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

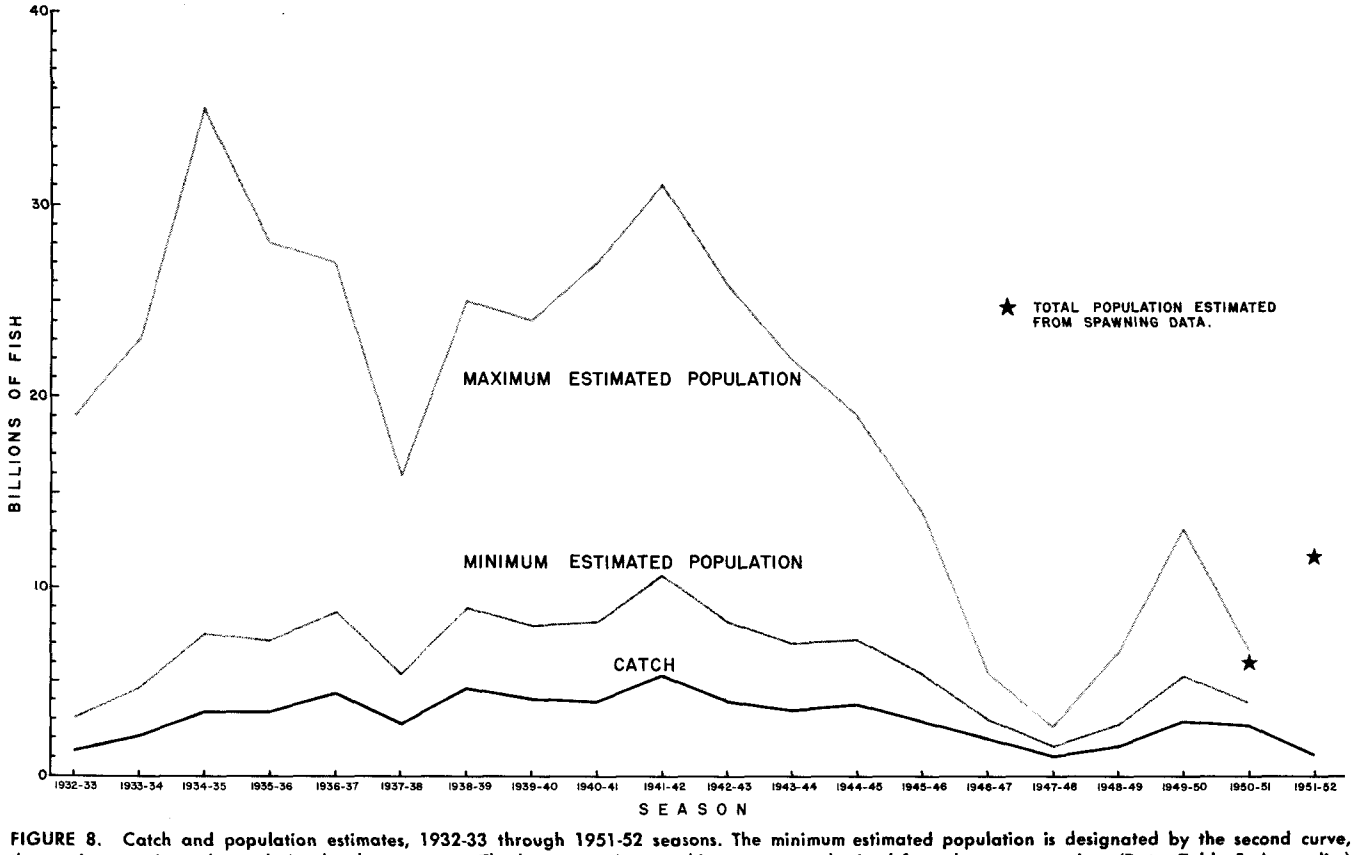

FIGURE 8. Catch and population estimates, 1932-33 through 1951-52 seasons. The minimum estimated population is designated by the second curve, the maximum estimated population by the top curve. The last two points on this curve were obtained from data on spawning. (Data, Table 5, Appendix.)

