EGGS AND LARVAE OF ANCHOVY, JACK MACKEREL, AND PACIFIC MACKEREL

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ANCHOVY

The eggs and larvae of anchovy are pelagic. They float passively in the upper layers of the ocean, seldom deeper than 300 feet. Anchovy eggs differ from the eggs of most pelagic fishes in that they are ovoid rather than spherical.

The eggs and early larval stages of the northern anchovy were first described by Bolin (1936). According to Bolin, anchovies spawn at approximately the same hour each night. He estimated that spawning takes place at about 10 p.m. In this respect, the anchovy is similar to the Pacific sardine, which spawns mostly during the four-hour period, 8 p.m. to midnight, with 10 p.m. taken to represent the midtime of spawning (Ahlstrom, 1943).

Fertilization of the eggs takes place in the water immediately after they are spawned. Fertilization in nature is so successful that an unfertilized egg is seldom encountered. Anchovy eggs require from two to four days to develop to hatching, depending on the temperature of the water in which they develop. During development, the eggs float with the long axis perpendicular to the surface of the water. The eggs are colorless and translucent (Figure 14). They blend so well with the water in which they develop that only by the most careful observation can living eggs be distinguished in a sample. The eggs of the anchovy are not unusual in this respect. The eggs of most pelagic fishes are clear and translucent. However, most fishes develop some pigment on the embryo before hatching, but the anchovy does not. The anchovy at hatching is colorless, lacking pigment on the body and in the eyes.

The larvae of the northern anchovy are quite similar in appearance to the larvae of the Pacific sardine (see Figure 15). They are elongated, transparent, threadlike organisms that at hatching measure only 2.5 to 3.0 mm in length, i.e., about one-tenth of an inch. They are so slender after they have absorbed their yolk material that they could literally swim through the eye of a needle. They do not begin to look like an anchovy until they grow to about an inch long. Until reaching this size, they have a terminal mouth, similar in appearance to that of the sardine. (In the adults, the mouth is underslung.) In fact, if it were not for a slightly shorter intestine and the location of the dorsal and anal fins on anchovy larvae, it would be difficult to distinguish them from sardine larvae. Even so, it is sometimes difficult or impossible to distinguish damaged specimens of the two species.

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The Area of Heavy Anchovy Spawning

Anchovy spawning, although it occurs from off British Columbia to below Magdalena Bay, Baja California, has been abundant in recent years only between Point Conception and Point San Juanico, Baja California (station lines 80-137, Figure 1). Between 1951 and 1955 there has been a steady increase in the number of anchovy larvae in this area. In fact, the number of anchovy larvae taken in 1954 and 1955 was double the number taken in 1951 (Table 12). It is assumed that the size of the spawning population has also doubled during the same period.

TABLE 12

COMPARATIVE ABUNDANCE OF ANCHOVY LARVAE, 1951-55
(Average monthly census estimates, in billions)

Area	Census estimate				
	1951	1952	1953	1954	1955
North of Pt. Conception (lines 60-77)	84	19	1	108	8
Southern Calif. (lines 80-93)	398	155	427	988	820
N. Baja Calif. (lines 97-107)	101	127	302	447	981
Upper central Baja Calif. (lines 110-120)	424	600	1,103	716	1,764
Lower central Baja Calif. (lines 123-137)	805	1,156	778	1,577	424
Total	1,812	2,057	2,611	3,836	3,997

Area	Percent of total				
	1951	1952	1953	1954	1955
North of Pt. Conception (lines 60-77)	4.64	0.95	0.02	2.81	0.20
Southern Calif. (lines 80-93)	21.96	7.54	16.36	25.76	20.51
N. Baja Calif. (lines 97-107)	5.57	6.17	11.58	11.66	24.55
Upper central Baja Calif. (lines 110-120)	23.40	29.16	42.25	18.66	44.12
Lower central Baja Calif. (lines 123-137)	44.43	56.20	29.79	41.11	10.62
Total	100.00	100.02	100.00	100.00	100.00

The area between Point Conception and Point San Juanico has a north-south extent of approximately 720 miles. It is convenient to divide the area into two equal parts, the northern sector being bounded by station lines 80-107 and the southern sector by station lines 110-137. These sectors are identical to the "northern" and "southern" spawning centers of the Pacific sardine. If it is desirable to further subdivide the area, the northern sector can be divided into the Southern California area (lines 80-93) and the northern Baja California area (97-107); the southern sector can be divided into the upper central Baja Cali-

