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# ABUNDANCE AND DISTRIBUTION OF EGGS AND LARVAE AND SURVIVAL OF LARVAE OF JACK MACKEREL (*TRACHURUS SYMMETRICUS*)

By DAVID A. FARRIS

FISHERY BULLETIN 187
From Fishery Bulletin of the Fish and Wildlife Service
VOLUME 61

PUBLISHED BY UNITED STATES FISH AND WILDLIFE SERVICE • WASHINGTON • 1961
PRINTED BY UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.
Price 30 cents

The series, Fishery Bulletin of the Fish and Wildlife Service, is cataloged as follows:


U.S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U.S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9—35239*

Library of Congress [59r55b1]

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## ABSTRACT

Distribution and abundance of eggs and larvae of the jack mackerel, *Trachurus symmetricus* (Ayres), and survival of the larvae are described, utilizing quantitative data collected on monthly cruises of the California Cooperative Oceanic Fisheries Investigations during 1951–54.

Spawning in the period 1951–1954 occurred from Washington to Magdalena Bay, Baja California. In each of the 4 years it began in February and ceased by October. The peak month of spawning was March in 1951 and May in 1952, 1953, and 1954. About 30 percent of the spawning occurred during the peak month. Estimates of egg abundance varied by less than a factor of 2 during the 4 years studied.

The effect of temperature on the rate of development of eggs was investigated. Regression statistics are given for the developmental rate. Reliability of the regression was checked by direct observation of developing eggs at controlled temperatures.

The annual estimates of survival for 1952, 1953, and 1954 indicate a reasonably constant survival of month-old jack mackerel larvae in these years.

The growth rate of jack mackerel larvae was approximated from data derived by direct observation of developing jack mackerel larvae under laboratory conditions and was described by two successive logarithmic growth curves. The second curve originates at yolk sac absorption and has the lesser slope.

Survival data may be broken into two periods: the first period, concurrent with the fast growth period, is characterized by poor survival and may be the critical period; in the second, survival is much better and growth much slower.

# ABUNDANCE AND DISTRIBUTION OF EGGS AND LARVAE AND SURVIVAL OF LARVAE OF JACK MACKEREL (*TRACHURUS SYMMETRICUS*)

By David A. Farris, *Fishery Research Biologist*
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The purposes of this study are to delimit both spatially and temporally the spawning of the jack mackerel, *Trachurus symmetricus* (Ayres) 1885, and to estimate the abundance of the eggs and the survival rate of the larvae. Quantitative data collected on monthly cruises of the California Cooperative Oceanic Fisheries Investigations, 1951 through 1954, are utilized in the study.

Data derived from the study of eggs and larvae may give insight into the present abundance and future fluctuations of the adult population, and estimates of larval mortality may aid in predicting future recruitment to the fishery. With knowledge of the fecundity, estimates of egg abundance may be used to ascertain the present size of the adult population. These data may also be compared with physical, chemical, and other biological data gathered by the California Cooperative Oceanic Fisheries Investigations.

To accomplish the stated purposes of this study, the following information was needed:

1. Boundaries of the area occupied by developing eggs and larvae.
2. Seasonal distribution of the eggs and larvae within those boundaries.
3. Quantitative depth distribution of the eggs and larvae.
4. Relation between temperature and rate of development of eggs and larvae.

The author appreciates the help and encouragement given him by E. H. Ahlstrom, D. E. Wohlschlag, and John C. Marr during the course of this study; the assistance of O. E. Sette in the preparation of the manuscript; and the valuable advice of Bruce Taft in the preparation of the statistical portion of this paper. George Mattson prepared most of the figures. Also, without the help of members of the California Marine Research Committee and its cooperating agencies and the staff of the South Pacific Fishery Investigations [1] this study could not have been undertaken. The laborious proofreading was done by Mrs. Paula K. Farris.