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

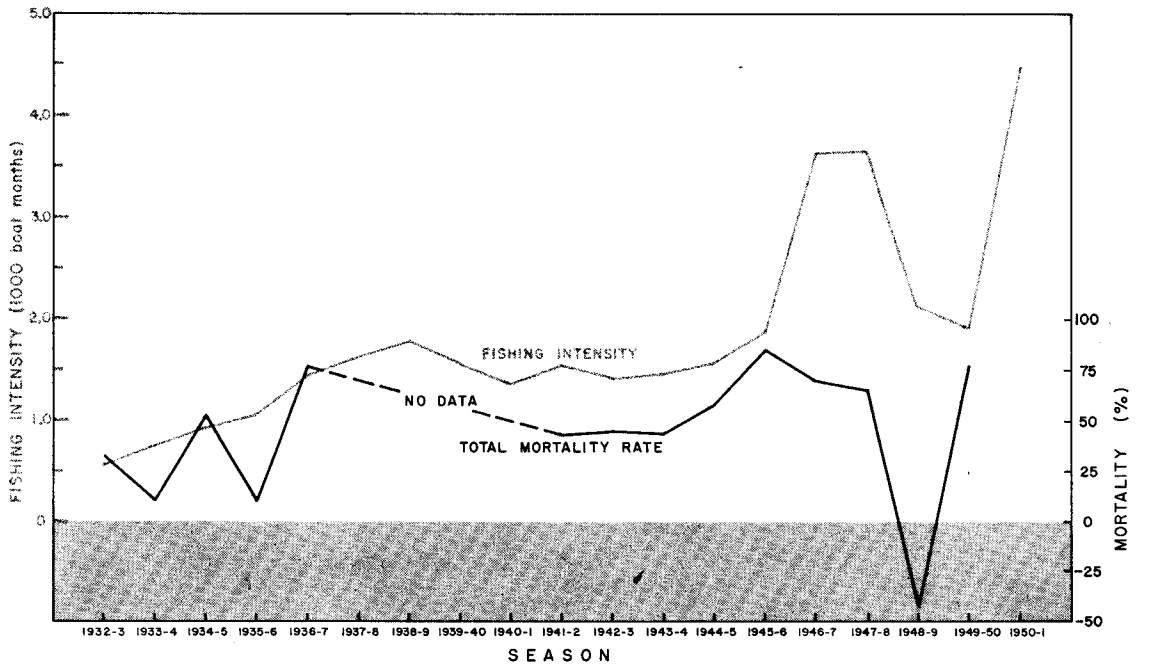

FIGURE 9. Total mortality rate and fishing intensity, 1932-33 through 1950-51 seasons. A negative mortality rate indicates that the fish became more available to the fishermen during the season.

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

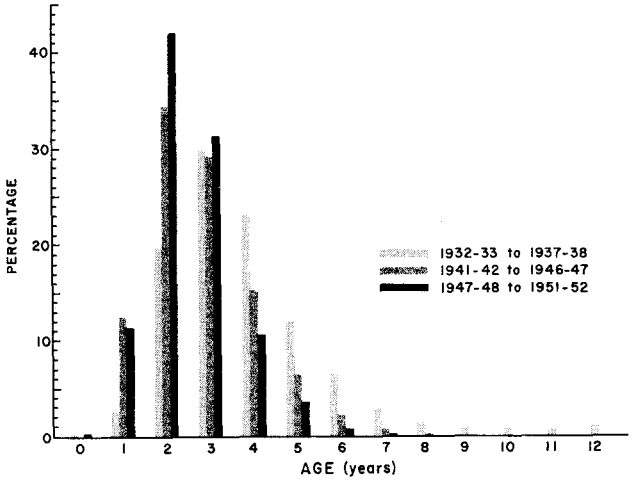

FIGURE 10. Percentage age composition based on numbers of sardines in the California fishery for three time intervals, 1932-33 to 1937-38, 1941-42 to 1946-47, 1947-48 to 1951-52. The latter period has seen very small percentages of older fish in the catch. (Data, Table 6, Appendix.)