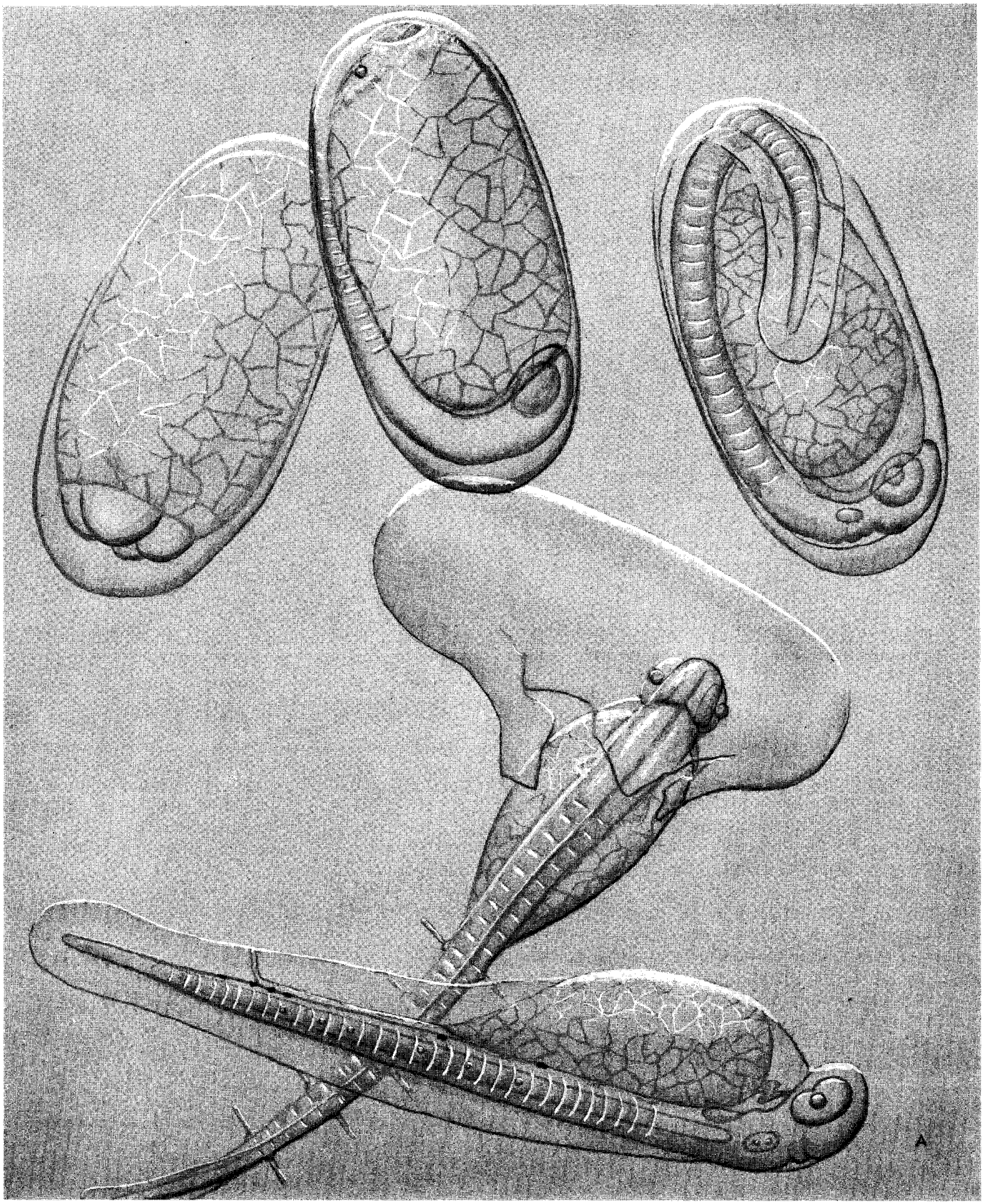
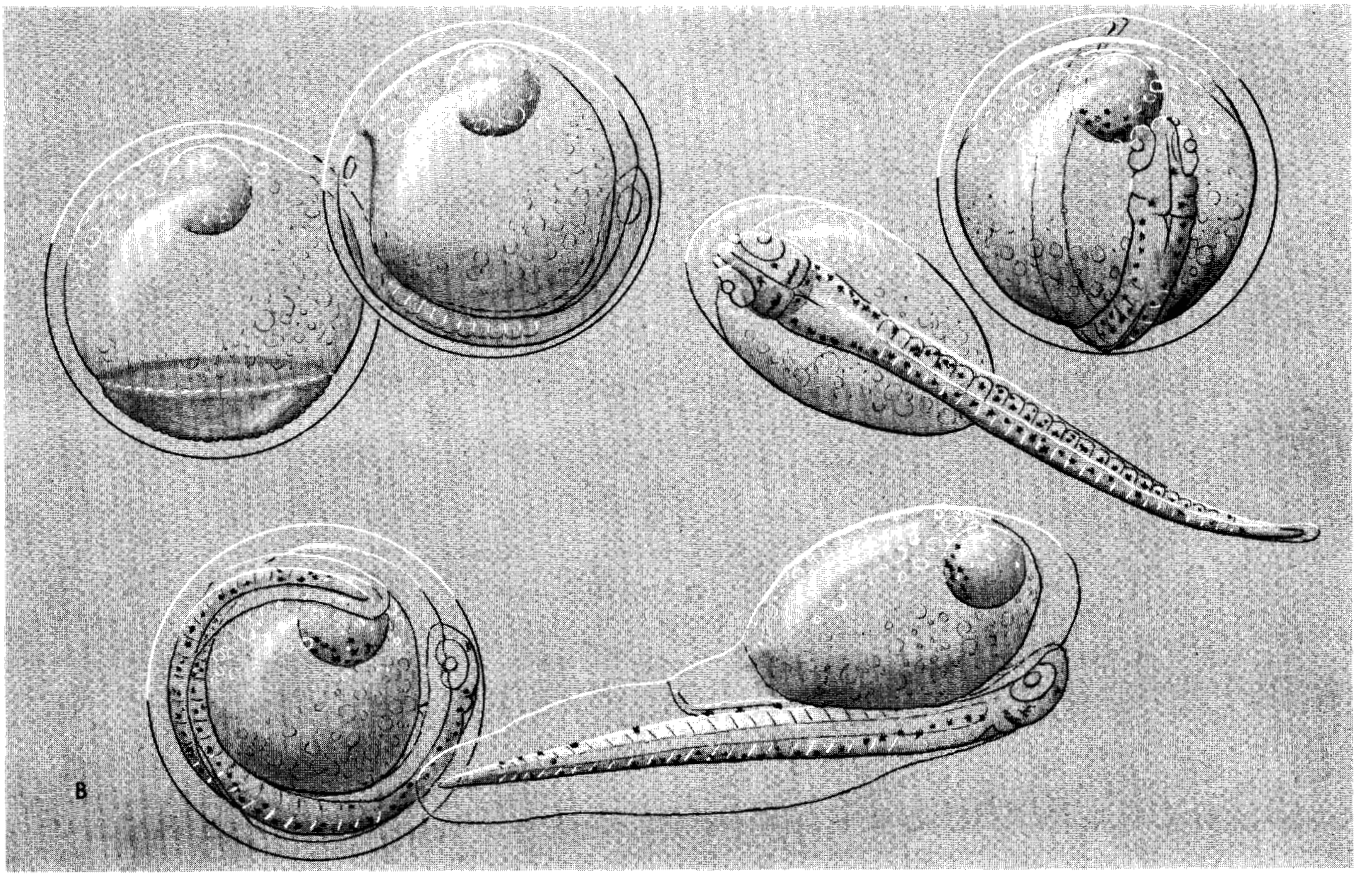


