DIVISION OF FISH AND GAME OF CALIFORNIA
BUREAU OF COMMERCIAL FISHERIES
FISH BULLETIN No. 41
Early Life History of the California Sardine (Sardina caerulea), with Special Reference to Distribution of Eggs and Larvae[*]

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[*] Prepared for publication, September, 1932.

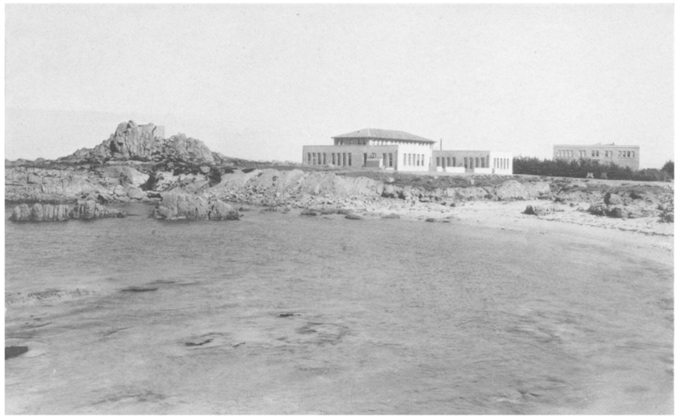

FIG. 1. The Hopkins Marine Station at Pacific Grove, the headquarters of the Hydrobiological Survey. In the foreground is the Jacques Loeb Laboratory and in the rear the Alexander Agassiz Laboratory. Photograph courtesy of Dr. W. K. Fisher, 1931.

FIG. 1. The Hopkins Marine Station at Pacific Grove, the headquarters of the Hydrobiological Survey. In the foreground is the Jacques Loeb Laboratory and in the rear the Alexander Agassiz Laboratory. Photograph courtesy of Dr. W. K. Fisher, 1931

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1. PROBLEM

From April, 1929, to September, 1932, the early life history of the California sardine (Sardina caerulea) was subjected to an intensive investigation. (Scofield and Lindner, 1930.) This work was sponsored by the Hydrobiological Survey of the Hopkins Marine Station, a cooperative oceanographical enterprise undertaken by the Bureau of Commercial Fisheries of the California Division of Fish and Game and the Leland Stanford Junior University. (Skogsberg, 1930.)

The ultimate aim of this work is to be able to predict and to show the causes of the presence or absence of dominant year groups in the commercial catch of sardines taken along the coast of California. In other words, it is intended that this investigation will establish a basis for the estimation of the relative success or failure of each year class two or three years before it enters the commercial catch. Forecasts of this nature are to be based upon the relative abundance of sardine larvae which are to be captured by specially constructed plankton nets operated quantitatively at key stations throughout the maximum spawning area.

Because of the magnitude of this problem, the first four years of the investigation were devoted to two major studies: (1) the determination of the maximum spawning area, and (2) the consistency of this location from year to year. Related secondary problems, such as the development of the eggs, and the food, drift and rate of growth of the larvae were carefully considered and studied whenever material was available.

2. GENERAL CONCLUSIONS

In the pursuit of these preliminary problems, approximately 15,000 miles of station lines were run, covering an area of about 252,000 square miles of ocean water. A total of 358 stations was made during the four-year period. The region covered lies between Eureka, California, on the north and Cape San Lucas, Baja California, on the south. Between Eureka and San Diego, California, the entire body of water out to 400 miles was covered by station lines. In the remainder of the region visited the exploratory work was confined to the proximity of the coast. (See Fig. 2.)

The results of this rather intensive work indicate with fair certainty that the maximum spawning area has been accurately determined and that its location was found to be fairly constant during the four years of the investigation. The maximum spawning region is a comparatively small area 200 miles in length and 100 miles in width.

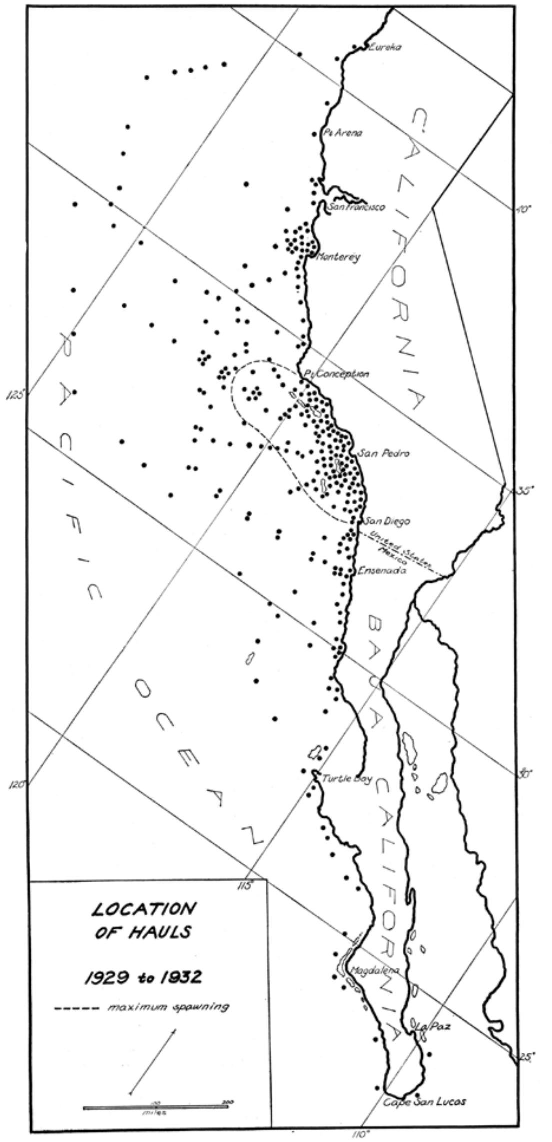

Eureka
Pt. Arena
San Francisco
Monterey
Pt. Conception
San Pedro
San Diego
United States
Mexico
Ensenada
Turtle Bay
Magdalena
La Paz
Cape San Lucas
CALIFORNIA
PACIFIC
OCEAN
BAJA
CALIFORNIA
LOCATION
OF HAULS
1929 to 1932
maximum spawning
125°
120°
115°
110°
40°
35°
30°
25°

FIG. 2.

FIG. 2

It is situated off the coast of southern California between San Diego and Point Conception and offshore to a distance of 100 miles. (See Fig. 2.) General spawning has been found to occur from near Cape San Lucas north to San Francisco and offshore to a distance of over 250 miles. The location of the maximum spawning area has remained constant from 1929 to 1932. The egg and larva productivity of this central region is more than double that of all other spawning areas combined.

The California sardine ranges over 2000 miles up and down the Pacific coast between southern Alaska and Lower California. No records are extant that this fish has been seen or known to occur farther than 300 miles from land. The fact that the great bulk of these sardines migrates to a centralized area for the purpose of spawning is no doubt the most important discovery of this investigation.

3. ACKNOWLEDGMENTS

During the course of this investigation I have become indebted to both Mr. N. B. Scofield, chief of the Bureau of Commercial Fisheries, and to Dr. Tage Skogsberg of the Hopkins Marine Station, in charge of the Hydrobiological Survey. Their guidance and helpful criticisms have been a great aid to me. The collection of material, which thus far has been the most important aspect of the investigation, has progressed smoothly, due in the main to the hearty co-operation of Mr. C. H. Groat, Supervising Fish Warden of the Bureau of Patrol and Law Enforcement, San Pedro district. He has placed the motor vessel *Bluefin* at my disposal during a period of six months each year.

Captain Walter Engelke of the motor vessel *Bluefin* and his crew have given every possible aid in the field work and, as a result, the many days spent at sea with them were most pleasant.

I wish to thank Mr. W. L. Scofield and Dr. Frances N. Clark of the California State Fisheries Laboratory for their helpful criticisms of this manuscript and Miss K. Karmelich for her aid in its preparation for publication.

4. SUMMARY OF THE 1929 WORK

The first work on the early life history of the California sardine was done in the region of Monterey Bay. At that time it was believed that the sardines lingered there prior to and just after spawning, which belief led one to assume that the spawning grounds were fairly close at hand. At Monterey the sardines are quite scarce during the spring and summer months when spawning is taking place. Canneries remain closed, because the availability of this fish is too uncertain. Sardines are known to be present, however, because gill nets and purse seines used in capturing other species often take them. Then, too, there are fishermen who supply the fresh fish markets daily with sardines taken in lampara nets. An examination of these spring and summer fish revealed nothing relating to a local spawning, though it has been learned since that during seasons when warmer water is prevalent at Monterey the sardines attain a higher degree of maturity. (Clark, 1934.)

Early each August these fish reappear in Monterey Bay in their usual great numbers. At this time their gonads are usually normal, so it is difficult to know whether or not they had spawned recently. They are taken in great numbers through the fall and winter until February or March, then once again they disappear until the following August. During the late winter months their gonads show a marked advance toward maturity, their oil content drops, and it is evident that they are about to spawn. Their departure at this time had been baffling, for where they went nobody seemed to know.

At San Pedro and San Diego, the southern major fishing ports on the California coast, there also appeared strong evidence that the sardines spawned in or close to the territory south of Point Conception. From May to October there is a marked scarcity of this species in this southern region. The young, or yearlings, are quite different in this respect since they are present all year in the shore region. The adults, however, return in great numbers in October, and once more the boats and nets are put to use and the canneries are generally able to operate at capacity. At this time the sardine gonads appear to be normal and, as at Monterey, there is no evidence to show whether or not they have recently spawned. These fish remain in this area until as late as April and a few until early May. By this time they all have eggs which are nearly mature. In fact, they reach a much higher degree of maturity than do the Monterey sardines in March. (Clark, 1934.) Semiweekly sampling of the sardine catches carried on by the California State Fisheries Laboratory reveal that no actually ripe eggs have ever been removed from sardines of the Monterey region, whereas several have been observed from the San Pedro region.

Having considered all this available information, it seemed probable that the spawning area was common to both northern and southern regions of the California coast. Since the Hydrobiological Survey had established its headquarters at Monterey, it was advisable that the search for the spawning grounds commence in the north and, if necessary, work to the south or offshore.

In April, 1929, there were 14 stations established in Monterey Bay and offshore to a distance of 45 miles. All of these stations revealed a wealth of fish eggs and larvae, but in no case were the eggs or larvae of sardines found. Similar failure was encountered when a line was run up the coast to Eureka during the early part of May. On this run four stations were made, and on the run back to Monterey two more stations were established. On June 1, the *Albacore*, which was being used for this work, returned south to San Pedro, her headquarters. It was on this run that at Station X, lat. 33° 45' N., long. 118° 32' W., or a few miles west of San Pedro, the first specimens of sardine eggs and larvae were taken.

Spurred on by this discovery, we devoted the entire month of June, 1929, to a prolonged search for the general spawning region. In pursuit of this objective, the work had to be carried on in conjunction with the patrol of the commercial fisheries which was the prime purpose of the *Albacore* used in this work. Therefore, the search for the spawning area was rather restricted, yet extensive enough to illustrate that this area was large and that spawning was intense.

A general summary of the few results established in 1929 showed that during this season, spawning occurred only south of Point Conception where the surface water averaged close to 18° C. Eggs and larvae were taken as far south as San Diego and offshore to a distance of 50 miles. Spawning was apparently very intense, since four-foot plankton nets took as many as 250 eggs in a single haul of 15-minute duration. A count of the eggs and larvae in each haul revealed the probability that spawning also occurred farther to the south and much farther offshore. (See Fig. 3.)

5. SUMMARY OF THE 1930 WORK

During the spring and summer of 1930 there was one objective in view—to establish the southern and offshore limits of the sardine spawning. As a consequence, a line was run in April as far south as Cape Colnett, which is situated on the west coast of Baja California, about 110 miles below the international boundary. Sardine eggs were taken as far south as this line was run. (See Fig. 3.)

During May a line was run offshore for a distance of 120 miles due west from San Pedro. Sardine eggs and larvae were taken at all stations on this run. Later in May a line was run up the coast to Pismo, about 50 miles north of Point Conception. Eggs and larvae were taken at all stations on this run, whereas in 1929 none had been taken north of Point Conception. (See Fig. 3.)

The *Steelhead*, operating in Monterey Bay, reported that in April, during an influx of warm water, it had taken many sardine eggs within the bay. It was apparent, therefore, that the sardines were spawning along nearly the full length of the coast of California in 1930. This fact appeared interesting in view of the increase in water temperatures north of Point Conception as compared to 1929 temperatures. (See Figs. 10 and 11.)

In order to learn to what extent the sardines were spawning directly off the coast north of Point Conception, a line was run from Pismo due west for 30 miles. Spawn and larvae were discovered in this region as well as at all stations established while on the Albacore's return trip to San Pedro from this point. (See Fig. 3.)

In May, 1930, the *Bluefin* was completed and, during the first of June, made her first scientific cruise. This line was made from San Pedro southwest for 214 miles, thence north for 137 miles and northwest for 100 miles, thence to Monterey. At 10 of the 14 stations made, the spawn or larvae of sardines were discovered. This find was not only startling, but also rather depressing as it uncovered the fact that future work would have to be extended several hundred miles to sea as well as along the entire coast line of California and Baja California. (See Fig. 3.)

Tentative conclusions drawn from the 1930 work were that sardine spawning was consistent south of Point Conception and was more or less spasmodic north of this point. Since a great amount of spawn was taken as far out as 200 miles from land, it was apparent that the offshore region to at least 300 miles should be thoroughly searched each season. It was also apparent that spawning was taking place well down the west coast of Baja California, as indicated by the numbers of eggs taken as far south as Cape Colnett.

