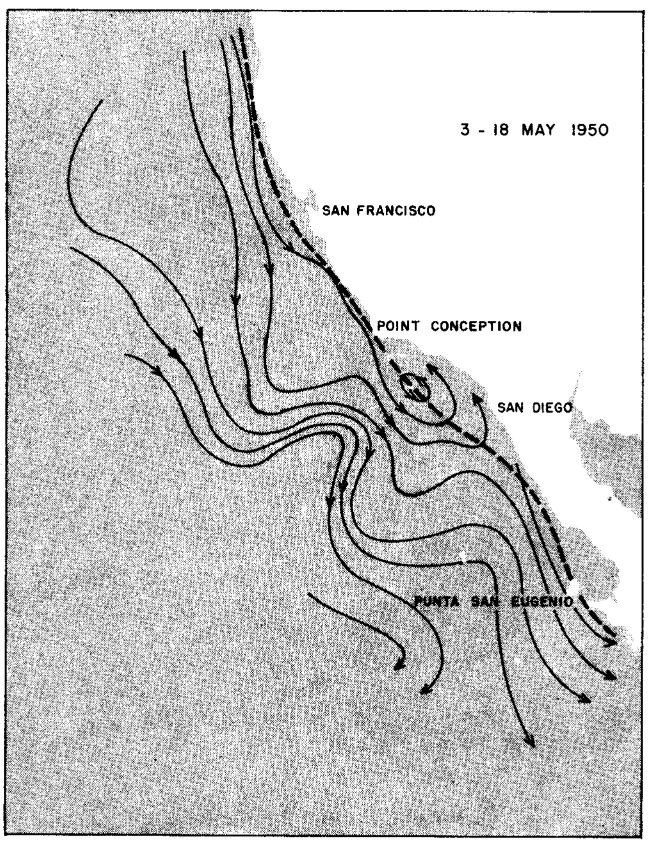


FIGURE 32. Current patterns off the California coast, 10 May-10 July 1939, 28 May-10 June 1949, 3-18 May 1950. The dashed line delineates the eastern edge of the south-flowing California current. Note the eddy off Point Conception on each chart.

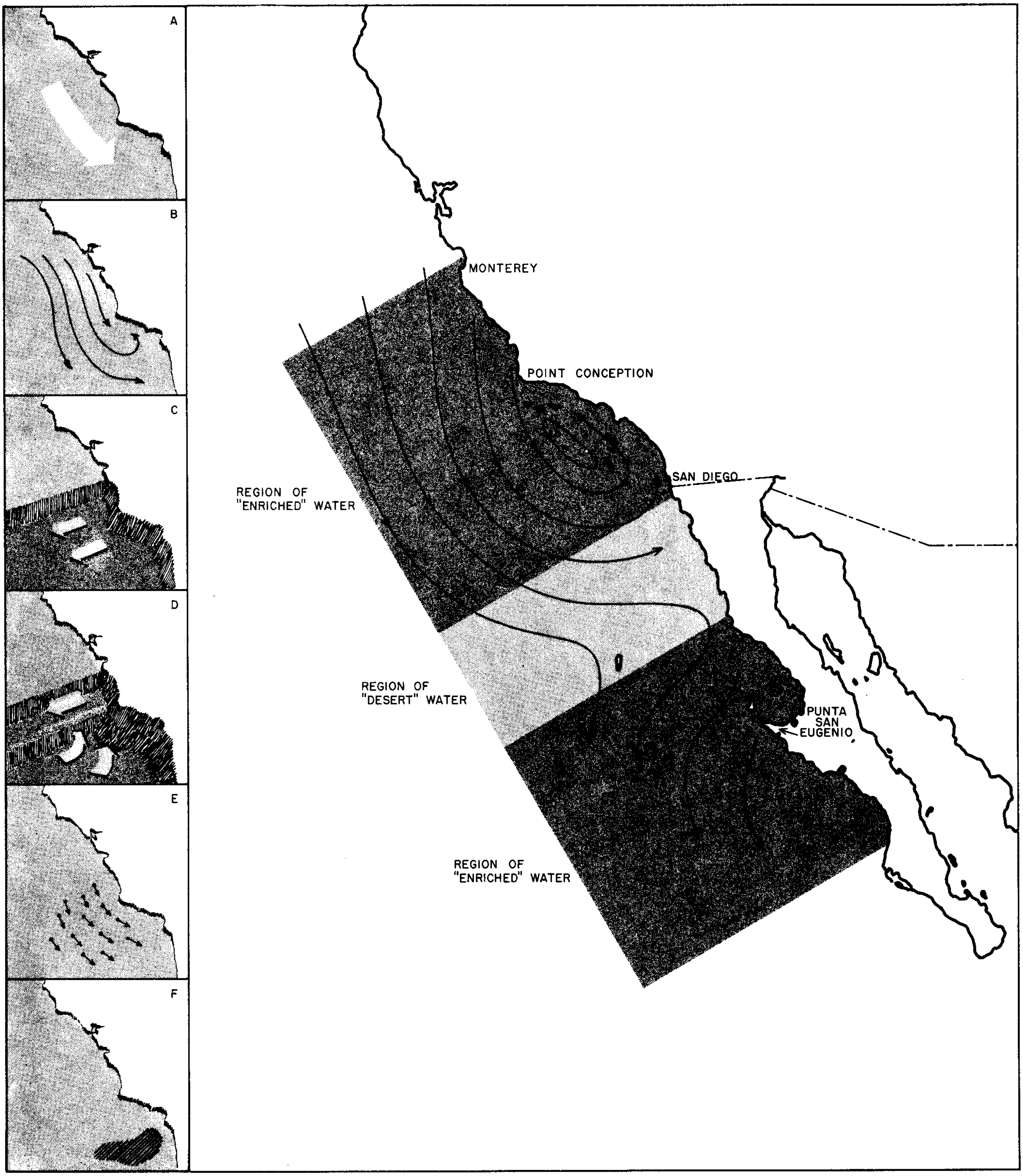


FIGURE 33. Upwelling along the California coast. A, Strong winds parallel to the coast favor upwelling. B, A counterclockwise eddy begins to form off Point Conception. C, The surface waters begin to move off shore. D, The colder, richer, and more saline waters rise from depth to replace the surface waters.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

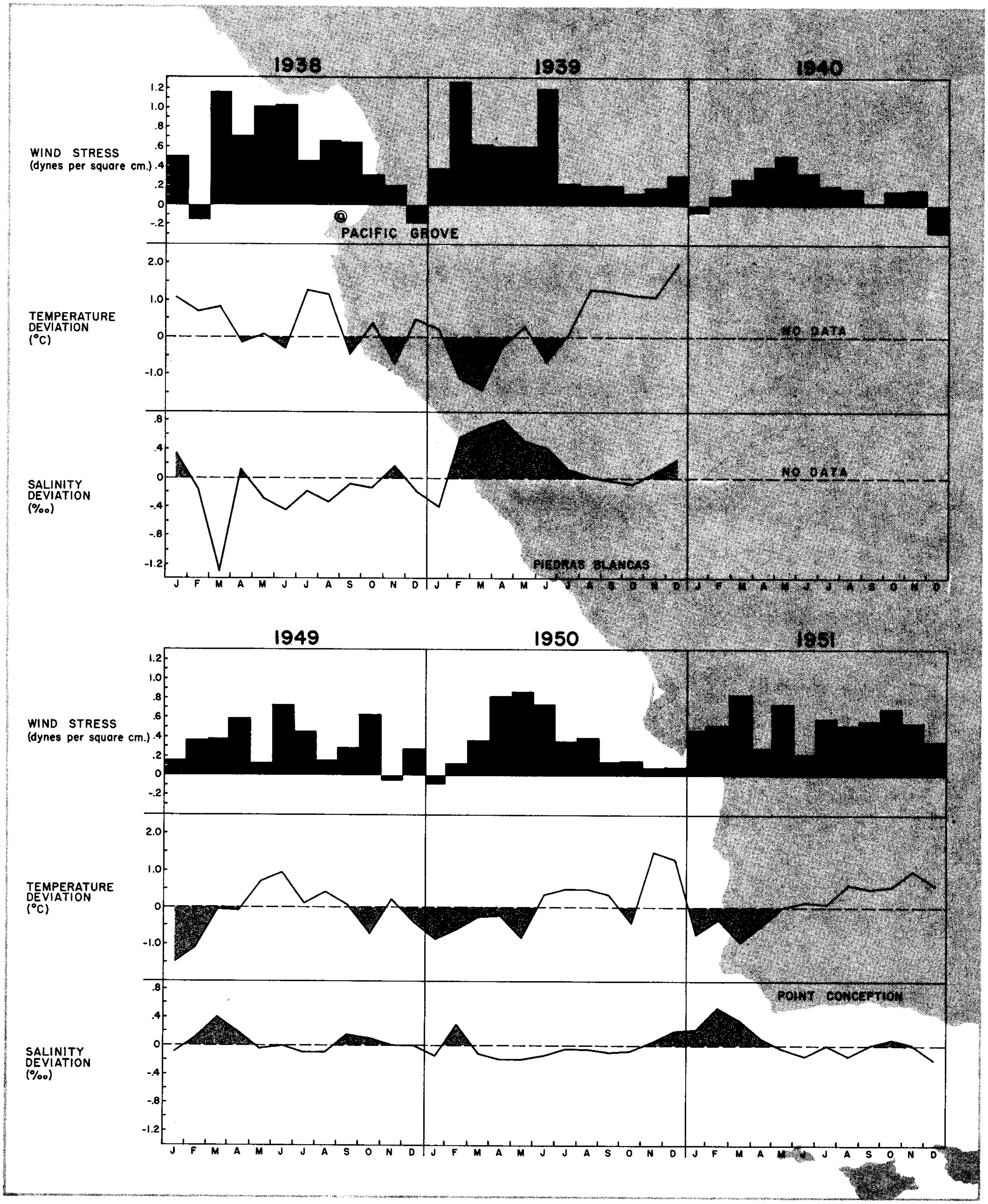


FIGURE 34. Indicators of upwelling, central California, 1938-40 and 1949-51. Wind stress has been computed for the entire area. Temperature and salinity deviations are from records collected at Pacific Grove. Only components of wind stress parallel to the coast have been measured. High wind stress parallel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