FIGURE 14. Eggs and yolk-sac larvae of (A above) anchovy, (B opposite page, upper) jack mackerel, and (C opposite page, lower) Pacific mackerel. The diameter of a jack mackerel egg is approximately one twenty-fifth of an inch. Drawings by George M. Mattson, U. S. Fish and Wildlife Service.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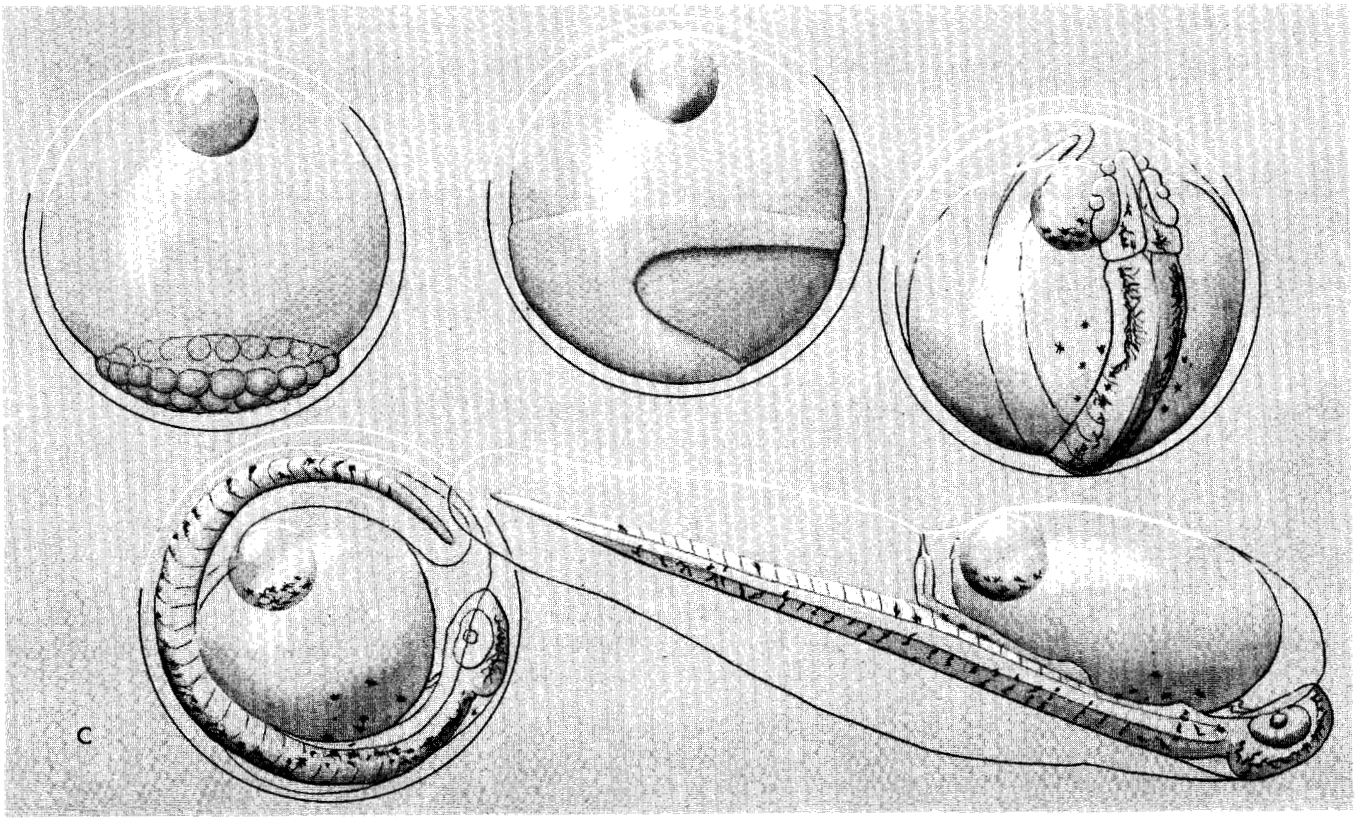
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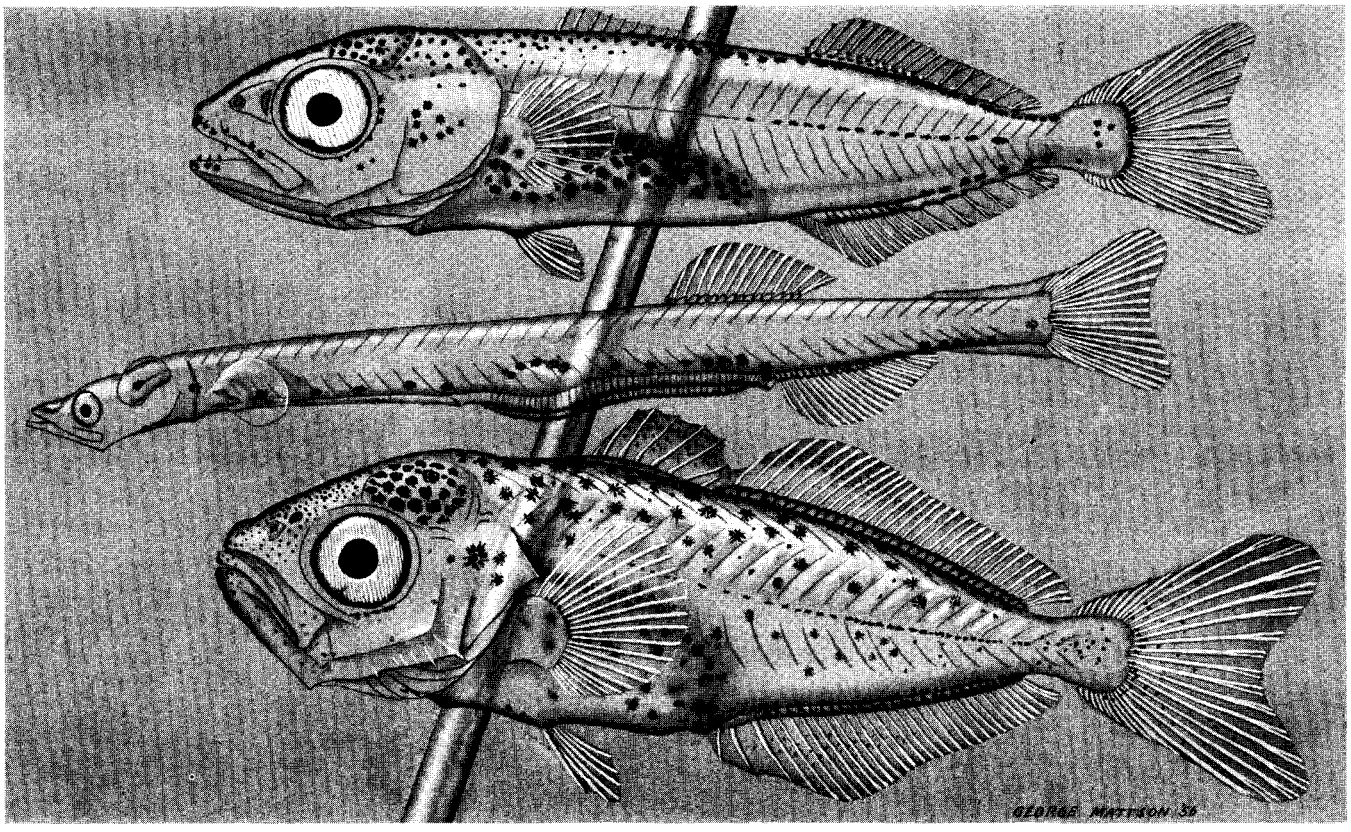