There also arose the question of temperature of water and spawning. Point Conception is a natural dividing line between two seemingly

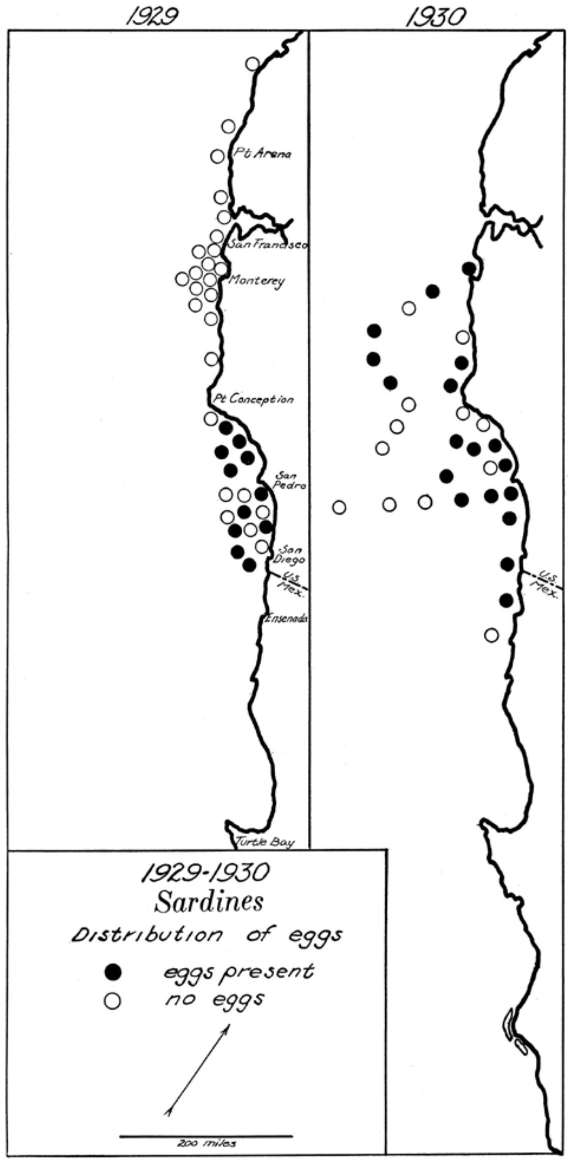

1929
1930
Pt Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S. Mex.
Ensenada
Turtle Bay
U.S. Mex.
1929-1930
Sardines
Distribution of eggs
eggs present
no eggs
200 miles

FIG. 3.

FIG. 3

different bodies of water. South of this point the water is about 18° C. and north it is about 13° C. during the spring and summer months. (See Figs. 10 and 11.) During 1930, when the temperature in Monterey Bay rose to 15° and 16°, sardine spawn was found. At Pismo and other points north of Point Conception, the same condition is true. The California current which parallels the coast of California is also known to be a warm body of water, averaging about 18° C. in temperature. Directly off San Pedro sardine eggs were taken in this current; thus there arose the question of how far north in this current the sardines spawn. It is quite possible that the sardines upon maturity move directly off the coast until they hit this warmer body of water known as the California current. It was this locality that was to be investigated the following year of 1931 to learn its productivity of young.

6. SUMMARY OF THE 1931 WORK

The sardine investigation conducted during the spring and summer of 1931 marked the beginning of quantitative hauls. The results obtained were of extreme value because a great number of stations was established, a large territory was covered, and very complete data were gathered. Close to 8600 miles of station lines were run over a period of six months, commencing in February and ending in August.

In February a section was sampled directly off the coast between San Pedro, California, and Ensenada, Baja California, and offshore to a distance of 250 miles. This station line revealed that spawning this early in the season was confined to the proximity of the coast line and not more than 100 miles out. (See Fig. 4.)

In March a section 100 miles wide, just to the north of the former section, was investigated. This took in a 50-mile strip north of Point Conception. Warm water of 16° C. was found to be present north of Point Conception and, as might have been expected, the eggs and larvae of sardines were found there in considerable numbers. (See Fig. 11.) Eggs and larvae were taken in this northern section as far offshore as the line was run or 100 miles out. In the entire section, however, the greatest number of eggs and larvae occurred south of Point Conception. (See Fig. 4.)

In April a line was run down the west coast of Baja California as far as Cape San Lucas and into the Gulf of Lower California as far north as La Paz. No eggs or larvae were taken south of a point 300 miles below the international boundary. Small sardines were taken in Turtle Bay, however, which indicated that spawning might have been under way much earlier in these southern waters. Since there were no larvae taken, it seemed more probable that these young fish had migrated to this region. However, as the adults are known to occur as far south as the Gulf of Lower California, it was decided at this time to investigate these waters at a much earlier date the following year of 1932.

In May, 1931, a line was run up the coast of California to Eureka, in the northern end of the State. On this run the greatest number of eggs were taken south of Point Conception, corresponding to the results established in March. A few eggs, however, were taken as far north as San Francisco. From Eureka a line was run offshore to a

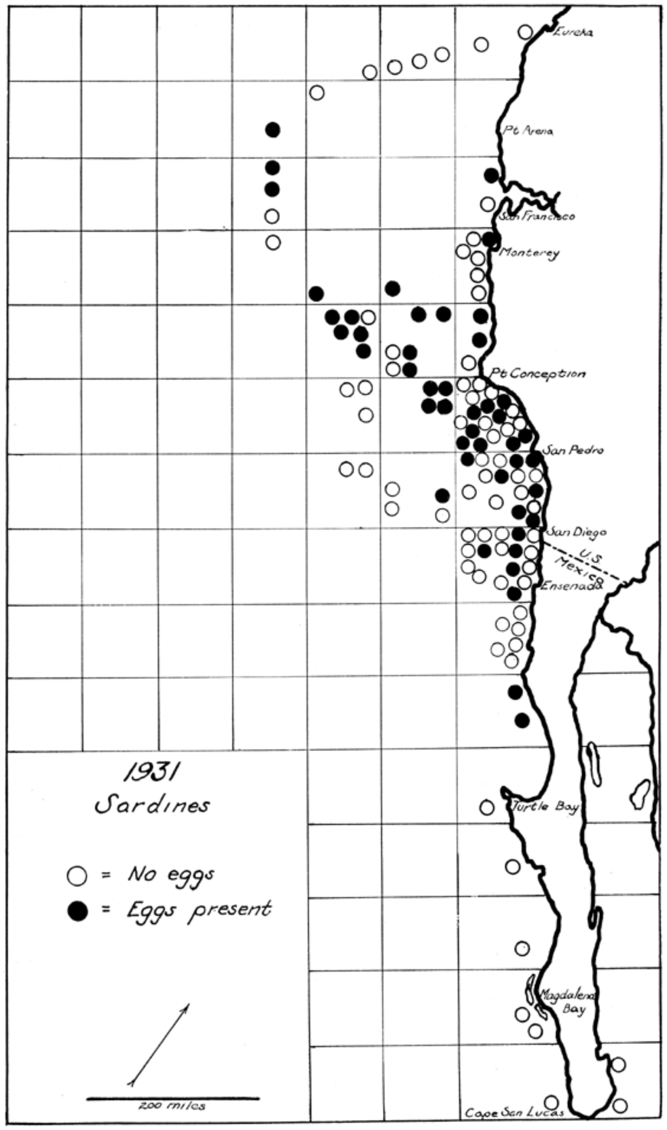

Eureka
Pt Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S.
Mexico
Ensenada
Turtle Bay
Magdalena Bay
Cape San Lucas
1931
Sardines
= No eggs
= Eggs present
200 miles

FIG. 4.

FIG. 4

distance of 300 miles, thence coastwise, to the southeast, to a point 400 miles west of San Pedro, thence inshore into this port. (See Fig. 4.) On this line, which was run well within the California current, it was learned that sardine eggs occurred as far north as a point 300 miles directly off San Francisco, which incidentally was the same northern distribution discovered along the inshore region. From this offshore point, sardine eggs were picked up in increasing numbers as we moved to the southeast. Below Point Conception, as before, we found the greatest numbers of sardine eggs and larvae. In this region hauls took as many as 10,000 to 50,000 eggs each, whereas to the north an individual haul never exceeded 500 eggs.

Late in May the section covered in February was repeated. Although a few eggs were taken out to the 250-mile mark, by far the greatest number were taken within the 100-mile line. This section also revealed that the greatest number of eggs lay directly off San Pedro, whereas all hauls (four) made from 100 to 250 miles off Ensenada were blank. (See Fig. 4.)

The important result of the 1931 work was that most intensive sardine spawning was found to occur between San Diego and Point Conception and out to a distance of 100 miles. Minor spawning was spread in all directions from this main area, though most important and worthy of note was the spawning down the west coast of Baja California and north in the California current. (See Fig. 4.)

7. SUMMARY OF THE 1932 WORK

The 1932 work was so arranged as to determine the offshore limits of spawning, the southern limits, and to recheck the region of maximum spawning as determined in 1931. To do this the quantitative hauls were maintained and approximately 6000 miles were run. The entire water area north to Monterey and offshore to a distance of 400 miles was covered in the region off central and southern California; whereas south of the international boundary the entire coast line was searched as far south as Magdalena Bay and offshore to 150 miles. (See Fig. 5.)

The first line to be run was in February down the west coast of Baja California, which took us as far south as Magdalena Bay. On this line the greatest number of sardine eggs were taken north of the international boundary; however, the larvae increased in numbers as we went south to a point 100 miles north of Magdalena Bay, after which we failed to take a single egg or larva. This might have indicated that spawning was much earlier in these southern waters as was suggested by the same run in 1931. These southern larvae were too few in numbers, however, to warrant this region being an outstanding producing area. It could have been possible that the spawning occurred here during December and January, which would account for the larvae in February; but this spawning would be insignificant since it has been shown by Clark (1934) that the main population of adult sardines that occur in great numbers off the California coast begin spawning in February, reaching a peak in April and May. For this reason it is probable that the major spawning area lies in the region where spawning is the most intense during April and May.

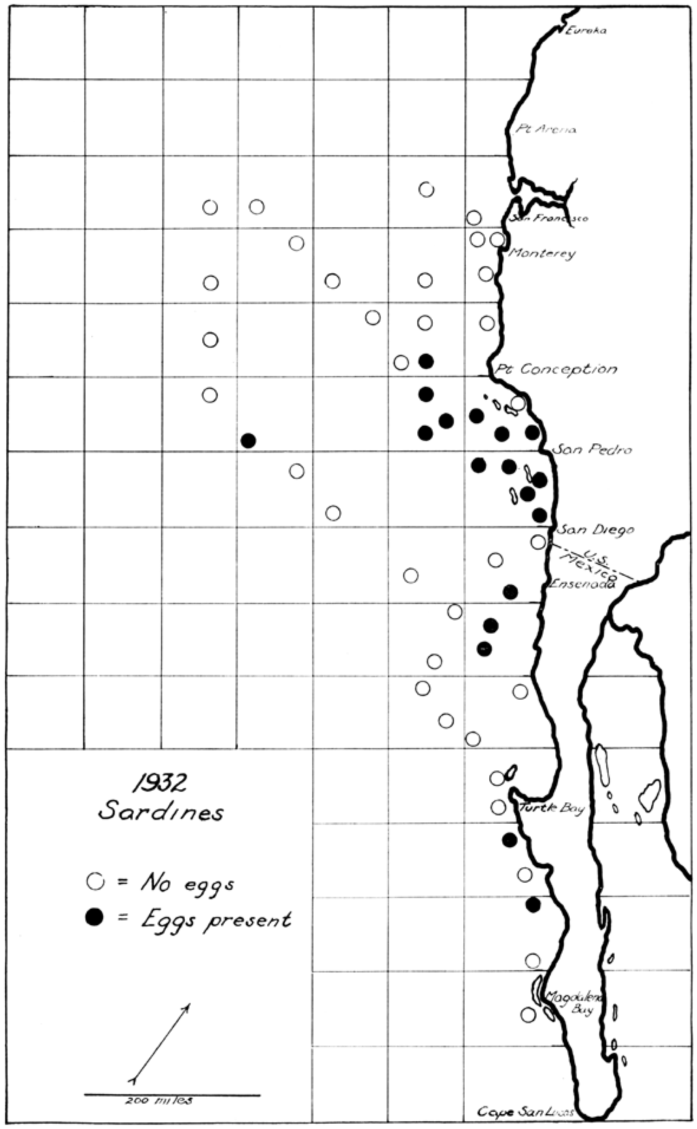

Eureka
Pt Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S.
Mexico
Ensenada
Turtle Bay
Magdalena Bay
Cape San Lucas
1932
Sardines
= No eggs
= Eggs present
200 miles

Fig. 5.

FIG. 5

In April a section to the west of San Pedro, 650 miles offshore (west) and 250 miles wide, was covered by station lines. The outward limit of this section was well within the California current and directly off San Francisco about 400 miles. The results obtained in this section were extremely interesting, for no eggs or larvae were taken beyond 100 miles from land, and, as occurred in 1931, the vast majority of eggs and larvae were taken south of Point Conception and north of San Diego. (See Fig. 5.) The California current was much colder than usual during this run, since it was found that the surface waters were from 13° to 15° C. South of Point Conception the water was from 14° to 17° C. This fact again brought up the question of temperature of water and spawning. (See Fig. 11.)

During the spring months at Monterey Bay the surface waters were reported to be less than 14° C. Though this temperature was normal for this northern region, it was believed that the sardines would not be spawning at this time. To check this assumption, a series of hauls was made by the *Albacore* in the region close to Monterey during April and May. At this time the surface temperatures were close to 12° C. (See Fig. 11.) No eggs or larvae of the sardine were taken. (See Fig. 5.)

There still remained the possibility, however, that the sardines were spawning farther offshore in the warmer water located in the edge of the California current. This theory was refuted by a line run early in May north to Monterey, thence directly offshore for 100 miles, and to the southeast paralleling the coast line. On the run north to Monterey sardine eggs and larvae were taken in great numbers as far north as Point Conception. North of this point not a single egg or larva was taken. Running southeast, 100 miles offshore, the water temperature remained below 13° C. and, as anticipated, no trace of the sardine eggs or young was found. (See Fig. 11.) Opposite Point Conception, and south, sardine eggs and larvae were again picked up in considerable quantities in water which was slightly less than 15° C. (See Fig. 5.)

The results of the 1932 work checked very definitely with those of 1931. The main spawning area was shown to occur between San Diego and Point Conception and offshore to about the 100-mile line. Spawning was found to be consistent each season down the west coast of Baja California, but only occasionally in the California current and inshore north of Point Conception. It is probable that spasmodic spawning may take place in all localities where the adult sardines occur. Just what effect these spasmodic spawnings have on the resulting population of sardines is not known. However, it is at present deemed advisable to look to the central spawning area as our main source of knowledge in judging the success or failure of each season's spawning and the resulting size of annual year classes.