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 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

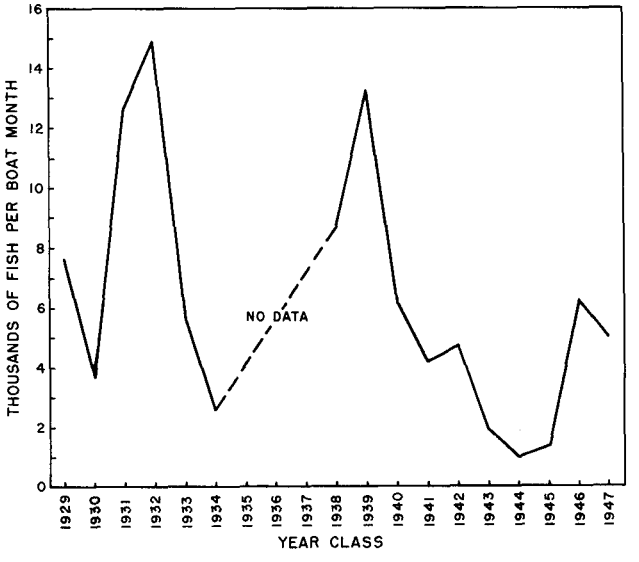

FIGURE 11. Relative year-class size of sardines as measured by the number of three-year-old fish caught per boat month in California. (Data, Table 7, Appendix.)

been spawned off Southern California and Baja California since 1948.

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

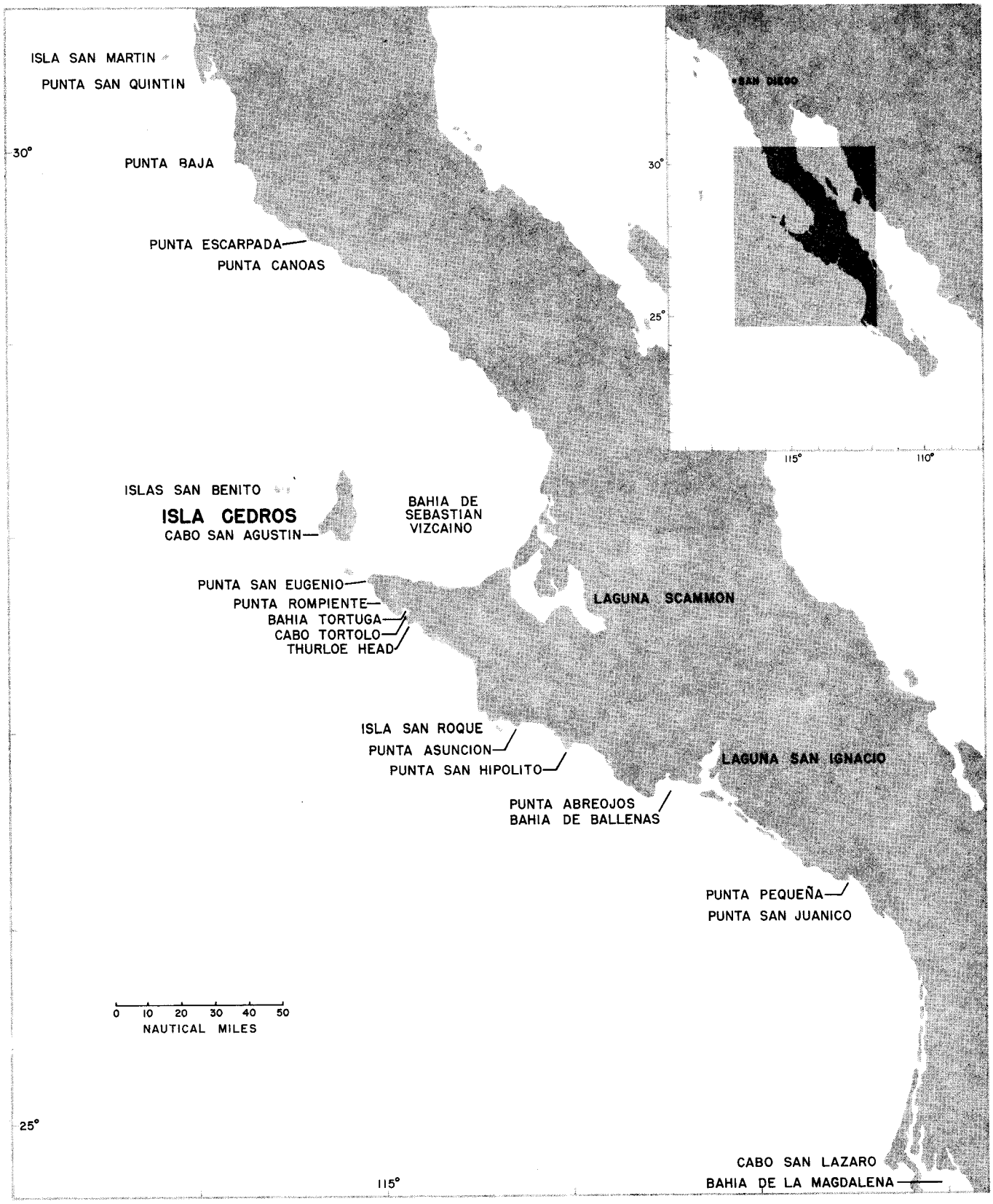

FIGURE 12. Cedros Island area, Baja California. Survey cruises have proved this region to be the major center of sardine spawning today. (See Figs. 13 through 27, and Fig. 47.)

