DESCRIPTION OF EGGS AND LARVAE OF JACK MACKEREL (*Trachurus symmetricus*) AND DISTRIBUTION AND ABUNDANCE OF LARVAE IN 1950 AND 1951

BY ELBERT H. AHLSTROM AND ORVILLE P. BALL

FISHERY BULLETIN 97

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*

FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

ABSTRACT

Development of jack mackerel (*Trachurus symmetricus*) is described for the embryonic, larval, and early juvenile stages. The egg is about 1 mm. in diameter, has a single large oil globule, a segmented yolk mass, a rather narrow perivitelline space, and a clear, tough, unsculptured eggshell. Diagnostic characters are given for several stages of embryonic development to aid in the identification of jack-mackerel eggs. The larva, on hatching, is about 2 mm. in length. The oil globule occupies a forward position in the yolk sac. Pigment is mostly confined to the dorsal and ventral margins of the body.

A dynamic approach is followed in discussing larval development. The sequences of fin formation, of ossification, of pigment changes, and of changes in body form are presented. The larval period is considered to end at approximately 16 mm., when fin formation is complete.

The regional and seasonal distributions of jack-mackerel larvae off western North America during 1950 and 1951 are presented. The center of abundance of jack-mackerel larvae lies off southern California, between 80 and 240 miles at sea. Abundance falls off both to the north and to the south of this area. The offshore distribution of jack-mackerel larvae has not been delimited completely. The season of greatest abundance is during the 5-month period, March through July.

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Drawings by GEORGE MATTSON

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By ELBERT H. AHLSTROM and ORVILLE P. BALL, *Fishery Research Biologists*

While investigating the distribution and abundance of sardine eggs and the survival of sardine larvae, the younger stages of most of the other fishes in our waters that have pelagic eggs and larvae were collected incidentally. The early stages in the life history of most of these have not been described. Inasmuch as we are interested in the species competing with or preying upon the sardine, we have identified the eggs and larvae of the other species occurring commonly in plankton hauls. Descriptions of the early stages of these other species will be published, this being the first paper in the projected series.

Collections of eggs and larvae of jack mackerel, *Trachurus symmetricus* (Ayres) 1855, were obtained on the monthly survey cruises of the California Cooperative Oceanic Fisheries Investigations. This program is sponsored by the California Marine Research Committee and is being carried out cooperatively by the Scripps Institution of Oceanography of the University of California, the California Department of Fish and Game, the California Academy of Sciences, the Hopkins Marine Station of Stanford University, and the South Pacific Fishery Investigations of the United States Fish and Wildlife Service. Since the spring of 1952, a voluntarily imposed tax of $1 a ton has been paid by California fish processors on all landings of jack mackerel, as well as other species, in support of the research being sponsored by the Marine Research Committee.

The jack-mackerel fishery has shown a most rapid growth since the decline of the sardine and Pacific-mackerel fisheries. Before 1933, the annual catch never reached a million pounds. From 1933 to 1946 the annual catch varied between 1 and 15 million pounds. With the 1947 season, a most rapid expansion of the fishery took place, the catch in that year totaling 129 million pounds. Since then, the annual catch has shown rather marked fluctuations, but it has never dropped below 50 million pounds, and during the 1950 and 1952 seasons it exceeded the amount taken during 1947. The 1952 catch of jack mackerel off California of 146 million pounds, the largest taken to date, was exceeded only by the landings of yellowfin tuna. Hence, the jack-mackerel fishery during the past few years has become one of the most important fisheries on our west coast. Most of the landings are made at San Pedro.

There is but a single species of *Trachurus* known to occur in the eastern Pacific between Baja California and British Columbia. According to Roedel and Fitch (1952), specimens of adult jack mackerel have been taken from central Baja California to British Columbia, and as far offshore as 600 miles (west of Los Angeles). The biology of the jack mackerel had been so incompletely known until recently, that large adults from Oregon and British Columbia were described as a separate species, *Decapterus polyaspis* (Walford and Myers 1944). But, Roedel and Fitch, after examining an extensive collection of jack mackerel obtained between central Baja California and Oregon, were able to show that *D. polyaspis* is a synonym of *Trachurus symmetricus*.

There has been considerable confusion in distinguishing between jack mackerel and Mexican scad. The latter species, *Decapterus hypodus*, occurs off Baja California and is occasionally taken as far north as southern California. It resembles the jack mackerel superficially, but can be separated readily from it on the basis of the following characters: (1) The last ray of both the second dorsal and the anal fin is widely separated from the preceding rays to form a distinct finlet in *Decapterus*, while in *Trachurus* the last ray is not widely separated; (2) *Decapterus* lacks the accessory lateral line present along the first dorsal in *Trachurus;* (3) the lateral line is gently deflexed in *Decapterus*, while it is much more abruptly arched in *Trachurus;* and (4) there are

scutes along only the posterior portion of the lateral line in *Decapterus*, while they extend along the entire length of the lateral line in *Trachurus*. We have taken a number of larvae off central Baja California, that we have tentatively identified as *D. hypodus*. They agree closely with the larvae of *Decapterus punctatus* described by Hildebrand and Cable (1930).

The eggs and larvae of jack mackerel are among the most abundant taken in our plankton collections. The larvae are as numerous as sardine larvae, and have a more widespread distribution. The center of abundance is off southern California. During the spawning season, jack mackerel occur as far seaward as our cruises extend. The largest concentrations of jack-mackerel larvae occur between 80 and 240 miles offshore. If the distribution of adult jack mackerel during the remainder of the year is similar to that found during the spawning period, then the fishery is exploiting only an inshore margin of the jack-mackerel population. However, the fishery takes the younger age groups of jack mackerel, and it may be that they have a more limited distribution, closer to shore, than do the older fish.

In discussing the early stages in the development of jack mackerel, we find it convenient to recognize four categories: (1) Egg stage, (2) yolk-sac larva, (3) larva, and (4) juvenile. The egg stage, or period of embryonic development, scarcely needs defining; it commences at fertilization and ends at hatching. It is convenient to separate the early period of larval development, when the yolk-sac is present, from the subsequent larval period. The larval period is considered to end at the completion of fin formation. Thereafter, young jack mackerel are classed as juveniles. Although the transition to the juvenile stage is considered to occur at about 16 mm. in length, there is no sharp line of demarcation between the larval and juvenile stages of the jack mackerel. There is no well-defined metamorphosis, such as occurs in many kinds of fish larvae.

Some workers have used a separation into three stages during the early postembryonic period: Yolk-sac larva, larva, and postlarva. Hubbs (1943) recommended a broad application of the term "larva" to include all developmental stages between the time of hatching and transformation, which could be subdivided, if desired, into prolarva and postlarva. The term "larva" is here used in such an inclusive sense; however, to designate the early larval period, the term "yolk-sac larva" is substituted for prolarva, and the term "post-larva" is not used.

It is with deep pleasure that the authors acknowledge the cooperation given by the Scripps Institution of Oceanography and the California Department of Fish and Game in the collection of data at sea. The whole staff of the South Pacific Fishery Investigations of the Fish and Wildlife Service has contributed, to a greater or lesser extent, to this study. The authors especially wish to thank John C. Marr, James Böhlke, and Theodore Widrig for helpful advice during the preparation of the paper; James Thrailkill for preparing the charts showing distribution and abundance of jack-mackerel larvae; Robert Counts for his help in the preparation of jack-mackerel material for study; and Dr. Rolf Bolin of Stanford University for critically reading the manuscript.

DEVELOPMENT OF JACK MACKEREL

EGG

(FIGURE 1)

The egg of the jack mackerel is spherical in shape, and of moderate size. It is a pelagic egg that is characterized by a single, fairly large oil globule, a more or less segmented yolk mass, a rather narrow perivitelline space, and a clear, tough, unsculptured eggshell.

The diameter of the jack-mackerel egg, based on measurements of over 500 eggs selected from various parts of the spawning range, averaged about 0.98 mm.; the diameter of the oil globule averaged 0.26 mm.; the diameter of the yolk 0.79 mm.; the width of the perivitelline space 0.09 mm. These measurements are given in more detail in table 1.

The yolk mass appears light yellow to amber in preserved material. It is irregularly segmented. In early developmental stages, the yolk immediately adjacent to the blastodisc often appears much more definitely segmented than the yolk material at the vegetative pole. The membrane around the yolk mass must be quite thin and easily ruptured. In our preserved material, most early-embryonic eggs (before the closure of the blastopore) show a considerable amount of yolk diffusion into the perivitelline space. It is assumed that this is due to

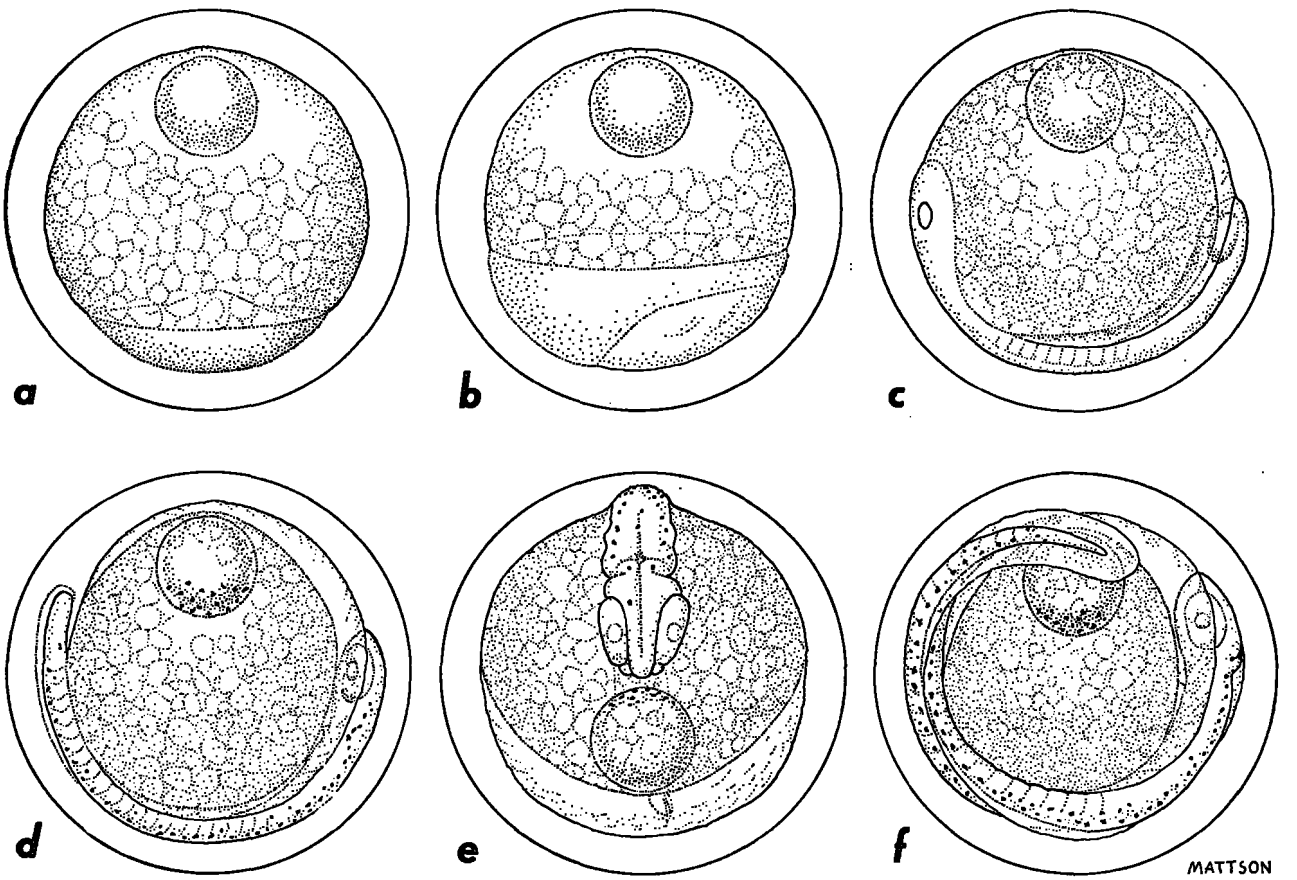

FIGURE 1.—Jack-mackerel eggs in various stages of development. *a*, *b*, and *c*, early embryonic period, *c* being the stage immediately preceding blastopore closure; *d*, intermediate period of embryonic development; *e* and *f*, late-period eggs with advanced embryos; *e* shows an egg as viewed from above; all other figures are lateral views.

TABLE 1.—*Measurements of jack-mackerel eggs, 1950*

Station	Date of collection	Number measured	Diameter in mm. of —					
			Eggshell		Yolk		Oil globule	
			Mean	Range	Mean	Range	Mean	Range
70.100	May 4	49	1.00	(0.92–1.05)	0.78	(0.68–0.85)	0.28	(0.22–0.35)
80.90	May 4	50	.99	(0.92–1.05)	.81	(0.72–0.90)	.26	(0.22–0.30)
83.70	Apr. 11	52	1.02	(0.95–1.08)	.85	(0.75–0.92)	.27	(0.20–0.32)
83.90	May 11	53	.97	(0.92–1.00)	.74	(0.70–0.80)	.26	(0.20–0.30)
87.80	Apr. 10	50	1.01	(0.95–1.08)	.82	(0.72–0.88)	.26	(0.22–0.30)
87.80	May 10	35	.97	(0.92–1.02)	.81	(0.75–0.85)		
90.90	May 6	50	.96	(0.92–1.00)	.79	(0.70–0.82)	.24	(0.18–0.30)
93.60	May 13	49	.99	(0.95–1.05)	.76	(0.68–0.85)	.25	(0.20–0.30)
97.40	May 15	50	1.00	(0.92–1.05)	.79	(0.72–0.85)	.25	(0.18–0.30)
100.60	May 15	50	.96	(0.92–1.00)	.82	(0.75–0.88)	.26	(0.20–0.30)
100.100	May 14	50	.96	(0.90–1.00)	.74	(0.68–0.78)	.24	(0.18–0.30)
Total (average)		538	.98	(0.90–1.08)	.80	(0.68–0.88)	.26	(0.18–0.35)

mechanical rupture of the yolk membrane during collection and preservation of the eggs, inasmuch as eggs in which the germ ring has encircled the yolk mass do not show this damage.

The oil globule is approximately spherical in shape. In some preserved samples, however, the oil globule may be irregularly distorted, occasionally even fractured into several droplets. The oil globule is yellow in preserved material.

During the early stages of development, the oil globule is centered at the vegetative pole, opposite the developing blastodisc. As spherical, pelagic eggs characteristically float with the vegetative pole uppermost, the oil globule is at the top of the

yolk mass. Immediately following the closure of the blastopore, a number of melanophores appear on the underside of the oil globule. During the later stage of embryonic development the oil globule becomes situated rather close to the head (fig. 1*e*), and on hatching is immediately under the forward part of the head (fig. 2). This feature is a reliable diagnostic character in the identification of jack-mackerel eggs, inasmuch as comparatively few species have the oil globule so situated. For example, the eggs of hake, *Merluccius productus* (Ahlstrom and Counts 1954), and Pacific mackerel, *Pneumatophorus diego* (Fry 1936), are similar in size and in superficial appearance to those of the jack mackerel, but in both the oil globule is situated close to the anus, with the result that after hatching, the oil globule is located at the posterior end of the yolk sac.

There is nothing unusual in the embryonic development of jack-mackerel eggs. Most pelagic-fish eggs follow a similar pattern of embryonic differentiation; that of the jack mackerel could be characterized as typical, hence, there seems little point in giving a detailed account. Of more concern to us are diagnostic characters that aid in the identification of jack-mackerel eggs at various stages in their embryonic development. We will list such characters for three embryonic periods: Early (fertilization to blastopore closure), intermediate (from blastopore closure until the separating tail begins to twist out of the plane of the embryonic axis), and late (eggs with advanced embryos).

Fish eggs usually are more difficult to identify during the early stages of development (before blastopore closure), than in later stages. In early stages, diagnostic characters are limited to such features as egg size and shape; number, size, color, and position of oil globules; size of perivitelline space; color and texture of yolk; and the character of the eggshell. However, the degree of development of the embryo before blastopore closure may be a useful diagnostic character. In later stages, when the embryo is better developed, such additional characters as pigmentation, position of the anus, and approximate number of myomeres can be used. In samples containing a number of jack-mackerel eggs there are usually several stages of development represented. In many samples all three periods of embryonic development, early, intermediate, and late, are present. Jack-mackerel eggs, like those of the sardine, seem to require only about 2 to 4 days to complete their embryonic development, the length of time depending on the temperature of the water (*cf.* Ahlstrom 1943). However, a detailed study has not been made of the relation between water temperature and the speed of embryonic development of jack-mackerel eggs.

Characters that aid in identification

1. *During early embryonic development (to closure of blastopore)* (fig. 1, *a*, *b*, and *c*):

Egg size: Approximately 1 mm.

Shell membrane: Unsculptured, clear.

Oil globule: Single, yellow, diameter approximately one-fourth of that of egg; situated at vegetative pole.

Perivitelline space: Rather narrow—about 0.1 mm. wide.

Yolk material: Color tan; probably colorless and translucent in living material; more or less segmented. Segmentation of the yolk material is usual for the eggs of isospondylid fishes, but unusual in those of percomorph fishes. Hence, the segmentation of the yolk is perhaps the most important diagnostic feature of early embryonic jack-mackerel eggs.

Embryo: Myomeres appear behind the head and the optic vesicles form shortly before blastopore closure.

2. *During the intermediate period of embryonic development* (fig. 1*d*).—Most of the characters listed under the early stage, such as egg size, color, size, and position of oil globule, width of perivitelline space, and color and segmentation of yolk mass, apply here. In addition, the following characters are of aid in identifying jack-mackerel eggs during this period of development:

Dorsal body pigmentation: Present on specimens soon after blastopore closure; consists of double row of small melanophores on either side of the notochord, originating behind the eyes and extending along most of the length of the body; arched on back of head. Usually some melanophores scattered over back between the double row.

Oil globule pigmentation: A group of discrete melanophores appears on the underside of the oil globule.

Oil globule position: At the periphery of the yolk in a median position between the head and tail region.

Number of myomeres: About 20 can be counted, and it is quite evident that the number will be low. The number of myomeres will correspond to the number of vertebrae.

3. *During the later part of the embryonic development* (fig. 1, *e* and *f*).—Most of the characters listed under the early and intermediate periods of embryonic development still apply. In addition, the following characters are of aid in identifying late-period jack-mackerel eggs:

Oil globule position: No longer median, but now nearer head than anus.

Pigmentation: In addition to the dorsal pigmentation, which arches anteriorly and ends about eight-tenths of the way back on the body, there is an irregular group of ventral melanophores beginning at the anus and extending as far posteriorly as the dorsal pigmentation. Also, embryos nearly ready to hatch often have a number of small, inconspicuous peritoneal melanophores.

Number of myomeres: Most of the myomeres are differentiated, and it can now be quite definitely determined that the number will not exceed 25.

Fin fold: A fairly wide fin fold develops before hatching. It extends around the body from the back of the head to the yolk sac. It lacks pigmentation.