8. LOCATION OF THE MAJOR SPAWNING AREA

The location of the major spawning area has been the outstanding result of these preliminary investigations. Roughly, this area lies between San Diego on the south, Point Conception on the north, and offshore for approximately 100 miles. (See Fig. 2.) Casual spawning is now known to take place as far north as San Francisco, as far

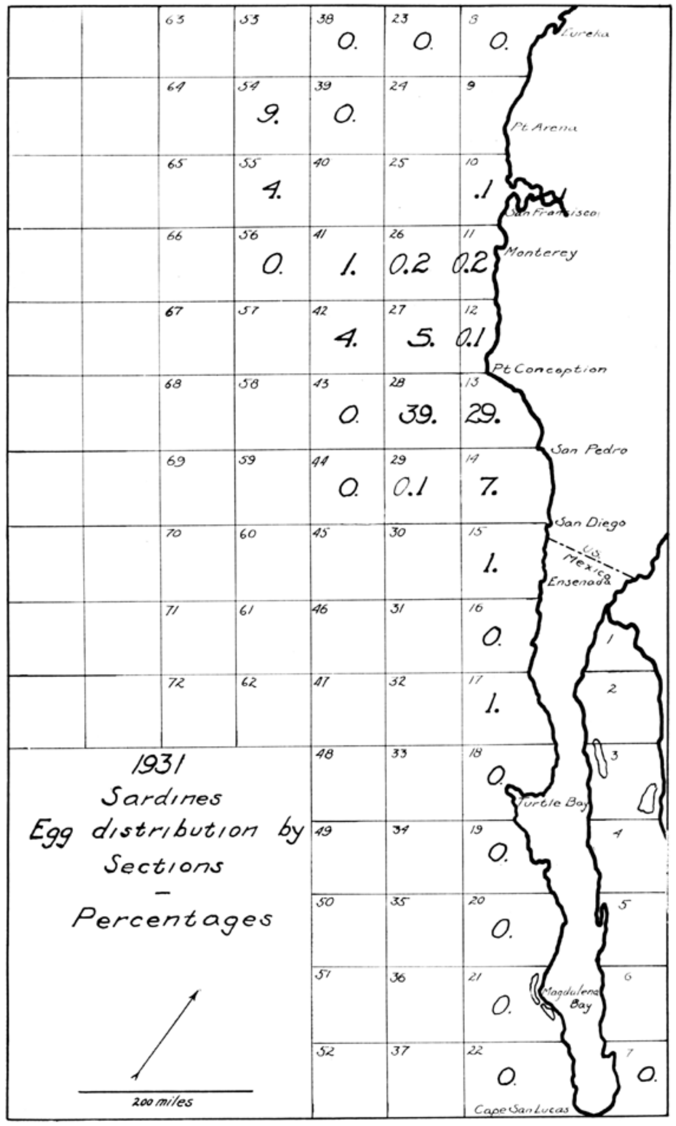

1931
Sardines
Egg distribution by
Sections
—
Percentages
200 miles
Eureka
Pt. Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S.
Mexico
Ensenada
Turtle Bay
Magdalena Bay
Cape San Lucas

FIG. 6.

FIG. 6

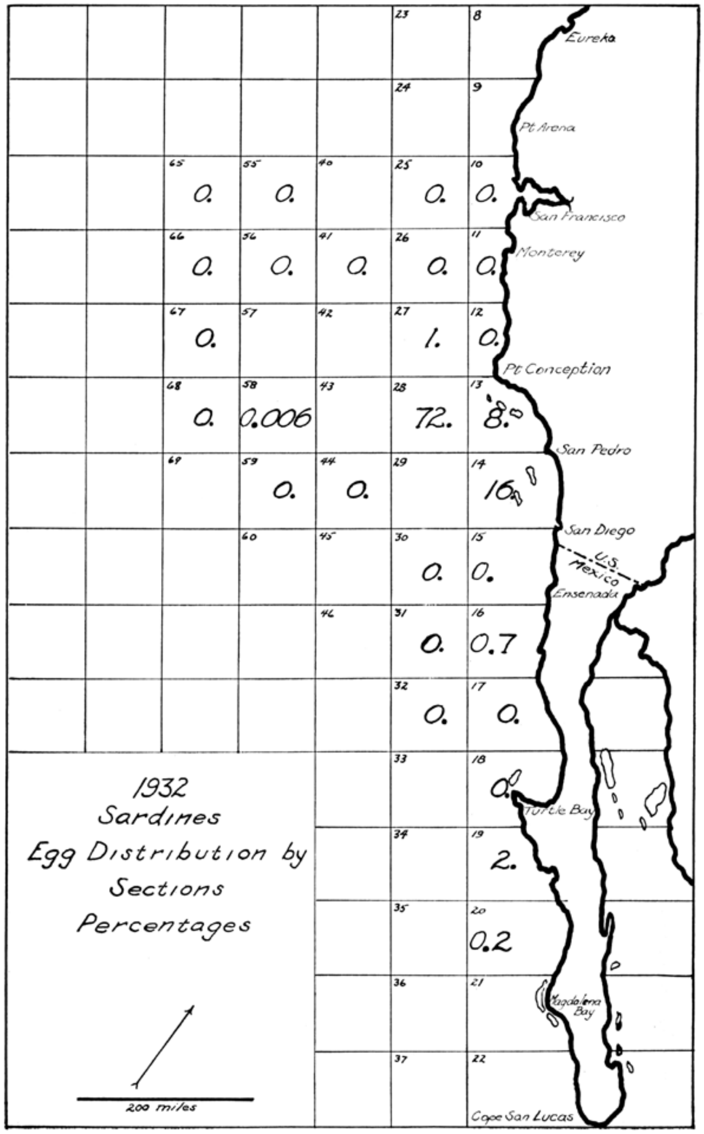
south as Magdalena Bay, and offshore to a distance of 250 miles. It is also quite possible that the sardines spawn spasmodically as far north and south as their range—or southern Alaska and the Gulf of Lower California. It is felt, however, that such casual spawning contributes little or nothing to the main population of California sardines.

To show graphically that the major spawning area is concentrated in this small area, the entire data were treated statistically and presented in figures 6 and 7. Figure 6 represents the percentage of eggs that each section contributed to the total number of eggs secured over the entire area for the full spawning season of 1931. These data in their original form can be observed in tables 1, 3 and 4. The positions of these hauls are shown in figure 4. The solid black circles represent hauls in which sardine eggs were taken, and the open circles are negative hauls.

For the sake of comparison the entire coastal region was divided into sections, each 85 miles square, save the sections along the coast line. From figure 4 it can be seen that some sections contained many more hauls than others. Negative hauls are well scattered, as are the positive hauls. In order to give equal weight to sections having only one or two hauls and sections having as many as twenty hauls, it was obvious that the data would have to be treated mathematically. To do this there was first established the percentage of positive hauls in each section. This figure was then multiplied by the average number of eggs per haul in each section. This result was then translated into the percentage of the total number of eggs for the whole area over the entire season. The percentage reached in this manner represents the part each section played in the contribution to the total amount of spawn. Therefore each section is of equal weight, even though some have only one haul and others a dozen or more.

Referring to figure 6 once more, it is seen that the two sections (28 and 13) just south of Point Conception stand out boldly as producing centers. Section 13 contributed 29 per cent of the spawn of 1931, whereas section 28, to the southwest, contributed as much as 39 per cent of the total. None of the other sections contributed more than 9 per cent. Section 54, directly off Point Arena, which contributed 9 per cent eggs, is hardly representative of this region. It is represented by a single positive haul containing nearly 500 eggs. Though this section appears to stand out by itself as a production center, it is hardly as important in this respect as section 14, just south of San Pedro, which contributed 7 per cent eggs. In this latter section the hauls were numerous, but many negative hauls entered into the total because of early and late seasonal visits. All the positive hauls were well over 1000 eggs each; so it is obvious that section 14 is a much more valuable contributing center than the section off Point Arena.

Passing on to similar work done in 1932, we find nearly the same results. Figure 5 illustrates that spawning was much more confined in 1932 than in 1931. The solid black circles, representing positive hauls, are very much centered about Point Conception and south as far as Magdalena Bay. There is one exception, and this was a haul some 350 miles southwest of San Pedro. This one haul took but a single egg. Though this result must be taken into consideration, it is hardly comparable to other hauls of several hundred eggs each.



1932
Sardines
Egg Distribution by
Sections
Percentages
200 miles
Eureka
Pt Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S.
Mexico
Ensenada
Turtle Bay
Magdalena Bay
Cape San Lucas

FIG. 7.

FIG. 7

These data were treated in the same manner as the 1931 data, and the results are shown in figure 7. Here again one can readily see that the main contributing center is below Point Conception and north of San Diego (sections 28, 13 and 14). Other valuable contributing sections occurred down the west coast of Baja California as far south as Magdalena Bay. As stated above, however, these extreme southern sections are thought to be the result of early spawning and are of little significance as major producing centers.

Results of the 1929 and 1930 work are shown in figure 3. During these two years the hauls were not quantitative, therefore the usual percentages can not be illustrated. The 1930 work shows spawning to be spread considerably. However, from a rough approximation of the number of eggs per haul, it was evident that the greatest number of eggs were to be found north of San Diego and south of Point Conception. The eggs taken out in the California current were few in numbers, as were the eggs north of Point Conception and in Monterey Bay.

All the accumulated evidence gathered in these four years of investigation points to the fact that spawning of the California sardine is variable, but that during each season the most intense spawning takes place south of Point Conception, north of San Diego, and offshore for approximately 100 miles. During 1930 and 1931, when the greatest variations occurred, water conditions varied also. The main peculiarity was that much warmer water than average prevailed along the entire California coast. During these two years the sardine spawn was found well scattered to the north and south and well offshore. During 1932, when colder water temperature was evident, the sardine spawn was in very restricted areas and only found south of Point Conception and comparatively close to the mainland. It might be assumed from this that 1929 also was a year in which the sardine spawn was restricted to a small territory, because that year, like 1932, experienced colder water temperatures.

Water temperatures along the California coast fluctuate from year to year; therefore, it is quite probable that there also occur fluctuations in the distribution of sardine eggs. In spite of these variations, we can use the major spawning area, south of Point Conception, as the source of our information on the annual success or failure of the spawning. This information should be supplemented by the larval distribution, for the number of these tiny creatures that survive determines the origin of dominant or subnormal year classes.

It has been established by other fisheries biologists that the relative abundance of spawn in the open ocean is rarely an index to the success or failure of a year class. For example, a year in which the abundance of eggs is above normal may result, mysteriously enough, in a very poor year class. Again, during a year when poor spawning is evident there may arise a dominant year class. This condition is due of course entirely to the favorable or unfavorable physical and chemical properties of the water in which the eggs are deposited. These conditions in their turn affect food supply. The eggs and very small larvae are extremely delicate and their survival is at the mercy of the sea. The older the fishes grow, the more stable they become in their existence. Hence, in determining the origin of dominant year classes,

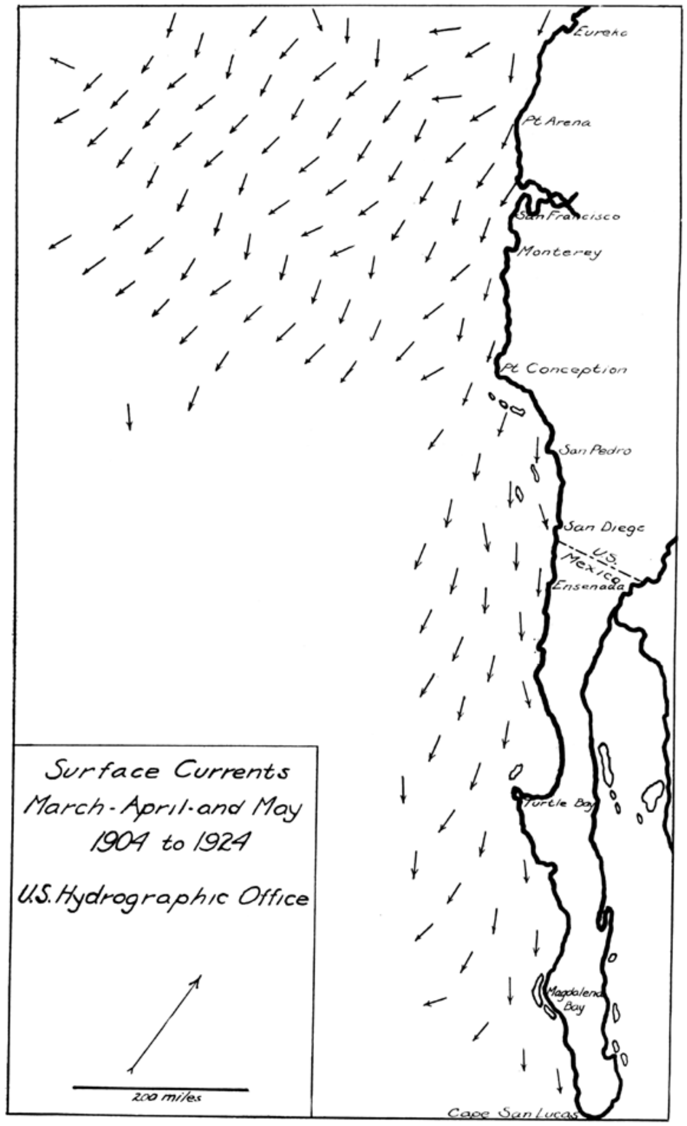

Eureka
Pt Arena
San Francisco
Monterey
Pt Conception
San Pedro
San Diego
U.S.
Mexico
Ensenada
Turtle Bay
Magdalena Bay
Cape San Lucas
Surface Currents
March-April-and May
1904 to 1924
U.S. Hydrographic Office
200 miles

FIG. 8.

FIG. 8

it would be advisable to secure quantitative data of fishes just before they enter the commercial catch. At this age the mortality rate is much reduced in contrast to the egg and larval stages. In the case of the California sardine, however, a measure of the abundance of sardines of this size would be very impractical. These fishes are schooling at this age, and the market and cannery demand is extremely variable. It would, therefore, be difficult to secure a measure of their abundance from the fishing boats. It would also be impossible to gather this information from boats fishing the adults, for they rarely take the young. It would be very expensive and impractical to gather our own data, for the young fish are not only schooling but occur along a coast line 800 miles or more in length.

It is evident, therefore, that to secure an accurate measure of the relative success of each year class, we must turn to the sardine larvae before they are schooling. In this state they are pelagic, and no doubt the larger individuals are swimming to some extent. By quantitative hauls, it is possible to secure a very accurate measure of their annual abundance.

9. LOCATION OF THE SARDINE LARVAE

The larvae of the California sardine should prove to be the best measure of the success of each year's spawning. Though mortality is heavy among the larvae, they have been chosen as a measure since it has been shown that an accurate measure of abundance would be impossible among older groups. To reduce the error, in this respect, as much as possible, only larvae above 10 mm. in length have been considered. This includes larvae up to the time of metamorphosis or approximately 35 mm. standard length.

To secure a quantitative measure of larvae it is necessary to know where they occur in the greatest numbers. It would not be probable that they would be found in the same sections where the eggs occur, for oceanic currents must be taken into consideration as well as the migrations of these tiny larvae. Published reports of the U. S. Hydrographic office state that the currents north of Point Conception during the spring and early summer months run south, paralleling the coast line, at the rate of half a knot per hour. This is particularly true of the California current, which is a part of the main circulation of the north Pacific. At Point Conception, however, this current swings to the southwest, where it joins the main equatorial current running west. Inshore, below Point Conception, the currents follow the coast line in a southeasterly direction. (See Fig. 8.) During some years there is a northwest current running from San Diego north. During late summer this current is always present. For a clearer explanation of these currents, refer to figure 8. These data are taken directly from the U. S. Hydrographic office charts.

