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.

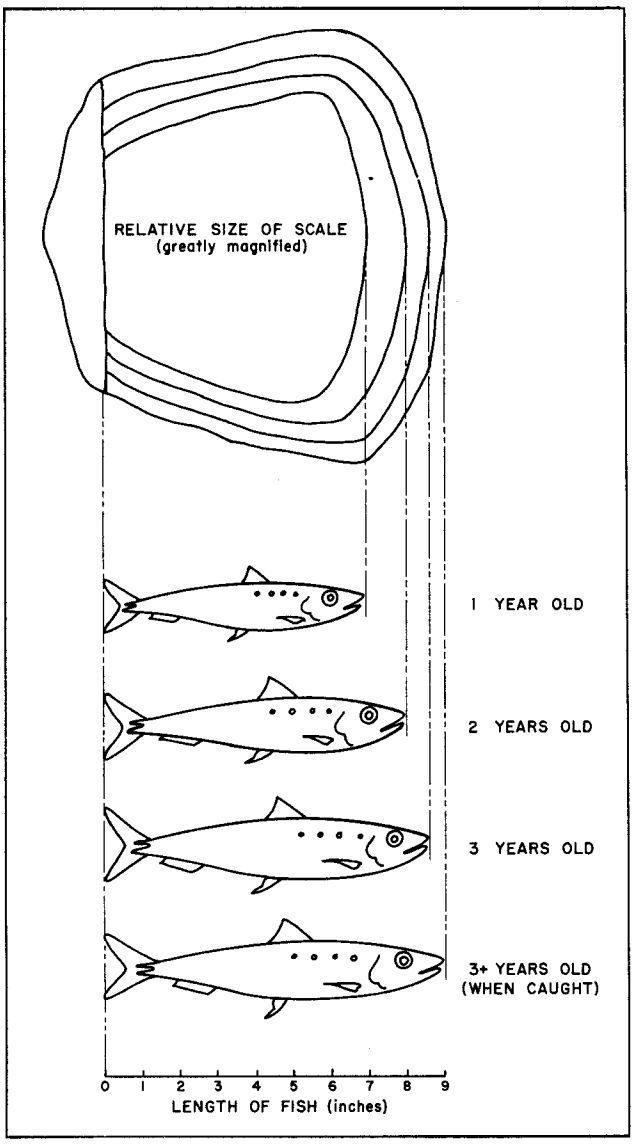
Three year classes the young of which were found in considerable numbers off California and northward were above average in abundance: the 1938 year class, 1.7 times the average, the 1939 year class, 2.5 times, the 1940 year class, 1.2 times. The 1950 and 1951 year classes, the young of which were found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

Unlike the egg and larvae surveys, the early youngfish 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.

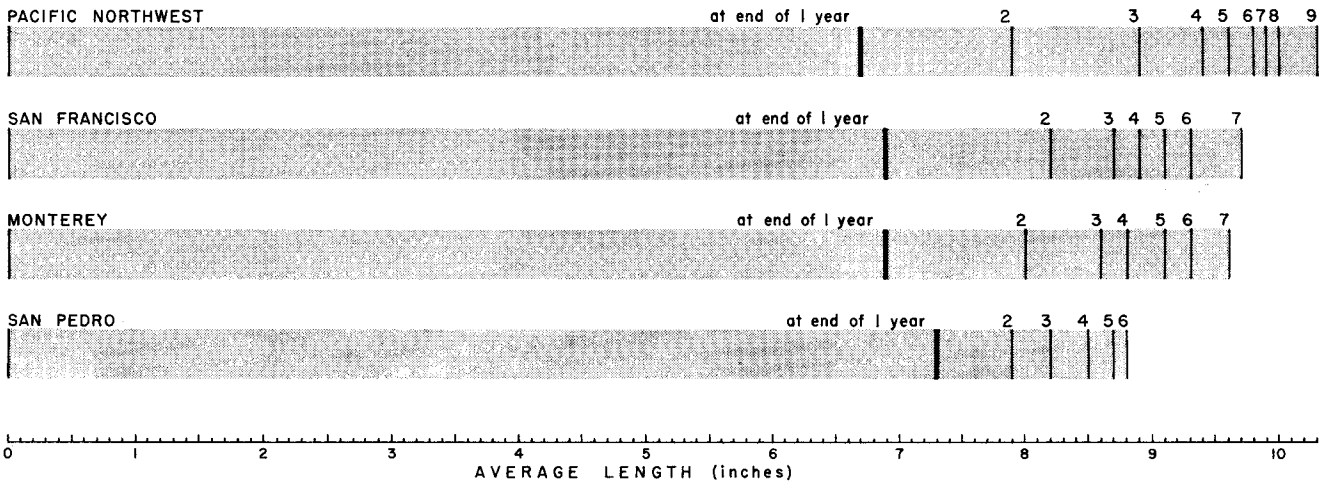


FIGURE 5. Means of averages of observed lengths of sardines taken in four areas from 1941-42 through 1951-52 seasons. Fish caught at San Pedro are longer at end of first year, shorter thereafter.