Yolk mass: Segmentation is still evident in the yolk mass. No pigmentation develops on the yolk membrane. In both respects, jack-mackerel eggs differ from those of the Pacific mackerel and hake.

Length of digestive tract: In late-stage jack-mackerel eggs it can be determined that the digestive tract will extend approximately six-tenths of the way back along the body.

Stage of development at hatching: Jack-mackerel eggs hatch in a relatively undeveloped condition: before the mouth is formed, before the eyes are pigmented, or before any fin formation. These features help to separate the eggs of jack mackerel from those of species that have a more extended embryonic development.

The distribution of pigment (including both its presence and absence) is the most important aid in identifying late-period jack-mackerel eggs.

Fishes differ greatly in the amount of development that takes place during the embryonic period of their life history. As a rule, species with demersal eggs have a more protracted embryonic period and hatch at a more advanced stage of development than species with pelagic eggs. But even among pelagic species there is considerable variation in this regard. The jack mackerel, like the sardine, anchovy, hake, Pacific mackerel and many other pelagic species, begins its postembryonic development in a relatively undeveloped condition. It hatches before the mouth is formed, before the eyes are pigmented, and before the pectorals are formed. In contrast, the saury [1] begins its postembryonic development with a functional mouth, pigmented eyes, functional pectorals, and even a developed caudal fin. There are some species with pelagic eggs, including a number of pleuronectids, which are intermediate between the jack mackerel and saury in the amount of development that takes place during the embryonic period.

Species that complete the embryonic development rapidly and in a relatively undifferentiated condition are usually species that spawn a large number of rather small eggs. Although the fecundity of jack mackerel is not known, the female undoubtedly spawns a very large number of eggs.

[1] The saury is considered to have pelagic eggs, even though the eggs occur in clusters held together by filaments. Saury eggs are commonly taken in plankton hauls.

YOLK-SAC LARVAE

(FIGURES 2 and 3)

Because of the rapid differentiation that occurs during the yolk-sac stage, we are discussing this stage of larval development as a separate category.

Size at hatching

Since all observations were made on preserved material, we have not been able to determine exactly the size at hatching. Measurements were made on yolk-sac larvae that had approximately the same amount of yolk material as eggs about ready to hatch; such larvae had a size range of 1.91 to 2.38 mm., with a mean of 2.07 mm. This mean value may be considered to approximate the average size at hatching as determined from preserved material. Not having studied living material, we cannot estimate the amount of shrinkage due to formalin preservation. However, based on personal experience with other fish larvae at the yolk-sac stage, a significant amount of shrinkage on preservation is to be expected, perhaps as much as 20 percent.

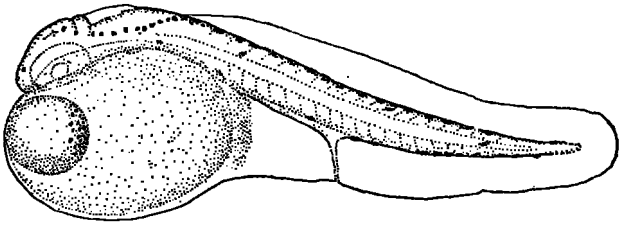

FIGURE 2.—Yolk-sac larva, 2 mm. Soon after hatching.

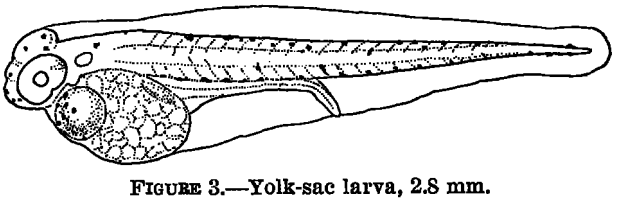

FIGURE 3.—Yolk-sac larva, 2.8 mm.

Size at end of yolk-sac stage

The yolk material has been absorbed by about 75 percent of the larvae by the time they reach 3.25 mm. in length, although one individual 3.8 mm. in length still retained some yolk.

Of the larvae used for measurements, the percentage of larvae retaining yolk material in different size groups was as follows:

Size group	Number examined	Number with yolk	Percentage with yolk
2.00–2.49 mm	8	8	100
2.50–2.99 mm	18	11	61
3.00–3.49 mm	16	4	25
3.50–3.99 mm	15	1	7
4.00–4.49 mm	15	0	0

Oil globule

The oil globule with its associated pigment spots remains fixed in position in the forward part of the yolk sac. In newly hatched larvae it is under the forward part of the head. As the yolk sac contracts, due to absorption of its contents, the oil globule is carried posteriorly to position just forward of, but ventral to, the pectoral bases; however, the globule still retains its anterior position within the yolk sac. It gradually diminishes in size, although a portion of the oil material persists until the end of the yolk-sac stage. The melanophores associated with the oil globule appear to be deposited in the ventral body wall, forming a conspicuous patch just behind the head.

The position of the oil globule within the yolk sac is an aid in the identification of the yolk-sac larva. The forward position of the oil globule has been described in other carangid larvae (Holt 1898, Ehrenbaum 1905, Delsman 1926, Sanzo 1933). The hake and Pacific mackerel are examples of species that have the oil globule in posterior position within the yolk sac. From our observations, the posterior placement of the oil globule is much more common in fish larvae than the anterior position found in most carangids.

Pigmentation at hatching

At hatching, the pigmentation on the jack mackerel larva is mostly confined to the dorsal and ventral margins of the body, and to the peritoneum. The dorsal pigmentation begins in the head region and extends posteriorly for about eight-tenths of the body length. It is similar to the embryonic pigmentation. It consists principally of a double line of dorsal pigment spots, usually parallel, but having a marked lateral arch immediately behind the eyes. There are usually some scattered dorsal melanophores. Peritoneal pigmentation is often present at hatching and soon forms a line of pigment spots along the dorsal surface of the abdominal cavity. The ventral pigmentation, except for that on the oil globule in the yolk sac, occurs behind the anus. It consists of a row of irregularly spaced pigment spots on either side of the body, just above the ventral margin. The ventral pigmentation, like the dorsal, ends some distance before the tip of the notochord. The fin fold neither has pigment at hatching, nor does it acquire any during larval development.

Development during yolk-sac stage

The jack-mackerel larva, on hatching, lacks a mouth, pigment in the eye, and fins of any sort (fig. 2). Other essential organs are in a similarly undeveloped state. Hence the postembryonic differentiation must proceed at a rapid rate during the few days that the yolk-sac larva can subsist on its yolk material.

By the time that the yolk material is absorbed, the development of the structures necessary for seeing, capturing, and utilizing food material has been accomplished, and there has been a similarly rapid differentiation of other essential organs, such as the gills. The eyes may begin to develop pigment in larvae as small as 2.2 mm. Pectoral buds may be observed on larvae about 2.5 mm. in length. These rapidly grow into functional, paired fins with fleshy bases and rather wide fan-shaped membranes without rays. The development of the mouth follows a pattern that we have observed in a number of other pelagic larvae: The lower jaw buds first appear at the posterior corners of the developing mouth and rapidly grow forward.

Ossification begins during the latter part of the yolk-sac stage. Structures containing a high percentage of calcium phosphate stain red with alizarin (Hollister 1934: 94), and we consider ossification to have begun as soon as a bone takes up any amount of alizarin stain. The cleithrum and jawbones are the first structures to ossify. The cleithrum stains with alizarin in some larvae as small as 2.95 mm., and in all larvae over 3.45 mm. in length. The jawbones begin to ossify at about the same time: The upper jaw in larvae between 3 and 3.5 mm. in length, the lower in larvae between 3.2 and 3.8 mm. in length.

LARVAL AND EARLY-JUVENILE STAGES

(FIGURES 4 to 9)

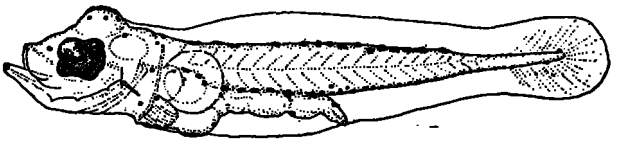

FIGURE 4.—Larva, 3.5 mm.

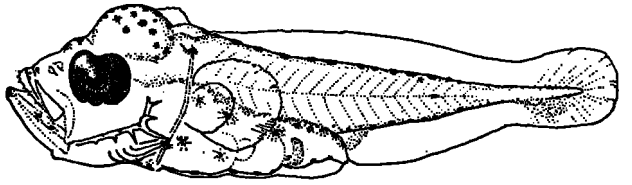

FIGURE 5.—Larva, 4.9 mm., lateral view.

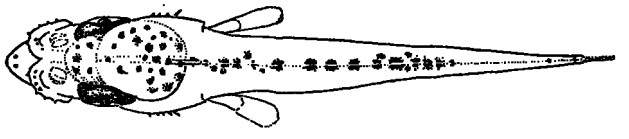

FIGURE 6.—Same specimen as figure 5, dorsal view.

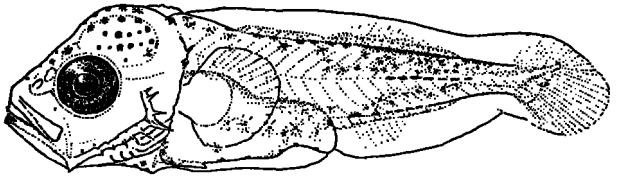

FIGURE 7.—Larva, 7.4 mm.

It has become almost conventional, in papers dealing with larval fish, for the investigator to describe individuals at a few stages in their development. This type of static approach is more or less forced on investigators who are basing their descriptions upon limited material. However, a more systematic investigation of the changes occurring during the larval period can be made when abundant material is at hand. Then, a dynamic approach can be used—the sequence of changes occurring during the larval period can be traced character by character. We have followed the latter approach.

In investigating the changes that occur in development from the time of hatching through the larval period to the early juvenile stage, we have selected at random specimens representative of the size range covered by our material. These specimens have been treated with potassium hydroxide, stained with alizarin and cleared in glycerin. Measurements and counts were made on a total of 182 individuals, and the results are summarized in table 2. The procedures followed in obtaining the measurements and meristic counts are discussed in the Appendix, page 244. An equally large number of unstained specimens were used in studying changes in pigmentation during the larval period.

Larval development will be discussed under the following headings: (1) Pigmentation changes during larval development, (2) changes in body form during larval development, (3) fin formation, and (4) sequence of ossification.

Pigmentation changes during larval development

The only chromatophores that are visible on formalin-preserved eggs and larvae of jack mackerel are melanophores. The pigmentation pattern of jack-mackerel larvae is subject at all sizes to considerable variation in both the amount of pigmentation and the size of individual pigment spots.

Head pigmentation.—There are a few melanophores on the head of the jack-mackerel larva at the end of the yolk-sac stage. The number gradually increases until, on larvae of about 3.5 to 4 mm., a cap of discrete melanophores is present and pigmentation extends forward between the eyes. In addition, a few melanophores are usually present forward of the nostrils and along the lower jaw, with a conspicuous group near the tip of the lower jaw. Pigmentation intensifies during the period of larval development. Lateral pigmentation on

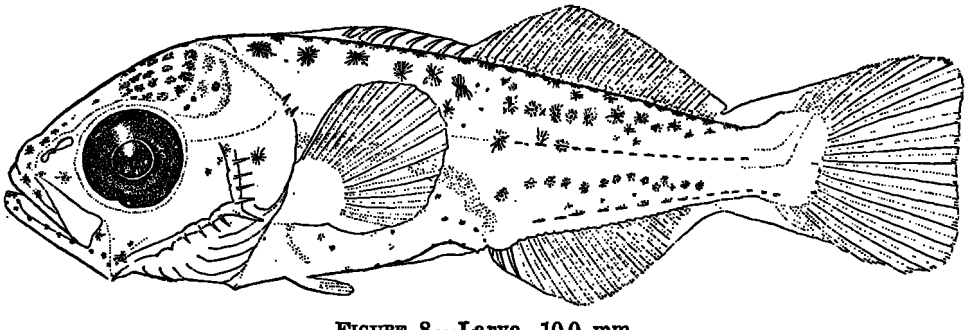

FIGURE 8.—Larva, 10.0 mm.

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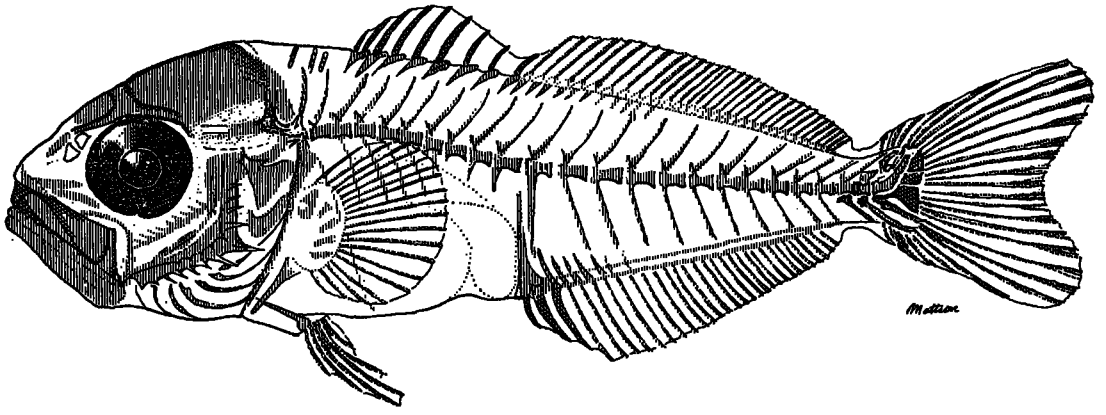

FIGURE 9.—Drawing of a cleared and stained larva, 13.0 mm. in length, showing details of the skeletal structure.

TABLE 2.—*Measurements and meristic counts of 182 jack-mackerel larvae and early juveniles*

[LP=larval pectoral; BF=base forming; F=forming]

Size	Number specimens examined	Average measurements (in mm.)					Meristic counts						
		Standard length	Head	Eye	Snout to anus	Depth	Vertebrae	Caudal [1]	Pectoral	First dorsal	Second dorsal	Anal	Ventral
2.0–2.4 mm	8	2.2		0.19	1.2	Yolk							
2.5–2.9 mm	18	2.8	0.47	.24	1.5	0.46			LP				
3.0–3.4 mm	16	3.2	.66	.30	1.8	.62			LP				
3.5–3.9 mm	15	3.8	.99	.39	2.2	.82			LP				
4.0–4.4 mm	15	4.2	1.25	.46	2.4	1.03		BF	LP				
4.5–4.9 mm	15	4.8	1.52	.54	2.8	1.23		BF	LP		BF	BF	
5.0–5.9 mm	15	5.4	1.65	.60	3.2	1.37	2.6	1.1	LP		BF	BF	
6.0–6.9 mm	15	6.5	2.06	.76	3.8	1.68	17.8	9.2	1.8		BF	[2] 1.4	
7.0–7.9 mm	16	7.5	2.49	.87	4.4	1.93	20.7	15.2	5.6	0 to VI	[2] 6.7	[2] 8.9	Bud.
8.0–8.9 mm	15	8.3	2.82	1.04	5.1	2.32	23.3	16.8	9.8	III to VIII	I, 18.2	[2] 17.8	F.
9.0–9.9 mm	7	9.3	3.23	1.15	5.6	2.58	23.9	17.0	12.2	VI to VIII	I, 22.8	II–I, 18.6	2.2.[2]
10.0–10.9 mm	8	10.6	3.69	1.26	6.3	2.90	24.0	17.0	14.2	VII or VIII	I, 27.3	II–I, 22.6	I, 4.2.
11.0–11.9 mm	2	11.5	4.1	1.40	6.8	3.2	24.0	17.0	15.5	VII or VIII	I, 29.0	II–I, 24.5	I, 5.
12.0–12.9 mm	4	12.2	4.1	1.51	7.0	3.4	24.0	17.0	17.2	VIII	I, 30.8	II–I, 26.5	I, 5.
13.0–13.9 mm	1	13.5	4.8	1.52	8.0	3.6	24.0	17.0	19.0	VIII	I, 30	II–I, 27	I, 5.
14.0–14.9 mm	1	14.4	5.4	1.72	8.6	4.1	24.0	17.0	22.0	VIII	I, 32	II–I, 28	I, 5.
15.0–19.9 mm	4	17.0	5.9	2.09	9.4	4.4	24.0	17.0	20.8	VIII	I, 33.8	II–I, 28.2	I, 5.
20.0–49.9 mm	5	32.1	10.0	3.27	17.4	8.1	24.0	17.0	22.8	VIII	I, 32.8	II–I, 29.4	I, 5.
50.0 mm. and over	2	52.8	14.7	4.50	28.8	12.8	24.0	17.0	21.5	VIII	I, 33.0	II–I, 28.5	I, 5.

[1] Principal caudal rays, i. e., the branched rays and the adjacent unbranched ray on either side.
[2] Spines and rays combined in counts during early differentiation.

the head, however, is usually lacking until the larva reaches about 7 to 8 mm. in length, and is seldom conspicuous even then.

Body pigmentation.—The body pigmentation of jack-mackerel larvae falls naturally into 3 areas:

1. Preanal, including the peritoneal pigmentation, extending from the head to approximately the ninth myomere.

2. Postanal, extending from about the 10th to the 20th myomere, the area of heaviest pigmentation.

3. Caudal peduncle, from about myomere 21 to the tip of the notochord (or base of caudal fin), an area that is inconspicuously pigmented.

Preanal body pigmentation.—At hatching (fig. 2), the pigmentation anterior to a vertical through the anus, which we are calling preanal body pigmentation, is usually confined to the dorsum and to the peritoneal region. Pigment spots do not appear along the median line of the belly until after yolk absorption.

The number of dorsal melanophores decreases soon after hatching. On newly hatched yolk-sac larvae, there is a double line of small melanophores along the back. During the yolk-sac stage, a ventral migration of some of the dorsal melanophores (shown in fig. 3) occurs and probably a coalescence of others. As a result, larvae between 3 and 4.5 mm. (fig. 4) have only 2 to 7 single (not paired) dorsal melanophores in the preanal region. About the time that fin formation commences, there is an increase in the number of dorsal melanophores, and on older larvae the pigmentation spreads laterally (fig. 8). Dorsal pigmentation in the preanal region characteristically is less heavy and

intensifies more slowly than in the region behind the anus.

The peritoneal pigmentation develops most heavily along the dorsal wall. It is present in some embryos before hatching, and is well developed on larvae before the absorption of yolk is completed. Although the peritoneal pigment often gives the impression of forming a solid streak, it is actually made up of discrete melanophores in close contact. The lateral spreading of peritoneal pigments varies markedly from specimen to specimen. Some lateral spreading is found on specimens as small as 4 mm., and at 7 to 8 mm. in length (fig. 7) the lateral melanophores may have spread over most of the abdominal wall. As the larva approaches the juvenile stage, the peritoneal pigmentation becomes less evident, due to the overgrowth of musculature.

Ventral pigmentation along the belly is usually weakly developed. In smaller larvae, ventral pigmentation is often confined to a few melanophores below the pectoral fins. This pigment apparently is derived from the pigment of the oil globule. On older larvae (figs. 5 and 7) a more or less continuous line of pigment spots is present, extending from the isthmus to the anus. There is no tendency toward lateral spreading of the ventral-gut pigment.