From these current data it would appear that the eggs deposited well off Point Conception in the California current would be swept to the south and southwest and eventually lost in the broad expanse of the Pacific. Data secured by the author on the localities of larvae apparently disprove this theory. One alternative is that these tiny larvae are capable of movement as a result of their swimming ability. It has been shown that the larvae move from the spawning ground to the

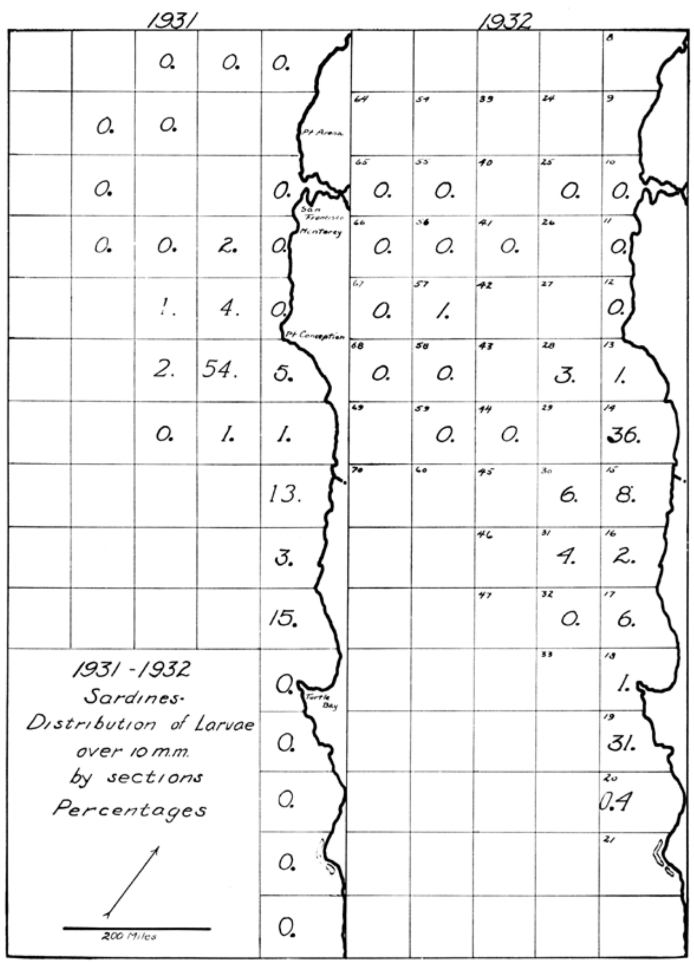

1931
1932
1931-1932
Sardines-
Distribution of Larvae
over 10 m.m.
by sections
Percentages
200 Miles
Pt Arena
San Francisco
Monterey
Pt Conception
Turtle Bay

Fig. 9.

FIG. 9

southeast and inshore. This movement takes place within the upper 25 fathoms of water, for numerous vertical hauls revealed that the larvae occur in greatest quantities above this depth. The U. S. Hydrographic office bases its current results on data collected by vessels as recorded from their daily set. This, of course, represents surface drift. Such drift oftentimes extends down as deep as 400 meters. But south of Point Conception we may have a subsurface drift quite different from that at the surface. It may be possible that this subsurface drift is only a few meters down. South of Point Conception the sloping front of the continental shelf extends well out into the edge of the California current. North of Point Conception the front of the shelf sinks rather abruptly. Here the lower edge of the shelf, or the 1000-fathom line, lies within five or six miles of land; whereas to the south this line extends out as far as 150 miles. This rather marked change in bottom contour from the north to the south might result in peculiar subsurface drifts of which we know nothing at the present time. It may be such a subsurface drift that is taking these larvae from the spawning grounds to the southeast and inshore. This larval movement, then, may not be the result of free swimming.

Whatever the cause of the movement of these larvae, let us consider the localities of these tiny fishes. In figure 9 is represented the percentage which each section contributed to the total number of larvae above 10 mm. for 1931 and 1932. All sections were given equal weight by the same procedure used in establishing the egg distribution. It will be seen that almost all these larvae are clustered about Point Conception and well down the west coast of Baja California. Contrast this figure with figure 4, which represents the egg distribution for 1931. During this season the eggs were well spread out, with the great bulk located from San Diego north. The larvae, however, are centered between Point Conception and southeast as far as Turtle Bay. This year showed a very pronounced southeast and inshore movement of the sardine larvae.

Considering 1932, we also find a decided southeast movement of the larvae. The egg distribution as represented in figure 5 shows the greatest abundance of eggs between Point Conception and San Diego. The larval distribution, however, lies between San Pedro and Magdalena Bay, or a much more southerly range. One would expect such a movement of the sardine larvae, for the main nursery grounds of the yearling sardines are located within the 10-fathom line (Godsil, 1930), probably from Point Conception south to Cape San Lucas. In the region adjacent to San Diego during July swarms of the recently metamorphosed sardines, approximately 45 mm. in length, appear on the shallow flats.

The movement of the sardine larvae is demonstrated more clearly by a comparison of the distribution of the very young with that of the oldest larvae. The young larvae, ranging in size from just hatched to 10 mm., occur in about the same region as do the eggs. There is a slight indication of a southern movement. The intermediate sized larvae, from 10 to 20 mm., appear to be variable in their distribution. During 1931 they revealed a marked inshore movement, but from the 1932 data they appeared to spread to some extent. The main movement, however, was to the southeast. The largest larvae, from 20 to

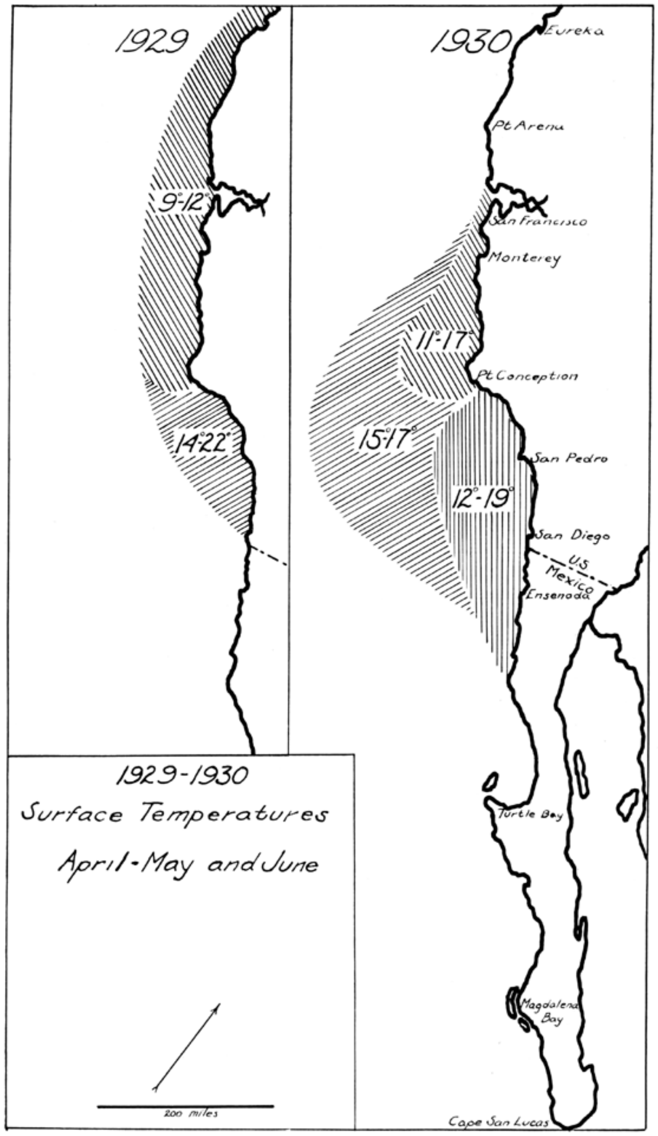


FIG. 10. Surface water temperatures in degrees Centigrade for April, May and June of 1929 and 1930.

FIG. 10. Surface water temperatures in degrees Centigrade for April, May and June of 1929 and 1930

35 mm., occurred in a very narrow strip along the mainland and around the Channel Islands south of Point Conception. This was especially true in 1931. In 1932, though the same distribution was prevalent, there was a slight scattering of these largest larvae. Some were taken well offshore, and others were taken north of Point Conception. The great bulk, however, was taken inshore below Point Conception.

Like the varied distribution of sardine eggs, we can expect a similar varied distribution of the larvae from year to year. We must take this point into consideration when estimating the relative abundance of larvae. With the past two years' study (1931–1932) of the distribution of the larvae, it is firmly believed that sufficient evidence is at hand to establish the region of the maximum number of larvae. This region, as can be observed from figure 9, is restricted to the two adjoining sections just south of Point Conception, and all coastwise sections south as far as Magdalena Bay. A quantitative study of the abundance of larvae in these eight sections each season promises to afford a very clear picture of the success or failure of each year class. In this restricted region should be employed the 10-foot larvae net described elsewhere in this publication. In deep water the net should be towed from the surface down to 25 fathoms, whereas in the shallow flats it should be towed on and just below the surface. The work should be limited to the hours of darkness, because at night these larvae migrate to the upper 5 fathoms of water.

10. FOOD OF THE LARVAE AND ADULT SARDINES

A brief study was made of the food of the various sizes of sardines in order to learn more about their movements. The results offered no clues in this respect as the young were found to feed mostly on small copepods. Copepods occur over the continental shelf and in swarms as deep as 250 fathoms. (Esterly, 1912.) Since the copepod distribution is so general, this animal as a food offered no clues as to the general behavior of the young sardines. One exception may be cited, which is that the larvae were most abundant at night in the surface layers of water, whereas during the day they were spread vertically from the surface down to 25 fathoms. If they follow the copepod swarms, they would be subject to diurnal migrations such as have been shown to occur among the copepods. (Russell, 1925.)

The food studies revealed that the stomachs of sardine larvae were generally empty. of the many larvae examined, only five contained food in their alimentary tracts, and this food was composed entirely of copepods. Among the young fish, ranging from 40 mm. up, there was a predominance of copepods in their stomachs. A few contained sand particles, one had traces of mud, and one had a single large schizopod. Sardines above 100 mm. feed primarily on diatoms, though copepods are at times prevalent. Among the adult sardines of 200 mm. or longer the food is mainly diatoms, and occasionally dinoflagellates or schizopods occur in major numbers. (See table 8.)

The fact that the very small sardines and the very large feed on entirely different foods led to a study of the gill rakers or straining processes by which this fish obtains its food. The results of this work were extremely interesting since it was learned that the straining processes or the gill rakers do not become fully developed until the sardine

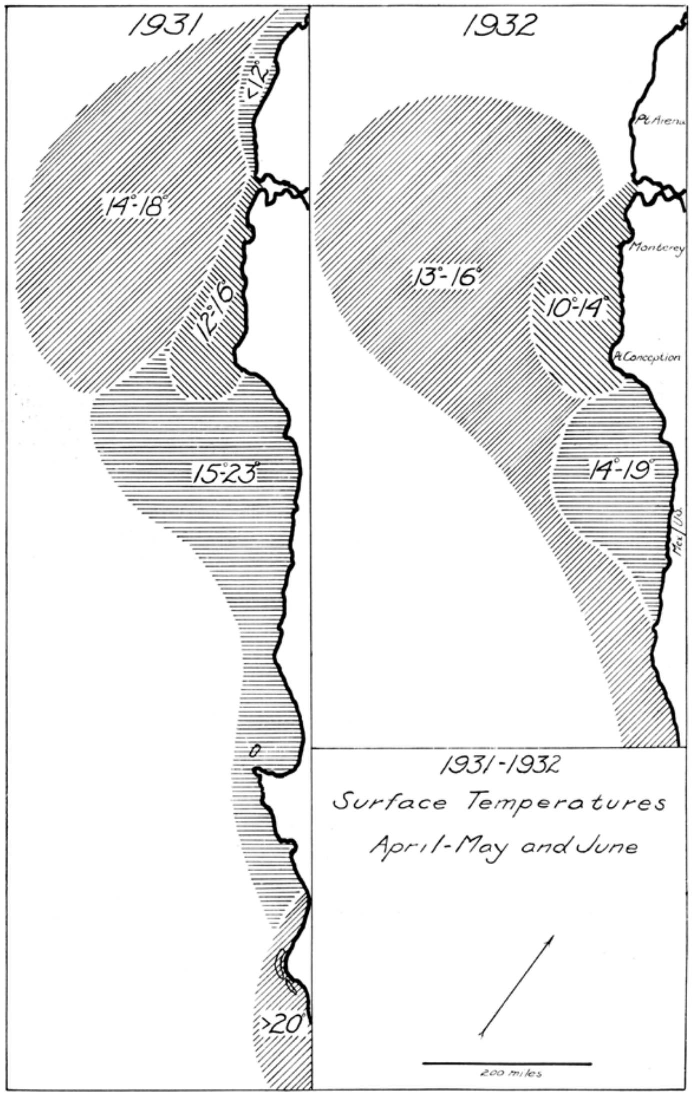


FIG. 11. Surface water temperatures in degrees Centigrade for April, May and June of 1931 and 1932.

FIG. 11. Surface water temperatures in degrees Centigrade for April, May and June of 1931 and 1932

is well over 100 mm. in length. (See Fig. 12.) This implies that diatoms would not be used as food until the sardines are over 100 mm. in length. The undeveloped gill rakers of young forms would undoubtedly cause a selection of larger food, such as copepods.