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

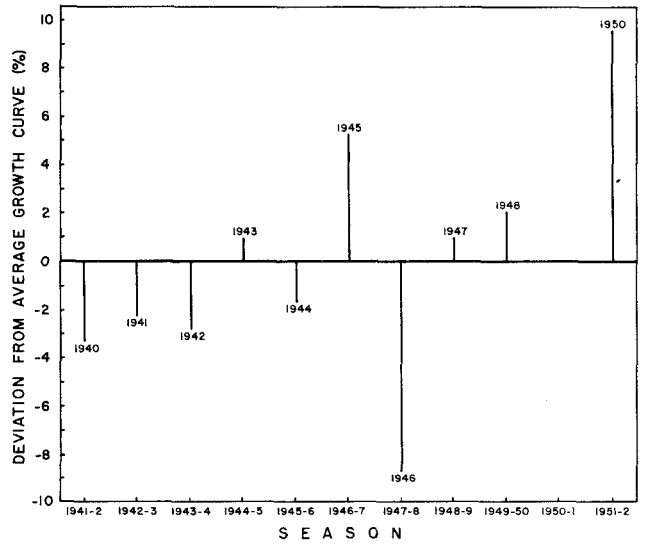


FIGURE 6. Deviations of one-year-old sardines in San Pedro fishery from average growth curve, 1941-42 through 1951-52 seasons. The 1945 and 1950 year classes, which at one year were longer than average, are tentatively assumed largely to have originated on the Baja California spawning grounds; the 1946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

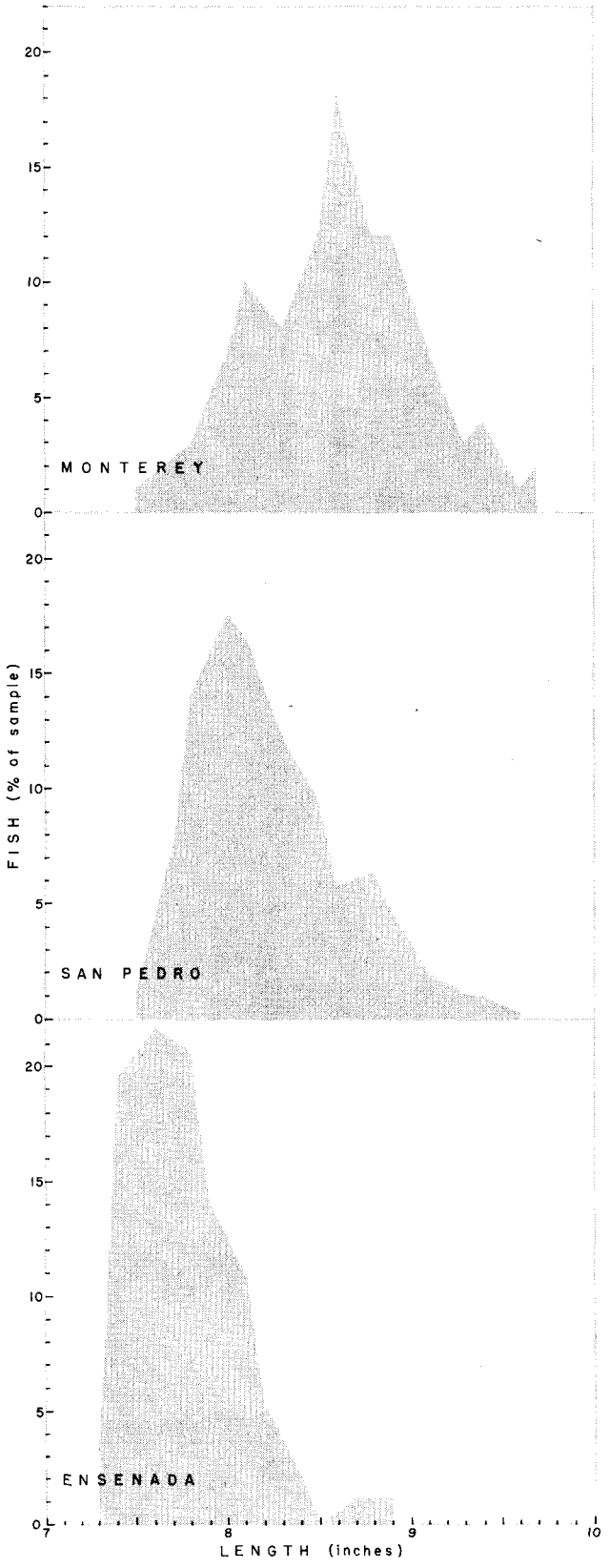


FIGURE 7. Size distribution of 1948 year-class sardines sampled at Monterey, San Pedro, and Ensenada in the 1951-52 season. Three-year-old sardines of southern origin would be shorter than those of northern origin. Very few southern fish were at Monterey, very few northern fish at Ensenada. (Data, Table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