FIGURE 15. Larvae of (A) Pacific mackerel, (B) anchovy, and (C) jack mackerel. The column in the background is a section of No. 8 nylon fishing leader, drawn to scale. Note transparency of larvae. The jack mackerel larva is approximately three-fifths of an inch long. Drawings by George M. Mattson, U. S. Fish and Wildlife Service.

fornia area (lines 110-120) and lower central Baja California area (lines 123-137).

The southern sector has consistently had a larger portion of anchovy eggs and larvae than the northern sector. The relative importance of the two sectors during the past five years can be seen in Table 13.

The northern sector had the smallest percentage of anchovy larvae in 1952, and since then there has been a consistent gain in the portion of the larvae found in this sector.

TABLE 13

PERCENTAGES OF ANCHOVY LARVAE FOUND IN DIFFERENT SECTORS OF CCOFI AREA, 1951-55

Year	Northern sector (lines 80-107) (percent)	Southern sector (lines 110-137) (percent)	Other sectors (percent)	Total (percent)
1951	27.5	67.8	4.7	100.0
1952	13.7	85.4	0.9	100.0
1953	27.9	72.0	0.1	100.0
1954	37.4	59.8	2.8	100.0
1955	45.1	54.7	0.2	100.0

As can be seen by referring to the distribution charts of anchovy larvae for 1954 and 1955 (Figures 16 and 17), the greatest abundance of larvae occurs near shore. A similar condition obtains for anchovy eggs. The zone of heavy concentration is within 60 miles of the coast, although some spawning occurs as far offshore as 200 to 250 miles.

It will be noted from the 1955 distribution chart (and Table 12) that the abundance of larvae (and eggs) was markedly less off lower central Baja California (station lines 123-137) in 1955 than in any recent year. Only about 11 percent of the larvae were taken in this area in 1955, while between 30 and 56 percent of anchovy larvae were taken in the area in the years between 1951 and 1954. The lowered abundance was probably associated with anomalous conditions in the area—increased upwelling, colder temperatures, and heavy concentrations of plankton. Anchovies spawn throughout the year in the area between Point Conception and Point San Juanico (lines 80-137). However, spawning is not equally heavy during all seasons. Since 1953, the peak of abundance has occurred during the winter and early spring months, January through March or April, and the period of lowest abundance has been in late summer and early fall. During the period of lighter spawning, most of the eggs and larvae are taken quite close inshore, in contrast to a more widespread distribution offshore in the period of heavy spawning.

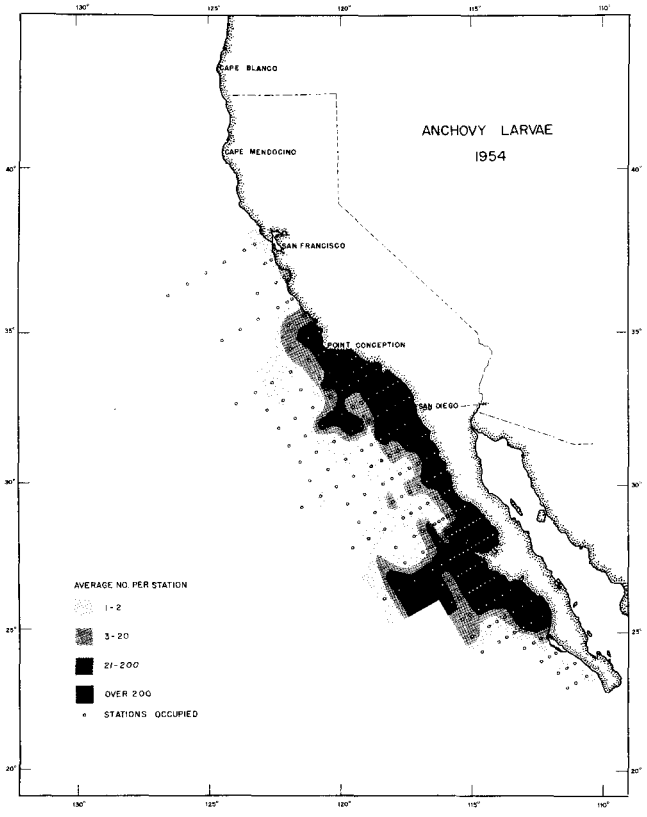

FIGURE 16. Distribution of anchovy larvae, 1954.