Postanal body pigmentation.—The heaviest pigmentation develops in the region posterior to the anus, between approximately the 10th and the 20th myomere. The only ventral pigmentation present at hatching is in this area, and it soon intensifies. The dorsal pigmentation is also more crowded, and there is a more rapid lateral spreading than in the preanal portion of the back (see fig. 7 of 7.4-mm. larva). In larvae about 4 to 4.5 mm. in length, dashes of pigment appear along the lateral midline, at first on only one or two myomeres, but gradually spreading along the length of the body. A somewhat similar pattern of postanal pigmentation, including the lateral-line streak, has been described for several species of carangids, including *Trachurus trachurus* (Ehrenbaum 1905, Schnakenbeck 1931), *Decapterus punctatus* (Hildebrand and Cable 1930), and *Seriola dumerili* (Hildebrand and Cable 1930, Sanzo 1933).

Caudal pigmentation.—The caudal pigment area takes in the posterior portion of the body from approximately the 21st myomere to the tip of the notochord. In older larvae we would term this area the caudal peduncle. Pigmentation is inconspicuous in this area. In fact, unless inspected closely, the caudal area has the appearance of being unpigmented. On closer examination, however, a row of minute, closely spaced melanophores may be seen along the ventral margin and a few scattered melanophores dorsally. After caudal-fin formation, a number of melanophores can be seen along the base of the caudal. Except for the fringe pigmentation, the caudal peduncle remains unpigmented until after fin formation is complete.

During the latter part of the larval period, pigmentation often occurs over most of the head and body of the jack mackerel; however, the melanophores are not uniformly distributed. Dorsal pigmentation is usually better developed than ventral. The areas on which pigment is often sparse or lacking, even on heavily pigmented larvae include: (1) The side of the head, (2) the lower portion of the abdomen just above the ventral pigment line, (3) the sides of the body just above the abdomen, and (4) the caudal peduncle. Except at the base of the caudal, there is no pigmentation on the fins during the larval period.

Pigmentation of juveniles (Figure 10)

In contrast with the pigment areas described for larvae, pigmentation of juveniles is sharply separated into dorsal and ventral areas. The conspicuous line of pigment along the lateral midline of the body separates the heavy dorsal pigmentation from the rather sparse ventral pigmentation. The dorsal melanophores are of several sizes, the larger cells, though scattered, being especially noticeable. The dorsal pigmentation extends from the tip of the snout to the base of the tail. The peritoneal pigmentation can be seen through the overlying musculature, heaviest dorsally, becoming scattered and finally dissipating ventrally.

In addition to the peritoneal markings, there are a number of scattered melanophores over the ventral body surface. Some individuals have very little ventral pigmentation; others have a scattering of large melanophores, most numerous above the anal fin.

The juveniles soon develop pigmentation on the fins, particularly the caudal and dorsal. The caudal membrane develops a line of closely spaced spots which parallel the principal rays. A

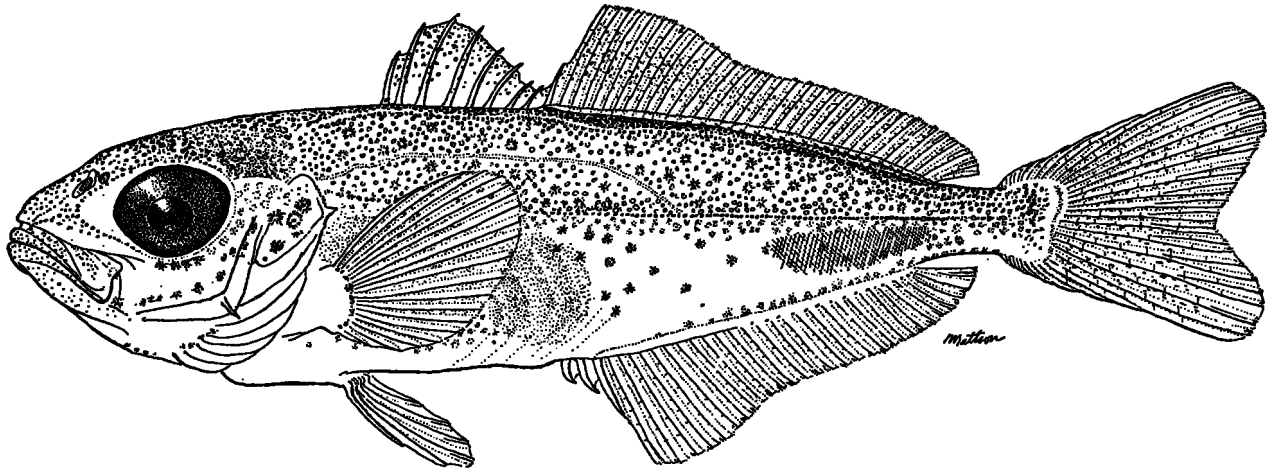

FIGURE 10.—Juvenile, 28 mm.

sprinkling of melanophores appears on the membrane between the spines of the anterior dorsal, especially distally. On the soft dorsal, melanophores first appear on the membrane in the anterior portion, and then spread posteriorly. The anal fin is largely unpigmented, having only a few melanophores near the outer forward margin. The pectorals are lightly pigmented near their dorsal margin. The pelvics are immaculate.

Changes in body form

The most striking changes in body form take place during and soon after the yolk-sac stage of larval development, before the larva attains a length of about 4.2 mm. During this period, the larva changes from the slender-bodied form which it was at hatching to a deep-bodied, stubby form with a large head.

Head.—During the early period of larval development, until approximately 4.2 mm. in length, the head increases in length at a more rapid rate than during later larval development. Two lines can be fitted to a regression of head length on standard length, one applying to larvae up to 4.2 mm. in length, the other to individuals between 4.2 and 17 mm. in length (fig. 11). At 4.2 mm., the head is approximately 1.25 mm. in length. Before attaining this size, the head increases at a rate of 0.56 mm. for each 1-mm. increase in body length; subsequently the head increases at a rate of approximately 0.38 mm. for each 1-mm. increase in body length (see table 3).

Body depth (at pectoral).—There is a correspondingly rapid increase in body depth before a length of 4.2 mm. is attained, and a slower rate of growth thereafter (fig. 12). At 4.2 mm., the body depth (at pectoral) averages 1.03 mm. In individuals smaller than 4.2 mm., the body depth increases at a rate of approximately 0.4 mm. for each 1-mm. increase in body length; subsequently, the depth increases at a rate of approximately 0.28 mm. for each 1-mm. increase in body length (table 3).

TABLE 3.—*Statistics describing regressions of body proportions on standard length for jack-mackerel larvae*

$\bar{x}$=mean of values of x
$\bar{y}$=mean of values of y
N=number of size groups
b=rate of increase of y
a=y-intercept of regression line
$sy{\cdot}x$=standard deviation from regression (standard error of estimate)

Independent variable x	Dependent variable y	Size of larvae	$\bar{x}$	$\bar{y}$	N	b	a	$sy{\cdot}x$
		Mm.						
Standard length	Head length	2.8–4.2	3.50	0.84	4	0.556	−1.104	0.026
Do	do	4.2–17.0	9.63	3.31	13	.378	−.335	.125
Do	Body depth	2.8–4.2	3.50	.73	4	.400	−.652	.027
Do	do	4.2–17.0	9.63	2.60	13	.278	−.080	.113
Do	Eye diameter	2.2–17.0	8.07	.94	17	.127	−.080	.041
Do	Distance from snout to anus	2.2–17.0	8.07	4.71	17	.581	+.020	.181

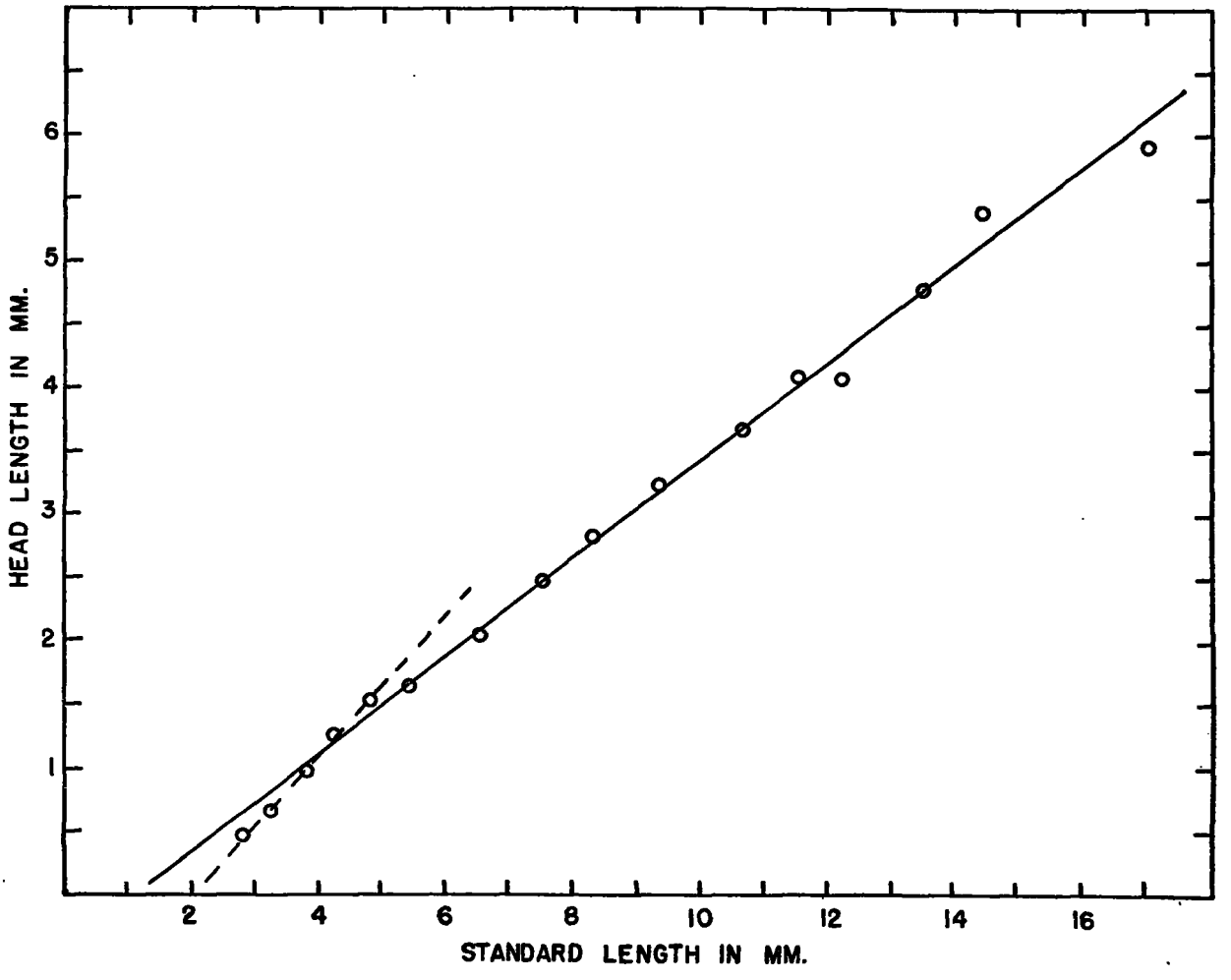

FIGURE 11.—Regression of head length on standard length. Each circle is the average group of measurements, usually 15 (refer to table 2, columns 2, 3, and 4). Two regression lines have been fitted to the data by the method of least squares, one for larvae 2.8 to 4.2 mm. in length, the other for individuals 4.2 to 17 mm. in length. Statistics describing the two lines are given in table 3.

Eye.—Throughout the period of larval development, the rate of increase in eye diameter is proportional to the increase in standard length—the eye increasing 0.127 mm. in length for each 1-mm. increase in standard length. This is shown in figure 13, where eye diameter is plotted against standard length. This relation is obscured by using proportionate measurements, as is so often done in taxonomic and larval studies. For when so expressed, the eye diameter is 8.5 percent of the standard length at hatching, 11 percent of the standard length at 4.2 mm., and over 12 percent of the standard length at 8.3 mm. in length (see table 4). But as we have seen, the eye actually is increasing at a constant increment in relation to standard length, not at a changing rate (some scientists have used such proportions as rates). The difference is due to the circumstance that the y-intercept differs significantly from zero (see in this regard, Marr [in press]). At hatching, the eye is approximately elliptical. Soon after hatching, the eye shape becomes distorted, assuming a somewhat squarish outline. By the time the larva has grown to 5 or 6 mm. in length, the eye usually has assumed the spherical form which it retains throughout its subsequent development. The eye is cleft ventrally.

Distance from snout to anus.—The distance from snout to anus not only increases at a constant rate in relation to standard length (there is an increase of 0.58 mm. in the distance from snout to anus with each 1-mm. increase in standard length) (fig. 14), but a line fitted to the regression of snout to anus on standard length approaches the

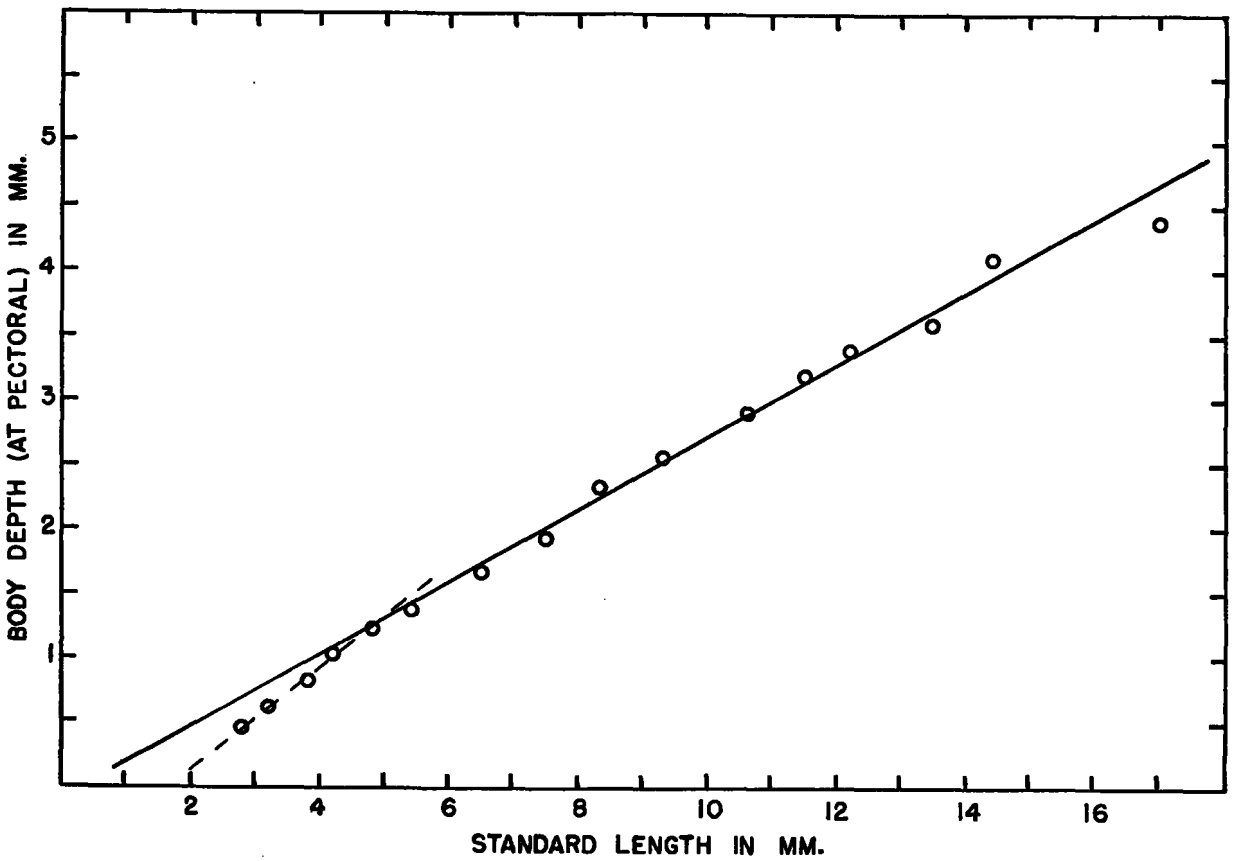

FIGURE 12.—Regression of body depth (at pectoral) on standard length. Each circle is the average of a group of measurements, usually 15 (refer to table 2, columns 2, 3, and 7). Two regression lines have been fitted to the data by the method of least squares, one for larvae 2.8 to 4.2 mm. in length, the other for individuals 4.2 to 17 mm. in length. Statistics describing the two lines are given in table 3.

TABLE 4.—*Body proportions of 182 jack-mackerel larvae and early juveniles*

[Based on values given in table 2, columns 1 through 7]

Size	Standard length	Proportion expressed as percentages of standard length			
		Head	Eye	Pectoral depth	Snout to anus
2.2–2.4 mm	2.2 mm.	----	8.5	----	56.1
2.5–2.9 mm	2.8 mm.	16.7	8.8	16.6	52.9
3.0–3.4 mm	3.2 mm.	20.6	9.2	19.3	55.8
3.5–3.9 mm	3.8 mm.	26.1	10.2	21.6	57.0
4.0–4.4 mm	4.2 mm.	29.8	11.0	24.6	58.2
4.5–4.9 mm	4.8 mm.	31.9	11.3	25.8	59.5
5.0–5.9 mm	5.4 mm.	30.3	11.0	25.1	59.6
6.0–6.9 mm	6.5 mm.	31.6	11.6	25.7	58.8
7.0–7.9 mm	7.5 mm.	33.1	11.6	25.7	59.2
8.0–8.9 mm	8.3 mm.	34.1	12.6	28.0	61.1
9.0–9.9 mm	9.3 mm.	34.6	12.3	27.6	59.7
10.0–10.9 mm	10.6 mm.	34.9	11.9	27.5	59.6
11.0–11.9 mm	11.5 mm.	35.5	12.2	27.8	59.1
12.0–12.9 mm	12.2 mm.	33.7	12.4	27.5	57.4
13.0–13.9 mm	13.5 mm.	35.6	11.3	27.0	59.3
14.0–14.9 mm	14.4 mm.	37.5	11.9	28.5	60.1
15.0–19.9 mm	17.0 mm.	34.6	12.3	26.1	55.2
20.0–49.9 mm	32.1 mm.	31.1	10.2	25.1	54.1
50.0 mm. and over	52.8 mm.	27.8	8.5	24.2	54.6

origin (the y-intercept value is only 0.02). Consequently, even proportionate measurements show a constant rate of increase in distance of snout to anus when related to increase in standard length.

The fins are formed in about the position they will retain during life. There is no marked forward movement of the dorsal fin as there is in the sardine and other clupeid larvae. At formation, the origin of the soft dorsal is immediately above the anus, and it retains this relative position during the larval and juvenile stages.

The digestive tract, conspicuous along the ventral portion of the body during the early larval period, is obscured by overlying tissue by the time the larva has attained approximately 10 mm. in length (fig. 8, 10-mm. larva). There is a single loop in the intestine, particularly noticeable in larvae between about 4 and 6 mm. in length. The air bladder is first noticed in larvae about 3.3 to 3.5 mm. in length. It very rapidly grows into a large conspicuous organ which is located just posterior to the pectoral fin, and in larger larvae is partly obscured by that structure. In larvae about 8.5 to 9 mm. in length, the air bladder be-

comes less evident due to intensification of the overlying musculature.