## REVIEW OF THE FISHERY

The carangids most commonly found in the area surveyed by the California Cooperative Oceanic Fisheries Investigations are listed by Barnhart (1936) and Fowler (1944). The family is largely tropical or subtropical in its distribution, *Trachurus symmetricus* being a notable exception. Only three members of the family are taken in any numbers by the California Cooperative Oceanic Fisheries Investigations: yellowtail, *Seriola dorsalis* Gill; Mexican scad, *Decapterus hypodus* Gill; and jack mackerel, *Trachurus symmetricus* (Ayres). The larvae of all three species are known, so that identification is possible. The yellowtail and jack mackerel are the only carangids of any economic importance in the area (Clothier and Greenhood, 1956).

Well over 80 percent of the jack mackerel fishery is located in waters off southern California (i.e., from Point Conception to the Mexican border). In some years 99 percent of the catch is made in this region. Less than 1 percent of the total catch is taken in waters as far north as Eureka, California (i.e., Point Conception to Eureka).

Before 1947 the jack mackerel catch never exceeded 7,550 tons (Roedel, 1949: p. 31–32), and since then it has not fallen below that figure. During 3 years, 1947, 1950, and 1952, the catch exceeded 62,500 tons. The fluctuations of the jack mackerel catch more or less complement fluctuations in the sardine catch (Clothier and Greenhood,

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Approved for publication, May 25, 1959. Fishery Bulletin 187.

[1] Presently the Bureau of Commercial Fisheries Biological Laboratory, La Jolla, Calif.