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 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.

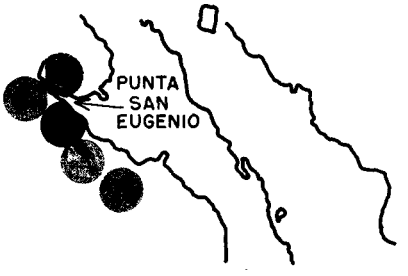

FIGURE 13. January, 1951—Sardine spawning confined to a coastal strip off central Baja California. Moderate in amount. Area covered: San Francisco to Cabo San Lazaro.

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.

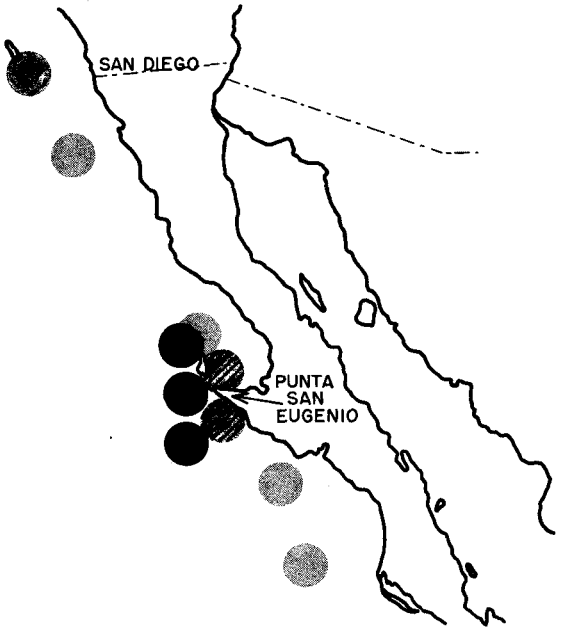

FIGURE 14. February, 1951—Spawning off central Baja California heavier than during January. Light spawning at a few stations off southern California. Area covered: Point Conception to Cabo San Lazaro.

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

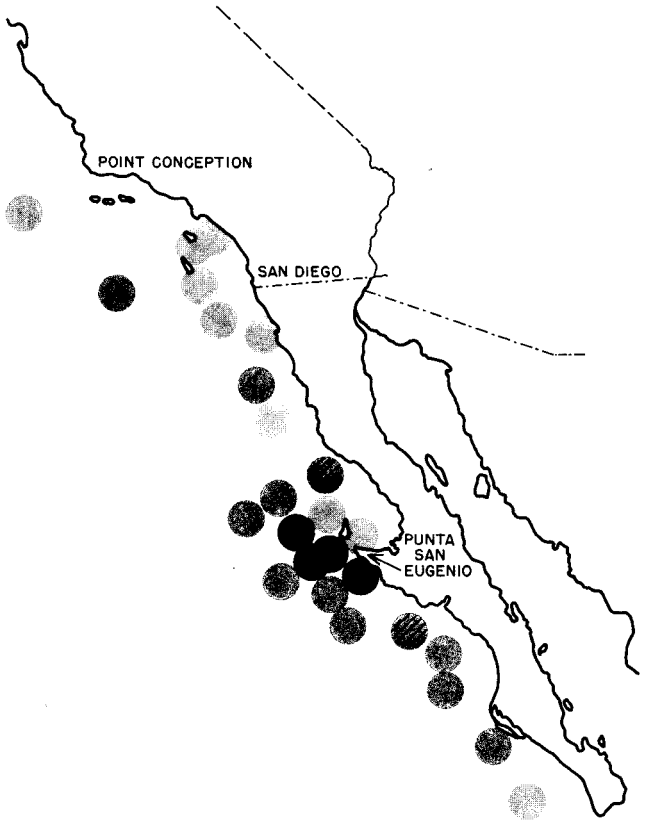

FIGURE 15. March, 1951—Very heavy spawning off central Baja California, more widespread than during January or February. Light spawning at several stations in the Southern California area. Area covered: Point Conception to Cabo San Lucas.