Gill rakers do not form on the gill arch until the larva is about 20 mm. in length. At this time the rakers are composed of slight, blunt

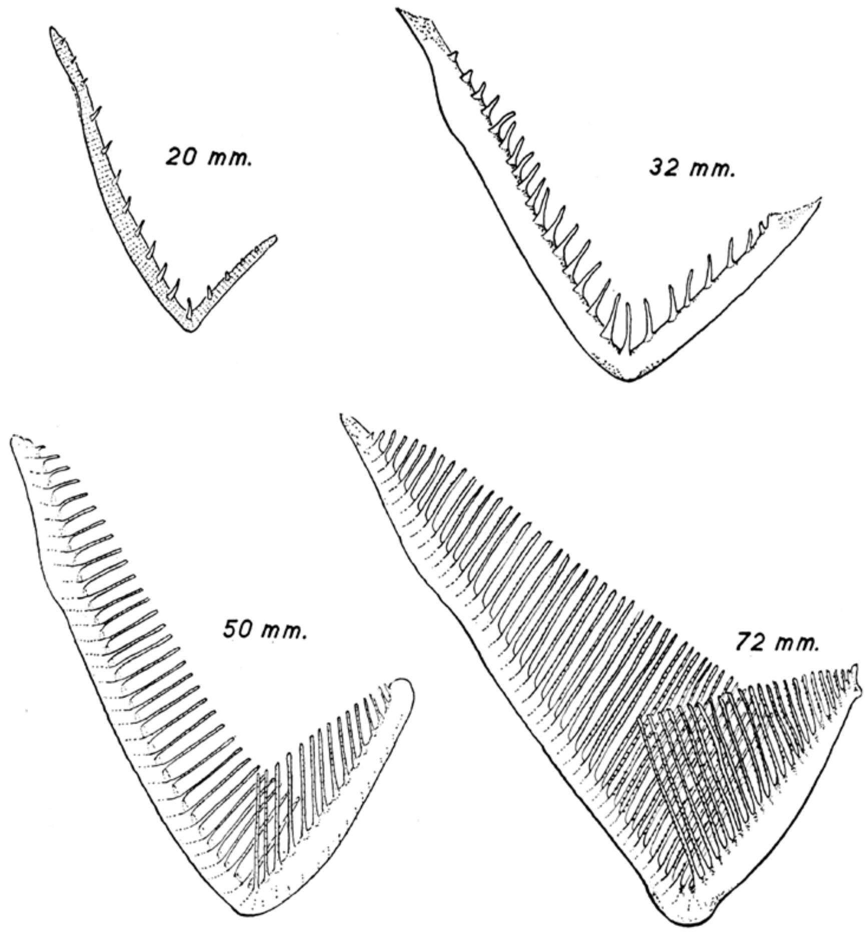


FIG. 12. The development of the gill rakers in the sardine (first arch). From a larva, 20 mm. in length, was removed the gill arch appearing in the upper left. The rakers, 16 in number, are just forming. To the right is the gill arch of a larva, 32 mm. in length. The rakers have increased in number and are more prominent. At the lower left is the gill arch of a very young sardine, 50 mm. in length, and on the right is that of a 72 mm. sardine. The rakers show a steady increase in numbers as well as a marked development. Processes on the rakers do not develop until the fish is about 50 mm. and they are not fully formed until the fish is over 100 mm.

FIG. 12. The development of the gill rakers in the sardine (first arch). From a larva, 20 mm. in length, was removed the gill arch appearing in the upper left. The rakers, 16 in number, are just forming. To the right is the gill arch of a larva, 32 mm. in length. The rakers have increased in number and are more prominent. At the lower left is the gill arch of a very young sardine, 50 mm. in length, and on the right is that of a 72 mm. sardine. The rakers show a steady increase in numbers as well as a marked development. Processes on the rakers do not develop until the fish is about 50 mm. and they are not fully formed until the fish is over 100 mm

projections. (See Fig. 13.) There are about 16 in all. At 30 mm. the rakers have increased in number to 26 and have elongated somewhat. They are still quite smooth and bear no processes. At 50 mm. the rakers number approximately 46, and have lengthened to about two-thirds the normal length of rakers in adult sardines. At this stage

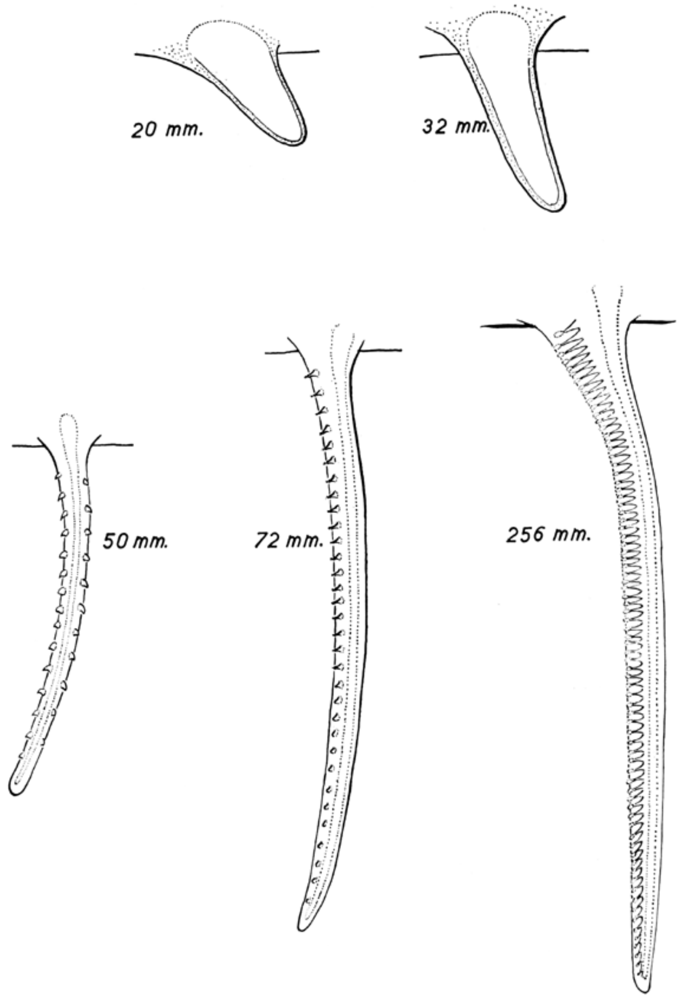


FIG. 13. The development of the gill rakers of the sardine. In the upper left appears one of the first rakers which form on the gill arch of a larva, 20 mm. in length. At the right is a gill raker from the gill arch of a sardine larva, 32 mm. in length. At the lower left appears a raker from a sardine, 50 mm. long, and as can be seen the processes used for feeding are just forming. To the right (center) a sardine, 72 mm. in length, possesses this type of raker. The processes have not only increased in number but have also enlarged. At the extreme right is the gill raker of an adult sardine, 256 mm. in length. The processes are well developed and closely spaced. Each raker bears two rows of processes.

FIG. 13. The development of the gill rakers of the sardine. In the upper left appears one of the first rakers which form on the gill arch of a larva, 20 mm. in length. At the right is a gill raker from the gill arch of a sardine larva, 32 mm. in length. At the lower left appears a raker from a sardine, 50 mm. long, and as can be seen the processes used for feeding are just forming. To the right (center) a sardine, 72 mm. in length, possesses this type of raker. The processes have not only increased in number but have also enlarged. At the extreme right is the gill raker of an adult sardine, 256 mm. in length. The processes are well developed and closely spaced. Each raker bears two rows of processes

the minute processes are first formed in a double row along the sides of the rakers; these processes are blunt nodules and are considered nonfunctional at this time.

At about 70 mm. the sardine possesses 70 rakers, each having approximately 30 processes in each row. These processes, though still rather blunt, have formed spiny nodules at their tips. (See Fig. 14.) The rakers are very elongate and tend to overlap from the two angles of the gill arch. At this stage it would appear that the sardine would be capable of straining such small forms as diatoms from the water. However, the processes on the gill rakers are not fully developed until the sardine is 100 mm. or over. At this length the rakers number about 110, forming a very fine, comb-like structure. The overlap of the rakers from the two angles of the gill arch is still more prominent. The processes have increased in numbers to 70 in each row. Each process bears a fully developed spiny nodule. (See Fig. 14.) The

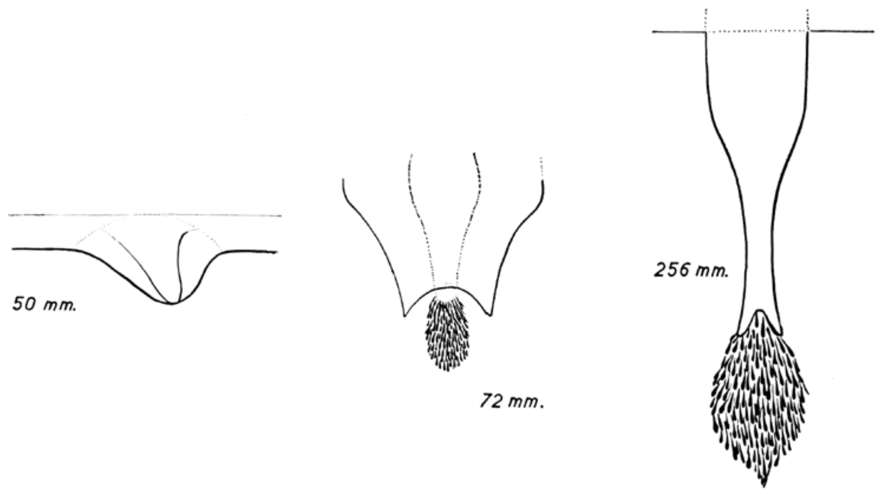


FIG. 14. The development of the processes on the gill rakers of a sardine. These processes do not develop until the sardine is about 50 mm. long. (See illustration at left.) The center figure reveals that a sardine, 72 mm. in length, bears processes on its gill rakers which are much more developed. The spines at the tip have already formed. At the extreme right there appears a gill raker process from an adult sardine, 256 mm. in length. It is with the aid of these spiny nodules that the sardine is capable of straining such fine food as diatoms from the water.

FIG. 14. The development of the processes on the gill rakers of a sardine. These processes do not develop until the sardine is about 50 mm. long. (See illustration at left.) The center figure reveals that a sardine, 72 mm. in length, bears processes on its gill rakers which are much more developed. The spines at the tip have already formed. At the extreme right there appears a gill raker process from an adult sardine, 256 mm. in length. It is with the aid of these spiny nodules that the sardine is capable of straining such fine food as diatoms from the water

entire structure is extremely well developed and very adaptable to the capture of such minute food as diatoms.

For a detailed account of the food of the adult sardine, see Lewis (1929), who made a quantitative analysis of the stomach contents of this species for the region of southern California. He shows a correlation between the prevalent type of food in the water and food contained in the stomachs of sardines taken in the same location.

11. DESCRIPTION OF THE SARDINE EGG AND LARVA

The identity of the sardine egg and larva has been well established. This was accomplished in three ways:

First: A comparison was drawn between the characteristics of ripe eggs taken from market specimens and the fertilized eggs taken

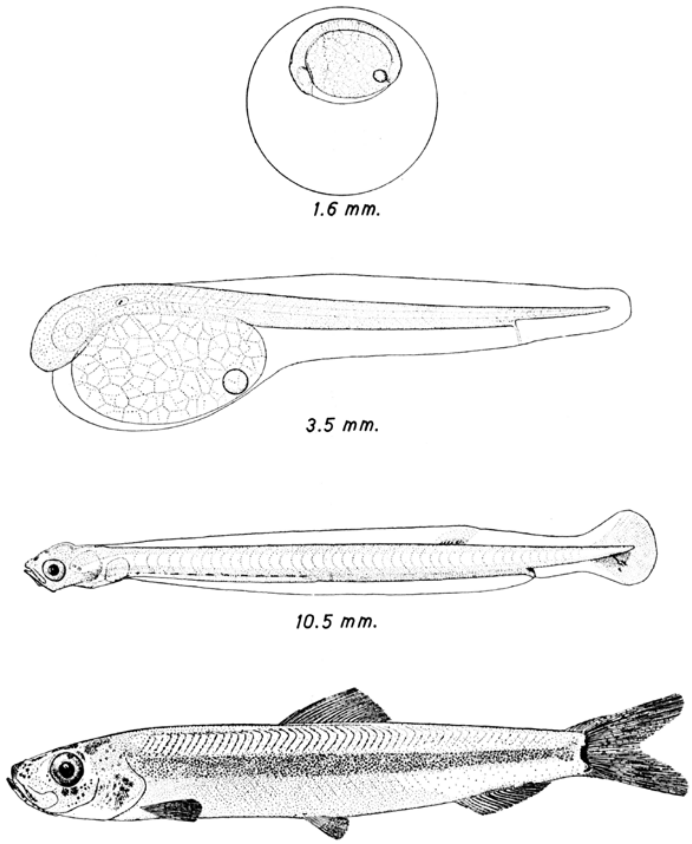


FIG. 15. A growth series of the sardine (*Sardina caerulea*). The egg has three distinct characteristics: a large perivitelline space, a single oil globule, and a yolk which is irregularly segmented. The 3.5 mm. specimen is just hatched, and the 10.5 mm. specimen is perhaps two weeks old. The 34 mm. specimen has completed its metamorphosis and is recognizable as a sardine by the position of its fins and vent, by the number of myotomes which total 33 plus 18, and by the striations on the opercle. Measurements of larvae in standard length. Drawings by Rolf L. Bolin.

FIG. 15. A growth series of the sardine (Sardina caerulea). The egg has three distinct characteristics: a large perivitelline space, a single oil globule, and a yolk which is irregularly segmented. The 3.5 mm. specimen is just hatched, and the 10.5 mm. specimen is perhaps two weeks old. The 34 mm. specimen has completed its metamorphosis and is recognizable as a sardine by the position of its fins and vent, by the number of myotomes which total 33 plus 18, and by the striations on the opercle. Measurements of larvae in standard length. Drawings by Rolf L. Bolin

in the open sea. The unfertilized eggs measured 1.24 mm. in diameter and the oil globule 0.16 mm. in diameter. (Clark, 1934.) The fertilized eggs taken from the open sea measured 1.6 mm. and the oil globule 0.16 mm. The difference in the two egg diameters was due to the fact that the deposited eggs absorbed sea water and swelled to some extent. Another characteristic common to both the unfertilized ripe egg and the fertilized egg was that the yolk sac was divided into many irregularly shaped segments.

Second: A growth series was established from the egg up to a young fish recognizable as a sardine. (See Fig. 15.) It has been impossible to secure ripe sardines of both sexes so that artificial propagation could be attempted. Market fishermen rarely bring in ripe specimens, and thus far no individual attempt has been made to secure spawning sardines. However, fertilized eggs were taken from the sea and allowed to hatch in the laboratory. The larvae were successfully hatched and lived for three days. With the aid of these young larvae it was possible to identify the material taken in the open sea. From this general material, gathered by means of plankton nets, there was arranged a series of stages through the metamorphosis and up to young fish measuring 45 mm. in total length. Many stages of development were drawn and these data demonstrated that each stage maintained certain characteristics by which it could be identified. Chief among these characteristics were: (1) The number of myotomes remained consistently at 48, counting from the edge of the gill cover. Anterior to this point the myotomes were indistinct and were therefore omitted in the count. The myotomes posterior to the vent were also rather indistinct, but a fair approximation could be made; thus these myotomes were included in the count. (2) The last ray of the dorsal fin was always from 5 to 7 myotomes anterior to the vent. The average myotome count to the vent was 40, and the count to the last dorsal fin ray was 34. This count was found to vary somewhat due to the forward shifting of both the vent and dorsal fin with the growth of the fish. In the adult sardine the myotome count to the last dorsal fin ray was 20 and to the vent it was 33, whereas the total count from the gill cover to the hypural was 48, which corresponded to that of the larva. The position of the dorsal fin in relation to the vent proved to be a valuable characteristic by which the sardine could be readily distinguished from other closely related forms, such as the anchovy and herring. (3) Typical pigment spots were consistent in their location and appearance in all stages of larvae. The more prominent pigments appeared along the ventral surface of the larvae, directly behind the vent, on the ventral side of the caudal peduncle and on a few of the lower rays of the caudal fin. (4) The young fish were recognizable as sardines because of the striations on the opercle and by the sardine-like scales. (See Fig. 15.)