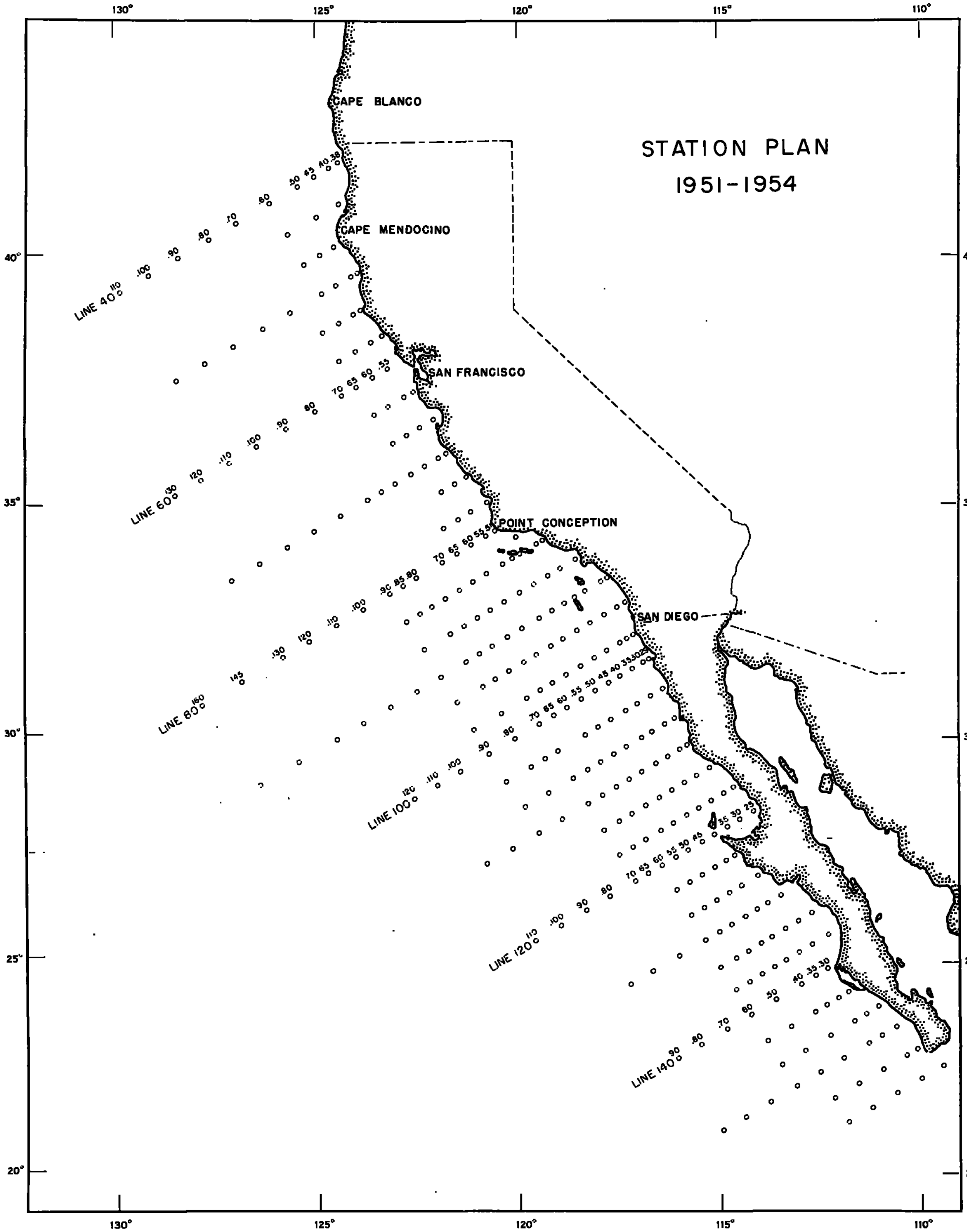


FIGURE 1.—Chart of stations occupied by the California Cooperative Oceanic Fisheries Investigations 1951–1954.

1956: p. 8 and 12). The catch fluctuations since 1947 arise primarily from three causes: (1) Availability of sardines and Pacific mackerel, (2) fluctuations in demand for canned jack mackerel, and (3) availability of the jack mackerel. Since jack mackerel are packed as "substitute sardines," catch data do not necessarily reflect the size of the adult population. Eventual independence of the industry is assured, however, by the world's increasing need for cheap protein and by technological advances in the packing of this species.

Jack mackerel are taken with a variety of gear; however, more than 99 percent are taken with purse seines and lampara nets. The operation of this gear is described by Scofield (1951). Some jack mackerel are taken by sport fishermen using live bait. In 1953, the sport catch was unusually large, nearly 200,000 fish being taken (Fitch, 1956: p. 27). However, this catch amounts to less than 2 percent of the commercial catch.

Except for a minor amount used in the fresh-fish market, the commercial catch is used for canning. Jack mackerel are principally packed sardine style, usually in tall, 1 pound cans. A small part of the catch is packed in other ways.

To date, the catch of jack mackerel has not undergone any sustained decline. Therefore, all the previously mentioned data take on an added significance when one considers that many fishery investigations are initiated after the industry has experienced a decline in the number of catchable fish (Walford, 1948). By noting the variations in the strength of spawning, stock size, mortality, et cetera, now while fishing mortality is relatively low, future observations under conditions of higher fishing mortality should permit the assessment of the effects of man on the population size of the jack mackerel.

## METHODS OF COLLECTING DATA

Since this study of jack mackerel constitutes but part of a larger and more comprehensive study of the ecology of pelagic fishes off the coast of California, the methods used are those originated by the Bureau of Commercial Fisheries Biological Laboratory at La Jolla and adopted by the staffs of the California Cooperative Oceanic Fisheries Investigations. These methods have been planned to maximize the amount of information obtainable from this ecological province.

The methods used in collecting and processing these data, with a summary of the previous year's work are found in reports of the California Marine Research Committee, the sponsoring organization of the California Cooperative Oceanic Fisheries Investigations, for 1950, 1952, 1953, 1955, and 1956. More detailed explanations are given by Ahlstrom (1948 and 1953), and in the following discussion.

The station pattern and numbering system are described in Station Positions of the California Cooperative Sardine Research Program, prepared by the Scripps Institution of Oceanography and the U.S. Fish and Wildlife Service (1952). The stations laid out in lines occupied during the period 1951–54 are shown in figure 1. The exact location of each station (at each occupancy) during 1951–54 is given by Staff, South Pacific Fishery Investigations (1952, 1953, 1954, and 1955). A plankton-net tow (Ahlstrom, 1953), Nansen bottle cast, and bathythermograph cast are made at each station. Temperature data are obtained from the reversing thermometers on Nansen bottles and from bathythermograms. The obliquely hauled plankton net is retrieved from a depth of approximately 140 meters (200 meters of wire out) at an average rate of 20 meters of wire per minute. The angle from the vertical of the towing wire is kept as close as possible to 45 degrees. A current meter placed in the mouth of the net measures the volume of water strained. The sample obtained is preserved in its entirety in a buffered formalin solution, and these preserved samples are subsequently examined for fish eggs and larvae. The numbers of jack mackerel larvae and localities in which they were taken during 1952–54 are given in Ahlstrom (1954a) and Ahlstrom and Kramer (1955, 1956). The numbers of jack mackerel eggs and localities in which they were taken in 1951–54 are given by Farris (1958).