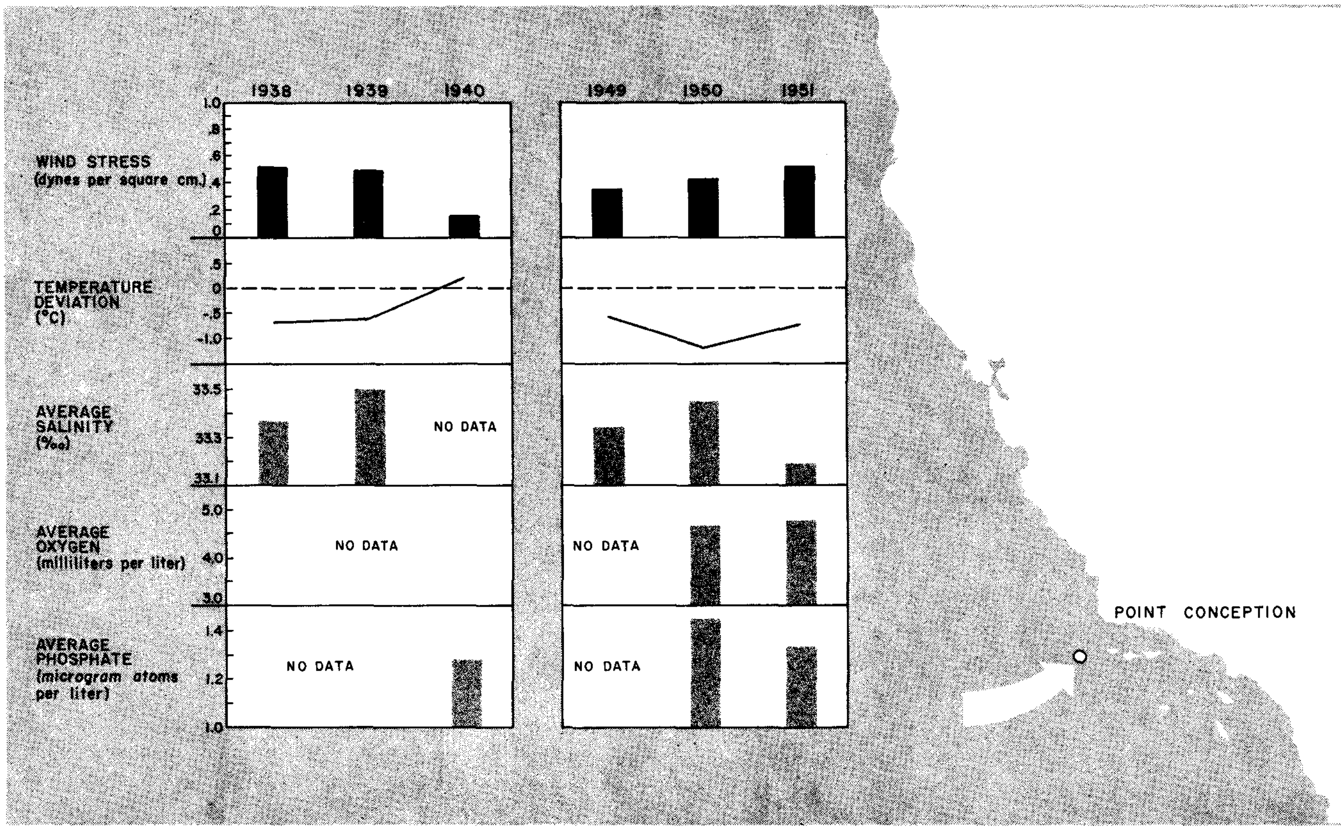


FIGURE 35. Indicators of upwelling, off Point Conception, 1938-40 and 1949-51. Wind stress was computed from weather maps. Temperature, salinity, oxygen, and phosphate data were collected at the station marked. The data indicate that 1940 was a very poor year for upwelling.

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

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

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

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

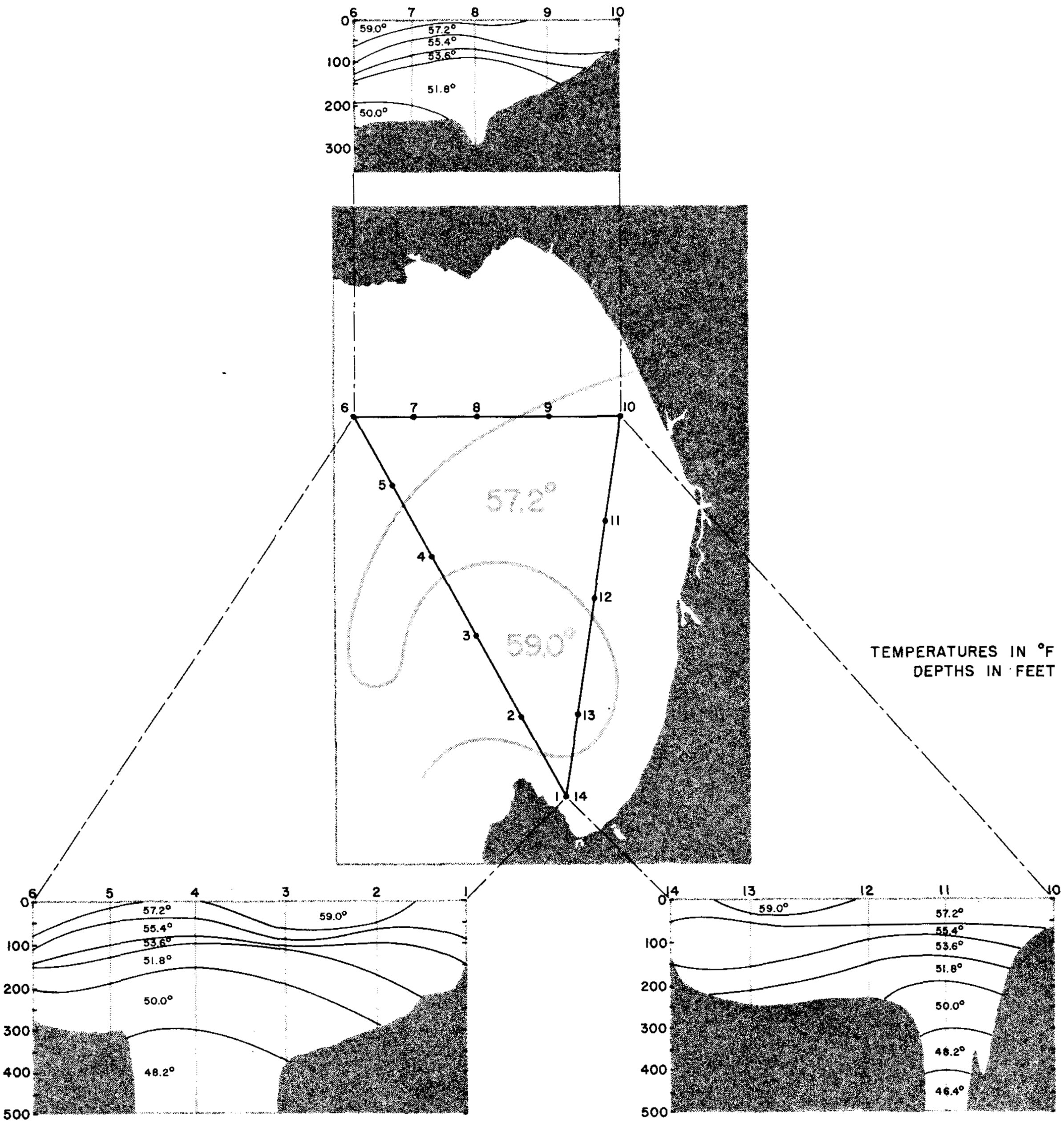


FIGURE 36. Temperature survey, Monterey Bay, 2 October 1951. The center chart gives course followed and the distribution of surface temperature. Stations 4 and 11 lie over Monterey Submarine Canyon. The smaller charts give cross-sections of temperature along each leg of course.

tual conditions. Yet they show several interesting things:

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

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

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

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

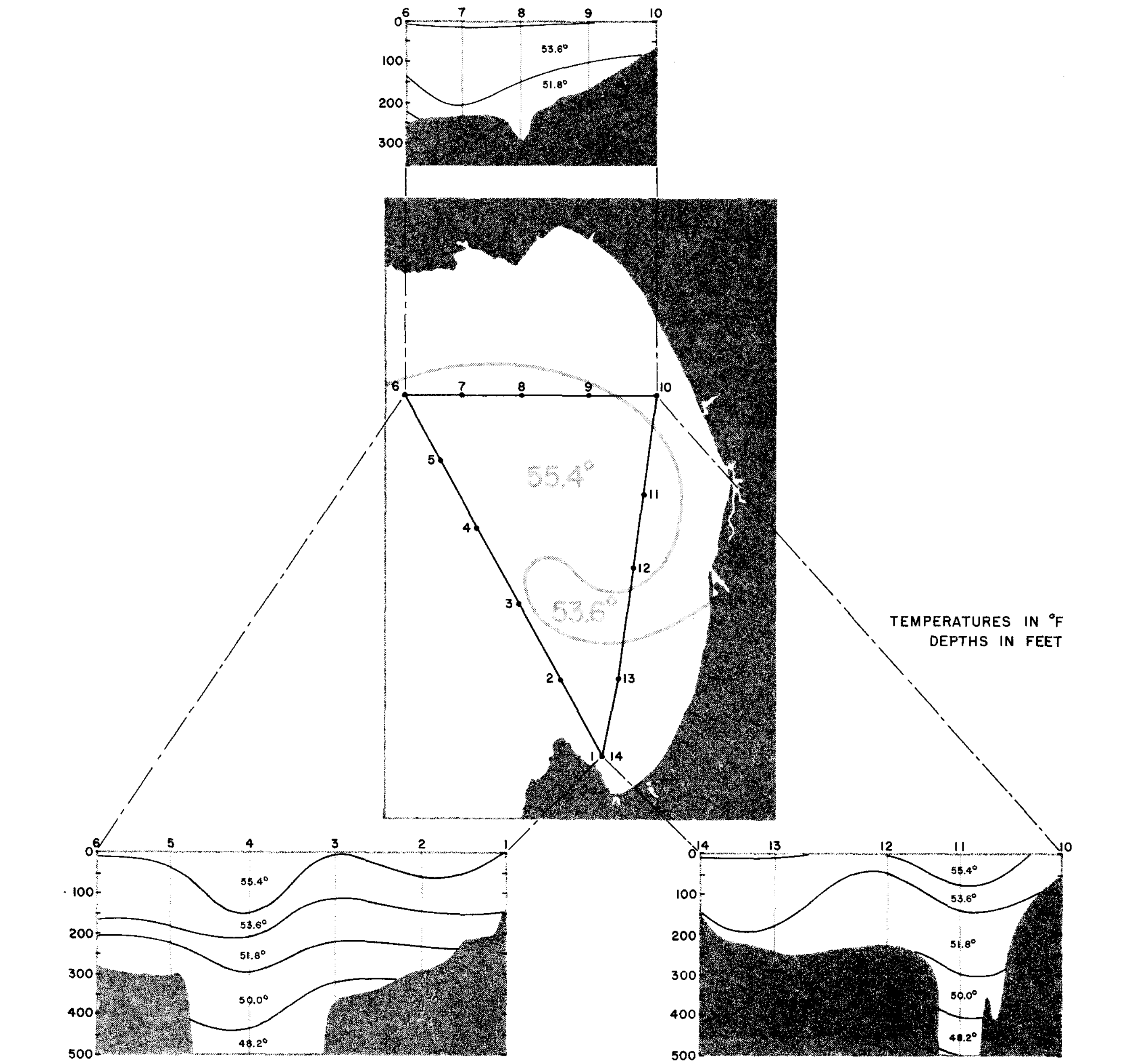


FIGURE 37. Temperature survey, Monterey Bay, 13 December 1951. The center chart gives the course followed and the distribution of surface temperature. Stations 4 and 11 lie over Monterey Submarine Canyon. The smaller charts give cross-sections of temperatures along each leg of course.

