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.

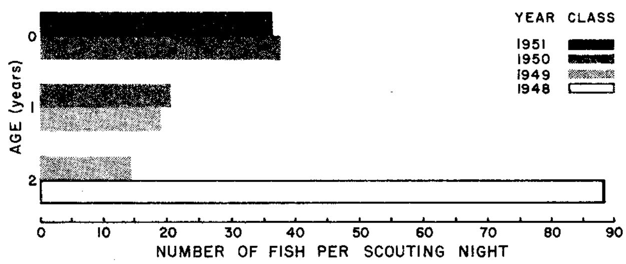

FIGURE 28. Comparison of abundance of 1948, 1949, 1950, and 1951 year classes of sardines at various ages, based on 1950 and 1951 young-fish surveys from Bodega Head, north of San Francisco, to Punta San Juanico, Baja California. These are average values; values for each of four localities are given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

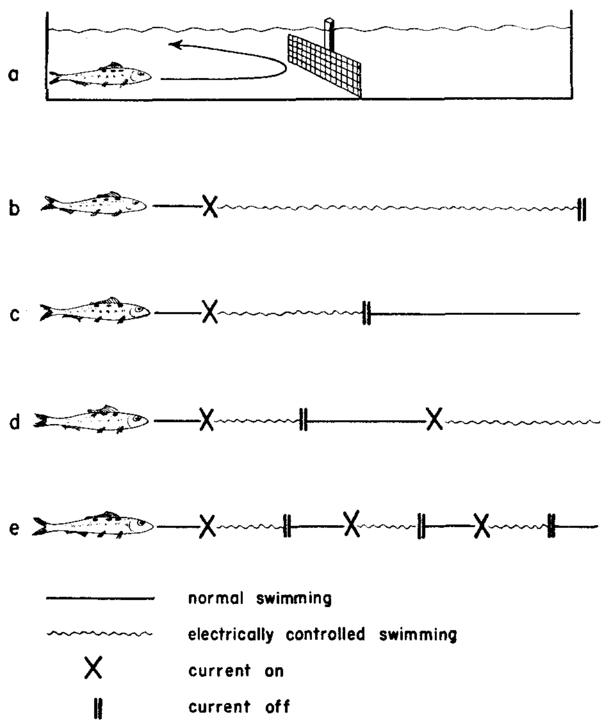

FIGURE 29. Diagram illustrating behavior of sardines in the absence and in the presence of an electrical field.

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.

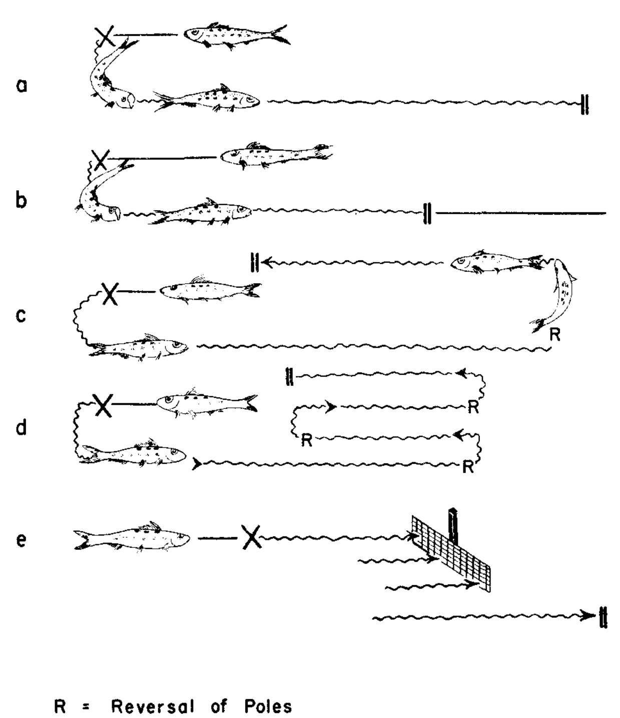

FIGURE 30. Diagram illustrating behavior of sardines in an electrical field.

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.