Fin formation

Fin formation follows a definite sequential pattern in jack-mackerel larvae. At hatching, there is no indication of any fin development. The subsequent development of the larval pectoral fin has already been touched upon. In the caudal area, faint traces suggesting rays can be detected shortly after the appearance of the larval pectoral fin (fig. 4, larva 3.5 mm. long). These striations are actinotrichia, rather than true caudal rays. However, the caudal fin is the first to lay down lepidotrichia (true rays or spines), followed in order by the pectoral, anal, soft dorsal, spinous dorsal, and ventral.

Caudal fin.—The fully formed caudal fin of the jack mackerel has 17 principal (15 branched rays and the adjacent unbranched ray on either side) and approximately 18 to 20 secondary rays. The principal rays are divided into two groups, 9 rays above and 8 below the midline of the body. There are 9 or 10 secondary rays on the dorsal margin of the caudal fin, and an equal number on the ventral margin.

The caudal fin forms in much the same manner as the caudal fin of most fish larvae. A ventral thickening can be observed near the posterior end of the notochord in larvae about 4.5 mm. in length (fig. 5). Rays can be distinguished in larvae between 5 and 6 mm. in length. They form at an oblique angle, and usually the first 4 to 6 rays form simultaneously. These are equally distributed between the two sides of what will be the center of the caudal fin (midline) when formed. Differentiation then proceeds in both directions. All principal rays are ventral in origin.

While the principal rays are being laid down, the urostyle goes through the flexion that brings the principal rays into the terminal position they occupy in the fully formed caudal. The princi-

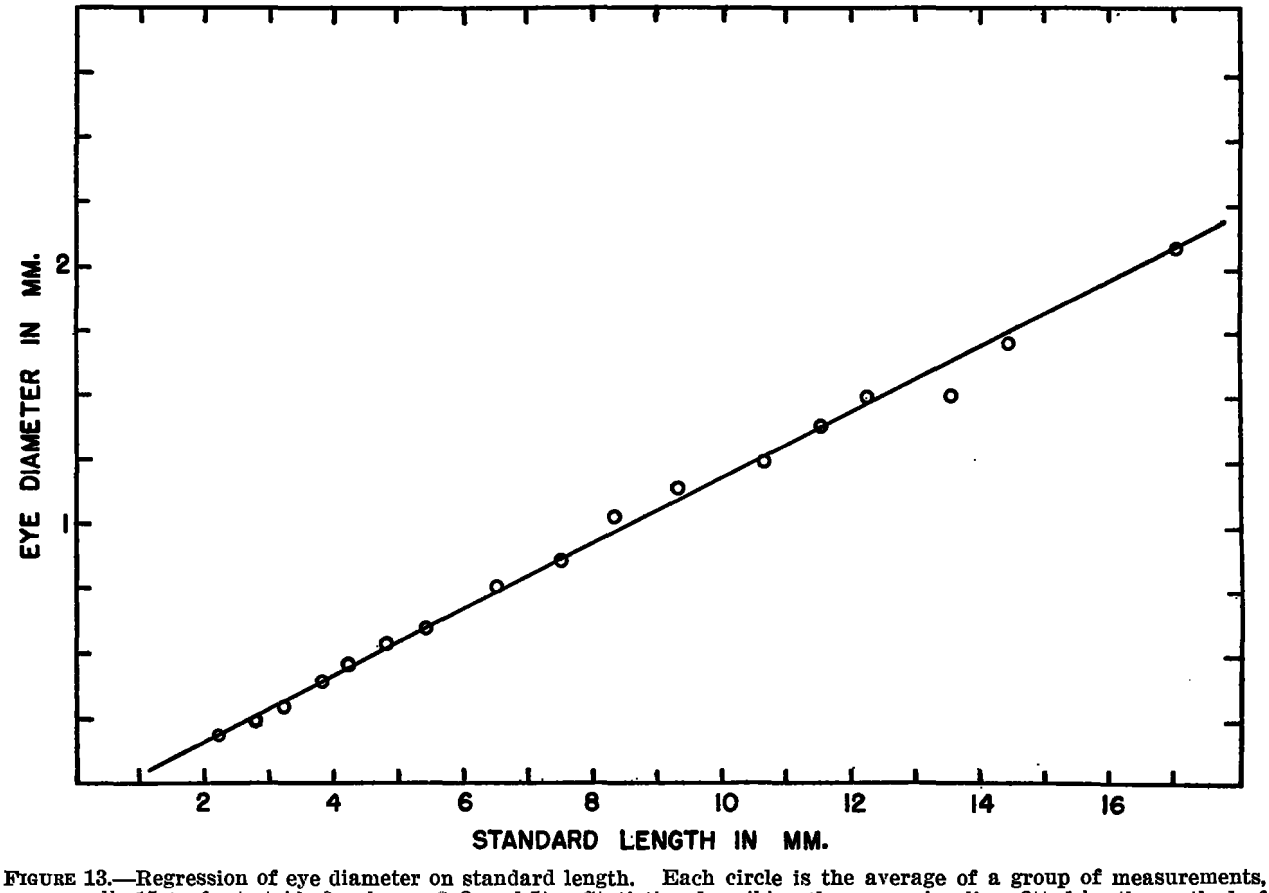

FIGURE 13.—Regression of eye diameter on standard length. Each circle is the average of a group of measurements, usually 15 (refer to table 2, columns 2, 3, and 5). Statistics describing the regression line, fitted by the method of least squares, are given in table 3.

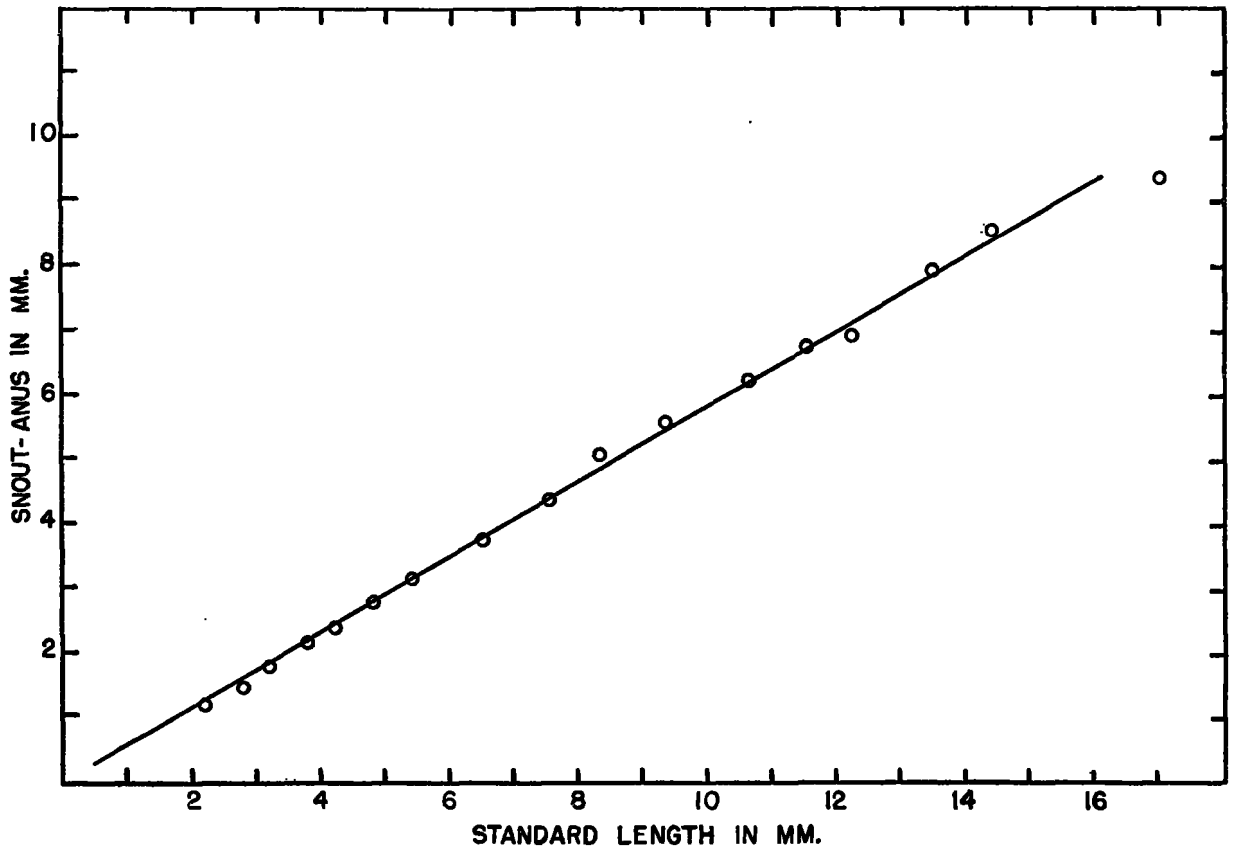

FIGURE 14.—Regression of the distance from snout to anus on standard length. Each circle is the average of a group of measurements, usually 15 (refer to table 2, columns 2, 3, and 6). Statistics describing the regression line, fitted by the method of least squares, are given in table 3.

pal rays are laid down at about 8 mm., but the flexion of the urostyle and development of the hypurals are not completed until about 11 mm. The secondary caudal rays are formed over a longer period, as is shown in the following chart, based on five specimens of selected lengths:

Size of larva	Number secondary dorsal-caudal rays	Principal caudal rays	Number secondary ventral-caudal rays
7.5 mm	0	14	0
8.2 mm	2	17	2
10.6 mm	3	17	4
12.5 mm	6	17	6
15.8 mm	9	17	9

The caudal fin is associated with the last three vertebrae (fig. 15). There are only four dorsal supporting structures, the anterior three being dorsal radials lying above the urostyle.[2] The middle dorsal radial is small and embedded, and does not support secondary caudal fin rays, as do the adjacent dorsal radials. The majority of the secondary fin rays along the dorsal margin are associated with the epural originating from the antepenultimate vertebra. There is no epural originating from the penultimate vertebra; the modified neural spine on this vertebra is expanded at its base but does not extend out for any distance.

There are 6 or 7 hypural elements, one of which would be classed as a ventral radial, and all but two of which are associated with the urostyle. Sixteen of the seventeen principal caudal rays are supported by hypural elements adjacent to the urostyle, and only one by the hypural originating from the penultimate vertebra. All secondary caudal rays along the ventral margin are supported by the anterior two hypurals, which originate from the penultimate and antepenultimate vertebrae.

There is one more hypural element discernible during the larval period than in older jack mack-

[2] We are using the same nomenclature as that given in Whitehouse (1910: 138) and Barrington (1937: 448). It should be noted that this terminology differs from that used by Hollister (1936: 259).

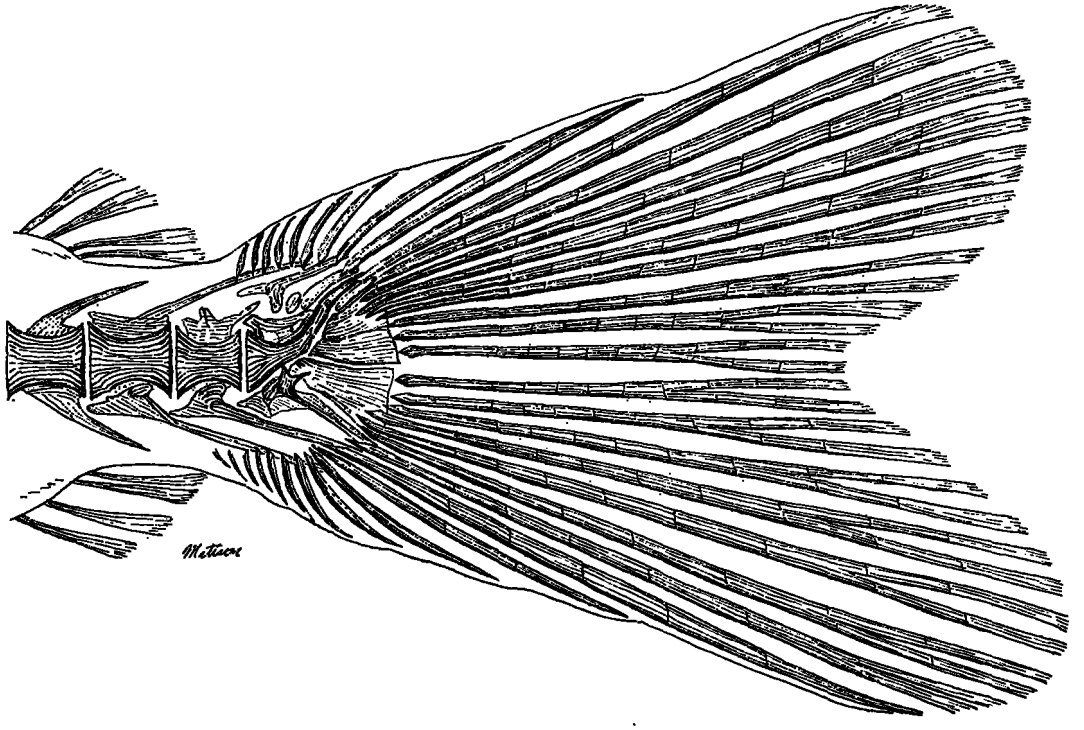

FIGURE 15.—Caudal fin and skeleton of a 24-mm. jack-mackerel larva. The last three rays of the soft dorsal and anal fins also are indicated.

erel. The principal hypural above the midline of the body is formed by the coalescence of two hypural plates, which can be distinguished as separate plates during the larval period.[3] Seven of the nine principal caudal rays above the midline of the body are associated with this hypural. There is a small, inconspicuous hypural located above the hypural just discussed. It is adjacent to the tip of the urostyle, and supports one ray. Six of the eight principal caudal rays below the midline of the body are associated with a single large hypural. A ventral radial completes the complement associated with the urostyle; it supports a single ray. This radial is connected by bony processes to the hypural above and often to the one originating from the penultimate vertebra. There is a bifurcate spine near the base of the radial.

Pectoral fins.—The next fin in which rays form is the pectoral. They are first distinguishable in some specimens about 6 mm. in length. As is usual in pectoral-fin development, the top (dorsal) rays first appear, and then rays are added ventrally. Hence, the bottom ray of the fin is the last to appear. The complete complement of 22 to 24 pectoral rays is usually attained at about 14 mm.

Anal fin.—The base of the anal fin can be observed in some larvae at about 5 mm. in length. Rays first appear in the developing anal fin in larvae between 6.7 and 7.3 mm. in length. The anterior rays take the stain first, then differentiation proceeds posteriorly. The first spine to form is at first indistinguishable from the adjacent rays, but soon differentiates as a spine. All three anal spines may be observed on some larvae as small as 7 mm., and on all larvae 9 mm. and over in length. The anterior of the three anal spines is the last to appear. Ray formation is not complete, however, until the larvae are about 14 mm. long. The full complement of spines and rays in the anal fin is II–I, 28 to 31.

Dorsal fins.—The soft, or second, dorsal fin in the jack mackerel forms before the spinous dorsal. The base of the soft dorsal fin can be seen in some

[3] Schnakenbeck (1931) found a similar sequence in the development of the caudal region of *Trachurus trachurus* (*cf.* his fig. 3). An examination of the caudal region of two other carangids (*Trachinotus* and *Oligoplites*), however, showed that in these species the two hypural plates remained separate in later stages, not coalescing as in the jack mackerel.

larvae of about 5 mm. Rays are evident in specimens about 7 to 7.5 mm. in length. As in the anal fin, the anterior rays appear first, then ray differentiation proceeds posteriorly. By 14 mm., ray formation in the soft dorsal is often complete. The spine at the anterior end of the soft dorsal is at first indistinguishable from the rays, but usually can be distinguished as a spine in specimens of 8 mm. When fully formed, the soft dorsal of our specimens had the formula I, 30 to 35.

The posterior 5 or 6 spines of the spinous, or first, dorsal fin appear almost simultaneously in specimens 7.6 to 8 mm. in length. The anterior 2 or 3 spines develop later, being present in some specimens as small as 10 mm., but not developing in other larvae until 12 mm. or so in length. The spinous dorsal when complete has VIII spines.

Ventral fins.—The bud of the ventral (pelvic) fins can usually be detected under, but slightly posterior to, the pectoral base in larvae 7 mm. in length. The rays may begin to form by 8.5 mm., but in the majority of larvae initial differentiation occurs between 9 and 9.5 mm. The course of differentiation is mesad (toward the midline). By 11 mm., the single spine and 5 rays were present on all specimens examined.

Sequence of ossification

Ossification of skeletal structures, including fin rays and spines, followed approximately the same sequence in all of the jack-mackerel larvae studied. This sequence is summarized in table 5.

Initial ossification has been dealt with briefly in the discussion of larvae in the yolk-sac stage. The cleithrum is the first bone to ossify. This is followed by the upper jawbones (premaxillaries), the lower jawbones, the preopercular spines, and the upper jaw teeth in rapid succession. The branchiostegal rays, branchial arches, and skull bones soon after show ossification. These are followed by the start of vertebral ossification. The beginning of fin-ray differentiation (caudal) occurs at approximately the same time as initial ossification of the vertebral components.

The neural spines of the anterior few vertebrae stain with alizarin in larvae 4.9 to 5.5 mm. in length. Vertebrae ossify progressively posteriorly. The neural spines of abdominal vertebrae and the neural and haemal spines of caudal vertebrae always show ossification before the centra of their respective vertebrae. In specimens 6 to 6.5 mm. in length, the centra of the first 3 or 4 vertebrae will show color, while the remaining 6 or 7 abdominal vertebrae (there are always 10 abdominal vertebrae) will have only their neural spines ossified, and the first 7 or 8 caudal vertebrae (there are almost always 14 caudal vertebrae) will show both neural and haemal spines as being ossified. The centra soon follow, ossifying progressively posteriorly.

TABLE 5.—*Sequence of ossification, exclusive of skull bones*

	Fish size at start	Fish size at finish
	Mm.	*Mm.*
Cleithrum	3–3.5	
Upper jaw	3–3.5	
Lower jaw	3.2–3.8	
Preopercular spines	3.2–3.8	
Teeth (upper jaw)	3.5–4	
Branchiostegals	4.5±	7.
Gill arches	4.5±	7.5–8.
Vertebrae	4.9–5.5	8–9.
Caudal fin	5–6	Approx. 16.
Pectoral fins	6.5–7	Approx. 14.
Anal fin	6.7–7.3	Approx. 14.
Dorsal (soft)	7–7.5	Approx. 14.
Gill rakers	7.5±	>40.
Dorsal (spinous)	7.6–8	10.0–12.
Ventral fins	9–9.5	11.
Teeth (lower jaw)	Approx. 17	
Scales	19–21	35.

The urostyle begins ossifying before the 2 or 3 vertebrae anterior to it. The urostyle first takes stain at its anterior base (at about 7.5 to 7.8 mm. in length) and then ossification progresses toward its distal tip. Simultaneously, the hypurals show evidence of ossification. All vertebrae usually are ossified in specimens 9 mm. in length. Details of skeletal structure are shown in figure 9.