Third: There is a very close resemblance in the egg and larva of the European species of sardine (Sardina pilchardus) to our own species (Sardina caerulea). In both species the measurements and general characteristics are quite similar. As Cunningham (1891) points out, the European pilchard egg is the only one of its kind which combines the three characteristics of a single oil globule, an

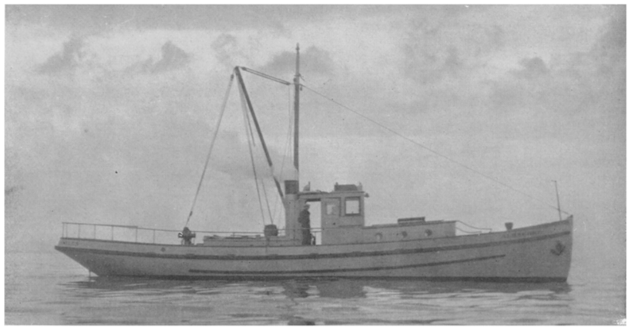


FIG. 16. The *Albacore*, a 56-foot diesel driven vessel, which has had fifteen years service in commercial fisheries law enforcement and scientific research. She is now (1931) stationed at Monterey Bay, where she is used regularly by the members of the Hydrobiological Survey. Photograph courtesy of *Pacific Fisherman*.

FIG. 16. The Albacore, a 56-foot diesel driven vessel, which has had fifteen years service in commercial fisheries law enforcement and scientific research. She is now (1931) stationed at Monterey Bay, where she is used regularly by the members of the Hydrobiological Survey. Photograph courtesy of Pacific Fisherman

irregularly segmented yolk and a perivitelline space. Similarly, the California sardine egg possesses these three features.

The following is a complete description of the sardine egg and larva:

1. **The egg averages 1.60 mm. in diameter.[*]**
2. **The yolk is comparatively small and is irregularly segmented.**
3. **The oil globule averages 0.163 mm. in diameter.[*]**
4. **The newly hatched larva is about 3.5 mm. in length.**
5. **The yolk sac is carried for perhaps four to seven days before being absorbed.**
6. **As the larva grows, it develops characteristic pigment spots behind the vent and on the lower rays of the caudal fin. Pigments are also prominent along the entire ventral surface.**
7. **The average number of myotomes from the edge of the gill cover to the last dorsal fin ray is 34 in the larva. As the fish grows the dorsal fin shifts forward until as an adult the number of myotomes from the gill cover to the last dorsal ray decreases to only 20.**
8. **The average number of myotomes from the edge of the gill cover to the vent is 40 in the larva. As the fish grows the vent shifts forward until as an adult the myotome count is 33 from the gill cover to the vent.**
9. **The total number of myotomes from the edge of the gill cover to the hypural is 48. This count remains the same for the larva as well as the adult.**
10. **The larva passes into the young fish stage at about 35.0 mm., body length.**

12. METHODS

12.1. Boats Used

The boat *Albacore* (see Fig. 16) was used in this investigation during the summer of 1929, the early spring of 1930, and occasionally during 1931 and 1932 while stationed at Monterey Bay. (Terry, 1931.) This boat is the property of the Division of Fish and Game of the State of California and is used in the patrol and law enforcement work of the commercial fisheries. It is 60 feet in length and has a 12-foot 6-inch beam. It is driven by a semidiesel engine, and has a cruising speed of 8.5 knots and a cruising radius of about 2200 miles. It can accommodate three people in addition to the regular crew, which includes captain, engineer and cook.

Until May, 1931, Captain Walter Engelke was in charge of the *Albacore* but on his transfer to the new *Bluefin*, Lars J. Weseth was selected as captain. In July, 1930, Captain Weseth piloted the *Albacore* from San Pedro, where she had been stationed since 1917, to Monterey, her new headquarters. Here she has been used regularly by the staff of the Hydrobiological Survey in the study of special problems and occasionally in making stations in conjunction with the sardine investigation.

The launch *Steelhead* is also stationed at Monterey, and at times when the *Albacore* was on patrol duty this boat was used by the

[*] Scofield and Lindner (1930) give the diameter of the sardine egg as 1.89 mm. and the diameter of the oil globule as 0.15 mm. A greater number of measurements recently completed corrects this error.

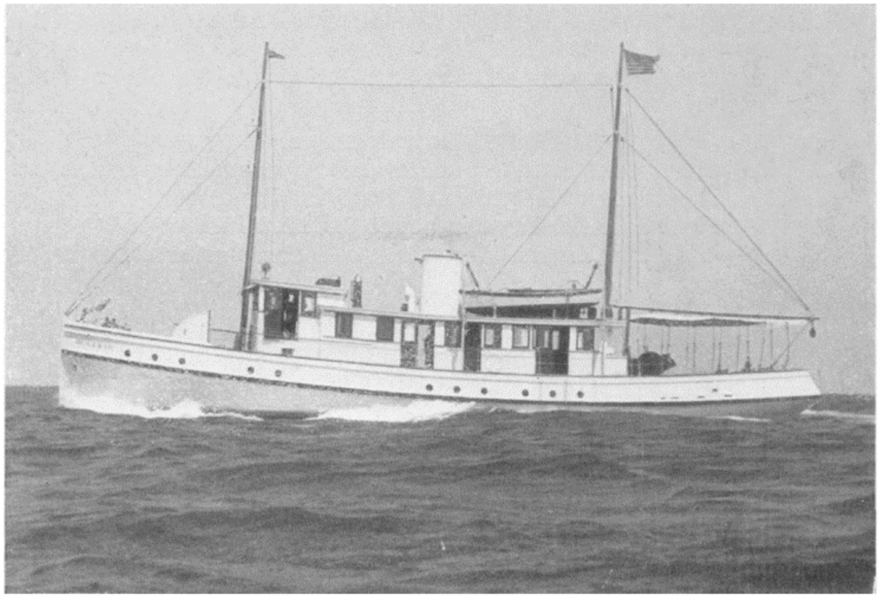


FIG. 17. The Bluefin, an 86-foot diesel driven vessel, has seen three years' service in patrol and scientific research. She was designed to fulfill two purposes, that of commercial fisheries patrol and that of oceanographic research. Her large size makes possible the extended trips which have become necessary in the course of the sardine investigation. Photograph by Donald H. Fry, Jr., 1931

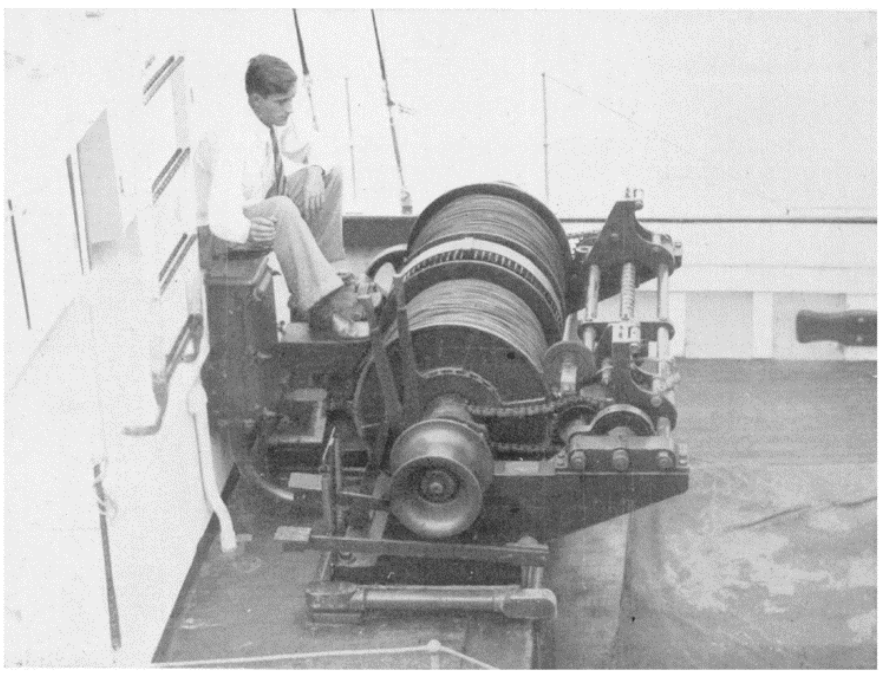


FIG. 18. The electric towing winch aboard the Bluefin carries 14,600 feet of 5/16-inch plow steel cable on its two drums. The drums are operated separately, and each is equipped with a meter wheel of special design. Photograph by Donald H. Fry, Jr., 1931

members of the survey to gather material and hydrographic data. On two occasions the *Steelhead* was used in gathering material in Monterey Bay for the author.

The motor vessel *Bluefin* (see Fig. 17) has made possible the collection of the greater portion of the material in the sardine investigation. This vessel was constructed for the Bureau of Commercial Fisheries to keep pace with the rapid development of the fisheries in the waters of southern California. It was completed in May, 1930, and stationed at San Pedro to replace the *Albacore*, which, as already noted, was later transferred to Monterey.

The *Bluefin* is 86 feet in length and is driven by a 200-horsepower diesel engine. She has a speed of 10 knots and a cruising radius of 6000 miles. She carries a crew of five and has accommodations for four guests. The vessel is equipped with an electrically driven towing winch which carries 14,600 feet of 5/16-inch plow steel cable on its two drums. (See Fig. 18.)

The *Bluefin* was used in the sardine investigation during the late summer of 1930 and the entire spring and summer of both 1931 and

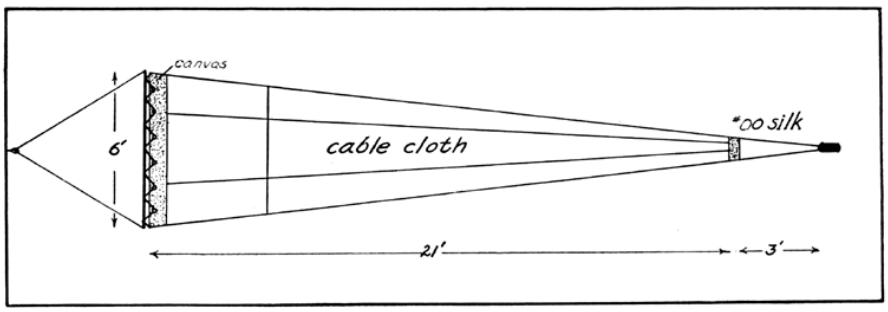


FIG. 19. A diagrammatic sketch of the plankton net used in the collection of sardine eggs and larvae. This type of net has met with complete success. (For construction, see figure 22.)

FIG. 19. A diagrammatic sketch of the plankton net used in the collection of sardine eggs and larvae. This type of net has met with complete success. (For construction, see figure 22.)

1932. She will undoubtedly be the mainstay in the future work of this investigation. Her large size makes it possible to run stations several hundred miles at sea.

12.2. Gear Used

The first net used for the capture of sardine eggs and larvae was of special construction. It was cone-shaped, 5 feet in diameter at the mouth and 18 feet long. Fifteen feet of the net was made of marquisette cloth, having an open mesh of approximately 1 mm. At the tip of the net was attached a 3-foot cone of number 0 silk bolting cloth. In the tip of the silk was inserted a large-mouthed jar which collected all plankton coarse enough to be retained in the net. The mouth of the net was buttoned to a ¾-inch pipe hoop from which led 3 ropes to a single thimble. The towing wire was attached to this thimble. This net was used successfully until washed overboard in May, 1929.

During the remainder of May and all of June a Bigelow net was used which was 1 meter in diameter and 12 feet long. During the spring of 1930 another 5-foot diameter net was constructed, but that

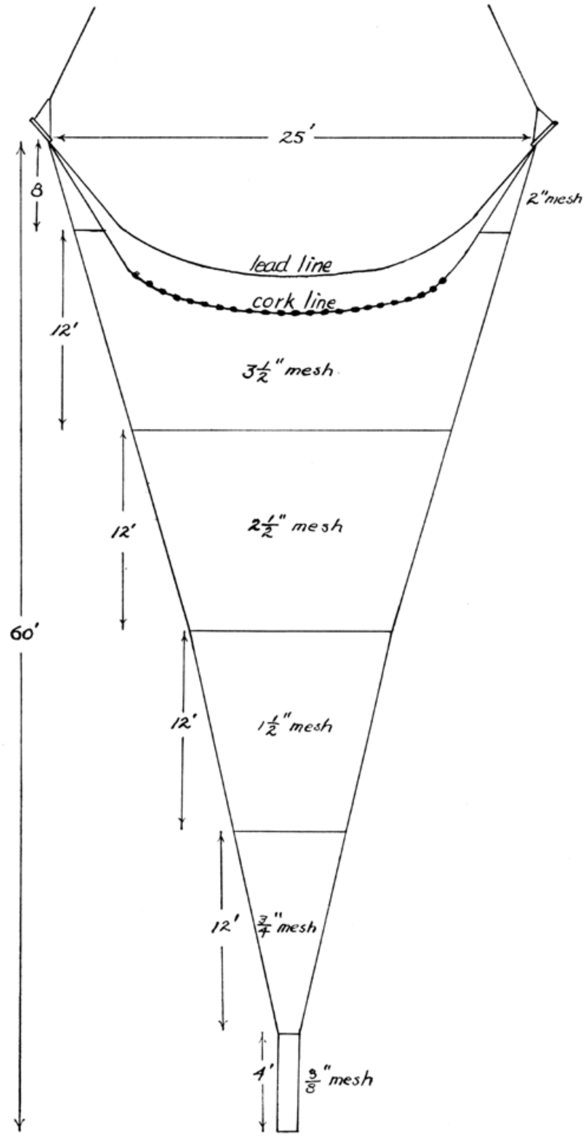


FIG. 20. Construction of the young fish trawl.

FIG. 20. Construction of the young fish trawl

also was lost while towing in a heavy sea. From May to August, 1930, two 4-foot diameter nets were used alternately. These nets functioned very nicely, though they did not collect as much material as the large-mouthed nets.

During 1931 a new plankton net was devised that strained more water in less time, yet was not bulky or awkward to handle. This net was 6 feet in diameter at the mouth and 24 feet in length. (See Fig. 19.) To make it strong and durable, it was built of cable cloth (a heavy, interwoven curtain cloth) of 1 mm. open mesh. Heavy canvas was sewed securely to the open mouth and then grommets inserted through which the net could be lashed to a 1-inch galvanized pipe hoop. To add extra strength to this net, the 5 lengthwise seams were covered by a 1-inch canvas tape, and a similar tape was sewed around the belly about 5 feet from the mouth. The 3-foot tip of the net was built of number 00 silk bolting cloth. Into this silk, which was tipped with light canvas, was inserted a large-mouthed jar.