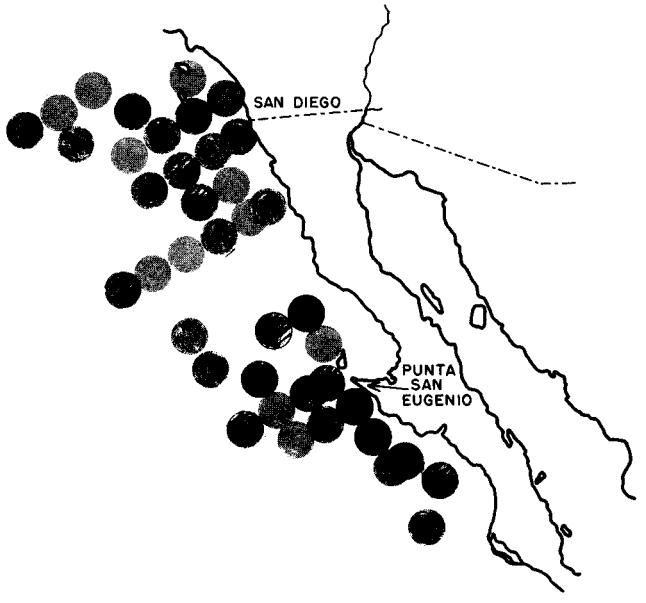

FIGURE 16. April, 1951—Heavy and fairly widespread spawning continuing off central Baja California. Light to moderate spawning widespread off Southern California and adjacent Baja California. Area covered: San Francisco to Cabo San Lazaro.

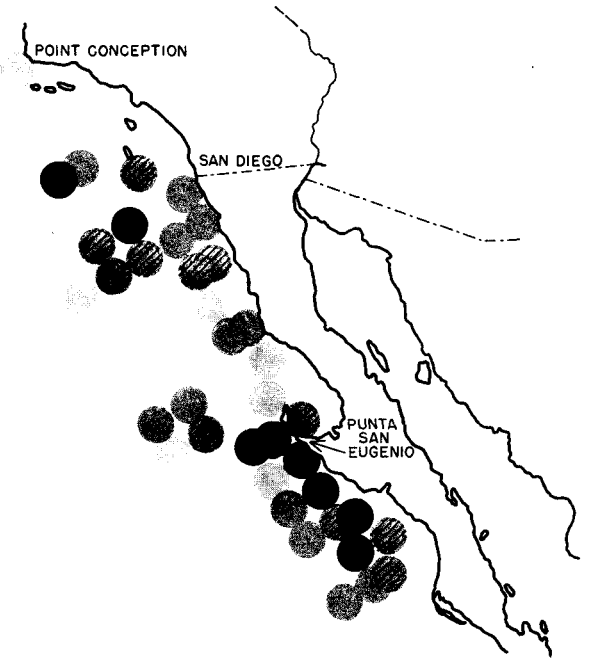

FIGURE 17. May, 1951—The peak month in the Southern California area. Off central Baja California, heavy spawning continuing. Sardine larvae were at their peak abundance in both spawning centers. Area covered: San Francisco to Cabo San Lazaro.