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

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

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

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

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

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

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

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

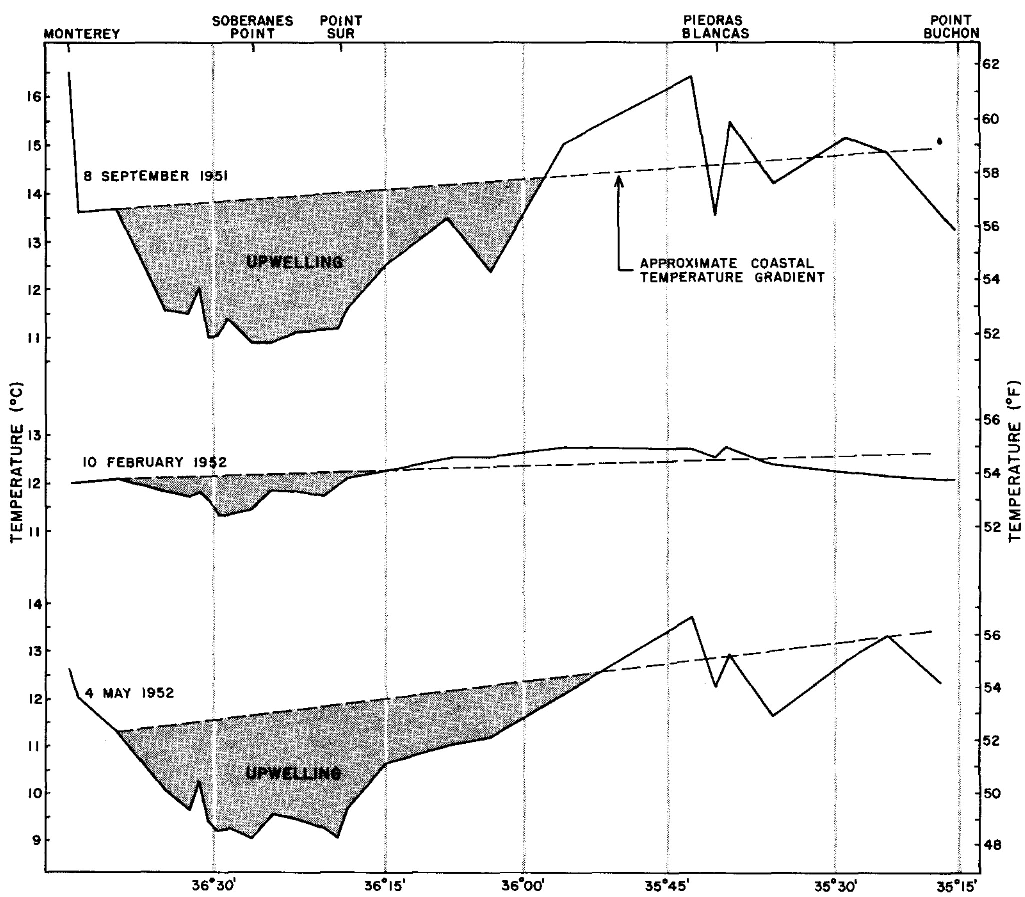


FIGURE 38. Upwelling along the coast south of Monterey, late 1951 and early 1952. The shaded areas indicate marked departures of temperature from approximate coastal temperature gradient.

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

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

Relation of Oceanographic Conditions to Other Factors

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

POPULATION SIZE

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

YEAR-CLASS SIZE

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

MORTALITY RATES

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

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

FISHING SUCCESS

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

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

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

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

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

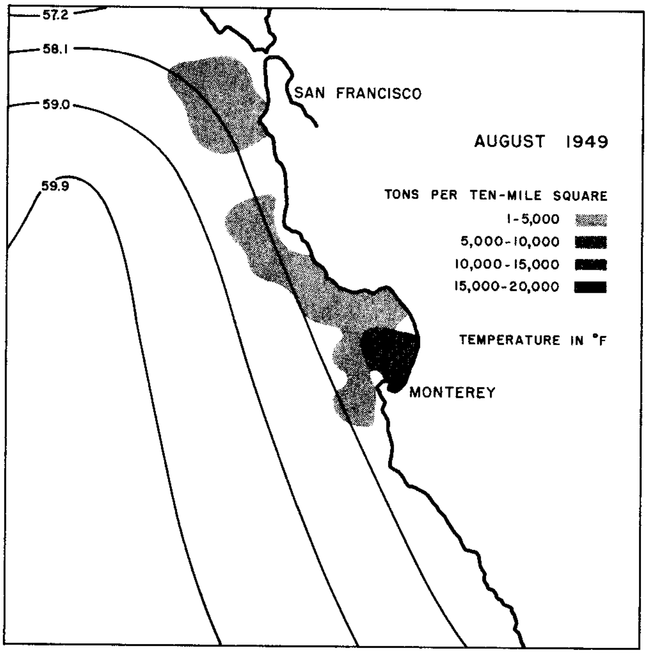


FIGURE 39. Sardine catch and surface temperatures, August, 1949.

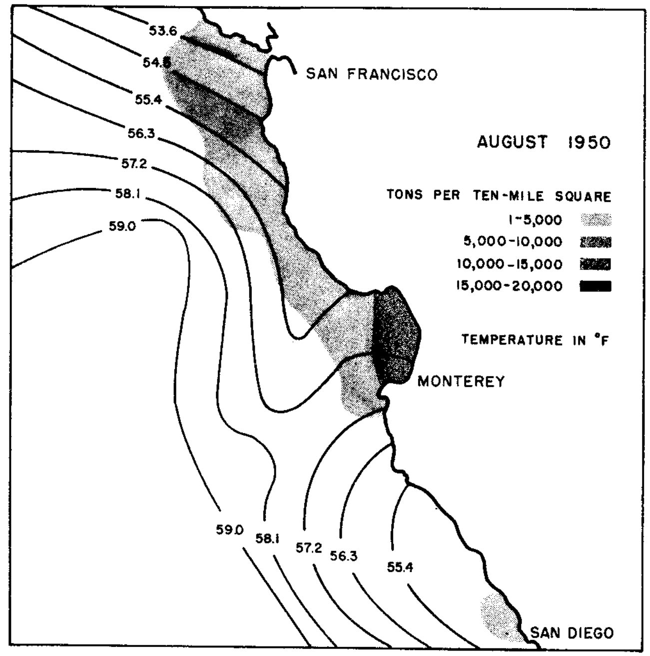


FIGURE 40. Sardine catch and surface temperatures, August, 1950.

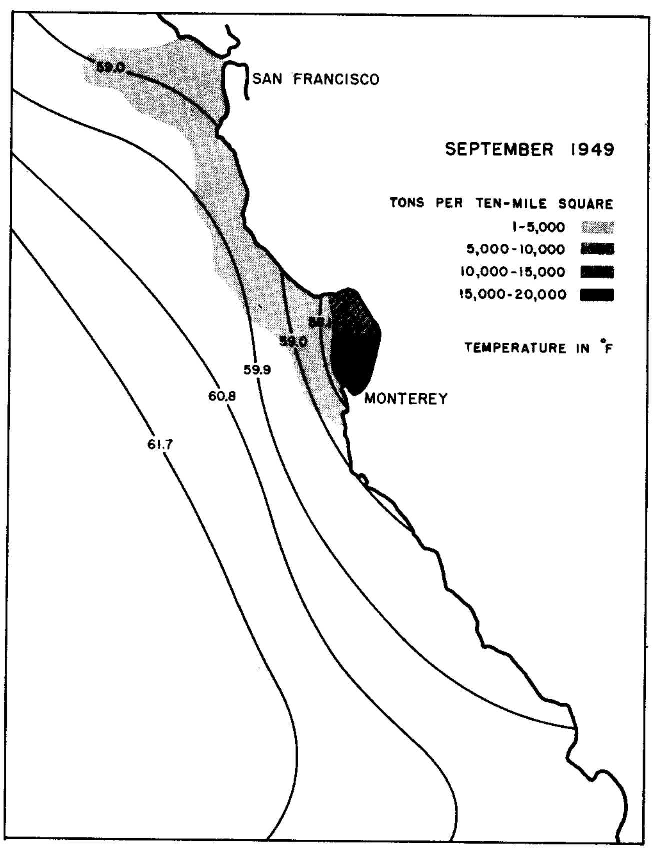


FIGURE 41. Sardine catch and surface temperatures, September, 1949.

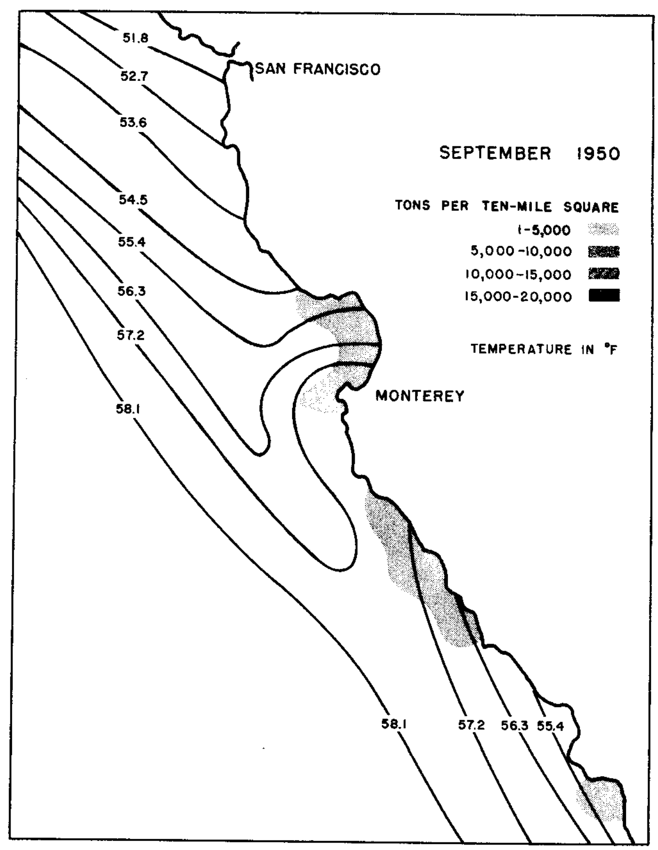


FIGURE 42. Sardine catch and surface temperatures, September, 1950.