The branchiostegals begin to ossify when the larva is about 4.5 mm. in length, and the process is usually complete by the time the larva reaches 7 mm. When fully formed, the number of branchiostegals is invariably 7 on a side.

The gill arches show ossification at about the same stage in development as the branchiostegals, beginning at approximately 4.5 mm. in length. The initial ossification of the arches is apparently complete at about 7.5 to 8 mm. Gill rakers can be observed on specimens between 7 and 8 mm. in length. The gill-raker counts on 8 specimens of selected sizes were as follows:

Size of specimen	Upper limb of first gill arch	Lower limb of first gill arch
7.0 mm	0	0
7.5 mm	0	10
8.5 mm	0	12
10.0 mm	0	16
15.5 mm	5	23
19.0 mm	7	26
33.5 mm	11	33
40.0 mm	12	35

By the end of the larval period (16 mm.), over 20 gill rakers are developed on the lower limb of the first gill arch, and 5 or 6 on the upper limb. A 40-mm. juvenile had several less rakers on each limb than the full complement, which, according to Roedel and Fitch (1952), should average 15 (13 to 18) on the upper limb, and 41 (37 to 45) on the lower limb of the first gill arch.

Larval armature of the gill cover occurs in a number of teleost groups. In the jack mackerel, the armature consists of spines that form on the rear edge of the preoperculum and on the preopercular crest, a ridge immediately anterior to the edge of the preoperculum. The spines on the edge of the preoperculum are larger, stronger, and more numerous than those on the preopercular crest. At the rear edge of the preoperculum, a corner spine, the largest and strongest, develops at approximately 3.5 mm. in length. Soon after the ossification of this spine, additional spines appear along the ascending and the anterior edges of the preoperculum. The spines increase in size and number during larval development, as many as 4 forming along the ascending edge and 7 along the horizontal edge. On the preopercular crest the spines are usually small and about equal in size; these usually consist of a single spine, rarely 2, on the ascending edge, and 4 to 6 along the horizontal edge. Soon after reaching the juvenile stage (i. e., in individuals more than about 16 mm. in length), the armature becomes less conspicuous. The disappearance of the preopercular spines appears to result from tissue filling in between the spines. In larvae 50 mm. in length, only the corner spine is noticeable.

Two or three small spines form on the upper edge of the operculum at about 5 mm. in length. They are inconspicuous, and may easily be overlooked. They persist until the juvenile stage. A more conspicuous feature, especially in stained material, is a serrated dorsal ridge or crest at the back of the head. It is most noticeable in larvae of about 4 to 8 mm. (figs. 5 and 7).

Teeth are usually observable in specimens of 3.5 to 4 mm. in length, and occasionally on smaller specimens. They first form as a row of minute teeth along the entire length of the upper jaw. By 5 to 6 mm. in length, the larvae have from 16 to 20 teeth in the upper jaw. Teeth do not appear in the lower jaw until the juvenile stage is reached. Individuals of about 17 mm. acquire a group of small teeth near the symphysis of the mandible. By 19 mm., a row of minute teeth is usually present along the lower jaw, similar in size and number to those of the upper jaw. By approximately 35 mm. in length, the dentition of the upper jaw shows signs of disintegrating, and by 50 mm. in length (these sizes are only approximate), the teeth have completely disappeared. The lower jaw teeth still persist in 50-mm. individuals.

The scales that first develop are the small scutes along the lateral line in the caudal peduncle area. These can be observed in juveniles as small as 19 to 21 mm. in length. On specimens 28 mm. long, the scutes along the posterior portion of the lateral line are better developed than those in the forward arched portion, while minute body scales are forming in the caudal peduncle area. On individuals 35 mm. in length, both the lateral-line scutes and body scales are well developed.

LARVAL DISTRIBUTION AND ABUNDANCE, 1950 AND 1951

Inasmuch as the jack-mackerel eggs taken in our samples have not been routinely identified and tabulated, while the larvae have been, the discussion that follows is based entirely on the distribution and abundance of larvae.

The basic data on abundance of jack-mackerel larvae during 1950 and 1951 have been published.[4] Approximately the same area was surveyed during the 2 years (figs. 16 and 17), although the 1951 coverage was somewhat more intensive, especially off Baja California, and was continued over a longer period. A total of 925 plankton hauls was obtained on the 8 routine survey cruises of 1950, distributed as follows: 367 hauls north of Point Conception (lines 20–77), 352 off southern California and adjacent Baja California (between Point Conception and Ensenada, Baja California,

[4] A record of the number of jack-mackerel larvae taken in individual plankton hauls during the 8 survey cruises of 1950 is given in Ahlstrom (1952, pp. 49–51) and a similar tabulation for the 12 survey cruises of 1951 in Ahlstrom (1953, pp. 42–44).

lines 80–100), and 206 off central Baja California (lines 110–130). A total of 1,440 plankton hauls was obtained on the 12 survey cruises of 1951, distributed as follows: 288 hauls north of Point Conception (lines 40–77), 597 hauls off southern California and adjacent Baja California (lines 80–107), 466 off central Baja California (lines 110–137), and 89 off southern Baja California. The difference in coverage during the 2 years should not affect the comparative value of the data. This information is summarized by months in table 6.

TABLE 6.—*Summary of monthly hauls and take of jack-mackerel larvae in survey area, 1950 and 1951*

	1950					1951				
	Number of hauls	Number of hauls taking jack mackerel	Percent of successful hauls	Estimated number of larvae in survey area	Percent of total taken monthly	Number of hauls	Number of hauls taking jack mackerel	Percent of successful hauls	Estimated number of larvae in survey area	Percent of total taken monthly
				Billions					*Billions*	
January						125	1	1	1	<0.1
February	114	4	4	14	0.1	98	12	12	212	1.6
March	111	20	18	1,871	10.4	[1] 107	66	62	3,789	28.0
April	125	50	40	4,880	27.1	138	89	64	4,913	36.3
May	129	74	57	6,996	38.9	127	61	48	1,165	8.6
June	106	49	46	2,020	11.2	[1] 136	85	63	3,137	23.2
July	140	53	38	2,127	11.8	109	37	34	228	1.7
August	93	12	13	56	.3	129	21	16	81	.6
September	107	7	7	21	.1	[1] 112	1	1	5	<.1
October	[2]					116	2	2	2	<.1
November	[2]					89	3	3	8	.1
December						65	0	0	0	0
Total	925	269	29	17,985	99.9	1,351	378	28	13,541	100.1

[1] 89 hauls taken off southern Baja California during March, June, and September, 1951, are not included.
[2] Hauls taken on special cruises made during October and November 1950 are not included.

Although the 1950 survey cruises covered only an 8-month period, February through September, they effectively bracketed the complete spawning season of the jack mackerel. Only 0.09 percent of the larvae collected during 1951 was taken during the 4 months not surveyed in 1950. With regard to the southward extension of coverage during 1951 below Point Abreojos, Baja California, this proved of no importance in the jack-mackerel study, save to show the almost complete absence of jack-mackerel larvae in the area. Although the coverage in some parts of the jack-mackerel spawning range was more intensive during 1951, especially in the area between Ensenada and Cedros Island, Baja California, this has been compensated for by our method of integration in space. Hence, the data of the 2 years should be comparable.

DISTRIBUTION

Jack-mackerel larvae were taken in greatest abundance off southern California and adjacent Baja California (between Point Conception and San Quintin, station lines 80–107). Approximately 80 percent of the jack-mackerel larvae collected during both 1950 and 1951 were taken in this area (figs. 18 and 19). Abundance of larvae falls off sharply both to the north and to the south of this area. The monthly abundance is summarized latitudinally in table 7. The values given in this table constitute an estimate of the total number of jack-mackerel larvae in different portions of the survey area at the time of each cruise, hence are comparable from month to month and year to year. From this table is derived table 8, giving the percent of the season total of jack-mackerel larvae taken in different areas month by month. These data are shown graphically in figure 20.

The center of distribution of jack-mackerel larvae differed somewhat during the 2 years, being more southerly in 1950. The area of greatest abundance of jack mackerel during 1950 centered off San Diego, while in 1951 it was just south of Point Conception. The northward shift in 1951 is shown also by the much larger number of jack-mackerel larvae being taken north of Point Conception—approximately 15 percent of the season total, as compared to 6½ percent during 1950; and by the lower percentage being taken off central Baja California—6⅔ percent of the season total in 1951, as compared to 11⅔ percent in 1950.

An estimate of the number of jack-mackerel larvae in the survey area at the time of each cruise is summarized in tables 6 and 7. The summation of the several cruises gives a comparable figure for the 2 years, although it is not an estimate of the

TABLE 7.—*Estimate of number of jack-mackerel larvae in survey area during each cruise, 1950 and 1951.*

[In billions. Estimates of abundance are monthly census estimates; see Appendix, p. 243, for explanation]

	January	February	March	April	May	June	July	August	September	October	November	December	Total
1950													
North of line 60		0	0	0	0	5	4	0	14				23
Lines 60–67		0	0	0	0	365	42	14	0				421
70–77		0	7	5	142	354	221	8	0	0			737
80–87		1	0	954	2,766	406	255	17					4,399
90–97		12	166	1,575	2,066	879	451	17	2				5,168
100–107		0	1,101	1,289	1,592		1,136		3				5,121
110–117		0	8	884	285	2	7		2				1,188
Line 120 and south		1	589	173	145	9	11		0		0		928
Total		14	1,871	4,880	6,996	2,020	2,127	56	21	0	0		17,985
1951													
North of line 60							0	13					13
Lines 60–67	0			38	0	77	18	0	0	0	0	0	133
70–77	0			86	8	1,748	30	0	0	0	0	0	1,872
80–87	0	99	1,461	2,617	13	845	15	8	0	0	0	0	5,058
90–97	0	113	1,061	1,131	376	320	42	45	0	1	6	0	3,095
100–107	1	0	1,050	522	694	95	79	13	5	1	2	0	2,462
110–117	0	0	125	465	60	30	21	2	0	0	0	0	703
Line 120 and south	0	0	92	54	14	22	23	0	0	0	0	0	205
Total	1	212	3,789	4,913	1,165	3,137	228	81	5	2	8	0	13,541

TABLE 8.—*Monthly take of jack-mackerel larvae by areas expressed as percent of the yearly total, 1950 and 1951*

[Estimates of abundance are monthly census estimates; see Appendix, p. 243, for explanation]

	January	February	March	April	May	June	July	August	September	October	November	December	Total
1950													
North of line 60		0	0	0	0	0.03	0.02	0	0.08				0.13
Lines 60–67		0	0	0	0	2.03	.23	0.08	0				2.34
70–77		0	0.04	0.03	0.79	1.97	1.23	.05	0	0			4.11
80–87		0.01	0	5.31	15.38	2.26	1.42	.09					24.47
90–97		.07	.92	8.76	11.49	4.89	2.51	.10	.01				28.75
100–107		0	6.12	7.17	8.85		6.32		.02				28.48
110–117		0	.04	4.91	1.59	.01	.04		.01				6.60
Line 120 and south		.01	3.28	.96	.81	.05	.06		0		0		5.17
Total		.09	10.40	27.14	38.91	11.24	11.83	.32	.12	0	0		100.05
1951													
North of line 60							0	.10					.10
Lines 60–67	0			.28	0	.57	.13	0	0	0	0	0	.98
70–77	0			.63	.06	12.90	.22	0	0	0	0	0	13.81
80–87	0	.73	10.79	19.32	.10	6.24	.11	.06	0	0	0	0	37.35
90–97	0	.84	7.84	8.35	2.78	2.36	.31	.33	0	0.01	0.05	0	22.87
100–107	.01	0	7.75	3.85	5.13	.70	.58	.10	.04	.01	.01	0	18.18
110–117	0	0	.02	3.43	.44	.23	.16	.01	0	0	0	0	5.18
Line 120 and south	0	0	.68	.40	.10	.16	.17	0	0	0	0	0	1.51
Total	0.01	1.57	27.98	36.27	8.61	23.15	1.68	.60	.04	.02	.06	0	99.99

total number of larvae in the area during the year. The estimate for 1950 is a third higher than for 1951. Inasmuch as there is an undetermined but, undoubtedly, fairly large error of estimate connected with these values, this difference may not be significant.

Jack-mackerel larvae occur at considerable distances from shore; in fact, the center of their abundance appears to be between 80 and 240 miles offshore. Further, the larvae are taken as far seaward as we have gone on survey cruises. A summary of the abundance of jack-mackerel larvae in relation to distance from shore follows:

Distance from shore	1950	1951
	Percent of season's total	Percent of season's total
40 miles or less	2.3	4.0
41–80 miles	4.9	8.6
81–120 miles	7.8	18.9
121–160 miles	18.6	20.0
161–200 miles	32.5	19.6
201–240 miles	11.6	16.1
241–280 miles	9.6	4.1
281–320 miles	9.7	6.6
321–360 miles	2.7	.9
361–400 miles	.3	1.2
Total	100.0	100.0

These data are illustrated graphically in figure 21. A more detailed summary is given in table 9.

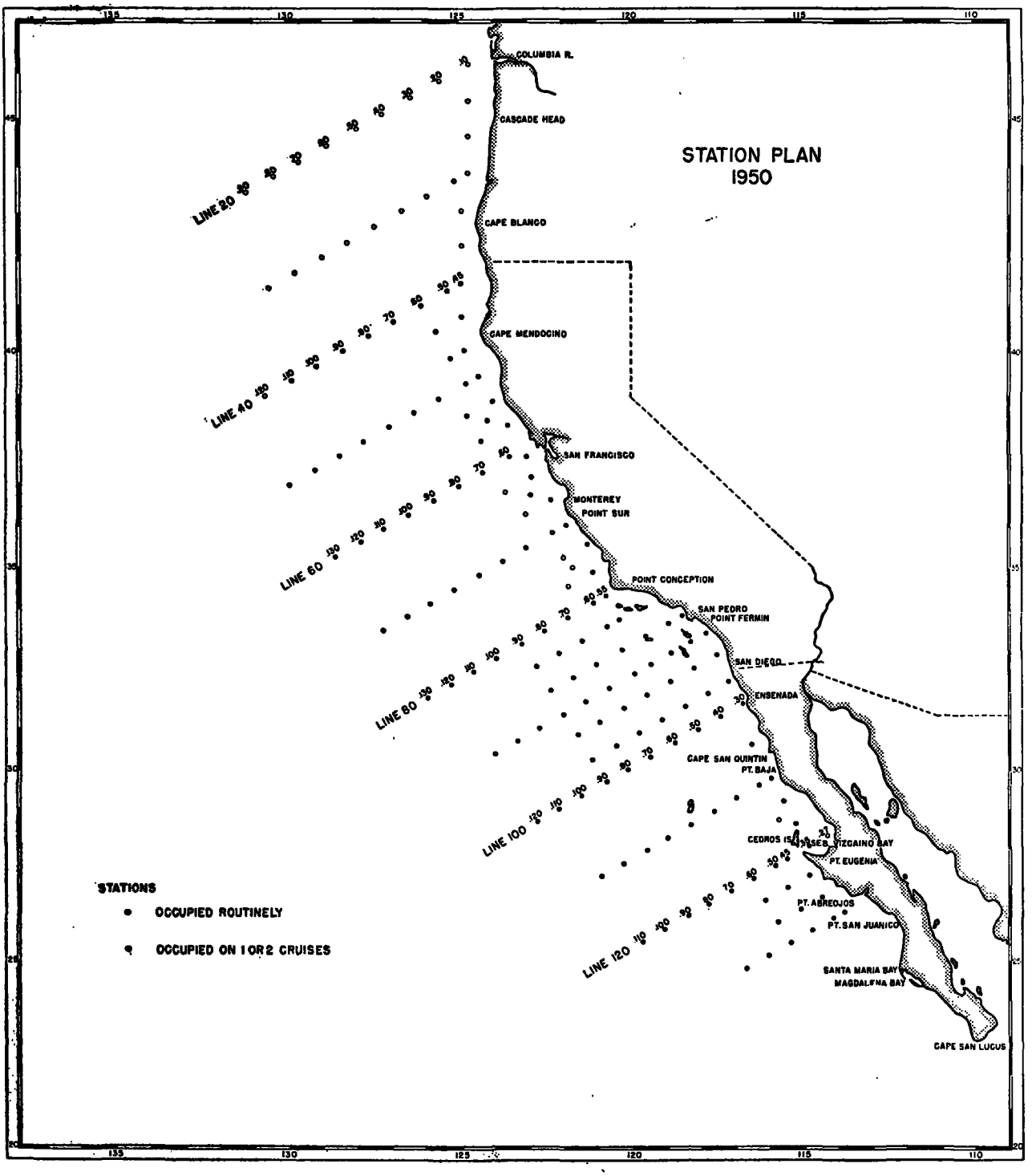

FIGURE 16.—Location of stations occupied during survey cruises made in 1950.

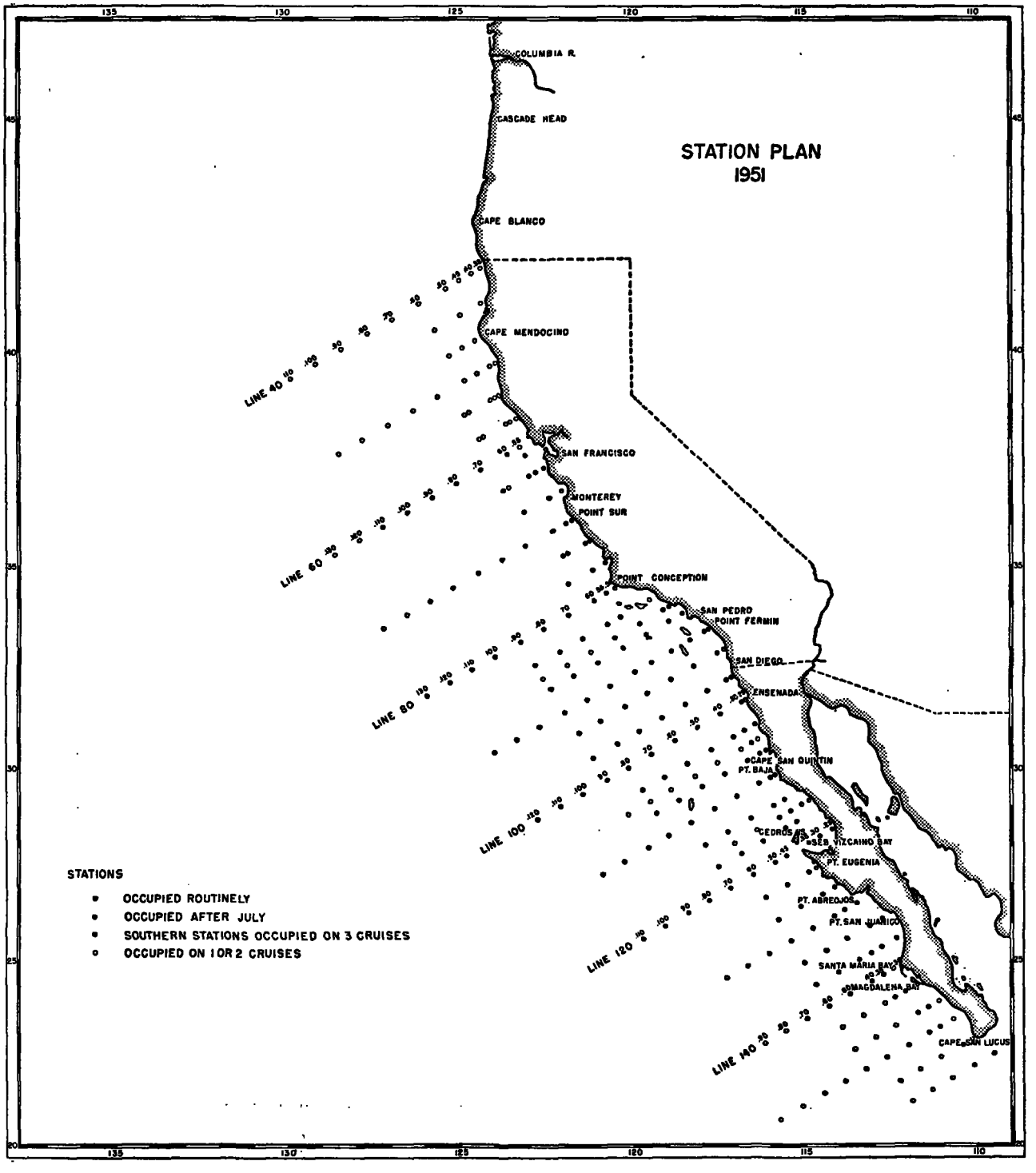

FIGURE 17.—Location of stations occupied during survey cruises made in 1951.