Five nets of this type were constructed during 1931. Unfortunately, two were lost at sea in February due to the heavy seas and to the method of towing. Later by alteration of the towing methods, the nets were subjected to less strain; therefore the three remaining nets were used successfully during the remainder of 1931 and all of 1932.

During 1930 a very large hoop net was constructed in order to secure sardine larvae as well as the very young sardines. This net was 10 feet in diameter at the mouth and 46 feet in length. A 12-foot section next to the hoop was made of 1-inch mesh webbing, and the middle section of 16 feet was made of ½-inch mesh. The 18-foot section on the end was made of durable interwoven cloth having an open mesh of 2 mm. This net proved to be very successful since it could be towed through the water at a fair rate of speed. It has, therefore, been very efficient in capturing larvae in considerable numbers.

In order to check the efficiency of this large hoop net, a small young fish trawl was constructed in 1930 with which it was hoped a comparison could be made. This comparison never materialized since the young fish trawl was totally inefficient. Its inefficiency was due primarily to the construction. Rather than take the time to remodel the trawl, it was decided to resort to the large hoop net for gathering sardine larvae.

This decision was reached after it was evidenced how awkward it was to handle otter boards of considerable weight on a boat which was not designed for that purpose. On the other hand, the hoop net was extremely easy to handle from the boat and could be towed at any speed with the assurance that the mouth would always remain open. As the sardine larvae occur in the upper 25 fathoms of water, it was not necessary to fish the bottom as the young fish trawl would be capable of doing. The hoop net therefore answered every purpose, even so far as straining as much or more water than the trawl.

The original young fish trawl consisted of two weighted otter boards, 5 feet in height and 1 foot wide, to which the wings of the trawl were attached. The spread of the boards when in operation was about 25 feet, and the bag was extended back nearly 55 feet. (See

Fig. 20.) The wings were of 2-inch mesh. The first 12-foot section was of 3½-inch mesh, the middle section was of 2½-inch mesh, the next 12-foot section was of 1½-inch mesh, the last section was of 1-inch mesh, and a short 5-foot tip was of #-inch mesh. The mouth of the trawl was held open by leads on the bottom rope and corks on the top rope.

While towing this trawl at a moderate rate of speed, the boards would spread to such an extent that the mouth would close. Though the angle of the boards was altered continuously, this fault could not be remedied. Rope wings, 60 feet in length, were finally added between the boards and the trawl proper; yet the net functioned improperly with this arrangement. The otter boards had free play and because of their small surface resistance they dove in such a way as to wind up the wings. Rather than experiment further with this gear it was decided to abandon the attempt of comparing the efficiency of the trawl and the hoop net and to resort to the latter type of gear.

A great deal of larval material was gathered at night while the boat was at anchor in harbors and coves. A reflector light was always placed over the side of the ship just above the water level. A great amount of general planktonic life was attracted by the light, and as a result wide varieties of forms were gathered with the aid of a dip net. It was upon these occasions that it was possible to observe the swimming abilities of small larvae. It was surprising to see the activity of the larger anchovy, herring and sardine larvae. They were exceptionally quick in their movements and more than once I saw them dart away from the gaping jaws of smelt and mackerel.

The young sardines or post-metamorphosed sizes were secured at times with the aid of a small beach seine on the gravel and mud beaches of the numerous islands common to the waters of southern California. This net was 28 feet long, 6 feet deep, and all its meshes were ½-inch. It was a straight wall type of net having no bag. This gear operated very effectively and took many of the desired forms.

12.3. Operation of Gear

of primary importance was the method of operation of the plankton nets. During 1929 and 1930, these nets were operated at random and at various levels. This was done because the sardine investigation in its first stages was purely experimental. At the outset of the work the locality of the spawning was not known. After this region was discovered, the levels of abundance of the spawn or larvae still remained unknown. Therefore, the nets were tentatively lowered to different depths, generally to 25 fathoms, and at night they were towed at the surface where the larvae were found to occur in greater abundance.

In 1931, the general region of spawning having been ascertained to a large extent, the stage had been reached when the hauls had to be made quantitative and comparable. In quantitative studies of this nature the most commonly applied technique is the one of vertical hauls. Such hauls strain a vertical column of water for any given depth. Nets used for this purpose can be opened or closed at will, thereby making all the material comparable. Vertical hauls were therefore given a thorough test as a means of securing quantitative numbers of sardine eggs and larvae. However, the specimens gathered by this method were too few in numbers to warrant any comparison of a series of such hauls. Most of the hauls took no eggs or larvae, and the most eggs or larvae in any haul were 10.

The next best method known was then attempted. This consisted of horizontal hauls at regularly spaced depths over a certain distance and at a certain speed. The net used in this work could be lowered to the desired depth before allowing it to strain any water. Once the boat was underway, the cable would be let out to maintain the net at the desired level. The amount of cable paid out to reach this certain depth or level depended upon the speed of the vessel and the amount of weight attached to the net. In the case of the *Bluefin*, while maintaining an average speed of 2 knots and with a 50-pound weight on the net, the ratio of the amount of cable out to the depth of the net was approximately 5 to 1. This condition was true for all depths down to 50 fathoms. Sounding tubes attached to the nets, which recorded the greatest depth attained, demonstrated this fact. At the conclusion of a haul the boat would stop, and as the net settled slack cable would be taken in. When the cable was nearly vertical a messenger would be released on the wire, the net would automatically close and the material would then be raised to the deck of the ship.

These horizontal hauls were by no means as accurate in securing quantitative material as were the vertical hauls, because there was always doubt as to the exact depth at which the net was fishing. However, due to the great amount of material gathered, any small error in the method would have been obscured. The vertical hauls, for instance, took 10 eggs or larvae per haul at the most, whereas the horizontal hauls of 15-minute duration took as many as 10,000 eggs. This example is sufficient to illustrate the advantages of horizontal hauls over vertical hauls in a quantitative measure of the abundance of sardine eggs and larvae in the ocean.

As a result of the vertical and horizontal hauls, it was learned that the sardine eggs and larvae occur in the upper 25 fathoms of water. The average level of eggs was about 15 fathoms. Larvae, however, varied in their levels of abundance, depending upon the stage of light. During the light of the day they were below the surface while at night they were all in the upper 5 fathoms. Because of this condition, it was necessary to do away with the quantitative horizontal hauls and inaugurate a stepladder haul. This type of haul fished each 5-fathom level from the surface down to 25 fathoms. At the point where the haul was to begin, the boat was set at a certain speed with or against the wind, depending upon the roughness of the sea. The net was cast overboard, then towed on the surface for two minutes, then lowered to the 5-fathom level for two more minutes, and so on until each 5-fathom level had been fished down to 25 fathoms. The net was then brought directly up without closing.

This method of towing would have functioned save for the great strain placed on the nets while being towed at different levels. After two nets had been lost due to excessive roughness, it was decided to lower the net continuously as the boat moved ahead. This did away with the sudden strain placed on the net as the result of the ship riding over large swells. To make a tow by this method, the boat was put ahead at about 108 revolutions per minute, or an approximate speed of two knots. The net was then cast. (See Fig. 21.) The cable was paid out at the rate of 18 meters per minute, thus allowing the net to pass through the water at a rate of little more than a mile per hour. At the end of 14 minutes, when 250 meters were out, the boat would be stopped and the net pulled directly in. This act of pulling in took 6 minutes, so the total duration of each haul was 20 minutes.

This latter method, which is a variation of the stepladder haul, has proved very successful and was used during most of 1931 and all of 1932. All hauls were maintained with considerable regularity, thus they are all very comparable. Though this type of haul is not the most accurate, it is quite probable that it is subject to no more than the minimum error which confronts work of this kind. For example, the roughness of the sea and the velocity of the wind might easily add to or lower the amount of plankton gathered. In view of these hazards under which this type of material is gathered, it must be understood

FIG. 21. The plankton net is being lowered away. As the vessel moves ahead at a set speed, the net is paid out at the rate of about 18 meters per minute so that at the completion of 14 minutes, 250 meters of wire are out. The boat is then stopped, and six minutes are required to haul the net aboard ; thus a quantitative haul of 20 minutes' duration is completed. Photograph by Donald H. Fry, Jr., 1931.

FIG. 21. The plankton net is being lowered away. As the vessel moves ahead at a set speed, the net is paid out at the rate of about 18 meters per minute so that at the completion of 14 minutes, 250 meters of wire are out. The boat is then stopped, and six minutes are required to haul the net aboard; thus a quantitative haul of 20 minutes' duration is completed. Photograph by Donald H. Fry, Jr., 1931

that the results must also be of a rough nature, especially if the field work is limited to a short period of time. However, where the field work covers a period of years, these errors tend to compensate and diminish with the accumulation of additional material.

Another error, though easily corrected, is due to the fact that new nets collect more plankton than do used nets. Older nets have frayed thread and many of the meshes are closed from dried plankton organisms. As a result, these nets strain much less water than new nets. For this reason, all new nets were used at least once before being subjected to quantitative hauls.

In order to make quantitative hauls it was essential that all the nets be of similar design. Each net was constructed from a certain pattern which called for certain materials and accurate dimensions. (See Fig. 22.)

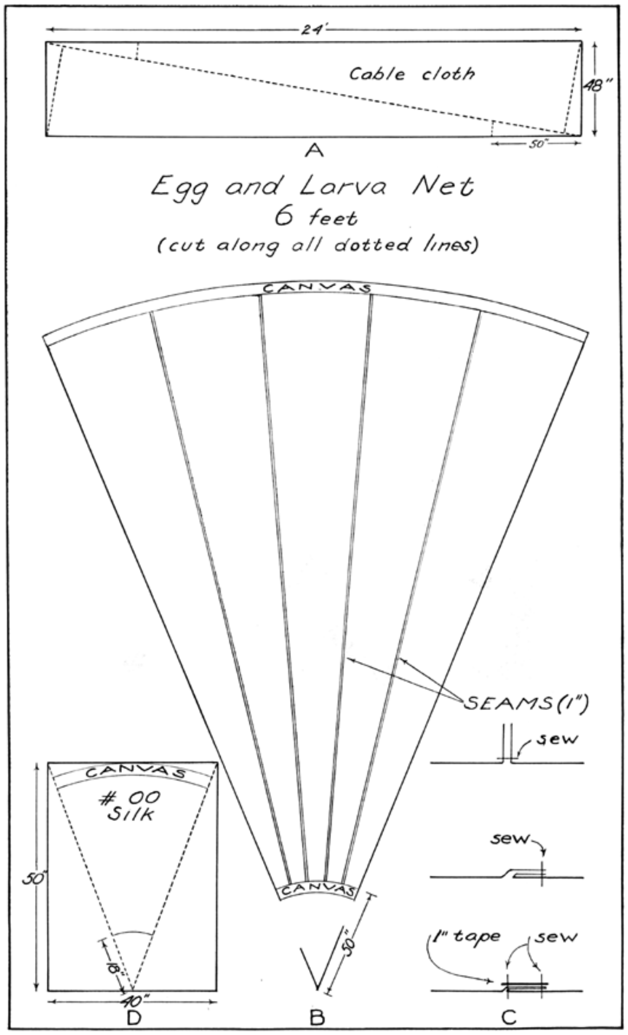


FIG. 22. Each plankton net is constructed from a set design, as illustrated above. The style of cable cloth selected was the Echo Bridge Brand Draperies, style 86. Three 24-foot lengths are cut diagonally and the ends trimmed, as shown in *A* above. Next, five strips are joined together, as illustrated in *B* and *C*. Heavy canvas, 16 inches wide, is doubled over the tip and sewed firmly to the cable cloth. Grommets are then attached. A 1-inch tape is sewed around the belly to add extra strength. A 50-inch tip is then cut away to be replaced by silk. The silk tip is constructed as in *D*. Lighter canvas is used here, preferably 8-ounce. An 18-inch tip of the silk is then cut away to make way for 8-ounce canvas, into which the bottle is inserted. After all this has been done, the two free ends of the net are joined together by merely lapping. It is not necessary to fold the seam over to sew nor is it necessary to add tape.

FIG. 22. Each plankton net is constructed from a set design, as illustrated above. The style of cable cloth selected was the Echo Bridge Brand Draperies, style 86. Three 24-foot lengths are cut diagonally and the ends trimmed, as shown in A above. Next, five strips are joined together, as illustrated in B and C. Heavy canvas, 16 inches wide, is doubled over the tip and sewed firmly to the cable cloth. Grommets are then attached. A 1-inch tape is sewed around the belly to add extra strength. A 50-inch tip is then cut away to be replaced by silk. The silk tip is constructed as in D. Lighter canvas is used here, preferably 8-ounce. An 18-inch tip of the silk is then cut away to make way for 8-ounce canvas, into which the bottle is inserted. After all this has been done, the two free ends of the net are joined together by merely lapping. It is not necessary to fold the seam over to sew nor is it necessary to add tape

12.4. Handling of the Plankton

When the net was brought to the surface after the completion of a tow, the lower end was allowed to remain in the water. Here it was given a good swashing to force the clinging material into the silk tip. Then the net was hoisted aboard and the bottle and silk placed in a bucket of water. (See Fig. 23.) Considerable care was taken to wash everything into the jar, which was then detached and taken directly to the laboratory aboard the ship. Here about 5 per cent formaldehyde was added and a label inserted giving the station number. Once the bottle was stowed away we would return to wash out the net and make it ready for the next haul. At the end of a station line, each net

FIG. 23. Before the net is hauled to the deck, it is given a good swashing to drive the clinging material into the silk tip. It is then hauled aboard and the silk bag inserted in a pail of water, where the entire contents are washed into the glass jar inserted at the tip. Photograph by Donald H. Fry, Jr., 1931

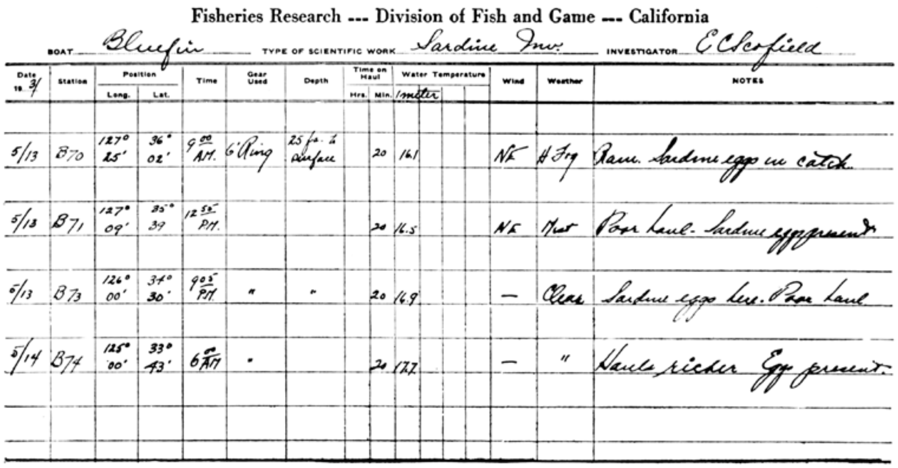
was soaked in fresh water and allowed to dry in the sun for several hours.