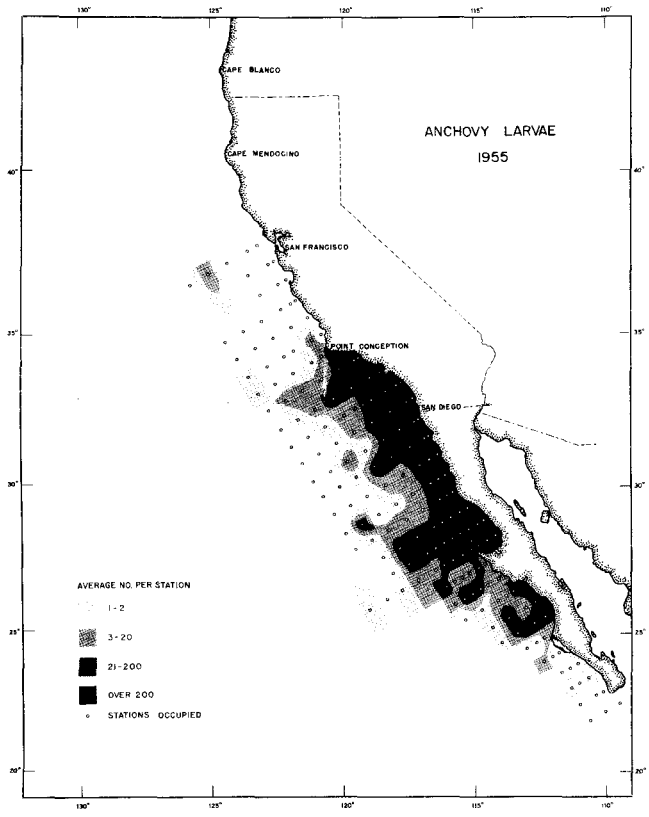

FIGURE 17. Distribution of anchovy larvae, 1955.

Anchovy Spawning to the North of Point Conception

In recent years anchovy spawning to the north of Point Conception has been variable in amount. It was heavy off central California in 1950, especially off Monterey, and lesser in amount but widely distributed in 1951 and light in 1952. Spawning may occur at considerable distances from shore in the central California area. In both 1950 and 1951 some spawning took place as far seaward as 200 miles. In 1953, anchovy spawning to the north of Point Conception was negligible in amount. In 1954, on the other hand, spawning was fairly heavy on line 77, about 40 miles north of the point (see Figure 16). I assume that anchovies from south of Point Conception moved into this area for spawning in 1954. A more marked northward shift was noted in spawning sardines in 1954, but in the latter species the shift was from central Baja California to Southern California; there was no evidence of sardine spawning to the north of Point Conception in 1954. There was very little anchovy spawning above Point Conception in 1955. It should be noted that the area to the north of Point Conception has not been regularly surveyed during the winter months and in other areas these have comprised the period of maximum spawning.

Anchovy Spawning Off Southern Baja California

Except in 1956, anchovy larvae have not been taken in abundance off southern Baja California (station lines 140-157). The area is not routinely occupied, but has been surveyed on one or more cruises per year since 1950. The most systematic coverage of the area was made in 1951, with cruises in March, June, and September, and in 1955, with cruises in January, February, March, and December. In the other years, coverage was limited to one or two cruises. During the period 1950-1955 only 362 anchovy larvae (standard haul totals) were taken off southern Baja California in 266 plankton hauls. This averages less than 1.5 larvae per haul.

Anchovies moved into this area in 1956. During January and February over 19,000 anchovy larvae (standard haul totals) were taken off southern Baja California in 49 plankton hauls. The majority were taken on line 140, but the larvae occurred at a number of stations on lines farther south (143 to 150). The southward shift in the spawning population may not represent a shift of more than 40 to 80 miles, but it is good evidence that such movements in the spawning population do occur.

Relation of Anchovy Spawning to Temperature

A fish that spawns over an extensive area during all seasons of the year must, of necessity, spawn over a wide range of temperatures. The temperature range over which anchovy eggs were taken during 1953 and 1954 was from 9.9° to 23.3° C., a range of 13.4° C. (Table 14). I have used the temperature at 10 meters' depth as representative of the temperature in the upper mixed layer in which anchovy eggs occur.

TABLE 14

TEMPERATURE RANGE OVER WHICH ANCHOVY EGGS WERE TAKEN IN 1953 AND 1954

(Temperature at 10 meters depth)

Temperature degrees C.	1953	1954	Total
9.5	1		1
10.0	3		3
10.5			0
11.0	5	3	8
11.5	8	1	9
12.0	8	5	13
12.5	7	6	13
13.0	15	13	28
13.5	21	32	53
14.0	32	44	76
14.5	15	34	49
15.0	17	30	47
15.5	19	36	55
16.0	14	12	26
16.5	9	11	20
17.0	6	10	16
17.5	13	7	20
18.0	6	10	16
18.5	5	5	10
19.0	2	2	4
19.5		7	7
20.0		3	3
20.5	1		1
21.0			0
21.5	1	1	2
22.0			0
22.5		1	1
23.0		1	1
Total	208	274	482

A wide range in temperatures was encountered at the same station at different times during the spawning season (Table 15). This was more marked at inshore than at deep-water stations. The point can be illustrated by giving the temperature range found at several inshore stations off Southern California in 1954.

TABLE 15

TEMPERATURE RANGE AT SEVERAL INSHORE STATIONS OFF SOUTHERN CALIFORNIA IN 1954

Station	Position		Temperatures at which anchovy eggs were taken (degrees C.)		
			Minimum	Maximum	Range
87.35	33°50′N	118°37.5′W	13.34	19.34	6.00
90.28	33°28.5′N	117°46.7′W	13.87	23.26	9.39
93.27	32°56′N	117°19.2′W	13.30	23.03	9.73
97.30	32°15.4′N	117°08.8′W	13.21	20.33	7.12

The temperature range over which anchovies spawn off Southern California is considerably greater than the range over which sardines ordinarily spawn in this area. One reason for this is that sardines spawn only in the period February through July, with heavy spawning confined to April through June, while anchovies spawn throughout the year in this area. Also, anchovies tend to spawn closer inshore than sardines, and, as noted above, inshore stations are subject to more marked temperature fluctuations than offshore stations. Perhaps the most marked difference in the spawning of the two species concerns the lower or threshold temperature. In the sardine, 13.0° C. has been shown to be a limiting temperature below which spawning ordinarily does not take place. The threshold temperature is lower in the anchovy; about 10 percent of the spawning sampled in 1953 and 1954 was at temperatures below 13.0° C.