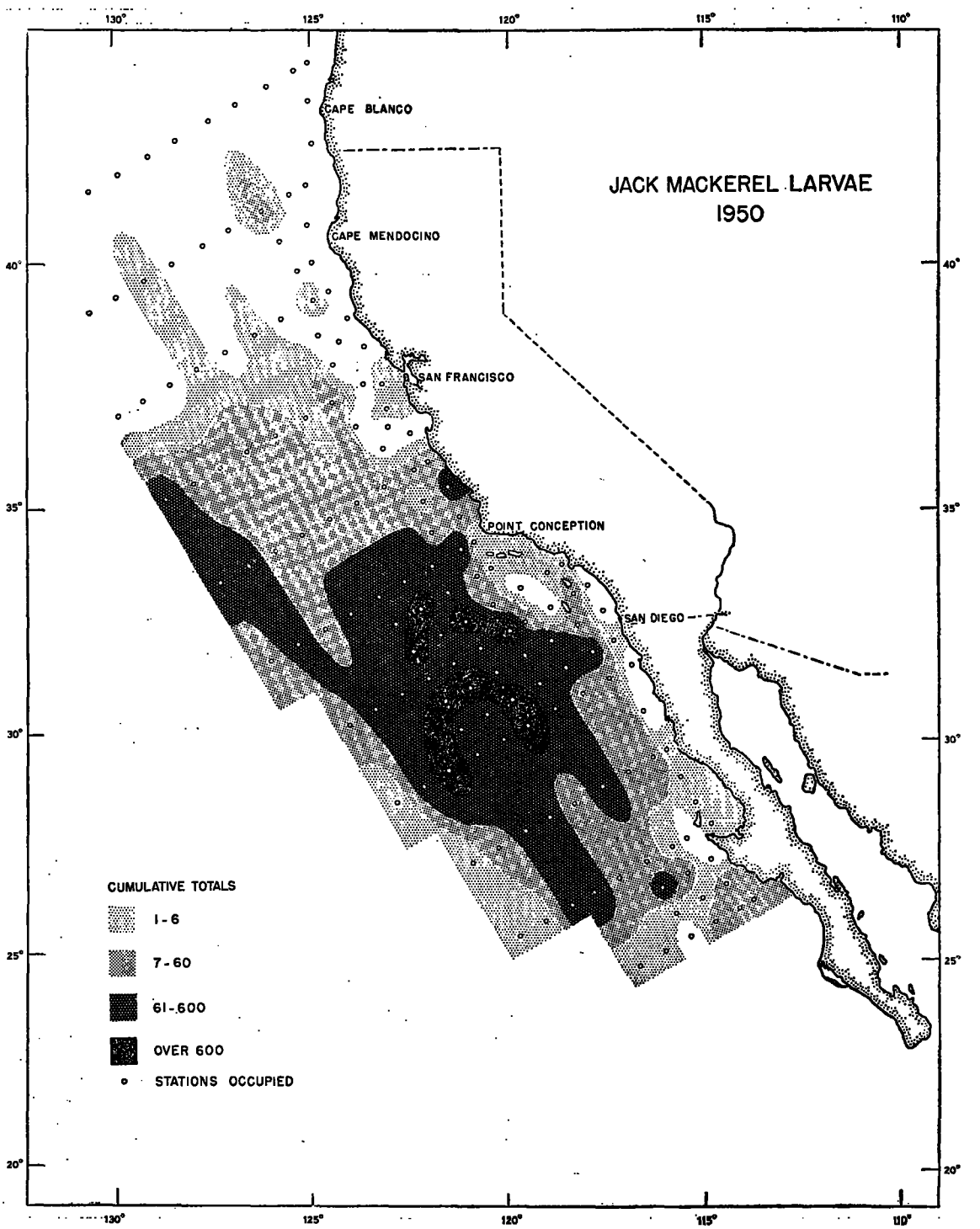

FIGURE 18.—Distribution and abundance of jack-mackerel larvae during 1950.

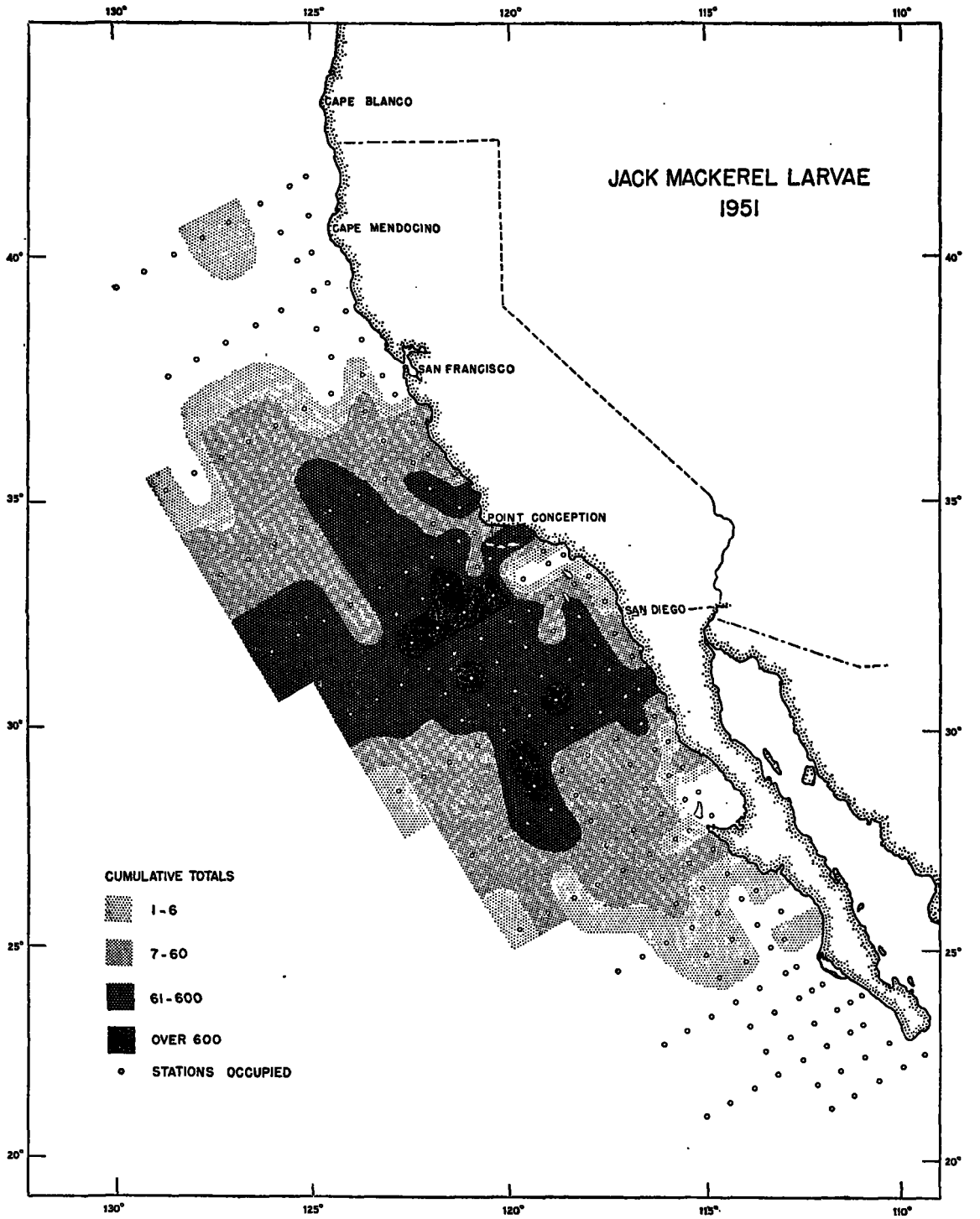

FIGURE 19.—Distribution and abundance of jack-mackerel larvae during 1951.

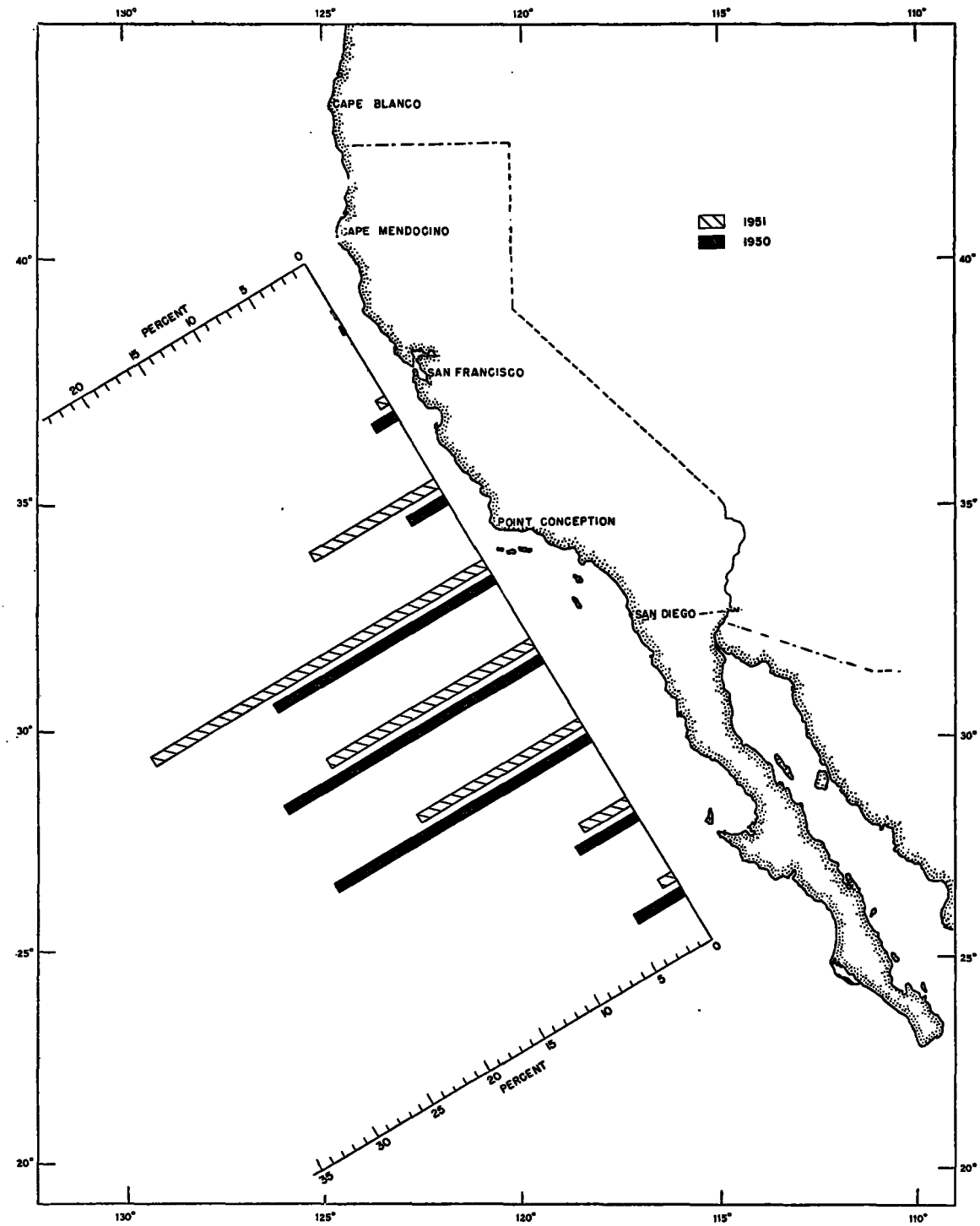

FIGURE 20.—Relative abundance of jack-mackerel larvae in different portions of the survey area during 1950 and 1951, grouped to show north-south distribution. The station lines included in each area are listed in the first column of table 8, the percentage values in the last column of table 8.

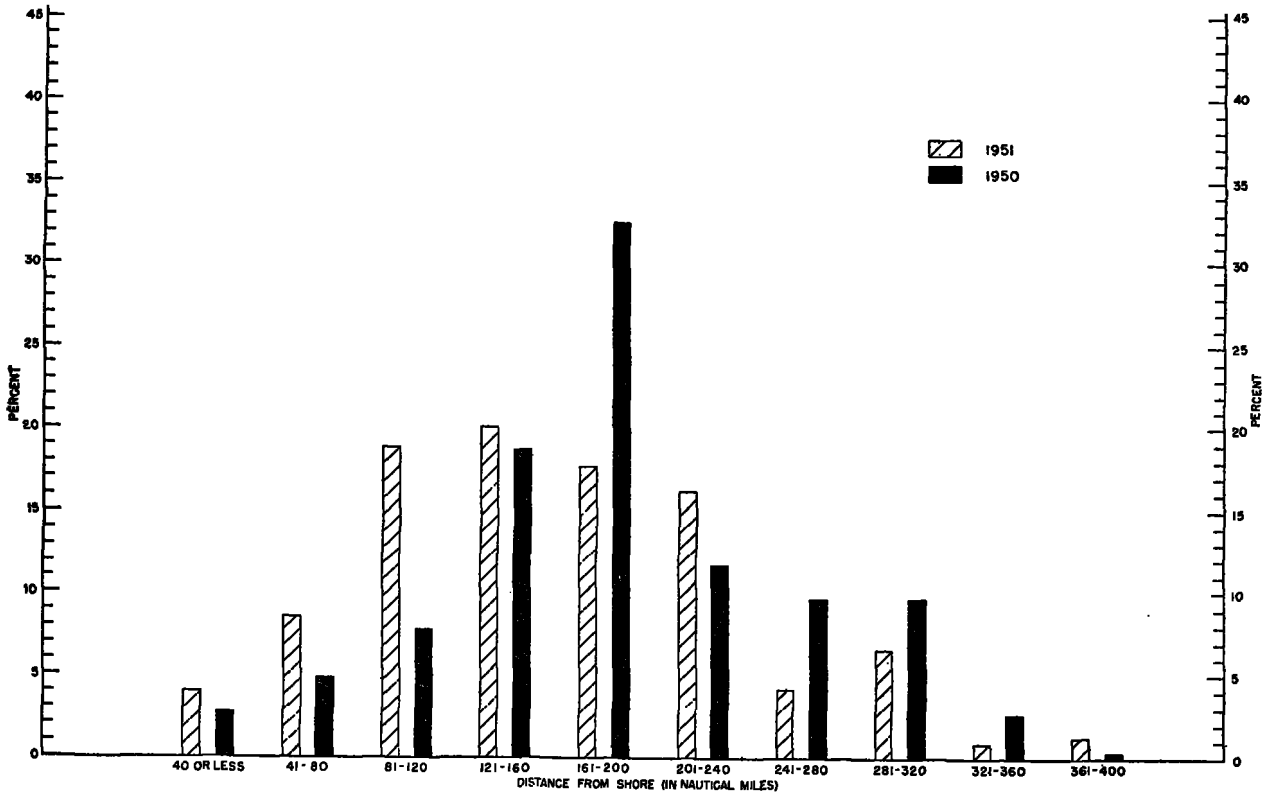

FIGURE 21.—The relative abundance of jack-mackerel larvae in relation to distance from shore, grouped by 40-mile intervals. The percentage values are derived from the data given in table 9.

TABLE 9.—*Abundance of jack-mackerel larvae during survey cruises in relation to distance from shore, 1950 and 1951*

[In billions. Estimates of abundance are monthly census estimates; see Appendix, p. 243, for explanation]

	Number of larvae at a distance from shore of—										Estimated total
	40 or fewer miles	41–80 miles	81–120 miles	121–160 miles	161–200 miles	201–240 miles	241–280 miles	281–320 miles	321–360 miles	361–400 miles	
1950											
January [1]											
February	1	0	0	1	0	12	0	0	0	0	14
March	5	1	2	208	519	147	721	261	7	0	1,871
April	65	192	204	670	2,037	949	272	285	168	38	4,880
May	122	309	982	1,710	1,602	760	488	777	241	5	6,996
June	41	188	144	252	573	142	234	411	35	0	2,020
July	148	154	58	503	1,127	67	3	8	43	16	2,127
August	6	38	3	1	3	5	0	0	0	0	56
September	2	0	9	0	0	3	7	0	0	0	21
October [1]											
November [1]											
December [1]											
Total	390	882	1,402	3,345	5,861	2,085	1,725	1,742	494	59	17,985
1951											
January	0	0	1	0	0	0	0	0	0	0	1
February	2	135	44	6	8	16	1	0	0	0	212
March	301	526	367	372	1,089	406	181	488	41	18	3,789
April	84	164	615	785	1,297	1,432	244	183	56	53	4,913
May	23	59	108	589	57	84	64	74	13	94	1,165
June	112	242	1,387	891	164	182	56	91	12	0	3,137
July	17	24	31	50	21	38	3	41	3	0	228
August	4	12	5	20	12	18	0	10	0	0	81
September	0	0	0	0	5	0	0	0	0	0	5
October	2	0	0	0	0	0	0	0	0	0	2
November	0	6	2	0	0	0	0	0	0	0	8
December	0	0	0	0	0	0	0	0	0	0	0
Total	545	1,168	2,560	2,713	2,653	2,176	549	887	125	165	13,541

[1] No survey cruise during month.

Although the pattern of offshore distribution is similar during the two seasons, there is about as great a difference between the two seasons in this feature as in the latitudinal distribution of the larvae. Jack-mackerel larvae were taken closer to shore in 1951 than in 1950. Over half of the larvae were taken within 160 miles of the coast in 1951; only about one-third during 1950.