## ESTIMATING EGG ABUNDANCE

The method used to estimate egg abundance has been described in detail by Sette and Ahlstrom (1948) and Ahlstrom (1954b). The monthly estimates of egg abundance are obtained from the relation—

$$C_M=\sum_{i=1}^{n} c_i w_i t_i$$

where

$C_M$=the monthly estimate of egg abundance

$n$ = the number of stations considered
$c_i$ = the average number of eggs spawned per day at the $i$th station[2]
$w_i$ = the weighting factor for space in standard area (i.e., units of 10 m$^2$ of sea surface)
$t_i$ = the time factor which is equal to one-half the time from the preceding occupancy of the station plus one-half the time to the succeeding occupancy.

An annual estimate of abundance is obtained by summing the monthly estimates for the entire year.

The eggs are identified and the number belonging to each species is recorded by station. The count for each station is adjusted so that all results are expressed as the number of eggs under a standard area which is 10 square meters of sea surface (Ahlstrom, 1953). This standardized haul value ($c'_i$) is the product of the raw count times a standard haul factor, which is derived for each haul by dividing 10 by the average volume of water strained per meter of depth for the entire water column.

### EFFECT OF TEMPERATURE ON LENGTH OF INCUBATION PERIOD

The length of the incubation period ($d_i$) is dependent on temperature of the water mass in which the eggs are developing, and may be predicted if the temperature coefficient for the rate of development is known.

The effect of temperature on the rate of development of jack mackerel eggs has been derived by two methods. In the first method, the eggs were taken from the sea shortly after they had been spawned, placed in a fish egg incubator (see appendix A) and observed at 4-hour intervals until they hatched. The temperature of the water in the incubator was maintained at about 14° C., the temperature of the sea water from which the eggs were collected. The observed hatching time was 108.5 hours. This experiment was repeated 1 year later at 15° C., with an observed hatching time of 84 hours.

The second method, which is indirect, was developed by Ahlstrom (1943) for the Pacific sardine and was also successfully used by Gamulin and Hure (1955) for sardines in the Mediterranean Sea. A series of arbitrarily chosen but precisely defined morphological stages is selected. Such a series of stages is described for jack mackerel in appendix B. The jack mackerel eggs from station samples are separated into stages and counted (Farris, 1958: table 2, p. 7–11).

Several successive days of spawning are indicated by the stage frequency modes present in each sample. A mode is interpreted as representing 1 day's spawn, inasmuch as spawning is limited to a short period each night and the modes represent stages separable by a day as determined from incubation experiments.

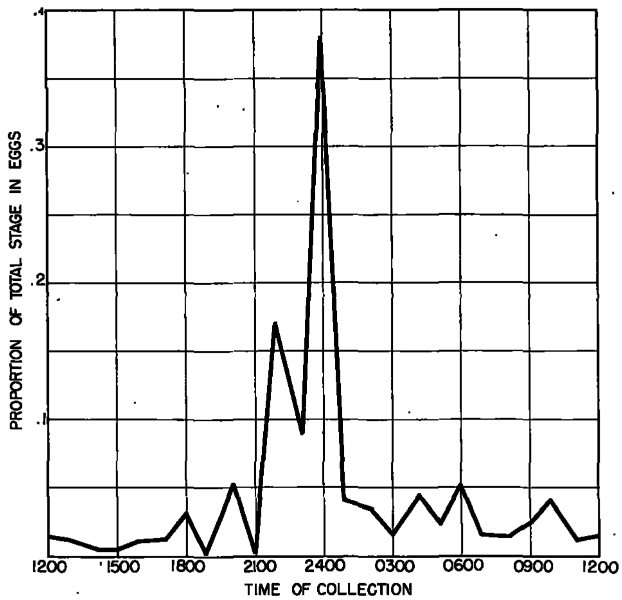


FIGURE 2.—Stage-I jack mackerel eggs collected in 1951 by hour of collection. All stage-I eggs collected at a particular hour are expressed as a proportion of the total stage-I eggs for the year.