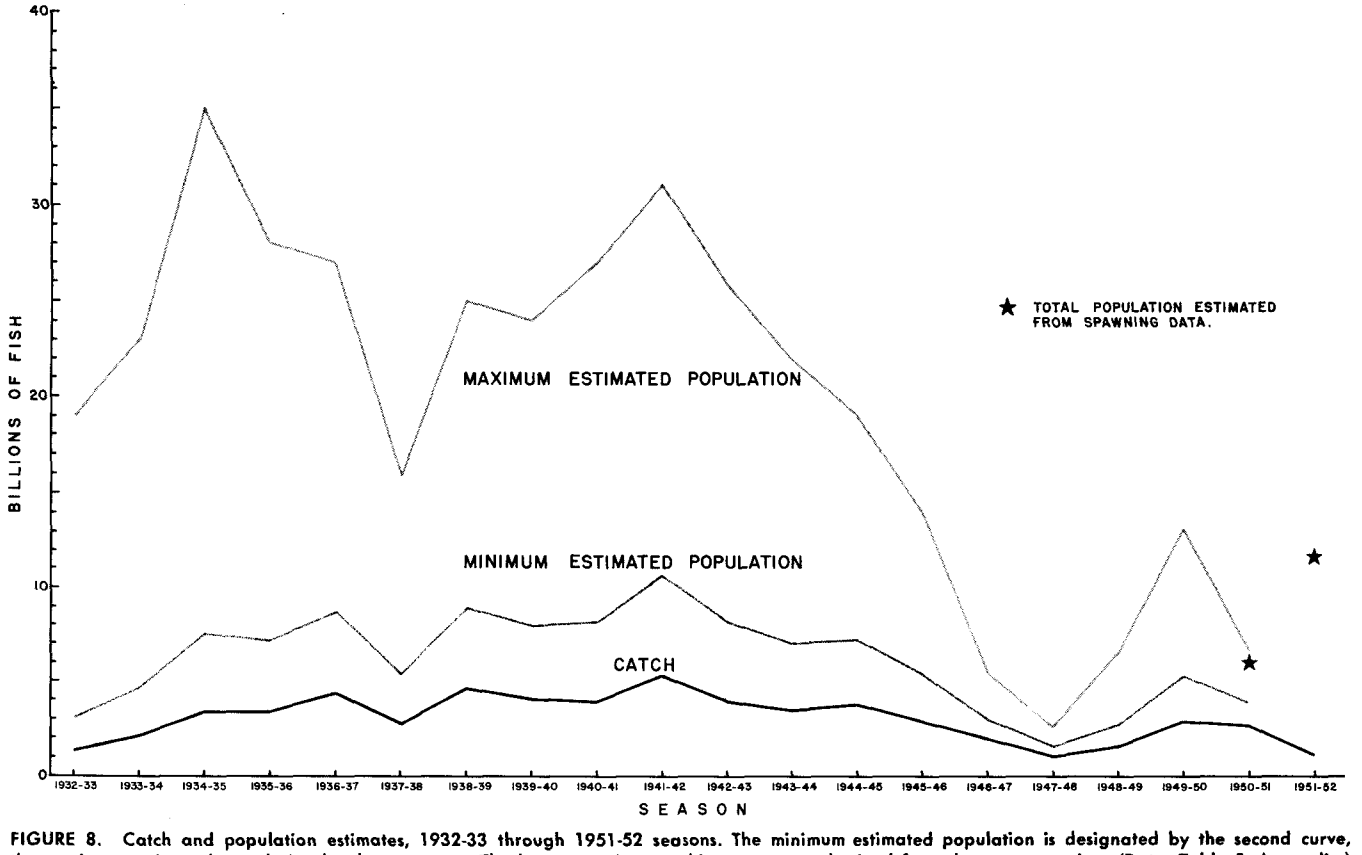


FIGURE 8. Catch and population estimates, 1932-33 through 1951-52 seasons. The minimum estimated population is designated by the second curve, the maximum estimated population by the top curve. The last two points on this curve were obtained from data on spawning. (Data, Table 5, Appendix.)