SEASON OF OCCURRENCE

Jack-mackerel larvae were taken in greatest abundance during the 5-month period, March through July. In 1950, about 99.5 percent of jack-mackerel larvae were taken during this period, and in 1951 about 98 percent of the larvae. The peak in the abundance of larvae was reached in April of 1951, a month earlier than in 1950 (fig. 24). Whether spawning was actually a whole calendar month earlier during 1951, or only 2 or 3 weeks, cannot be determined from our data, since our sampling is spaced at monthly intervals. Not only jack-mackerel larvae, but hake larvae as well, reached the peak of abundance a month earlier in 1951.

A study of water temperatures off southern California and Baja California during the late winter and early spring months revealed somewhat warmer temperatures in the upper 50 meters in 1951, as compared with 1950. In the area between Point Conception and Point Abreojos, the average temperature of the upper 50-meter stratum was 0.49° C. higher during the 3-month period, February through April, 1951, than during the corresponding period of 1950. This was associated with less intense upwelling during the first third of 1951. The earlier onset of spawning in 1951 was probably related to the warmer conditions prevailing during that season.

The monthly distribution and abundance of jack-mackerel larvae during February through August of each year are shown in figures 22 through 28.

RELATION OF DISTRIBUTION TO TEMPERATURE

Over what temperature range do jack-mackerel larvae occur? Inasmuch as the depth distribution of the larvae is imperfectly known, it is difficult to determine this with any degree of precision. Accepting the data we have on depth distribution as typical, that jack-mackerel larvae occur mostly within the upper 50-meter stratum with the largest concentrations at about 20 meters' depth, we are using temperature values at 20 meters.

Jack-mackerel larvae were taken over a fairly wide temperature range: from 10° to 19.5° C. However, over 70 percent of the larger concentrations of larvae (50 or more larvae per standard haul) occurred within a 2° range: 14° to 16° C. The temperature distribution of jack-mackerel larvae was very similar for successive seasons, 1950 through 1952. The data are summarized in table 10.

TABLE 10.—*Temperature distribution of jack-mackerel larvae, 1950 to 1952*

[Larvae grouped according to abundance per standard haul]

Temperature at 20 meters	Number of samples containing—															
	1–10 larvae				11–50 larvae				51–100 larvae				101 larvae and more			
	1950	1951	1952	Total	1950	1951	1952	Total	1950	1951	1952	Total	1950	1951	1952	Total
° C.																
10.01–10.50	1			1												
10.51–11.00		1		1												
11.01–11.50		2		2												
11.51–12.00	1	1		2	1			1	1			1				
12.01–12.50	3	5		8		4	1	5		1		1				
12.51–13.00	6	3		9	2	4		6		1		1	1			1
13.01–13.50	9	9	3	21	5	7	4	16	3	1	1	5	2	1		3
13.51–14.00	7	8	7	22	6	11	4	21	4	4	1	9	9	6	3	18
14.01–14.50	5	17	6	28	9	8	11	28	2	3		5	12	9	4	25
14.51–15.00	11	12	11	34	10	11	10	31	4	4	6	14	7	8	10	25
15.01–15.50	11	18	10	39	7	12	10	29	7	3	4	14	11	7	3	21
15.51–16.00	9	24	6	39	10	18	17	45	2	3	6	11	8	7	6	21
16.01–16.50	22	26	11	59	11	9	11	31	3	1	4	8			4	4
16.51–17.00	12	20	5	37	1	10	6	17	2		1	3			1	1
17.01–17.50	8	9	2	19	1	3	1	5								
17.51–18.00	8	6	2	16		2		2								
18.01–18.50	4	5		9												
18.51–19.00	3	2		5												
19.01–19.50						1		1								
19.51–20.00																
Total	120	168	63	351	63	100	75	238	28	21	23	72	50	38	31	119

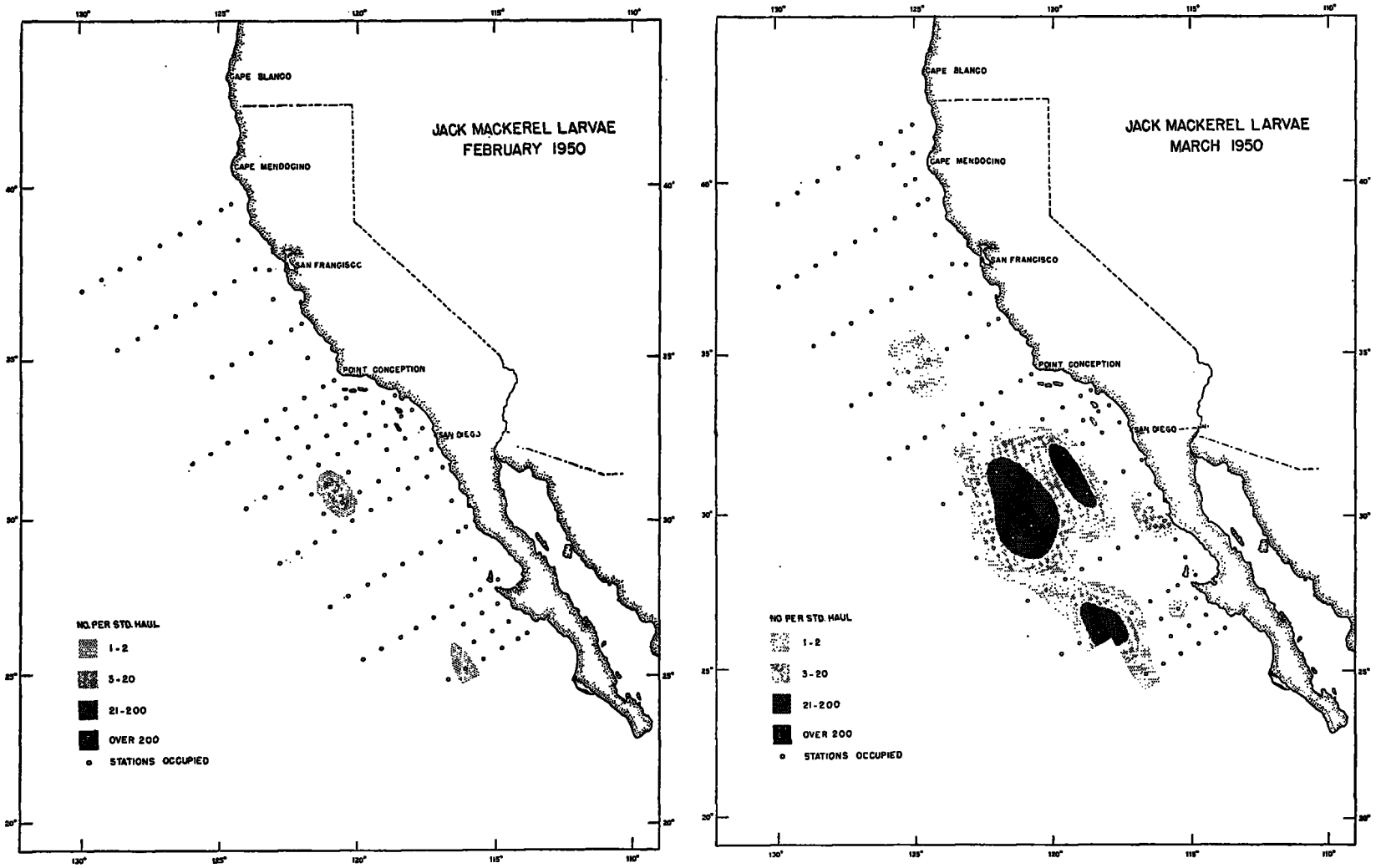

FIGURE 22.—Distribution and abundance of jack-mackerel larvae during February and March 1950.

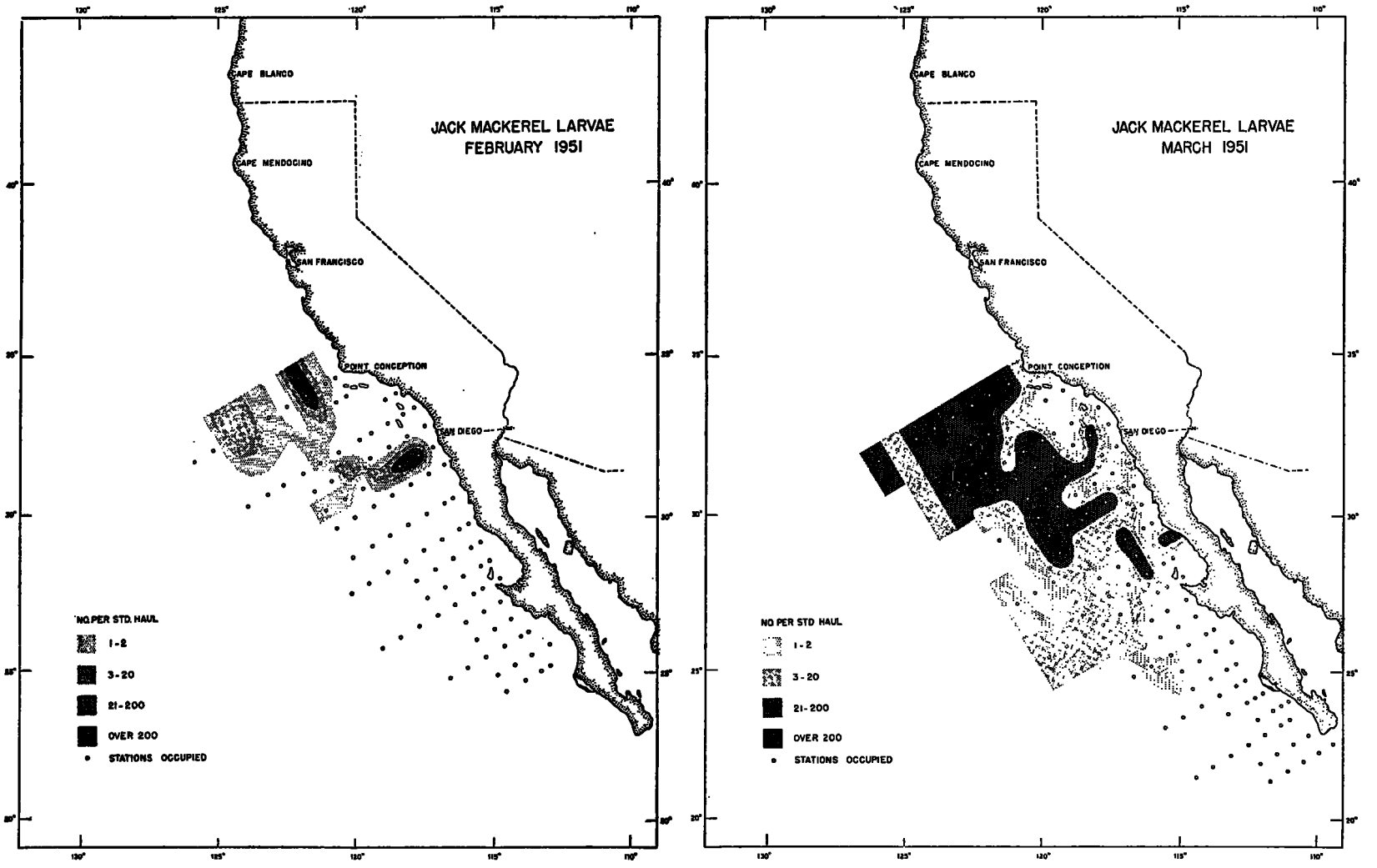

FIGURE 23.—Distribution and abundance of jack-mackerel larvae during February and March 1951.

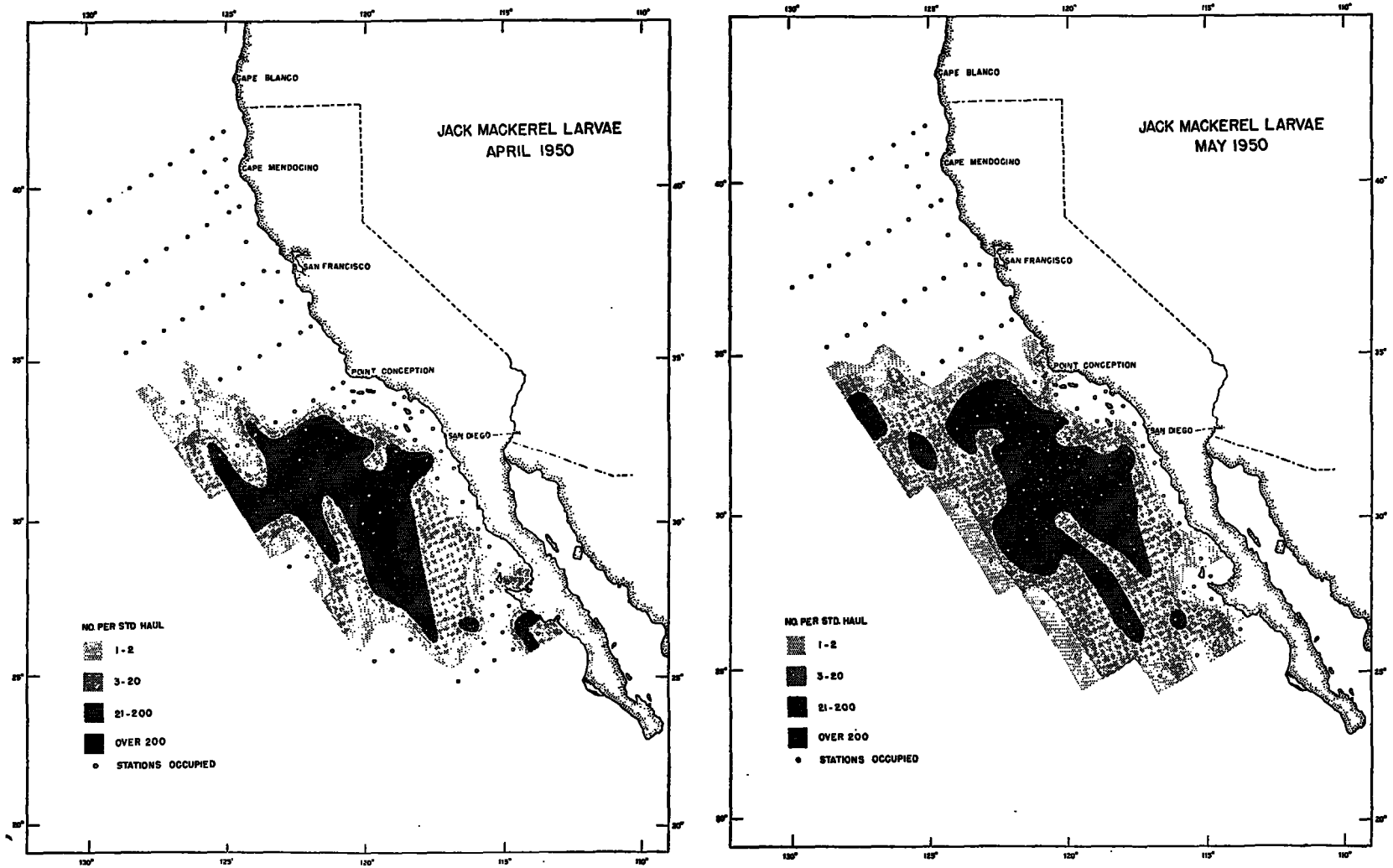

FIGURE 24.—Distribution and abundance of jack-mackerel larvae during April and May 1950.

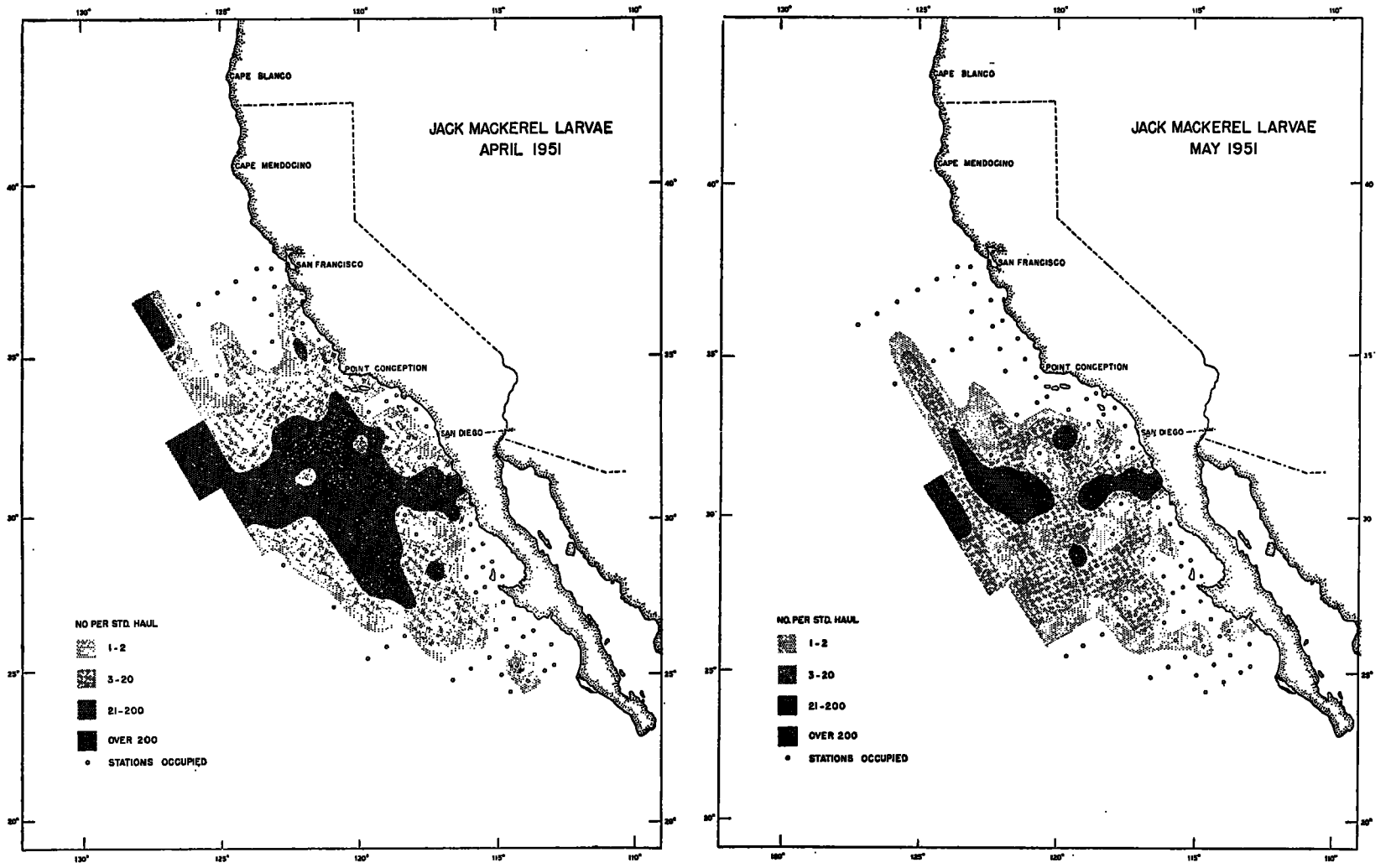

FIGURE 25.—Distribution and abundance of jack-mackerel larvae during April and May 1951.