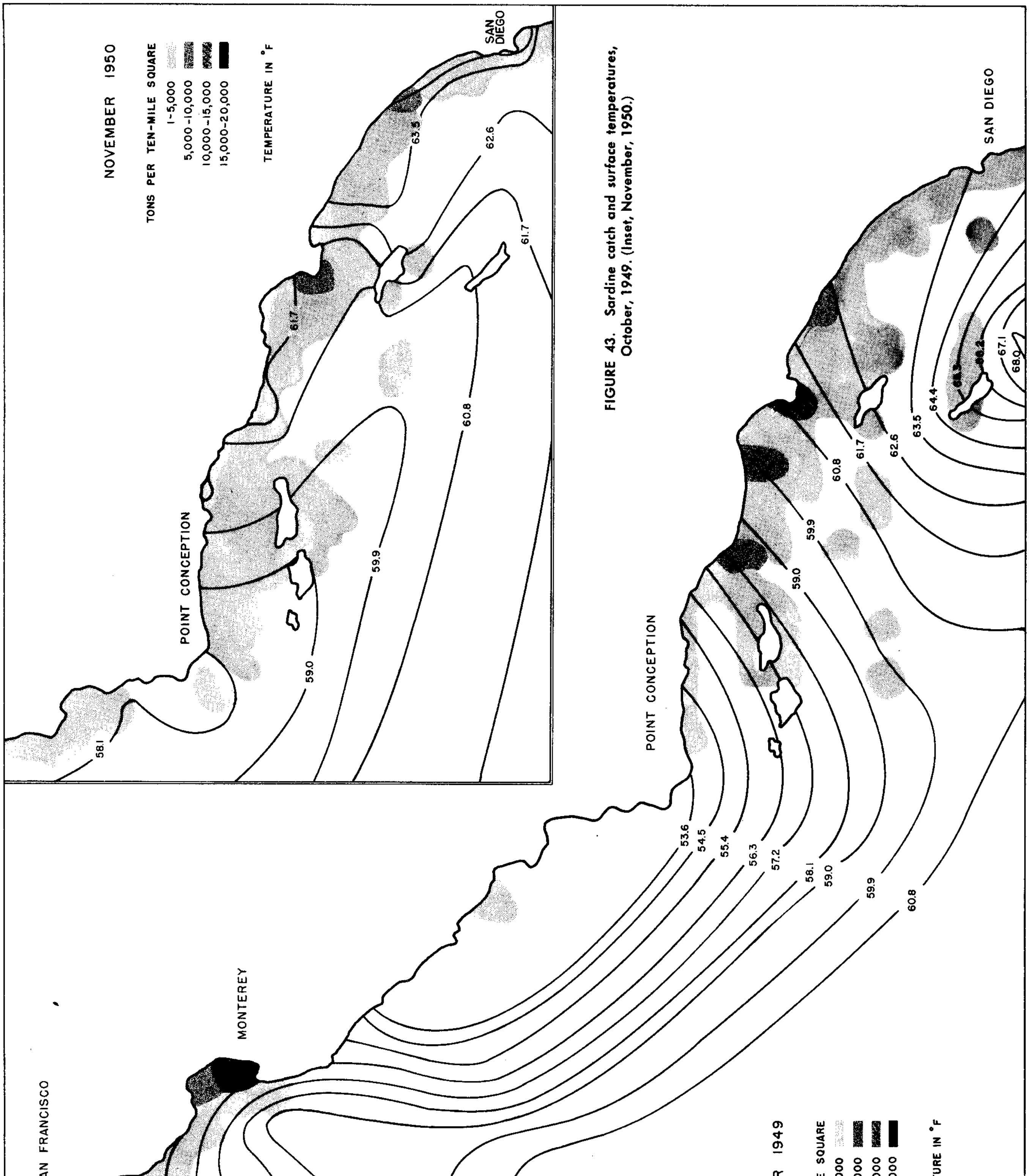


FIGURE 43. Sardine catch and surface temperatures, October, 1949. (Inset, November, 1950.)

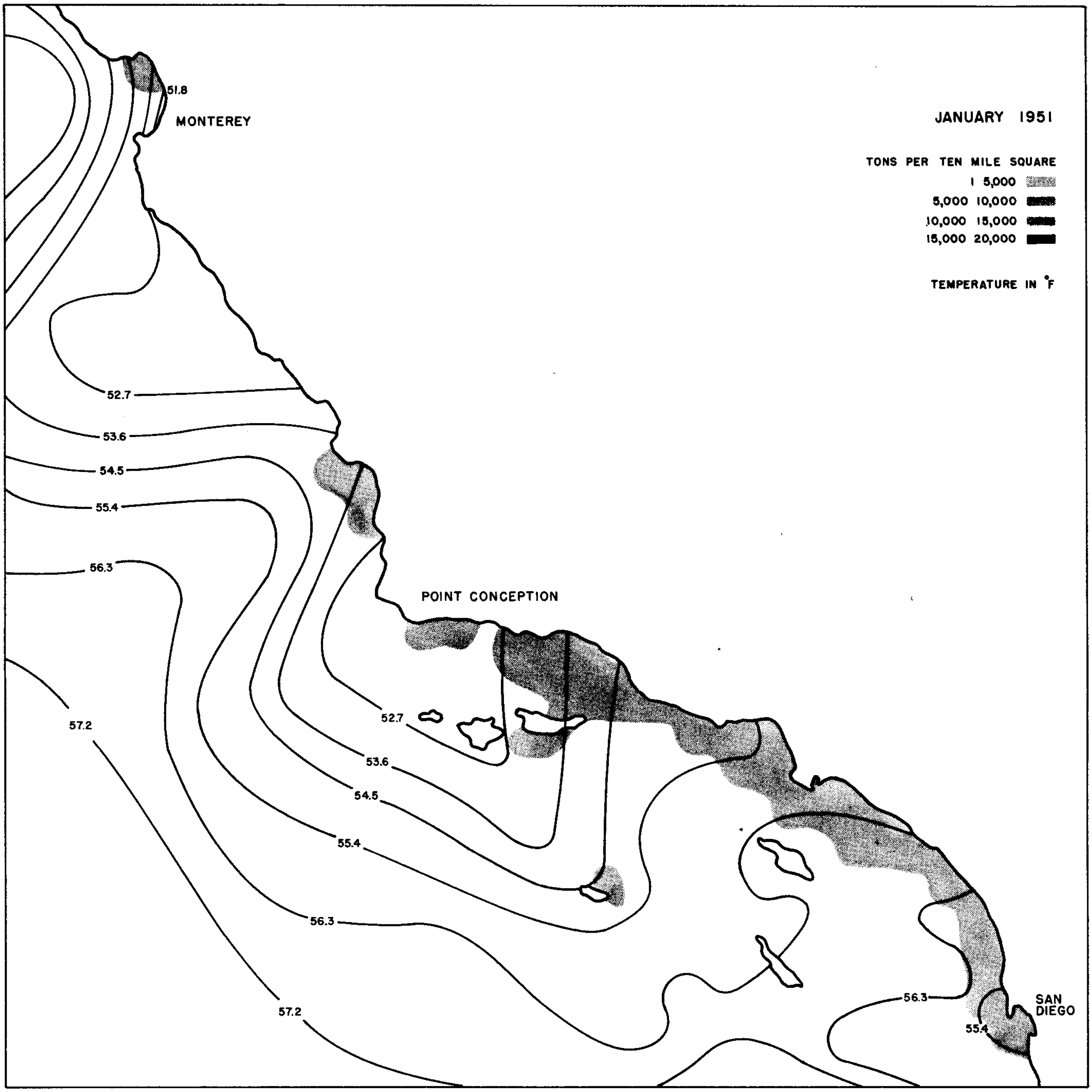


FIGURE 44. Sardine catch and surface temperatures, January, 1951.

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

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

The Food Supply

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

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

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

Predators and Competitors

BACTERIA

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

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

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

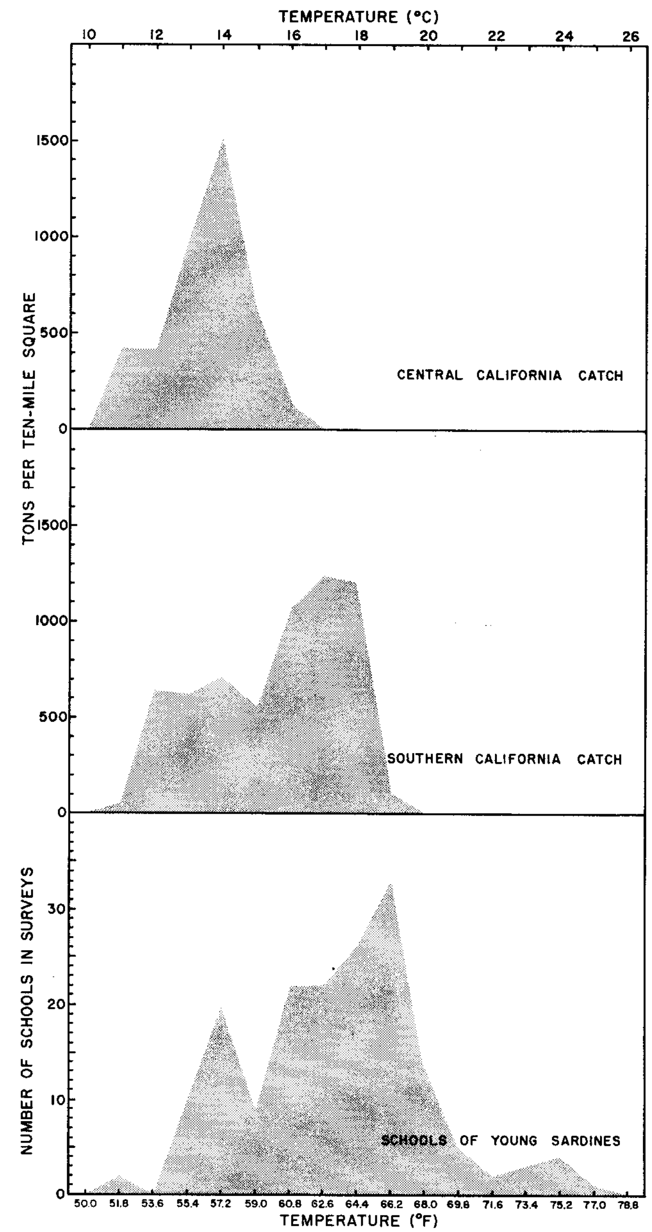


FIGURE 45. Sardine catch (1949-50 and 1950-51) and schools of sardines located during the surveys (1949, 1950, and 1951) as related to surface temperature.