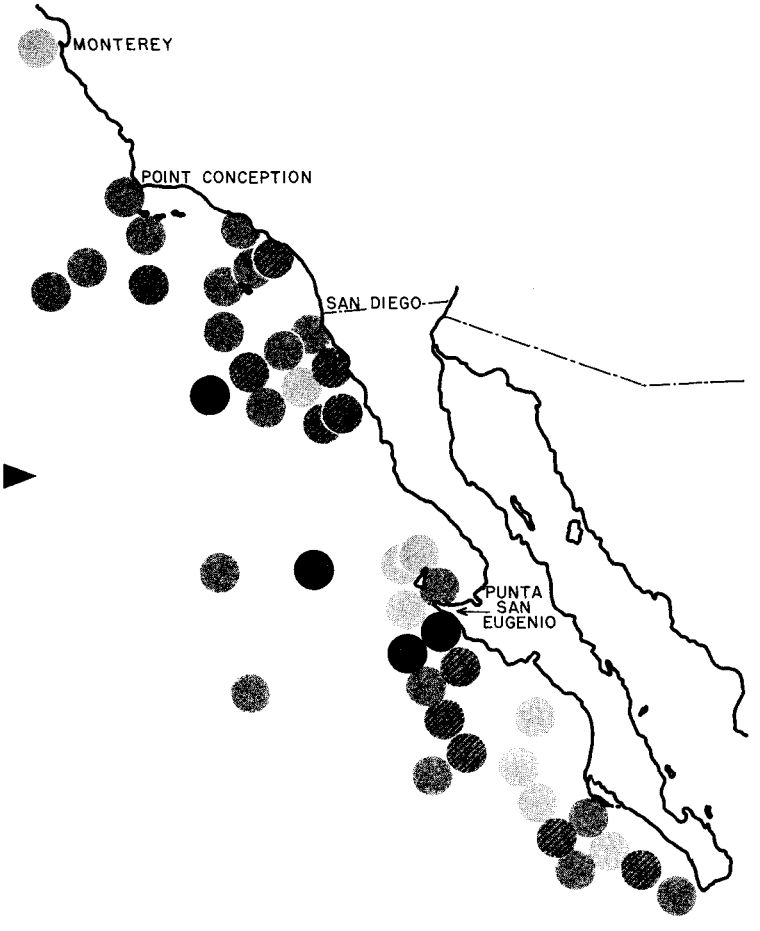

FIGURE 18. June, 1951—Spawning more widespread than during any other month. Marked decrease in abundance of eggs in collections from off central Baja California, but sardine larvae still taken in fairly large numbers in this area. In the Southern California area, collections of eggs and larvae nearly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

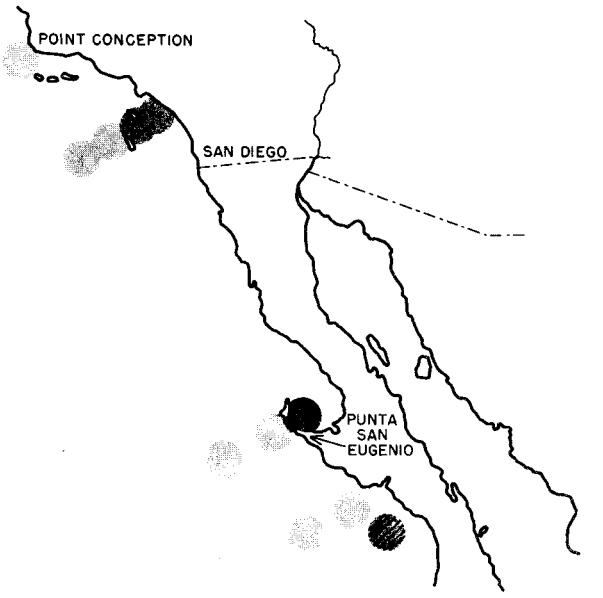

FIGURE 19. July, 1951—Spawning markedly decreased in amount and extent. Light in both spawning centers. Area covered: Cape Blanco to Cabo San Lazaro.

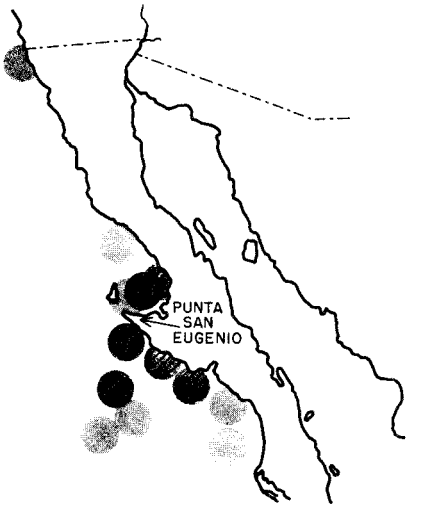

FIGURE 20. August, 1951—Spawning mostly confined to central Baja California, heaviest in Sebastian Vizcaino Bay. Area covered: Cape Blanco to Cabo San Lazaro.

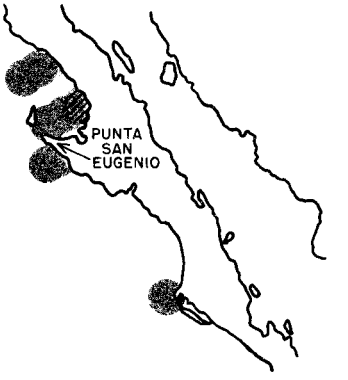

FIGURE 21. September, 1951—Mostly confined to Sebastian Vizcaino Bay. Area covered: San Francisco to Cabo San Lucas.