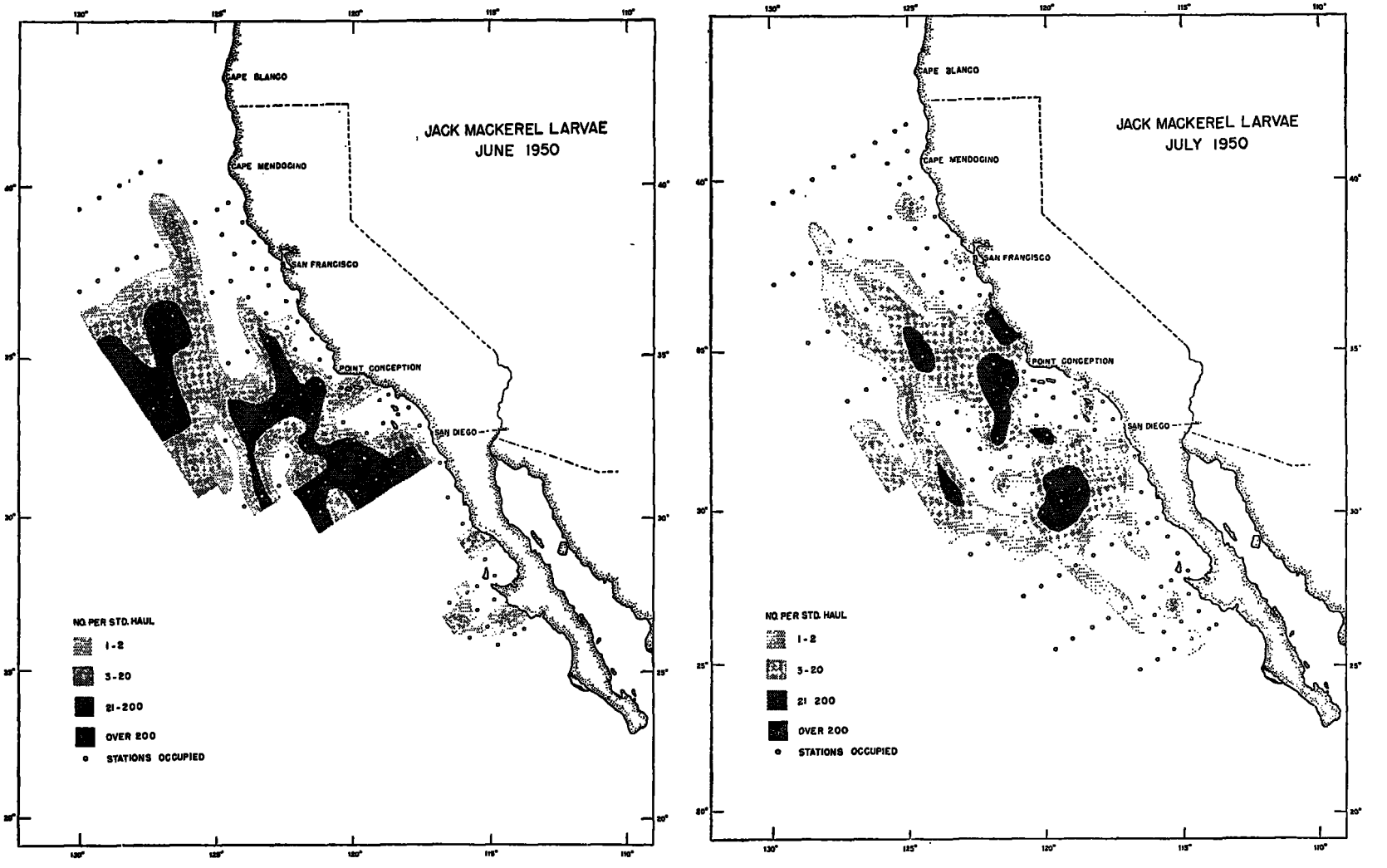

FIGURE 26.—Distribution and abundance of jack-mackerel larvae during June and July 1950.

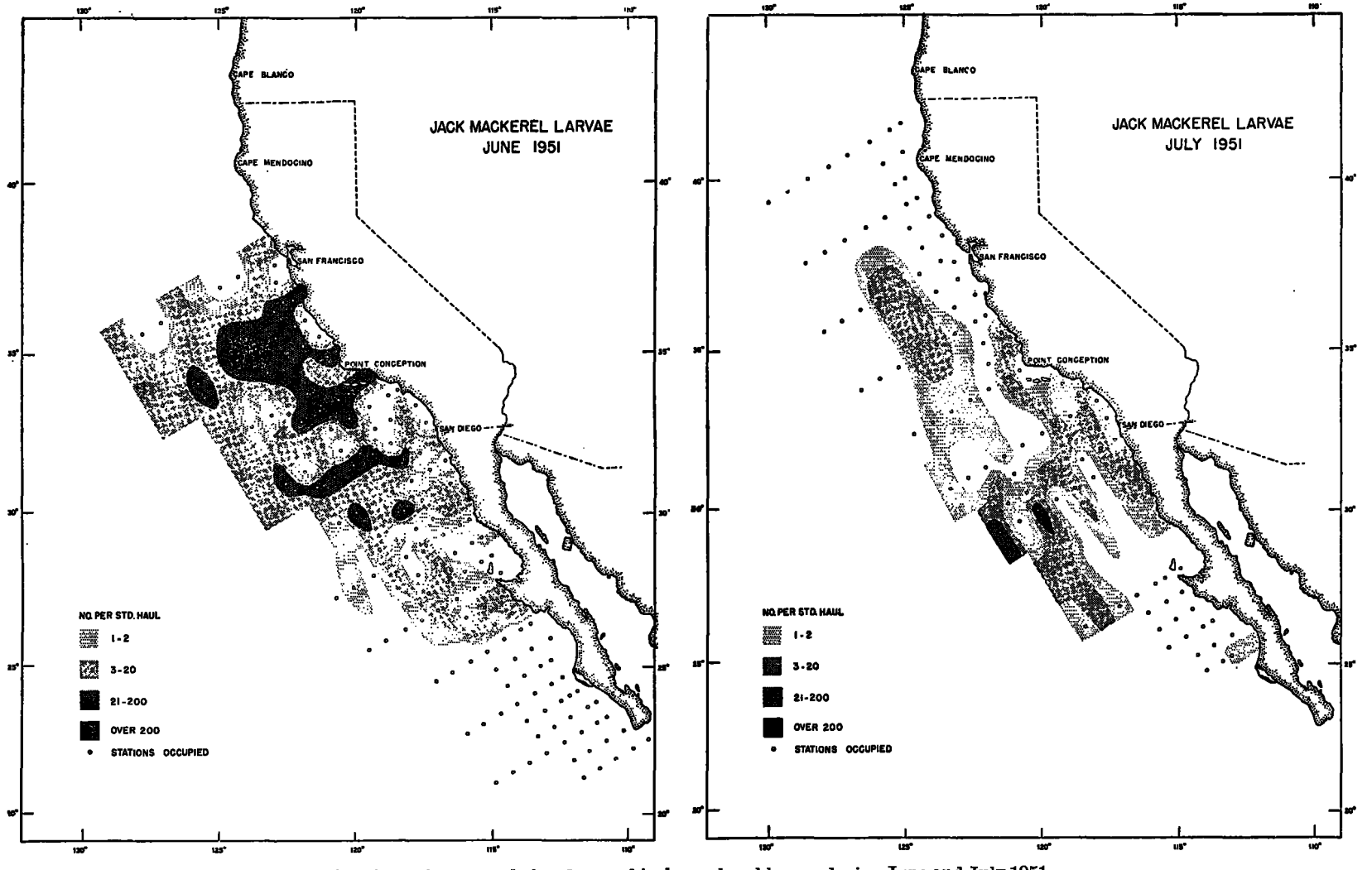

FIGURE 27.—Distribution and abundance of jack-mackerel larvae during June and July 1951.

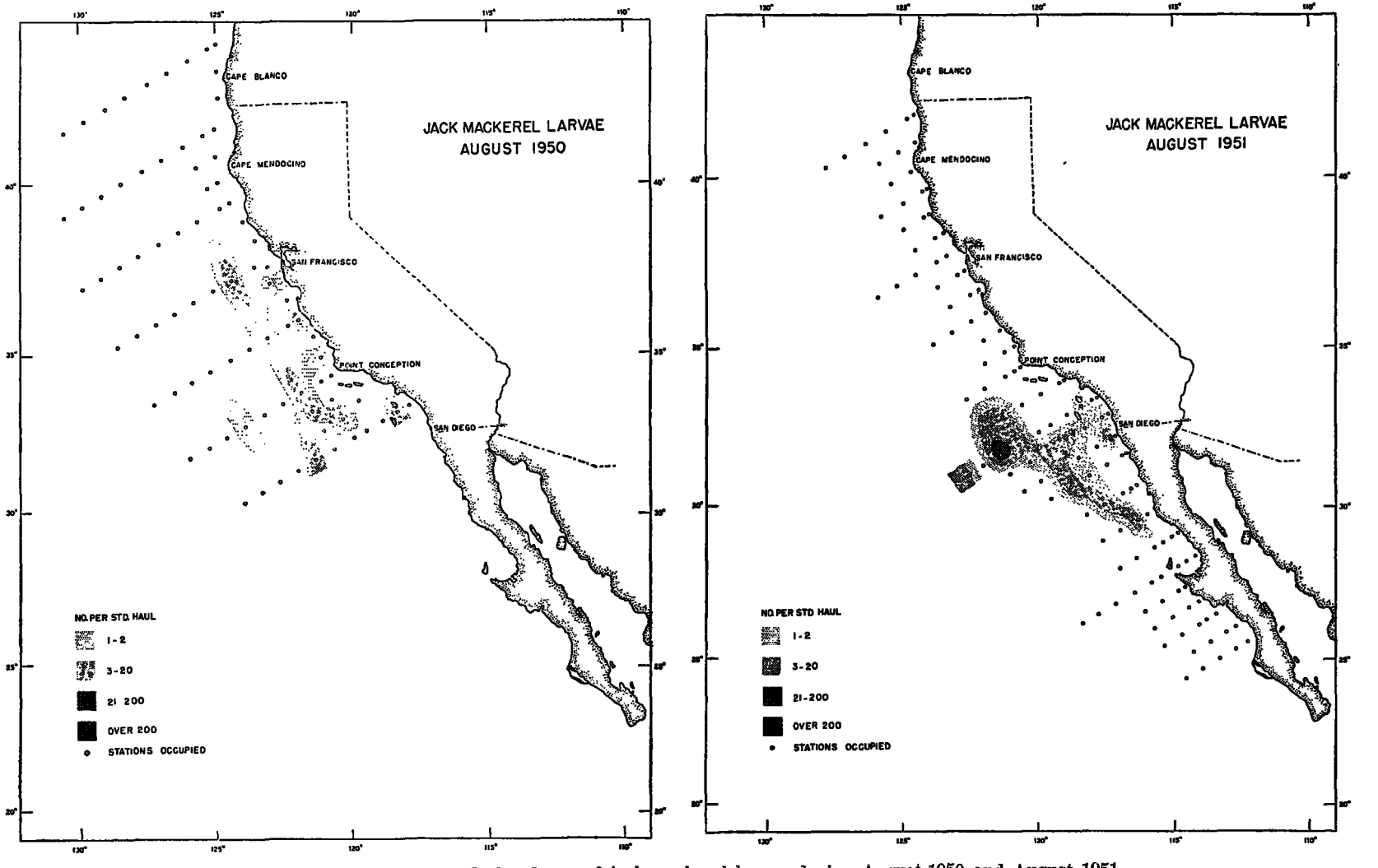

FIGURE 28.—Distribution and abundance of jack-mackerel larvae during August 1950 and August 1951.

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APPENDIX

METHODS OF COLLECTING EGGS AND LARVAE

Eggs and larvae used in the description of the embryonic and larval stages of the jack mackerel were collected on cruises of the California Cooperative Oceanic Fisheries Investigations, which have covered an extensive oceanographic area off California, Baja California, and at times Oregon, usually at monthly intervals, since March 1949. The cruises employ 2 to 4 vessels covering different sections of the area being surveyed. They have been run cooperatively by the Scripps Institution of Oceanography and the South Pacific Fishery Investigations of the United States Fish and Wildlife Service, with the Bureau of Marine Fisheries of the California Department of Fish and Game participating on some of the cruises. Discussion of the distribution and abundance of jack-mackerel larvae has been limited to the 1950 and 1951 cruises, inasmuch as the data for 1949 are not as complete as for later years, and the 1952 material has not been completely worked up as yet.

Nets used.—The plankton nets used throughout the survey period have been 1 meter in diameter at the mouth, and approximately 5 meters long. The anterior section of the nets, approximately a meter in length, is cylindrical, while the longer, posterior section is conical. A cod-end bag, approximately 14 cm. in diameter and 30 cm. long, is attached to the end of the net by a bronze coupling device. The body of the nets has been constructed of No. 30xxx grit gauze (a sturdy grade of Swiss silk bolting cloth); the posterior 40 cm. of the cone and the cod-end bag of No. 56xxx grit gauze. The grit-gauze numbers refer to the number of threads per lineal Swiss inch, which has a slightly different length than the English inch.

Method of sampling.—The plankton nets were hauled obliquely while the vessels were moving at a speed of about 1.5 to 2 knots. During 1949 and 1950, the hauls sampled approximately the upper 70 meters of depth; since then the depth of the stratum sampled has been approximately 140 meters, except at shallow stations. In making a haul, the net is lowered at approximately 35 meters a minute, and retrieved at a rate of either 3.5, 7, or 14 meters a minute. These figures are an estimate of the actual vertical distance being covered, and not of the length of the towing wire payed out or retrieved.

Measurement of the volume of water strained by the nets.—Throughout our operations, each plankton net was provided with a current meter, held rigidly in the center of the mouth opening by three bronze rods. The current meters are routinely calibrated before and after each cruise on which they are used. The details of calibration, as well as the method of computing the volume of water entering a net during a haul, are given by Ahlstrom (1948 and 1953).

Standardization of plankton hauls.—Although our plankton hauls have differed in the depth of the stratum sampled and in the speed of hauling, we can determine for each haul the average amount of water strained per unit of depth sampled. For comparability, all hauls have been referred to a standard haul of 10 cubic meters of water strained per unit of depth sampled.

A basic requirement of this procedure is that the vertical distribution of the organism be encompassed. Hauls that are not deep enough to sample the complete depth distribution will underestimate the abundance of the organism. We have no reason to suppose that even the shallower stratum routinely sampled during 1949 and 1950 did not encompass the depth distribution of jack-mackerel larvae. Although our data on the depth distribution of jack-mackerel larvae are fragmentary, they indicate a shallow distribution, mostly above 50 meters. Also, the fact that somewhat larger standard numbers of jack-mackerel larvae were taken during the 1950 season than during the 1951 season, despite the difference in vertical depth covered by the hauls, tends to support this belief.

CENSUS ESTIMATES

It has not been possible for us to derive estimates of actual abundance of jack-mackerel larvae at different stages of larval development. The techniques for making such estimates are discussed in Ahlstrom (1954). One of the requirements is a determination of the size composition of all jack-mackerel larvae taken in net hauls. Size measurements have not been made routinely on jack-mackerel larvae collected during 1950 or 1951. The rate of growth of the larvae has not been determined as yet, and this information is also needed in deriving population estimates.

The estimate used is a census estimate of the number of jack-mackerel larvae in the survey area

at the time of each cruise. It is obtained by integrating the standard-haul totals for larvae over area. Since it is made on total jack-mackerel larvae, equal weighting is given to larvae of all sizes, whether newly hatched or approaching the juvenile stage. Since the cruises were spaced at regular monthly intervals during both years, the totals should be comparable. The estimates of abundance given in tables 6 through 9 are monthly census estimates.

MEASUREMENTS AND MERISTIC COUNTS

This study is based on plankton material preserved in buffered 10-percent formalin (4-percent formaldehyde). Living material has not been available, but this is not considered a serious lack, since our need, and that of most investigators, will be to identify preserved material. Larvae on which detailed size measurements and meristic counts were made had been previously stained with alizarin and cleared in glycerin. The material was selected at random from collections of jack-mackerel larvae made during 4 years of systematic surveys, 1949 through 1952, and it was representative of the distribution of jack-mackerel larvae both in time and space. Unstained material was used for studying larval pigmentation.

Most measurements were made with the aid of an ocular micrometer under a low-power binocular dissecting microscope. No magnification greater than 36 times was used. On larger specimens it was necessary to use calipers for most of the measurements.

The clearing and staining method used was modified from the technique described by Hollister (1934). A good generalized discussion of this technique is given in a short article by Evans (1948).

We feel that this type of prepared larval material should play an important role in accurate descriptive work. Cleared and stained material is especially useful for making accurate meristic counts; when the fins are developing it is indispensable. It is also the only simple means of following the sequence of ossification, and of determining accurately the vertebral number.

The procedures followed in making measurements and in enumerating meristic elements will be briefly described.

Standard length.—In yolk-sac larvae before differentiation of the mouth, we considered the measurement from the forward tip of the head to the end of the notochord to be equivalent to the standard length. In larval stages before the caudal fin is formed, we used the measurement from the tip of the snout to the end of the notochord; when the caudal fin is fully formed, at about 11 mm. in length, we measured from the tip of the snout to the base of the caudal.

Head length.—The measurement was made from the tip of the snout to the posterior edge of the operculum. In yolk-sac larvae, and even in some small larvae, the length of the head is difficult to measure exactly. Inasmuch as the head length very closely approximates the length from the snout to the pectoral base, this latter measurement was taken to be equivalent to the head length in small larvae.

Eye diameter.—Measured on the horizontal.

Snout to anus.—The length from the tip of the snout to the anal opening. In the earlier stages the tip of anal papilla was considered equivalent to the anal opening.

Depth at pectoral.—Body depth was measured at the base of the pectoral fin. This is usually the point of greatest depth. The measurement was not made on specimens that still retained yolk material, hence is lacking for yolk-sac larvae.

Fin rays and spines.—In making meristic counts of fin rays and spines, only those elements that stained with alizarin were counted. Usually, rays and spines stain a deep red with alizarin; however, all rays that took any color, even a slight pinkish tinge, were counted. It is often difficult to distinguish spines from rays when these structures are first forming; consequently, for a period during fin differentiation, some spines were counted as rays. This applied to the soft dorsal, anal, and pelvic fins. In the soft dorsal, for example, the single spine that precedes the rays could not be distinguished as such in larvae of about 7 to 8 mm., and for this size group it was counted as a ray.

Vertebrae.—The neural and haemal spines take stain on small specimens before the centra. A vertebra is considered as forming if any of its elements stain red with alizarin.

Tabulation of larval measurements and meristic counts (table 2).—A summary tabulation of larval measurements and meristic counts is presented in table 2. For larvae between 2 and 5 mm. in length, the measurements are summarized for each 0.5-mm. size interval; for larvae between 5 and 15

mm. in length, the measurements are grouped by 1-mm. intervals; while for specimens beyond 15 mm. (juveniles), the grouping is irregular depending upon available material.

For each interval, the number of individuals measured is indicated. Approximately 15 individuals were used for each category, when available. The size measurements and meristic counts given under any interval are the mean values for the specimens measured.

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