JACK MACKEREL

The eggs of the jack mackerel are spawned in the open ocean far from shore. Like most pelagic fishes, the jack mackerel spawns in the upper mixed layer of water. This layer, which is seldom more than 300 feet thick and often much shallower, is both warmer and better supplied with food than the deeper zones. The egg of the jack mackerel is spherical in shape and moderate in size. Twenty-five eggs placed in a row would extend only one inch. Like the anchovy egg, the jack mackerel egg in nature is colorless and translucent (see Figure 14). The yolk mass is segmented and contains a single large oil globule. Many fish eggs contain one or several oil globules. Sardine, hake, and Pacific mackerel are examples of other common species that have an oil globule. However, the eggs of the northern anchovy, Pacific halibut, and round herring lack oil globules, so this structure must play only a secondary role in the development of fish eggs. It may aid the egg to float, for the oil globule is situated at the top of the jack mackerel egg as it ordinarily floats in the water, while the embryo develops on the under side of the egg. During development, pigment forms on the under side of the oil globule and along the back and belly of the embryo. The oil globule is situated in the forward part of the yolk sac on hatching, just under the unpigmented eyes. This is an unusual placement for the oil globule.

The newly hatched jack mackerel larva is a small, defenseless organism. It is barely a twelfth of an inch in length, lacks fins for swimming, pigmented eyes for seeing, and even a mouth for feeding. In the two or three days that the yolk material remains after hatching the young larva develops rapidly, however, so that by the time the yolk is gone it has a functional mouth, pigmented eyes, and paired pectoral fins.

The larva of the jack mackerel is very different in appearance from the larva of the sardine or anchovy (see Figure 15). It is a stubby larva with a big head and a big mouth. The big mouth is useful in capturing and swallowing larger plankton organisms, particularly copepods, than the young stages of sardine or anchovy can eat. In fact, a jack mackerel larva that is only a fifth of an inch long can utilize food

material that a sardine larva could not ingest until it became two or three times this long. Hence, jack mackerel larvae do not directly compete with small sardine or anchovy larvae for food, but they do compete with older larvae.

The young stages of jack mackerel larvae seem to have definite food preferences. They are especially partial to a small, brightly colored copepod to which has been given the scientific name of *Microstella norvegica*. This copepod is considered to be truly cosmopolitan. It occurs everywhere in the oceans, though seldom in large numbers. The jack mackerel larvae are very adept at capturing it, as well as several other kinds of widely distributed "colored" copepods. This preference for cosmopolitan food items may be one of the reasons why jack mackerel larvae are able to "make a living" in offshore waters.

Jack mackerel spawn over a much more extensive area than the Pacific sardine, northern anchovy, or Pacific mackerel. Within the area routinely surveyed on CCOFI cruises, there are few stations at which jack mackerel eggs or larvae are not taken during a season, and these are located either close inshore or at the southern end of the survey area. The center of greatest abundance of the eggs and larvae is located off Southern California and adjacent Baja California (Point Conception to San Quintín), as is shown in Figure 18. Abundance falls off sharply to the south of the center and also decreases in amount to the north as well. However, we know from our early surveys off Oregon (1949) and from the extensive coverage of NORPAC that some spawning occurs as far north as Washington and as far offshore as 150° W. Actually, the offshore extent of spawning has never been adequately delimited. Jack mackerel eggs and larvae have been taken as far north and as far seaward as our cruises have extended.

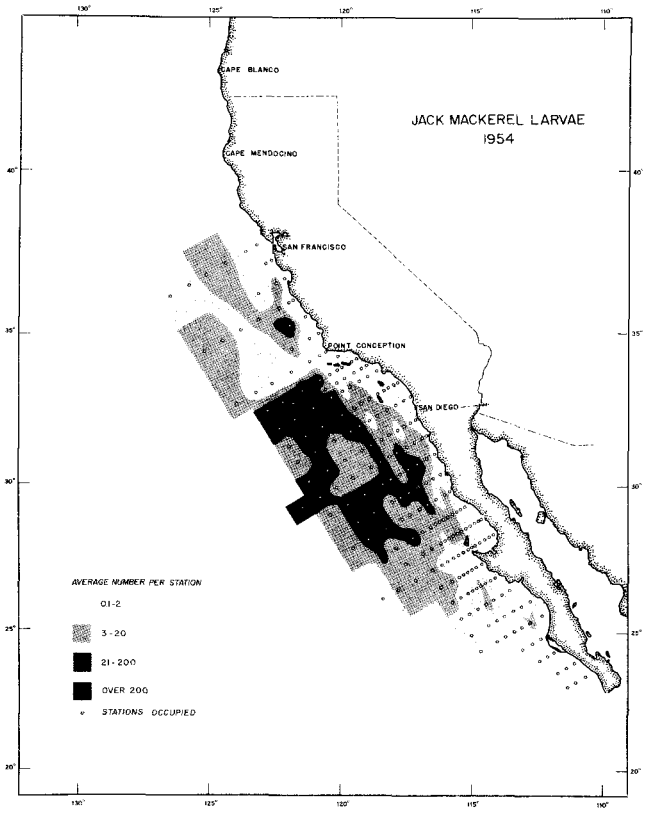

FIGURE 18. Distribution of jack mackerel larvae, 1954.

Jack mackerel eggs and larvae ordinarily are found at some distance from shore; in fact, the center of their abundance appears to be between 80 and 240 miles off shore. A tendency has been noted for the center of spawning to move closer inshore as the spawning season draws to a close.

The season of spawning off California and Baja California is mostly confined to the five-month period, March through July. There is some spawning at other times, but it is small in amount (between 1 and 5 percent of the season total). The peak of spawning has occurred as early as April (1951) and as late as June (1953 and 1954).

Spawning begins as early in the year off Southern California as it does off Baja California, but a gradual northward progression of spawning occurs above Point Conception. In 1950, for example, spawning occurred off Northern California in June and July. In 1949, when stations were regularly occupied off Oregon, spawning was found to occur in that area from July through September. In August, 1955, on the extended coverage afforded by NORPAC, jack mackerel eggs and larvae were taken at a number of stations off Oregon and Washington (Figure 19). In contrast, jack mackerel eggs and larvae were taken in only a few hauls off California and Baja California on NORPAC, representing in these areas the tag ends of spawning. A more detailed account of the distribution and abundance of jack mackerel larvae is given in Ahlstrom and Ball (1954).