The time of day at which spawning takes place was determined by plotting the relative abundance of precleavage eggs (stage I) against time of collection (fig. 2). The time the samples were collected is given in a report of the South Pacific Fishery Investigations (1952). These data showed the time of maximum spawning for jack mackerel was approximately midnight.

The age of the earliest stage is computed by subtracting the hour of collection from midnight. The age of the second mode is estimated by adding 24 hours to the age of the first mode, and the age

[2] $c_i$ is derived as follows: $c_i = c'_i/d_i$ where $c'_i$ = the standard number of eggs at the $i$th station; $d_i$ = the time interval in days from spawning to hatching.

of subsequent modes is determined in the same manner.

Temperature data for the stations were supplied by the Scripps Institution of Oceanography. If the temperatures within the upper 30 meters of water did not vary by more than 0.1° C., the data from the station were used.

The effect of temperature on rate of development was shown by a regression of log hours of development against temperature for each stage.

$Y$=hours of development

$X$=temperature °C.

$$\text{Log } Y=a+bX$$

Separate regressions were made for three stages (table 1) so that the regression statistics might be compared. If a relation exists between rate of development and temperature, the slopes for the three regressions should be about the same. The $Y$-intercepts were not compared, since the lines are almost parallel and occur at different levels; the intercepts, as one would expect, are different.

TABLE 1.—*Temperature regression coefficients for the rate of development of jack mackerel eggs*

| Statistic | Stage V | Stage VIII | Stage IX |
|---|---|---|---|
| $a$ | 2.996 | 3.047 | 3.257 |
| $b$ | −0.093 | −0.088 | −0.088 |
| $\bar{X}$ (temperature °C.) | 15.71 | 15.40 | 15.40 |
| $\bar{Y}$ (log hours) | 1.580 | 1.690 | 1.891 |

The close correspondence of the slopes for the three regressions indicates a uniform relation between developmental rate and temperature. By using the graph of the regression for the oldest stage (stage IX), the incubation period to the closest day could be predicted directly (fig. 3). This regression was used in determining the number of whole days elapsing in the egg stage ($d_i$) as mentioned above.

The incubation period (in hours) as predicted by the regression for stage-IX eggs was compared with the incubation period actually observed under conditions of controlled temperature (see p. 250). The close agreement between prediction and observation is shown in the following table:

| Temperature (°C.) | Predicted hours | Observed hours |
|---|---|---|
| 14 | 106 | 108.5 |
| 15 | 86.5 | 84 |



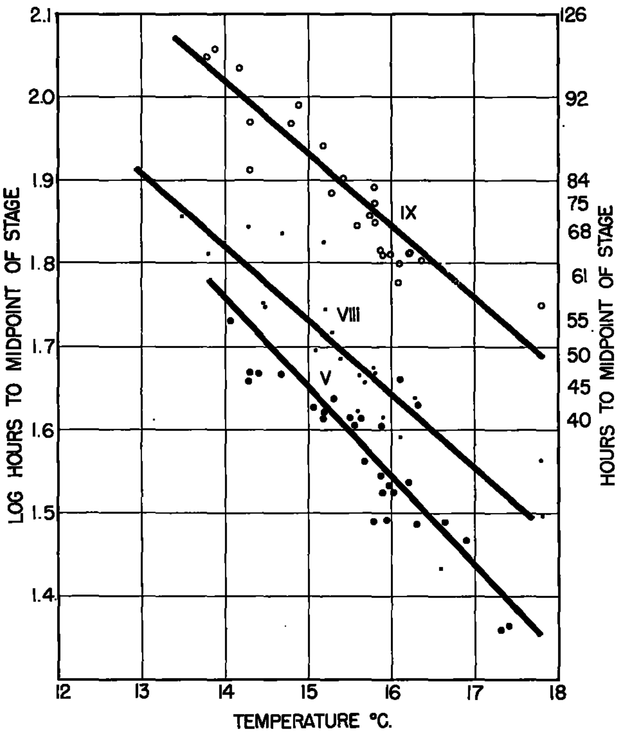


FIGURE 3.—Relation between temperature and rate of development for three stages of jack mackerel eggs.