In the laboratory ashore (California State Fisheries Laboratory, Terminal Island) the collection was searched for sardine eggs and larvae. This was a very tedious operation and took several hours to a single quart of plankton. The eggs, if not in too great numbers, were counted one by one, then placed in small vials for future reference. At times a single haul contained several thousand eggs, in which case the catch was divided into six equal parts and only one-sixth counted.

The number of larvae, however, rarely exceeded 2000 per haul, so as a rule the entire catch was examined for them. On the average, the hauls took close to 1000 eggs and 200 larvae, and the maximum ever taken was 51,000 and 2200, respectively.

The most difficult task in working over the gathered material was to look through a catch especially rich in plankton for perhaps a dozen or less eggs or larvae. These hauls always proved valuable because they revealed that sardine spawn did occur in certain sections, though in small numbers. In the early stages of this investigation it was as essential to establish the presence of only a small amount of spawn in a region as it was to establish the region where maximum spawning occurred.

Sardine larvae were removed from each catch and preserved in vials according to length. Using their total length as a measure, the larvae were classed in three categories—small, medium and large. The small included sizes up to 10 mm., medium included sizes between 11



Fisheries Research --- Division of Fish and Game --- California

BOAT Bluefin TYPE OF SCIENTIFIC WORK Sardine Inv. INVESTIGATOR E C Scofield

Date 19 31	Station	Position Long.	Position Lat.	Time	Gear Used	Depth	Time on Haul Hrs.	Time on Haul Min.	Water Temperature 1 meter	Wind	Weather	NOTES
5/13	B70	127° 25′	36° 02′	9 00 AM.	6′ Ring	25 fa. to surface		20	16.1	NE	H Fog	Rain. Sardine eggs in catch.
5/13	B71	127° 09′	35° 39	12 55 PM.				20	16.5	NE	Haze	Poor haul. Sardine eggs present.
5/13	B73	126° 00′	34° 30′	9 05 PM.	"	"		20	16.9	—	Clear	Sardine eggs less. Poor haul
5/14	B74	125° 00′	33° 43′	6 00 AM	"			20	17.7	—	"	Hauls richer Eggs present.

FIG. 24. A page from the *Bluefin's* log book.

FIG. 24. A page from the Bluefin's log book

and 20 mm., and large larvae included sizes from 21 mm. to 35 mm. or the length at which they metamorphose into the young sardine. By arranging the material in this manner, it has been possible to learn a great deal about their drift and general behavior as they grow into the metamorphosed forms, also something as to their mortality rate.

During these four years of collecting, a great deal of plankton was gathered. After the sardine eggs and larvae, as well as other young fish forms were removed, the entire collection was turned over to the Hopkins Marine Station at Pacific Grove. Here the material was sorted and given to several students who were working on various marine biological problems. This material, therefore, has proved of some value in serving these research workers.

12.5. Records

While in the field there were three types of records made of the general observations. First, a log was kept, giving the name of the boat, type of scientific work, date, station number, position at sea, time of haul, gear used, depth fished, duration of haul, water temperatures, wind, weather and general notes. (See Fig. 24.) This log was kept in duplicate, one copy of which was filed in a safety deposit vault. Second, a personal notebook was kept of records of hauls, type of weather and general conditions under which a haul was made or a line run. Third, a ship's log was kept by the captain of the vessel and may be consulted at any time.

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TABLE 1

Number of Sardine Eggs and Larvae per Haul—1931

Haul	No. of eggs	No. of larvae	Haul	No. of eggs	No. of larvae	Haul	No. of eggs	No. of larvae
B3	14	1	B46	0	459	B89	0	0
B4	1,496	2	B47	0	517	B90	0	0
B5	0	0	B48	4	10	B91	0	78
B6	1,366	0	B49	0	193	B92	0	0
B7	0	0	B50	1	471	B93	0	0
B8	0	0	B51	0	5	B94	0	0
B9	0	0	B52	1,073	29	B95	0	48
B10	0	1	B53	0	30	B96	0	0
B11	0	0	B54	0	0	B97	0	0
B12	0	0	B55	0	0	B98	0	0
B13	4	4	B56	5	0	B99	0	0
B14	0	2	B57	0	0	B100	105	0
B15	102	10	B58	0	0	B101	0	0
B16	34	1	B59	0	0	B102	0	0
B17	0	10	B60	18	0	B103	0	0
B18	3,000	0	B61	0	0	B104	0	0
B19	69	176	B62	0	0	B105	0	0
B20	270	81	B63	0	0	B106	0	0
B21	4	0	B64	0	0	B107	0	0
B22	698	2	B65	0	0	B108	0	0
B23	42	31	B66	0	0	B109	0	0
B24	11	12	B67	0	0	B110	0	0
B25	562	699	B68	0	0	B111	0	0
B26	234	16	B69	457	0	B112	1,076	37
B27	73	2,212	B70	573	0	B113	96	31
B28	8,761	1	B71	281	0	B114	0	30
B29	752	1,373	B72	0	0	B115	0	0
B30	193	23	B73	---	---	B116	167	0
B31	0	96	B74	39	0	B117	6	0
B32	4,043	878	B75	380	0	B118	0	0
B33	145	121	B76	249	0	B119	0	0
B34	0	0	B77	115	0	B120	0	0
B35	0	0	B78	0	30	B121	---	---
B36	0	0	B79	5,949	0	B122	---	---
B37	0	0	B80	51,342	0	B123	0	0
B38	0	0	B81	4,617	27			
B39	0	0	B82	0	302	A124	322	0
B40	0	0	B83	0	4	A125	0	0
B41	0	0	B84	20	21	A126	0	0
B42	0	0	B85	661	246			
B43	2	5	B86	1,233	94			
B44	0	32	B87	109	174			
B45	0	120	B88	0	18			

TABLE 1

Number of Sardine Eggs and Larvae per Haul—1931

TABLE 2

Number of Sardine Eggs and Larvae per Haul—1932

Haul	No. of eggs	No. of larvae	Haul	No. of eggs	No. of larvae	Haul	No. of eggs	No. of larvae
B124	0	0	B150	0	0	B175	624	78
B125	5	6	B151	0	0	B176	---	17
B126	224	30	B152	0	0	B177	(lost)	
B127	0	0	B153	0	0	B178	---	6
B128	0	0	B154	0	0	B179	---	561
B129	0	0	B155	0	0	B180	---	380
B130	0	16	B156	0	0	B181	---	396
B131	0	15	B157	1	11	B182	(lost)	
B132	0	0	B158	0	0	B183	---	25
B133	1,512	308	B159	0	0	B184	---	3
B134	0	16	B160	0	17	B185	---	12
B135	0	4	B161	0	32	B186	---	160
B136	0	0	B162	24	12	B187	---	141
B137	140	0	B163	0	342	B188	---	14
B138	(lost)		B164	8,556	64	B189	---	6
B139	0	18	B165	1,576	0	B190	---	0
B140	4,592	85	B166	0	0	B191	---	10
B141	1,435	63	B167	0	0	B192	---	11
B142	1,784	64	B168	(lost)		B193	---	1
B143	4,432	80	B169	0	0	B194	---	0
B144	352	32	B170	0	0	B195	---	0
B145	5,360	144	B171	0	0	B196	---	1
B146	32,660	0	B172	0	0			
B147	6,000	0	B173	1,608	48	A127	0	0
B148	0	0	B174	0	0	A128	0	0
B149	0	0						

TABLE 2

Number of Sardine Eggs and Larvae per Haul—1932

TABLE 3

Number of Hauls by Sections—Bluefin Series, 1931-1932

Section No.*	Haul numbers: 1931									Haul numbers: 1932						
7	39	40														
8	62	63														
10	60	61								170						
11	57	58	59	A124	A125	A126				168	169	A127	A128			
12	21	55	56							167						
13	3	4	5	19	20	51	52	53	54	144	145	165	166	188	189	190
	80	81	82	83	84	110	111	112	113	191						
	114	123														
14	18	28	29	49	50	96	97	98	99	140	141	142	143	164	176	178
	100	108	109	115	116	117	118			179	183	184	185	186	180	181
										187						
15	14	15	16	17	30	31	32	46	47	124	125	163	192	196		
	48	92	93	94	95	101	106	107								
16	44	45	102	103	104	105				126	162	193	194			
17	33	43								130	139					
18	34									131	132	195				
19	42									133	134					
20	35									135	137					
21	36	41								136						
22	37	38														
23	64	65	66													
24																
25										171						
26	24									172						
27	7	22	23	26	78	86				148	173	174				
28	6	27	79	85						146	147	175				
29	12	13	90	91												
30										160						
31										127	161					
32										128	129					
38	67															
39	68															
41	74									150						
42	8	25	75	76	77	87				149						
43	9	10	88													
44	11	89								159						
54	69															
55	70	71	72							152						
56	73									151						
58										157						
59										158						
65										153						
66										154						
67										155						
68										156						

A: *Albacore* series.
*For location of section numbers, see figure 6.

TABLE 3
Number of Hauls by Sections—Bluefin Series, 1931–1932

TABLE 4

Sardine Eggs—Productivity of the Various Sections, 1931

Section number*	Number of hauls	Number of positive hauls	Number of negative hauls	Per cent positive hauls	Total eggs	Average number of eggs	Per cent positive hauls × average number of eggs	Per cent
10	2	1	1	50	9	4	200	.04
11	6	1	5	17	322	54	918	.18
12	3	2	1	66	9	3	198	.04
13	19	9	10	47	60,053	3,161	148,567	28.88
14	16	7	9	44	12,792	799	35,156	6.83
15	17	5	12	29	4,376	257	7,453	1.45
17	2	2	0	100	147	73	7,300	1.42
26	1	1	0	100	11	11	1,100	.21
27	6	4	2	66	2,207	368	24,288	4.72
28	4	4	0	100	8,049	2,012	201,200	39.11
29	4	1	3	25	4	1	25	.005
41	1	1	0	100	39	39	3,900	.76
42	6	5	1	83	1,415	236	19,588	3.81
54	1	1	0	100	457	457	45,700	8.88
55	3	2	1	66	854	285	18,810	3.66

*For location of section numbers, see figure 6.

TABLE 4
Sardine Eggs—Productivity of the Various Sections, 1931

TABLE 5

Sardine Eggs—Productivity of the Various Sections, 1932

Section number*	Number of hauls	Number of positive hauls	Number of negative hauls	Per cent positive hauls	Total eggs	Average number of eggs	Per cent positive hauls × average number of eggs	Per cent
13	4	3	1	75	7,288	1,822	136,650	7.57
14	6	5	1	83	20,799	3,466	287,678	15.93
15	3	1	2	33	5	2	66	.00
16	2	2	0	100	248	124	12,400	.69
19	2	1	1	50	1,512	756	37,800	2.09
20	2	1	1	50	140	70	3,500	.19
27	3	1	2	33	1,608	536	17,688	.98
28	3	3	0	100	39,284	13,095	1,309,500	72.53
58	1	1	0	100	1	1	100	.006

*For location of section numbers, see figure 6.

TABLE 5
Sardine Eggs—Productivity of the Various Sections, 1932

TABLE 6

Sardine Larvae—Productivity of the Various Sections, 1931

Section number*	Number of hauls	Number of positive hauls	Per cent positive hauls	Total larvae	Average number of larvae	Per cent positive hauls × average number of larvae	Per cent
13	20	14	70	344	17	1,190	5.35
14	16	3	19	145	9	171	.77
15	17	11	65	724	43	2,795	12.56
16	6	2	33	114	19	627	2.82
17	2	2	100	66	33	3,300	14.83
26	1	1	100	4	4	400	1.80
27	6	5	83	59	10	830	3.73
28	4	2	50	967	242	12,100	54.36
29	4	2	50	21	5	250	1.12
42	6	2	33	35	6	198	.89
43	3	2	66	19	6	396	1.78

*For location of section numbers, see figure 6.

TABLE 6
Sardine Larvae—Productivity of the Various Sections, 1931

TABLE 7

Sardine Larvae—Productivity of the Various Sections, 1932

Section number*	Number of hauls	Number of positive hauls	Per cent positive hauls	Total larvae	Average number of larvae	Per cent positive hauls × average number of larvae	Per cent
13	8	4	50	40	5	250	1.13
14	15	12	80	1,517	101	8,080	36.44
15	5	4	80	110	22	1,760	7.94
16	4	3	75	28	7	525	2.37
17	2	2	100	28	14	1,400	6.31
18	3	2	66	5	2	132	.60
19	2	2	100	138	69	6,900	31.12
20	2	1	50	4	2	100	.45
28	3	1	33	65	22	726	3.27
30	1	1	100	13	13	1,300	5.86
31	2	1	50	32	16	800	3.61
58	1	1	100	2	2	200	.90

*For location of section numbers, see figure 6.

TABLE 7
Sardine Larvae—Productivity of the Various Sections, 1932

TABLE 8

Food of the Sardine

Locality	Date	Depth of water (fathoms)	Length range, mm.	Number of specimens	Stomach contents
Haul B82	May, 1931	50	10 to 21	7	Empty
Haul 1B	June, 1929	50	16 & 27	2	Empty
Haul 1L	June, 1929	100	13	1	Empty
Haul 10	April, 1930	500	16 to 21	5	Empty
Haul B46	April, 1931	400	18 to 29	8	2 contained copepods; 6 empty
Haul B114	July, 1931	5	24	1	Empty
Haul B78	May, 1931	50	20	2	Empty
Haul B95	May, 1931	100	20 & 23	2	Empty
Haul B113	July, 1931	5	23	1	Empty
Haul 1M	June, 1929	25	40	1	Copepods
Pismo Harbor	July, 1930	10	32 & 49	2	Copepods in both
Avalon Harbor	June, 1929	6	34 to 50	3	Copepods in two; 1 empty
Avalon Harbor	Aug., 1931	5	44 to 77	16	Copepods; 5 with coarse sand; 1 with shrimp
Catalina Harbor	July, 1929	5	58 to 88	15	Copepods; 1 empty
Catalina Harbor	Aug., 1930	5	69 to 85	6	2 contained copepods; 4 empty
Avalon Harbor	Sept., 1930	5	68 to 88	10	Copepods
Turtle Bay	April, 1931	25	70 to 97	9	Copepods
Santa Monica	July, 1931	12	71 to 107	10	Copepods
Anacapa Island	Aug., 1930	10	76	1	Copepods
Long Beach	Aug., 1930	10	83 to 110	9	Copepods
Monterey Bay	July, 1928	25	220 to 309	25	Diatoms dominant; dinoflagellates prominent; copepods, schizopods present

TABLE 8
Food of the Sardine