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

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

OTHER FISHES

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

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

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

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

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

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

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

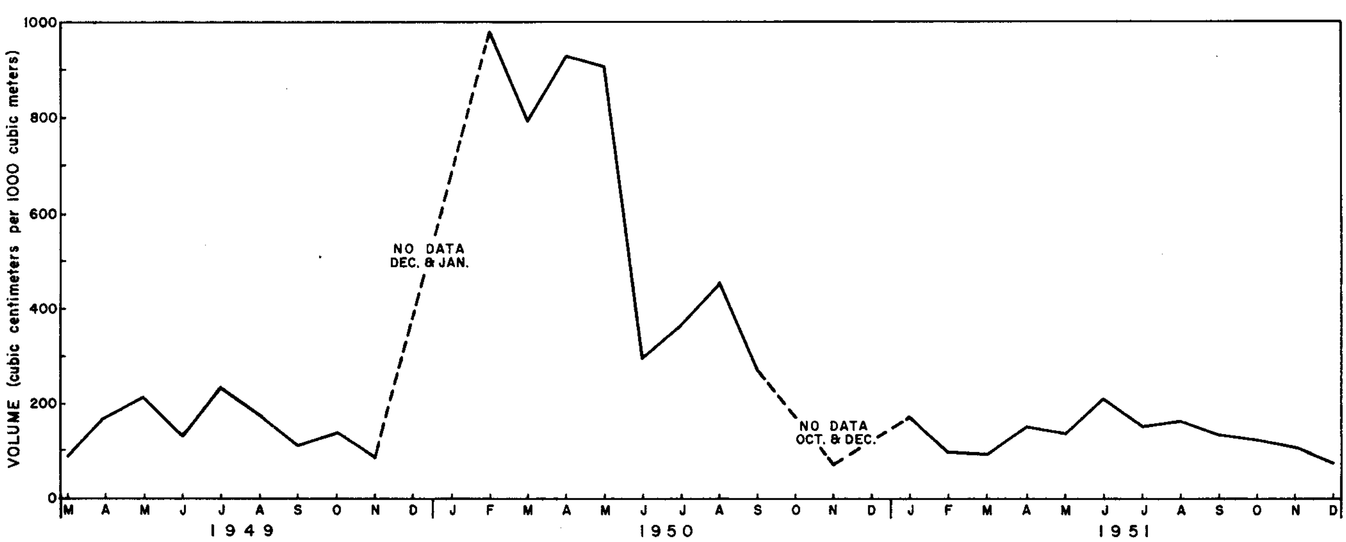


FIGURE 46. Average volume of plankton, in cubic centimeters per 1000 cubic meters of seawater taken in California Cooperative Sardine Research Program cruises, March, 1949, to December, 1951. (Data, Table 11, Appendix.)

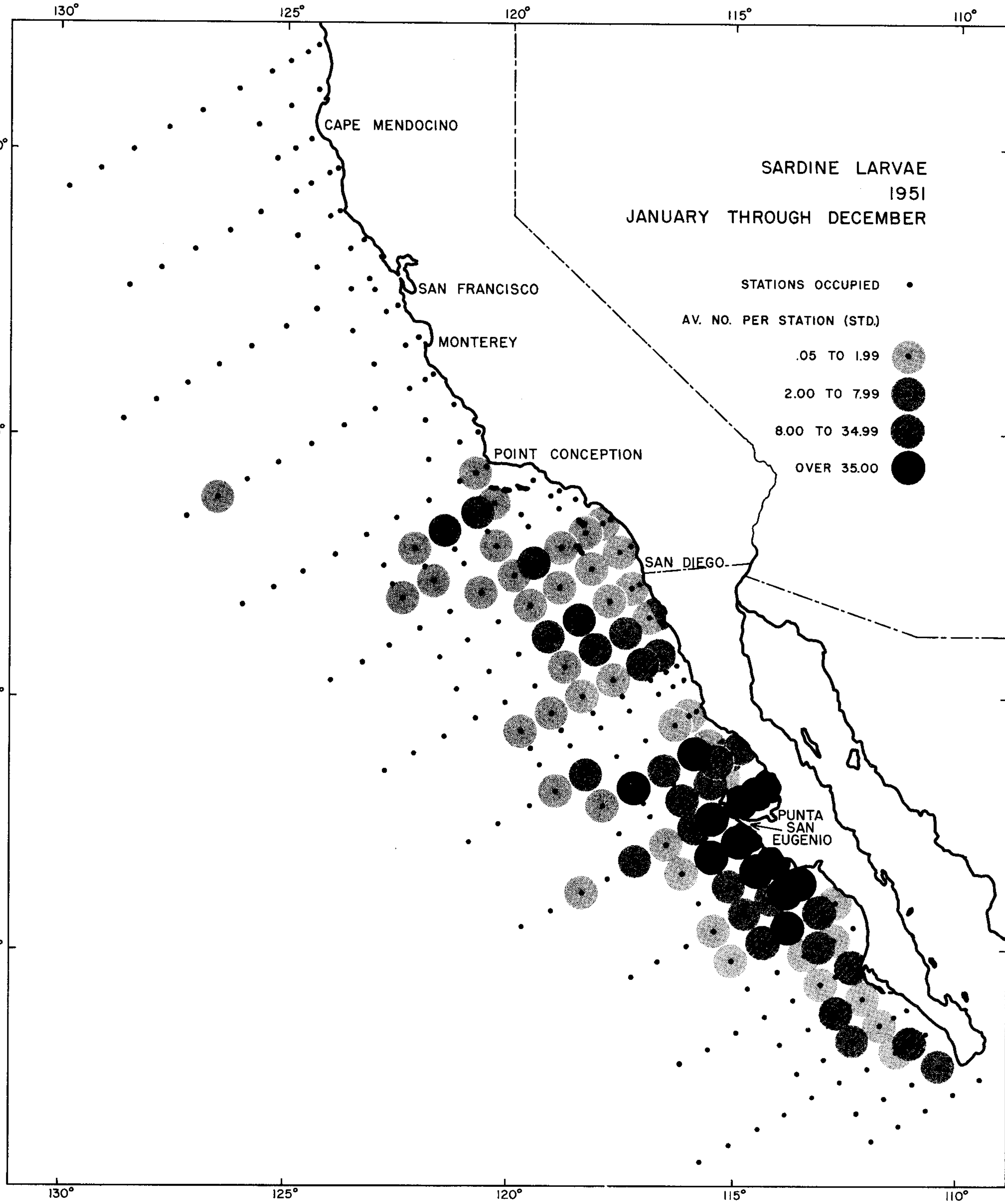


FIGURE 47. Sardine larvae, January through December, 1951.

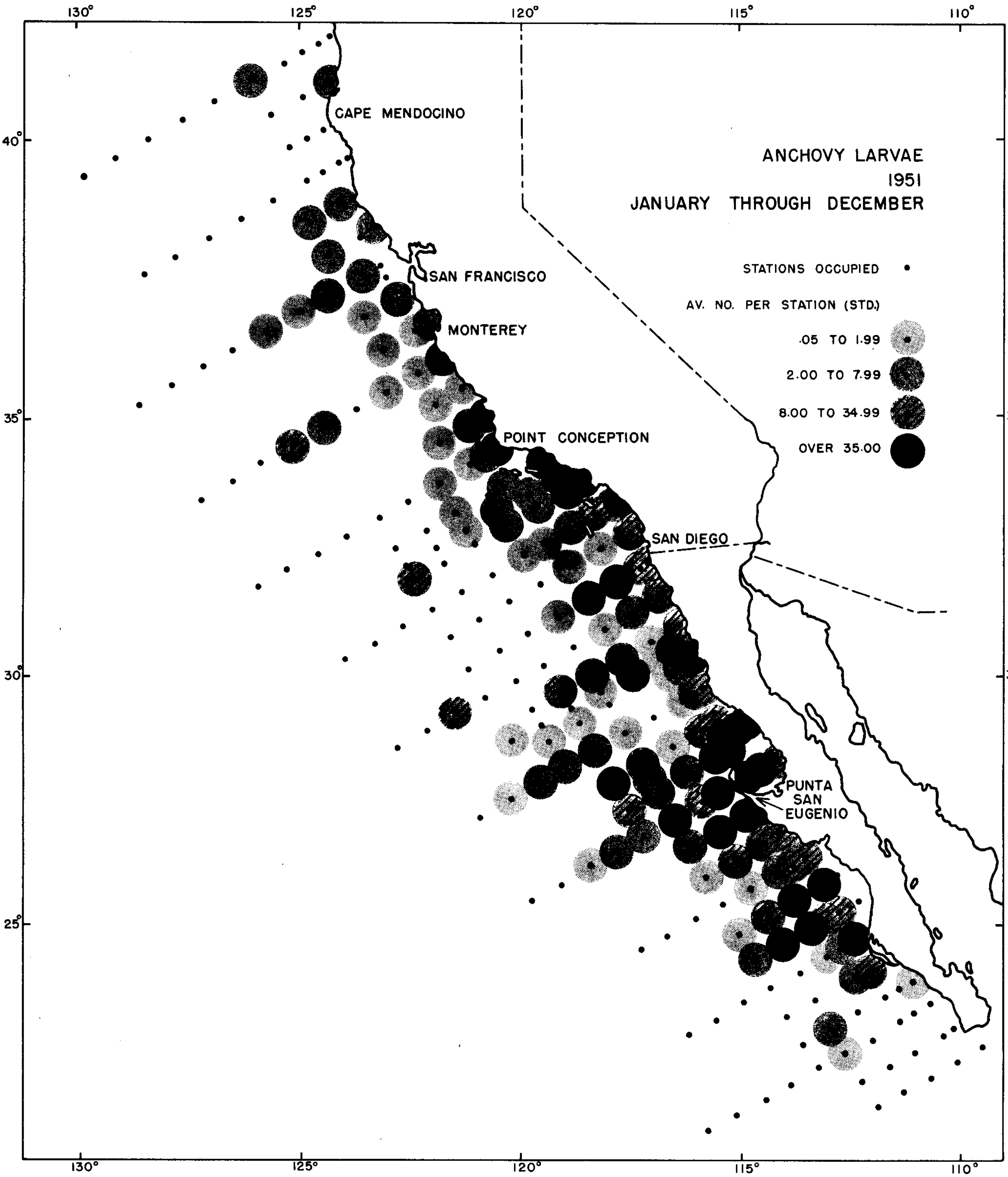


FIGURE 48. The northern anchovy spawns along the whole extent of the area being surveyed, and for an undetermined distance to the north of the area. During 1951 the largest concentrations of anchovy eggs and larvae were taken off central Baja California: an area of especially heavy concentration was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