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.

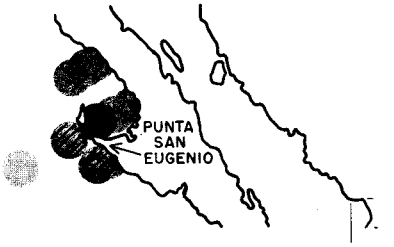

FIGURE 24. December, 1951—Confined to central Baja California, mostly in Sebastian Vizcaino Bay. Area covered: San Francisco to Punta Abreojos.

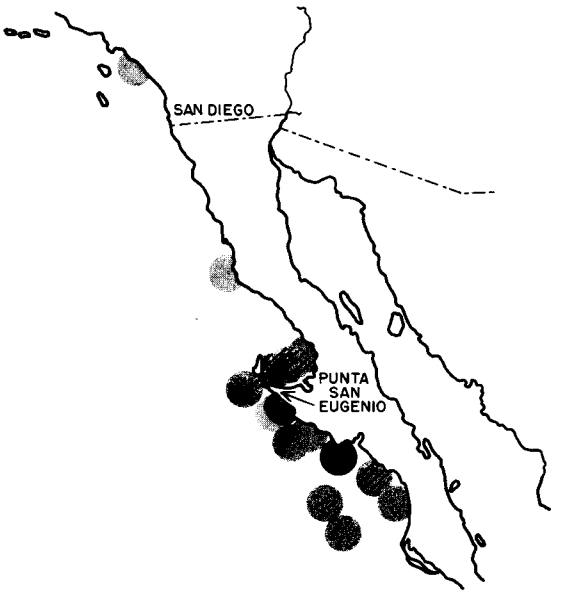

FIGURE 25. January, 1952—Confined to central Baja California, heaviest off Punta Abreojos. Area covered: Point Conception to Cabo San Lazaro.

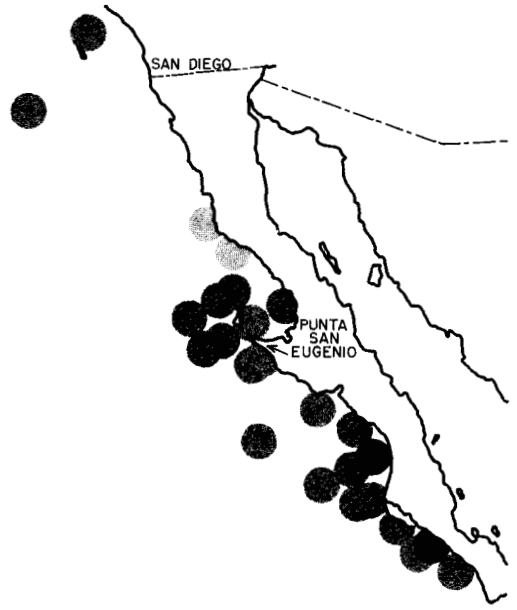

FIGURE 26. February, 1952—Spawning around Cedros Island and inshore southern Baja California. Some spawning off Southern California. Area covered: Point Conception to Cabo San Lucas.

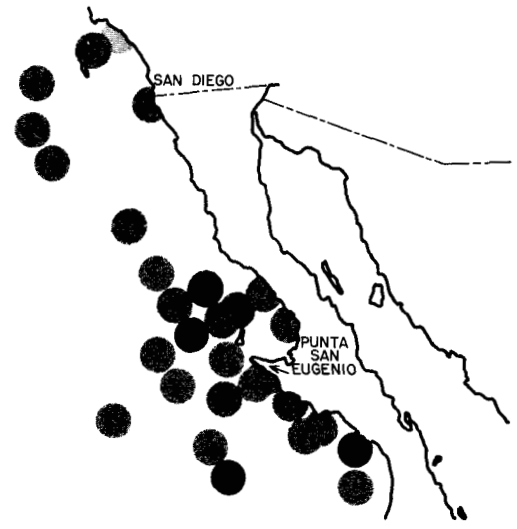

FIGURE 27. March, 1952—Spawning more plentiful and extending seaward. Area covered: Point Conception to Cabo San Lazaro.

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.