Rate of Development

The eggs of Pacific mackerel and jack mackerel take longer to develop to hatching than those of the Pacific sardine. The rate of development of all kinds of fish eggs is directly related to the temperature at which development takes place. Incubation of sardine eggs, for example, requires approximately $4\frac{1}{3}$ days at 12° C., a little less than three days at 15° C. and only about $1\frac{1}{2}$ days at 20° C. The relation of temperature to the length of the incubation period of sardine eggs is known in detail, but our knowledge of the rate of development of other species is less complete. However, work is being done on a number of other species, as this information is a prerequisite in determining the amount of spawning and the survival rate of eggs and larvae. Recently, incubation experiments have been conducted on jack mackerel and Pacific mackerel

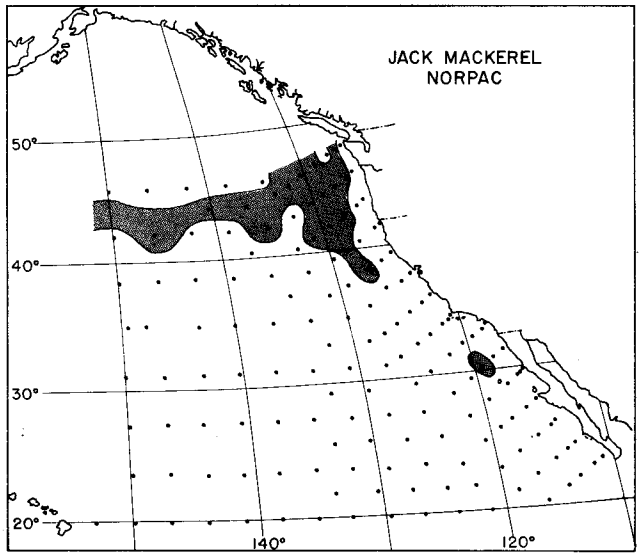

FIGURE 19. Distribution of jack mackerel eggs and larvae, NORPAC project.

eggs. The eggs, collected at sea about 150 miles off San Diego, were incubated at about 14.3° C. The jack mackerel eggs required approximately four days to develop to hatching at this temperature, the Pacific mackerel eggs 4½ days. For comparison, the sardine requires less than 3¼ days to develop at this temperature. Interestingly enough, the rate of development of Pacific mackerel eggs at this temperature is almost identical to that reported for the Atlantic mackerel by Worley (1933).

Depth Distribution

We have made a number of studies on the depths at which fish eggs and larvae occur in the water. For most species, the distribution is limited to the upper mixed layer above the thermocline and to the upper portion of the thermocline. The depth of the upper mixed layer varies with latitude, with distance from shore, with season, and with wind conditions; hence it is a layer of variable thickness. In our area it is seldom more than 300 feet deep, and often much shallower. In some places it is as shallow as 50 feet or even less.

The depth distributions of fish eggs and larvae show a corresponding variation, and, in addition, larvae may have a different position within the upper mixed layer during night-time as compared to the day. Hence for every species, there is a variable depth range at which eggs and larvae may occur, but for most species the lower limit of the distribution is seldom deeper than 300 feet.

The depth distributions of the larvae of five common species of fish are given in Table 16. These data represent the summation of a number of depth distribution series, and it should be noted that there was considerable variation in the depth distribution for all species from series to series. Larvae of the Pacific mackerel, sardine, and anchovy occurred in greatest abundance in the upper 23 meters, jack mackerel had their greatest abundance between 24 and 48 meters, hake larvae occurred in greatest abundance between 65 and 88 meters.

TABLE 16

DEPTH DISTRIBUTION OF FISH LARVAE: PERCENT TAKEN IN DIFFERENT DEPTH STRATA

Depth stratum (meters)	Pacific mackerel (percent)	Sardine (percent)	Anchovy (percent)	Jack mackerel (percent)	Hake (percent)
0-23	75	68	46	30	2
24-48	24	25	33	49	2
49-64	1	4	16	5	8
65-88	0	3	5	13	71
89-122	0	less than 0.1	less than 0.1	2	5
123 and below	0	0	0	0	12

PACIFIC MACKEREL

The eggs and larvae of the Pacific mackerel are superficially similar in appearance to those of the jack mackerel (see Figures 14 and 15). The eggs of both species are spherical, they have a single oil globule of similar size, and in both there is very little space between the yolk mass and the outer unsculptured shell membrane. The larvae of both species are stubby and big-headed; they develop their fins at about the same sizes and transform into juveniles when only about three-fifths inch in length.

However, a practiced eye finds little difficulty in distinguishing between the young stages of the two species. There are a number of small differences between the eggs of Pacific mackerel and jack mackerel. The Pacific mackerel eggs are somewhat larger; 1.15 mm as opposed to 1.0 mm in diameter. This difference may seem slight, but actually a mixture of eggs of the two species can be readily separated on the basis of size alone. A more striking difference is in the character of the yolk, which is irregularly segmented in jack mackerel, but homogeneous in the Pacific mackerel. Two differences that can be used in distinguishing later stage eggs are body segment or myomere number and pigmentation. The number of myomeres corresponds to the number of vertebrae which will later develop: Pacific mackerel almost always has seven more than the jack mackerel; 31 as compared to 24. There are a number of differences in pigmentation of late stage eggs. There is considerable pigment on the forward part of the head of the developing Pacific mackerel embryo and little or none on the jack mackerel embryo. Another difference is the presence of some pigment on the yolk of Pacific mackerel eggs, while none develops on the yolk of jack mackerel eggs. There are additional differences in the distribu-

tion of pigment over the body of the embryos, which I will not attempt to describe in detail. The eggs and early larval stages of the Pacific mackerel have been described by Fry (1936), the larvae by Roedel (1949).

One of the things that makes it difficult to associate the egg and larval stages of pelagic fishes is the marked difference in pigmentation that is usually found between eggs and larvae. In many species of fish, the embryonic pigment is distributed along the dorsal surface or back, while the larval pigment is mainly or entirely confined to the ventral or belly side. The change is accomplished by an actual migration of pigment. The change usually takes place during the yolk sac stage after hatching from the egg, although in some species (including the Pacific mackerel) the migration may commence before hatching. The migration and rearrangement of the pigment is usually completed before the end of the yolk sac stage.