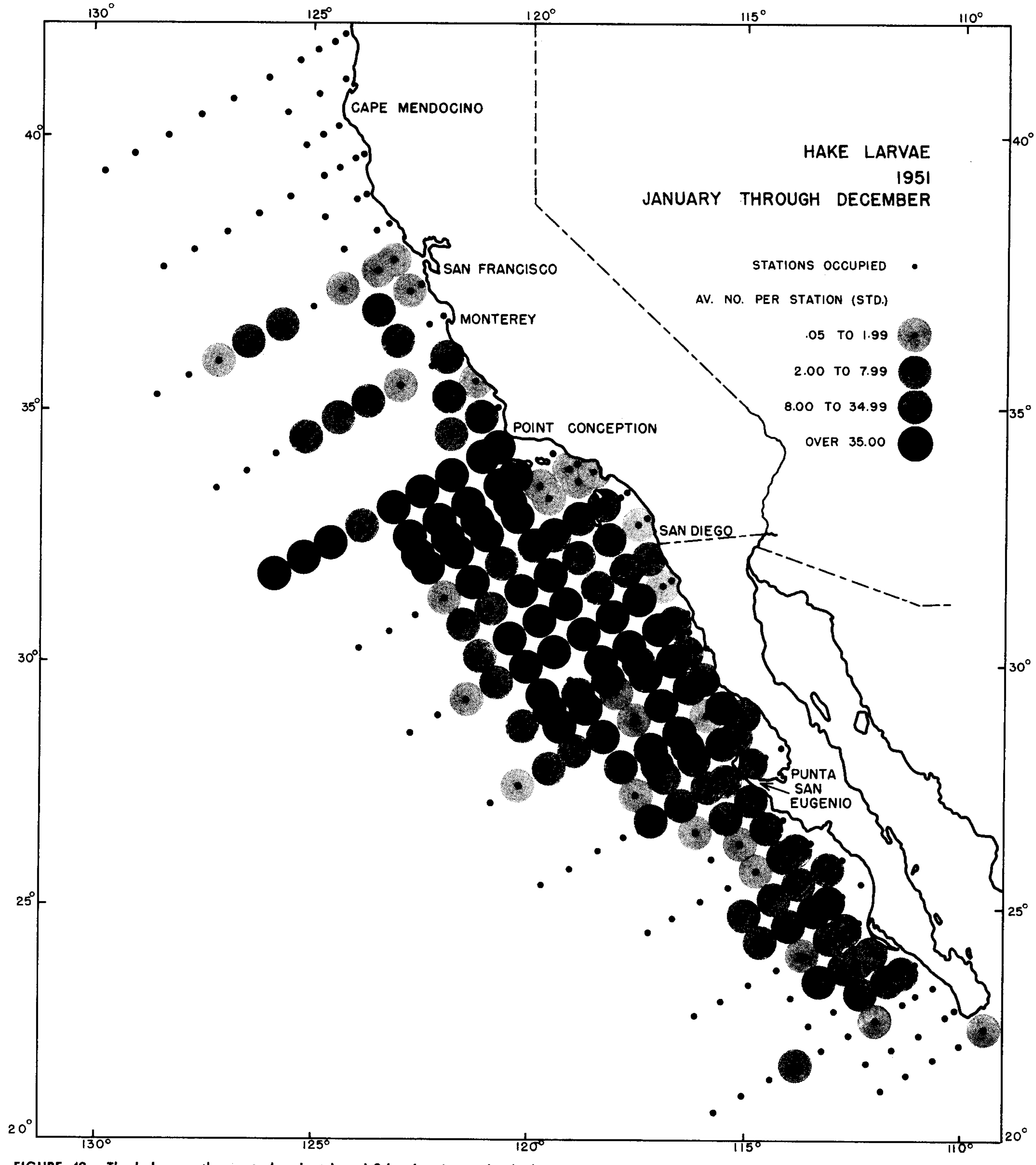


FIGURE 49. The hake was the most abundant larval fish taken in our hauls during 1951. The larvae were widely distributed, with the center of abundance occurring off Southern California and adjacent northern Baja California. The hake has a relatively short spawning season; in 1951 most hake larvae were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

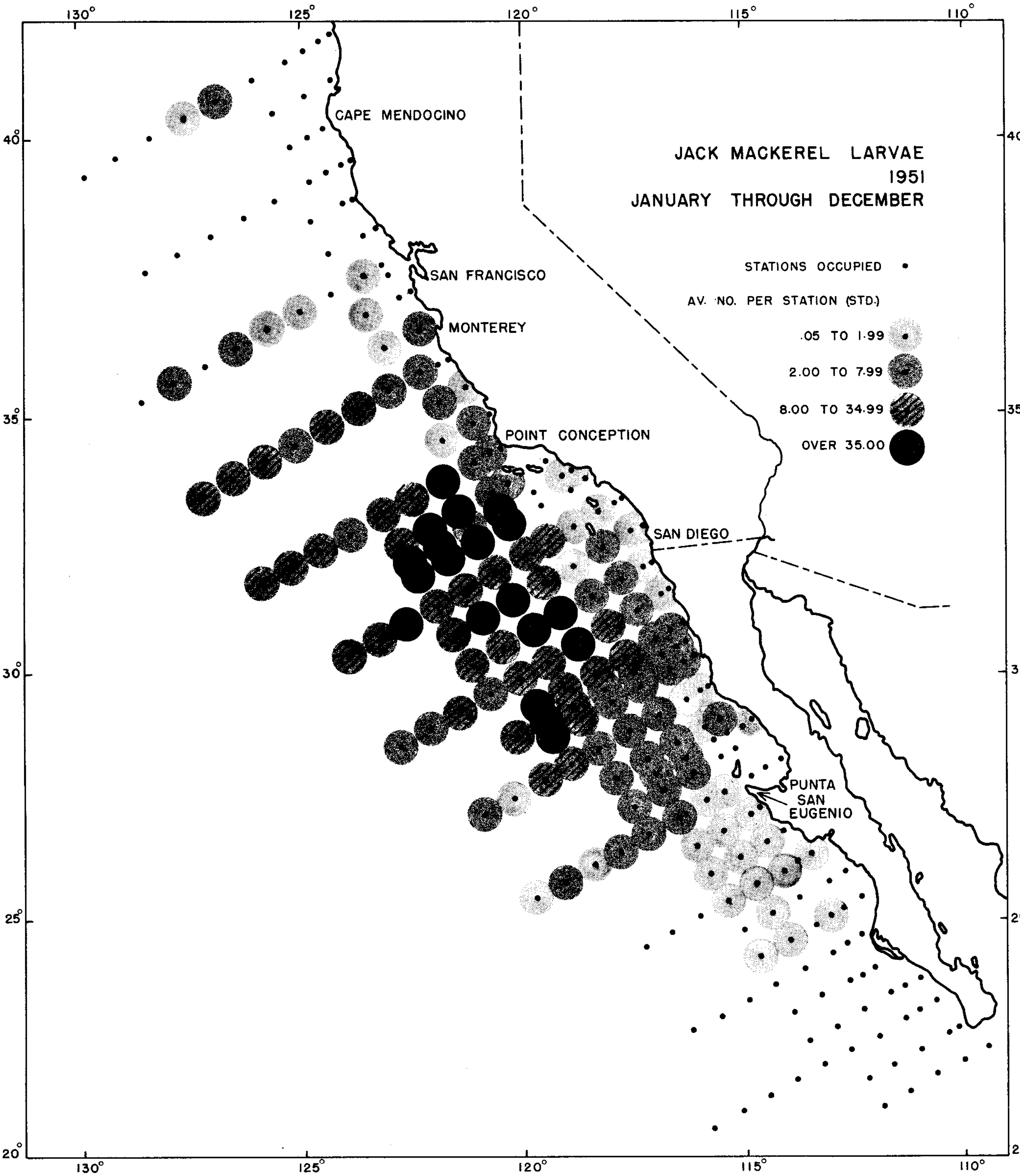


FIGURE 50. Information on the distribution and abundance of jack mackerel larvae is another of the incidental by-products resulting from the sardine spawning surveys. The larvae have been found to be very widely distributed with the center of abundance occurring well offshore off Southern California.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