The close agreement between incubation period predicted and actually observed lent confidence to the reliability of the indirect method.

The temperature-dependent incubation period ($d_i$) is used to compute the average number of eggs spawned per day at the $i$th station ($c_i$) in the following manner.

The standard number of eggs at the $i$th station ($c'_i$) is divided by $d_i$.

After computing the estimate of the average number of eggs spawned per day at the $i$th station of 10 square meters, the number of eggs is integrated over space to the surrounding stations by an area factor ($w_i$). The sample is then weighted on the basis of the area it represents. The boundaries of an area are formed by the perpendicular bisectors of lines drawn to the stations immediately surrounding the one under consideration.

The time factor ($t_i$) is derived by taking the number of days from the previous occupancy of the station to the occupancy of the station immediately succeeding the one under consideration and dividing by 2. The products ($c_i w_i t_i$) are summed for the month to give an estimate of total monthly egg abundance ($C_M$).

## ESTIMATES OF EGG ABUNDANCE AND SEASONAL-REGIONAL DISTRIBUTION OF SPAWNERS

Using the method of Ahlstrom (1954b) previously described, the monthly estimates by region were obtained for the 4-year period, 1951–54 (tables 2–5). Spawning does not occur uniformly over the area throughout the spawning season and the seasonal-regional variation is discussed in the following section.

The estimates of egg abundance revealed that during this 4-year period, the highest annual estimate (1951) was less than twice that of the lowest (1954). Furthermore, no trend was apparent from 1951 through 1954. Spawning averaged 666 trillion eggs per year, with a range of 873 trillion to 462 trillion.

The seasonal distribution of spawners was inferred from the monthly estimates of egg abundance and the number of eggs spawned per month expressed as a percent of the annual total for each year. Although the percentages have been carried to hundredths, no statistical significance should be attached to these postdecimal places which merely serve to indicate trace amounts of spawning. These figures are given in the last row in tables 2 through 5.

TABLE 2.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1951*

[Cruise numbers in parentheses. No eggs taken during cruises 5101 and 5110 to 5112]