On the newly hatched Pacific mackerel larvae, the pigment, which had been dorsal until soon before hatching, is streaming down the sides of the body between the myomeres. Within a couple of days the larval pigment pattern has appeared. It consists essentially of pigment in three areas: (1) a cap of pigment spots on top of the head; (2) pigment along the peritoneal cavity; and (3) a row of ventral spots, extending from behind the anus to the end of the notochord. Several differences between the newly hatched larvae of jack mackerel and Pacific mackerel might be pointed out. Perhaps the most conspicuous difference is in dorsal pigmentation. The jack mackerel larva retains considerable pigment on the back, while the Pacific mackerel does not. A striking difference is in the position of the oil globule, which is located at the anterior end of the yolk sac in newly hatched jack mackerel larvae, and at the posterior end of the yolk sac in Pacific mackerel larvae. A third difference is in the position of the anus, which is much farther forward in the Pacific mackerel than in the jack mackerel larva. The newly hatched larvae of jack mackerel are slightly smaller than those of Pacific mackerel, but the difference is not great enough to be of help in differentiating the two forms.

Distribution of Pacific Mackerel Spawning

Although adult Pacific mackerel are known to occur from northwest Alaska to the Gulf of California, eggs and larvae have not been taken to the north of Point Conception. Some spawning occurs off Southern California and northern Baja California, but the bulk of spawning occurs off central and southern Baja California (see Figure 20), and in the Gulf of California.

There is a striking similarity between the distribution and season of Pacific mackerel spawning and that of the Pacific sardine. Off Southern California and northern Baja California the spawning of both species

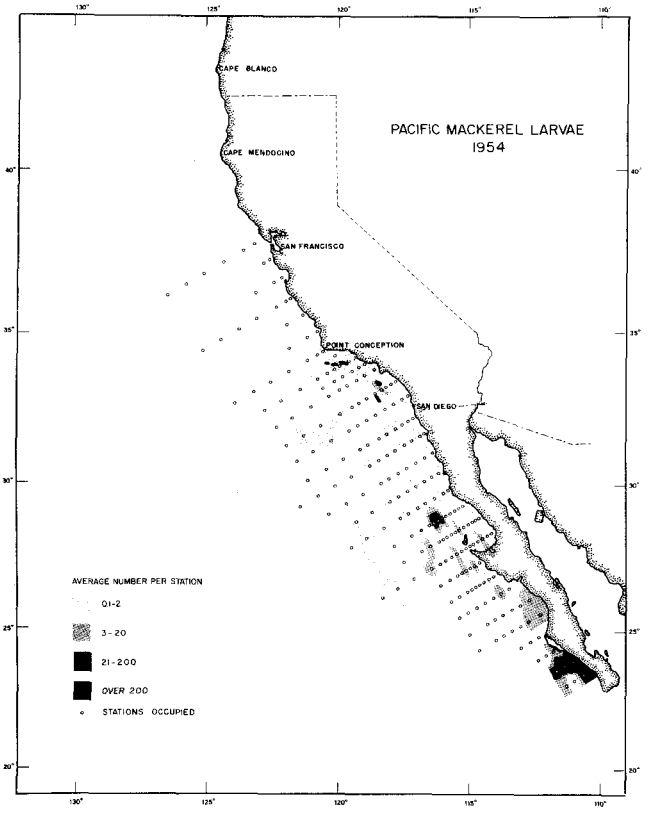

FIGURE 20. Distribution of Pacific mackerel larvae, 1954.

may occur at considerable distances from shore, and the season of spawning is similar (March through July). Pacific mackerel, like the sardine, spawn throughout the year off central Baja California. The number of Pacific mackerel larvae taken off central Baja California has been four to six times as large as the number occurring off Southern California and northern Baja in most recent years. The ratio was nearly 20 to 1 in 1953, a season with unusually low water temperatures.

The area off southern Baja California has not been routinely occupied, but has been surveyed on 12 cruises during a six-year period (1950-1955). Pacific mackerel larvae have been taken in this area on most cruises, and occurred in considerable abundance in January, 1954. No systematic coverage of the Gulf of California was attempted prior to the current season (1956), when the gulf was surveyed on two occasions (Cruises 5602 and 5604). The collections of the earlier of the two cruises have been worked up, and Pacific mackerel larvae were taken at many stations in the gulf. The distribution and abundance is shown in Figure 21. Judging from abundance found on this cruise, there must be a larger spawning population in the gulf than on the outer coast.

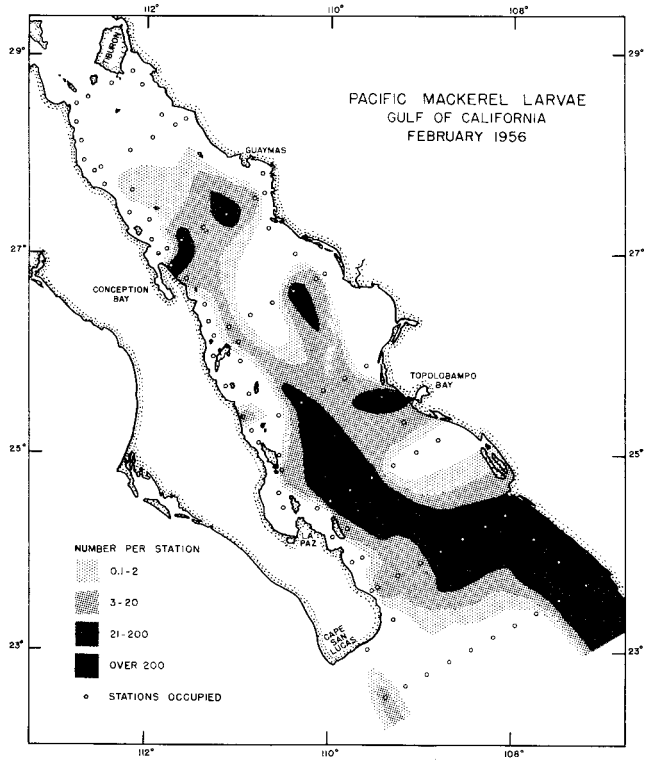

FIGURE 21. Distribution of Pacific mackerel larvae, Gulf of California, February, 1956.

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