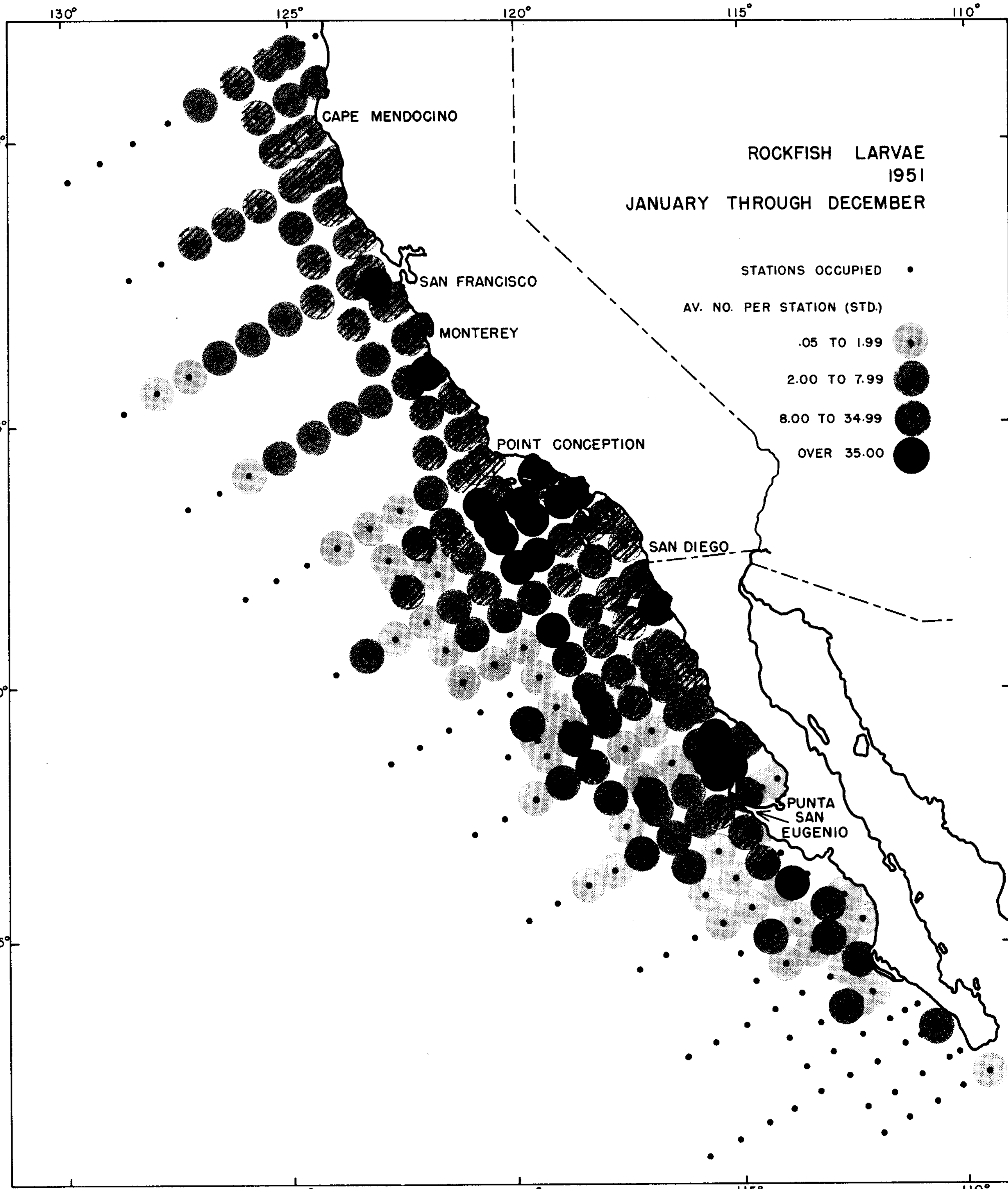


FIGURE 51. Rockfish larvae include several species of Sebastodes. The larvae are widely distributed during every month of the year. The persistent occurrence of rockfish larvae well offshore (up to 300 miles) suggests that some species of rockfish may lead a pelagic existence. As noted above, rockfish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

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

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

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

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

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

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

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

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

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

FUTURE STUDIES

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

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

Part 2: The Outlook for the Fishery

2) on the basis of these facts to make the best possible estimates of the fluctuations in the abundance and availability of the sardine and to predict the outlook for the fishery;

With the exception of the Department of Fish and Game, which has the dual function of research and management, none of the cooperating research agencies, nor the research-directing Marine Research Committee, is required by law to make management recommendations. The committee was established to sponsor fact-finding research on the State's marine fisheries. It has set as an objective for the cooperating research agencies the extrapolation of known facts into the future, in the form of a prediction of the outlook for the fishery.

This report so far has been concerned solely with picturing the present status of the sardine population as compared to that of several years ago. In this section, we shall attempt to use this information to discover what the immediate future holds for the industry.

Four types of information are required before a reliable prediction can be made:

a) Knowledge of the numerical size of the year classes that have been in the fishery in previous seasons;
b) Knowledge of the numerical size of the year class which will be entering the fishery for the first time;
c) Knowledge of how available the fish of each year class will be during the coming season;
d) Knowledge of the mortality rates.

There are two valid lines of reasoning leading to predictions of the future catch that agree in principle though not in detail. They differ in the weight given the results of separate investigations, the spawning surveys and the young-fish surveys, and in the emphasis placed on the factor of availability.

The first line of reasoning and the evidence upon which it is based can be summarized as follows:

1) The 1951 surveys indicate spawning population almost double the size of that of 1950. This could indicate either that sardines of the 1948 year class did not spawn appreciably in 1950 or that some other year class, presumably the 1949 year class, first spawned in 1951 and did not enter the 1951-52 catch in proportion to its true abundance. Since one-half of all sardines are mature at a length of 8.5 inches and all are mature at about 9.3 inches, one would expect that one-third to one-half of the fish of the 1948 year class would have spawned in 1950 and about three-fourths or more in 1951. If the increase in number of eggs spawned in 1951 was due largely to the increased growth of the fish of the 1948 year class, no increase in catch should be anticipated. If, however, the increase was brought about by fish of the 1949 year class, then this year class is larger than previously thought and apparently up to now has been distributed to the south of the regular fishing grounds.

2) There is little evidence on the size of the 1951 year class.

3) In the 1951-52 season, the 1948 year class made up the bulk of the catch and the 1949 and 1950 year classes appeared to be of below average size. Even assuming that in the 1952-53 season the entering 1951 year class will be of about average size, the outlook for the 1952-53 season is not a good one. This is only a guess, however, since the fish might be less available than in previous seasons and the catch would be even lower than expected, or the fish could be more available and the catch would be greater than might be expected. One indication that the catch statistics do not reflect the total population with full accuracy is the increase in spawning, as mentioned above.

The second line of reasoning and the supporting evidence can be summarized:

1) During 1951-52, the 1948 year class contributed 65 percent of the tonnage taken and older year classes 30 percent. These groups supplied 120,000 tons in the past season, and it is improbable that they will contribute any increased tonnage in the coming seasons. A decrease of 50 percent or more is much more likely. As a result, in the next one or two seasons the fishery will be more and more dependent on the younger year classes, spawned in 1949, 1950, and 1951. Age analysis of the fish in the 1951-52 catch indicates that the 1949 year class is a small one, and this is borne out by the results of the young-fish surveys, which covered Baja California as well as the California fishing grounds. These surveys indicate that the 1949 year class is about one-sixth as abundant as the 1948 group. Since the 1948 year class as it has appeared in the catch is of only average or slightly less than average strength, there is little hope for an improvement in fishing based on the 1949 year-class contribution.

2) The young-fish surveys of abundance of the 1950 and 1951 year classes show approximately equal abundance for each of these groups when about six months old (spawning surveys indicate an egg and larvae abundance of approximately one to two for 1950 and 1951), and that their strength is only slightly greater than that of 1949.

3) There is little hope for improved fishing in the 1952-53 or 1953-54 seasons and the evidence suggests that conditions may be worse. The factors that affect availability are as yet unmeasured. If availability should be exceptionally high it might tend to offset the sparsity of fish.

It will be seen that these two lines of reasoning lead to predictions for the coming season that on the whole are very discouraging.

The consensus is that the industry, if it depends on the sardine alone, and if availability does not operate so as to increase the catch, must for at least the next two seasons subsist upon the smallest catches in more than a generation.

Appendix

TABLE 1. AVERAGE NUMBER OF LARVAE PER STATION PER CRUISE DURING PERIOD MARCH-AUGUST OFF SOUTHERN CALIFORNIA

Species	Year		
	1941	1950	1951
Sardine	30.20	12.30	5.23
Anchovy	50.23	30.46	35.37
Jack Mackerel	1.62	22.50	26.38
Sebastodes	11.61	34.97	44.63
Hake	14.17	8.19	50.38*

* Apparent increase in abundance of hake during 1951 is probably due to deepening our tows, hence getting a more complete sample of this species. Hake larvae tend to be considerably deeper than those of the other fishes in the above list.

TABLE 2. NUMBER OF SCHOOLS OF YOUNG SARDINES FOUND IN VARIOUS LOCALITIES IN YEARS 1938, 1939, 1940, 1950, AND 1951 (see Fig. 2)

Locality	Number of schools by year class				
	1938	1939	1940	1950	1951
Central California (Bodega Head to Pt. Conception)	4	31	62	4	1
Southern California (Pt. Conception to Ensenada)	779	3	79	6	8
Northern Baja California (Ensenada to Pt. San Eugenio)	14	26	60	8	11
Central Baja California (South of Pt. San Eugenio)	21	3	3	6	8
Totals	818	63	204	24	28

TABLE 3. PERCENTAGE OF THE SARDINE CATCH TAKEN IN THE FOUR MAJOR FISHING AREAS DURING ELEVEN SEASONS (see Fig. 3)

Fishing area	Season										
	1941-42	1942-43	1943-44	1944-45	1945-46	1946-47	1947-48	1948-49	1949-50	1950-51	1951-52
San Francisco (Pt. Montara and North)	25.1	24.7	24.2	13.1	14.7	1.2			1.4	.6	
Monterey (Pt. Montara to South of Pt. Sur)	46.4	32.4	44.0	52.2	42.0	9.4	9.4	21.1	34.9	6.2	.1
Morro (South of Pt. Sur to Pt. Conception)	2.7	2.6	3.0	2.3	.8	2.1		1.0	7.4	8.4	13.2
Southern California (South of Pt. Conception)	25.6	40.2	28.5	32.5	42.5	87.3	90.3	77.7	56.5	84.8	86.6
Totals	99.8	99.9	99.7	100.1	100.0	100.0	99.7	99.8	100.2	100.0	99.9

TABLE 4. SIZE DISTRIBUTION OF 1948 YEAR CLASS SARDINE SAMPLES AT ENSENADA, SAN PEDRO, AND MONTEREY IN THE 1951-52 SEASON (see Fig. 7)

Length (mm.)	PORTS						Length (inches)
	Monterey		San Pedro		Ensenada		
	Number of fish	Percent of total sample for port	Number of fish	Percent of total sample for port	Number of fish	Percent of total sample for port	
185					1.5	3.2	7.3
187							
189					9	19.6	7.4
191	0.5	1	4	1.1			7.5
193					10	21.7	7.6
195			26.5	7.5			7.7
197					9.5	20.7	7.8
199	1.5	3	49.5	14.0			7.8
201					6.5	14.1	7.9
203	3.5	7	62.5	17.7			8.0
205					5	10.9	8.1
207	5	10	58.5	16.5			8.1
209					2.5	5.4	8.2
211	4	8	43.5	12.3			8.3
213					.1	2.2	8.4
215	6	12	34	9.6			8.5
217							8.5
219	9	18	20.5	5.8			8.6
221					0.5	1.1	8.7
223	6	12	22.5	6.4			8.8
225					0.5	1.1	8.9
227	6	12	17	4.8			8.9
229							9.0
231	3.5	7	7	2.0			9.1
233							9.2
235	1.5	3	4	1.1			9.3
237							9.3
239	2	4	3.5	1.0			9.4
241							9.5
243	0.5	1	1	0.3			9.6
245							9.6
247	1	2					9.7
Totals	50.0		354.0		46.0		

TABLE 5. CATCH, MINIMUM INITIAL POPULATION AND MAXIMUM INITIAL POPULATION

(Billions of fish)

Season	Catch	Minimum initial population	Maximum initial population
32-33	1.3	3.1	19
33-34	2.1	4.8	23
34-35	3.5	7.6	35
35-36	3.4	7.2	28
36-37	4.4	8.8	27
37-38	2.8	5.5	16
38-39	4.7	9.0	25
39-40	4.1	8.0	24
40-41	4.0	8.2	27
41-42	5.3	10.6	31
42-43	4.0	8.2	26
43-44	3.5	7.0	22
44-45	3.8	7.2	19
45-46	2.8	5.3	14
46-47	1.9	3.0	5.4
47-48	.9	1.4	2.6
48-49	1.5	2.7	6.5
49-50	2.8	5.2	13.0
50-51	2.6	3.8	6.5
51-52	1.0	----	----

TABLE 7. RELATIVE YEAR-CLASS SIZE OF SARDINES, MEASURED BY THE NUMBER OF THREE-YEAR-OLD FISH CAUGHT PER BOAT-MONTH IN CALIFORNIA (see Fig. 11)

Season	Number of fish caught per boat-month	Year-class measured
1932-33	7,686	1929
1933-34	3,718	1930
1934-35	12,669	1931
1935-36	14,974	1932
1936-37	5,607	1933
1937-38	2,584	1934
1938-39	No data	1935
1939-40	No data	1936
1940-41	No data	1937
1941-42	8,609	1938
1942-43	13,247	1939
1943-44	6,121	1940
1944-45	4,149	1941
1945-46	4,702	1942
1946-47	1,876	1943
1947-48	930	1944
1948-49	1,337	1945
1949-50	6,211	1946
1950-51	4,958	1947

TABLE 6. PERCENTAGE AGE COMPOSITION BASED ON NUMBERS OF SARDINES IN THE CALIFORNIA FISHERY FOR THREE TIME INTERVALS, 1932-33 TO 1937-38, 1941-42 TO 1946-47, 1947-48 TO 1951-52 (see Fig. 10)

Age	Percentage		
	1932-33 to 1937-38	1941-42 to 1946-47	1947-48 to 1951-52
0	.2	----	.3
1	2.4	12.4	11.3
2	19.7	34.2	42.0
3	29.8	29.1	31.3
4	23.0	15.1	10.7
5	12.0	6.3	3.6
6	6.3	2.1	.7
7	2.8	.6	.1
8	1.3	.1	----
9	.8	----	----
10	.7	----	----
11	.5	----	----
12	.8	----	----
Totals	100.3	99.9	100.0

TABLE 8. NUMBERS OF SCHOOLS OF SARDINES BY YEAR CLASS AND REGION PER SCOUTING NIGHT FOR THE 1950 AND 1951 SURVEYS

Locality	Year class						
	1950 survey			1951 survey			
	1950	1949	1948	1951	1950	1949	1948
Central California (Bodega Head to Pt. Conception)	33.3	------	2.8	0.5	4.1	1.4	9.0
Southern California (Pt. Conception to Ensenada)	14.4	8.3	113.0	20.3	7.0	8.4	55.9
Central Baja California (Ensenada to Pt. San Eugenio)	53.8	35.5	150.2	58.4	40.1	31.2	91.0
Southern Baja California (Pt. San Eugenio to Magdalena Bay)	81.7	53.3	48.0	107.0	48.0	14.4	29.4
All regions (averages)	37.7	19.2	88.2	36.3	20.7	14.4	53.4

TABLE 9. FOOD ITEMS IN STOMACHS OF 273 ADULT SARDINES AS COMPARED WITH PLANKTON CONTENT OF WATER SAMPLES TAKEN ALONG WITH SARDINE SAMPLES (see Fig. 31)

Item	In percent of stomachs	In percent of water samples	Average number per fish	Item	In percent of stomachs	In percent of water samples	Average number per fish
Diatoms	75	Not analyzed	1,200,000	Snails (adults and larvae)	49	68	2
Dinoflagellates	71	Not analyzed	13,000	Zoaea larvae	29	44	1
Radiolaria				Annelid larvae	36	58	1
Silicoflagellates	46	Not analyzed	1,000	Amphipods	19	17	x
Tintinnids				Barnacle nauplii	18	18	x
Small copepods	100	100	560	Fish larvae	17	23	x
Larvaceans	93	96	170	Barnacle cypris	16	15	x
Copepod nauplii	47	26	130	Siphonophores	15	82	x
Large copepods	70	85	12	Mysids	13	19	x
Arrow worms	73	90	11	Salps	15	15	x
Euphausiid eggs	32	36	9	Shrimp larvae	8	11	x
Fish eggs	79	71	8	Ostracods	4	10	x
Euphausiid calyptopis and furcilia				Brachiopod larvae	4	5	x
larvae	50	53	8	Megalops larvae	3	8	x
Cyphonautes larvae	64	75	7	Doliolids	2	20	x
Cladocera	65	76	6	Stomatopods	x	0	x
Euphausiid nauplii	40	47	4	Octopus	x	0	x
Clam larvae	48	55	3	Isopod	x	0	x
Euphausiids	24	22	2				

x—Less than one item per fish.

TABLE 10. AVERAGE NUMBER OF FOOD ITEMS PER ADULT SARDINE PER MONTH (WEIGHTED AVERAGES FOR A VOLUME OF 2.0 ML PER FISH)

	November 1949	December 1949	January 1950	February 1950	March 1950	May 1950	August 1951
Diatoms	2,300	50,000	6,400,000	26,500	9,000,000	790,000	212,000
Dinoflagellates	3,300	6,300	26,800	----------	104,000	12,000	42,000
Small Copepods	4,700	1,100	400	1,100	300	300	860
Larvaceans	5	100	100	----------	28	460	220
Chaetognaths	17	6	34	----------	----------	15	10
Fish eggs	x	8	4	40	----------	19	10
Euphausiids	----------	7	----------	----------	----------	4	x
Euphausiid larvae	x	10	x	80	16	20	4
Cyphonautes larvae	5	5	18	15	----------	2	24
Cladocera	15	4	8	15	x	11	6
Large Copepods	2	8	12	45	40	31	6
Number of fish	15	39	81	10	4	63	61
Average volume per fish	1.2 ml	2.1 ml	1.0 ml	0.4 ml	1.0 ml	2.1 ml	1.0 ml

x—Less than one item per fish.

TABLE 11. PLANKTON VOLUMES (WET) CC/1000 M^3 (see Fig. 46)

	Date	Number of stations	Average volume cc. per 1,000 M^3	Percent deviation from seasonal average		Date	Number of stations	Average volume cc. per 1,000 M^3	Percent deviation from seasonal average
Cruise	**1949**				**Cruise**	**1950**			
1	March	69	87.7	—40.1	11	February	113	980	+75.0
2	April	92	166	+12.9	12	March	101	790	+41.1
3	May	106	208	+41.5	13	April	118	928	+67.7
4	June	80	128	—12.9	14	May	124	904	+61.4
5	July	110	230	+57.1	15	June	107	295	—47.3
6	August	118	175	+19.7	16	July	140	361	—35.5
7	September	113	109	—25.8	17	August	96	450	—19.6
8	October	104	134	— 8.8	18	September	129	260	—53.6
9	November	112	85.7	—42.8	19	Anchor Cruise			
10	Anchor cruise				20	November	95	69	—87.7
Average for 1949=147.1 cc					Average for 1950=559.7 cc				

TABLE 11. PLANKTON VOLUMES (WET) CC/1000 M^3 (see Fig. 46)—Continued

	Date	Number of stations	Average volume cc. per 1,000 M^3	Percent deviation from seasonal average
Cruise	1951			
21	January	125	165.92	+25.8
22	February	98	99.1	—25.0
23	March	136	86.04	—34.8
24	April	135	147.4	+11.6
25	May	121	135.08	+ 2.6
26	June	121	205.59	+56.0
27	July	105	149.38	+13.17
28	August	118	160.71	+21.9
29	September	102	134.0	+ 1.48
30	October	88	119.1	— 9.8
31	November	88	103.33	—21.7
32	December	64	77.22	—41.5

Average for 1951=132.0 cc

TABLE 12. OCCURRENCE OF THE LARVAE OF OTHER FISHES IN HAULS CONTAINING SARDINE EGGS OR LARVAE, JANUARY THROUGH JULY, 1951

	Southern California and adjacent Baja California		Central and Southern Baja California		All areas	
	Number of occurrences	Percent occurrence	Number of occurrences	Percent occurrence	Number of occurrences	Percent occurrence
Sardine	79	100.0	96	100.0	175	100.0
Northern Anchovy	33	42.0	81	84.5	114	65.0
Jack Mackerel	63	80.0	24	25.0	87	50.0
Hake	54	68.5	64	66.7	118	67.5
Rockfish (Sebastodes spp.)	66	83.5	65	68.0	131	75.0

TABLE 13. CONCENTRATION OF THE PRINCIPAL FISHES SAMPLED DURING THE 1950 AND 1951 YOUNG-FISH SURVEYS AS MEASURED BY NUMBERS OF SAMPLES PER SCOUTING NIGHT BY REGION

Region	1950 survey				1951 survey			
	Sardines	Jack Mackerel	Pacific Mackerel	Anchovies	Sardines	Jack Mackerel	Pacific Mackerel	Anchovies
Bodega Head to Cape San Martin	0.33	0.78	0.00	0.67	0.00	0.29	0.00	0.43
Point Piedras Blancas to Point Arguello	0.67	0.67	0.00	0.67	0.50	0.25	0.00	0.50
Point Arguello to Punta Banda (Southern California and Northern Baja California)	2.10	2.00	1.25	2.40	1.06	1.39	0.56	1.39
Punta Banda to Punta Baja	2.50	2.00	0.83	2.00	1.83	1.33	0.00	1.33
Punta Baja to Punta Eugenio (Sebastian Vizcaino Bay)	2.71	0.57	0.29	0.29	2.67	0.56	0.33	0.56
Punta Eugenio to Punta Abreojos	1.80	0.60	0.60	1.40	2.25	1.25	1.75	2.00
Punta Abreojos to Cabo San Lazaro	2.50	0.00	0.00	4.50	1.00	0.00	0.00	2.00
All regions combined	1.83	1.31	0.67	1.65	1.35	0.94	0.41	1.08

About This Report:

3) to make these facts and estimates promptly known to the appropriate management agencies, to the industry, and to the public at large.

Six thousand copies of this report have been printed for distribution to the fishing industry, research institutions, and government agencies in this country and abroad. The report was illustrated by Mr. Robert W. Kirk of the Scripps Institution of Oceanography.

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66980 8-52 6M