| | Feb. (5102) | Mar. (5103) | Apr. (5104) | May (5105) | June (5106) | July (5107) | Aug. (5108) | Sept. (5109) | Annual total | Percent of total for all areas |
|---|---|---|---|---|---|---|---|---|---|---|
| North of Point Conception: | | | | | | | | | | |
| Lines 40–57 | -------- | -------- | -------- | -------- | -------- | 1,365 | 2,907 | -------- | 4,272 | -------- |
| 60–77 | -------- | -------- | 8,616 | 8,099 | 62,487 | 22,235 | 206 | 0 | 101,643 | -------- |
| Total and percent | -------- | -------- | 8,616 | 8,099 | 62,487 | 23,600 | 3,113 | 0 | 105,915 | 12.13 |
| Southern California: | | | | | | | | | | |
| Line 80 | 44,060 | 50,497 | 2,476 | 47 | 7,915 | 1,228 | 53 | 12 | 106,288 | -------- |
| 83 | 0 | -------- | 0 | 3,863 | 4,932 | -------- | -------- | 0 | 8,795 | -------- |
| 85 | -------- | 40,344 | -------- | -------- | -------- | 0 | 890 | 0 | 41,234 | -------- |
| 87 | 0 | -------- | 9,706 | 30,784 | 1,973 | -------- | 0 | -------- | 42,463 | -------- |
| 90 | 2,829 | 48,338 | 33,804 | 22,298 | 13,712 | 10,412 | 7,334 | 15 | 138,742 | -------- |
| 93 | 8,930 | 30,972 | 18,977 | 9,568 | 3,107 | 2,559 | 2,071 | 0 | 76,184 | -------- |
| Total and percent | 55,819 | 170,151 | 64,963 | 66,560 | 31,639 | 14,199 | 10,348 | 27 | 413,706 | 47.40 |
| Northern Baja California: | | | | | | | | | | |
| Line 97 | 6,379 | 10,564 | 15,014 | 6,486 | 12,964 | 7,421 | 1,442 | 16 | 60,286 | -------- |
| 100 | 1,970 | 7,469 | 19,735 | 18,484 | 3,761 | 21,484 | 907 | 0 | 73,810 | -------- |
| 103 | -------- | 14,487 | 16,490 | 3,614 | 3,708 | -------- | -------- | 8 | 38,307 | -------- |
| 105 | 0 | -------- | -------- | -------- | -------- | -------- | 307 | -------- | 307 | -------- |
| 107 | -------- | 11,282 | 6,152 | 7,348 | 2,433 | -------- | -------- | 0 | 27,215 | -------- |
| Total and percent | 8,349 | 43,802 | 57,391 | 35,932 | 22,866 | 28,905 | 2,656 | 24 | 199,925 | 22.91 |
| Upper central Baja California: | | | | | | | | | | |
| Line 110 | 0 | 20,092 | 19,439 | 7,263 | 8,754 | 890 | 424 | 0 | 56,862 | -------- |
| 113 | 0 | 17,053 | 6,756 | 3,746 | 10,209 | -------- | -------- | -------- | 37,764 | -------- |
| 115 | -------- | -------- | -------- | -------- | -------- | -------- | 445 | 0 | 445 | -------- |
| 117 | 0 | 20,430 | 8,530 | 3,248 | 256 | -------- | -------- | -------- | 32,464 | -------- |
| 120 | 0 | 291 | 4,781 | 2,318 | 14,993 | 341 | 115 | 0 | 22,839 | -------- |
| Total and percent | 0 | 57,866 | 39,506 | 16,575 | 34,212 | 1,231 | 984 | 0 | 150,374 | 17.23 |
| Lower central Baja California: | | | | | | | | | | |
| Line 123 | 0 | 42 | 560 | 204 | 213 | 18 | 3 | 0 | 1,040 | -------- |
| 127 | 0 | 42 | 30 | 41 | 40 | 0 | 0 | 0 | 153 | -------- |
| 130 | 0 | 63 | 451 | 101 | 0 | 0 | 0 | 0 | 615 | -------- |
| 133 | 0 | 28 | 369 | 430 | 0 | 16 | 0 | 0 | 843 | -------- |
| 137 | 0 | 0 | 0 | 49 | 0 | 0 | 0 | 0 | 49 | -------- |
| Total and percent | 0 | 175 | 1,410 | 825 | 253 | 34 | 3 | 0 | 2,700 | .31 |
| Southern Baja California: | | | | | | | | | | |
| Line 140 | -------- | 165 | -------- | -------- | 0 | -------- | -------- | 0 | 165 | -------- |
| 143 | -------- | 39 | -------- | -------- | 0 | -------- | -------- | 0 | 39 | -------- |
| 147 | -------- | 0 | -------- | -------- | 0 | -------- | -------- | 0 | 0 | -------- |
| 150 | -------- | 0 | -------- | -------- | 0 | -------- | -------- | 0 | 0 | -------- |
| Total and percent | -------- | 204 | -------- | -------- | 0 | -------- | -------- | 0 | 204 | .02 |
| Grand total | 64,168 | 272,198 | 171,886 | 127,991 | 151,457 | 67,969 | 17,104 | 51 | 872,824 | -------- |
| Percent[1] | 7.35 | 31.19 | 19.69 | 14.66 | 17.35 | 7.79 | 1.96 | 0.01 | 100.00 | -------- |

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see text above).

The regional (north-south) distribution of spawning fish was inferred from the regional distribution of eggs. The number of eggs found in a region was expressed as a percent of the total for all regions (i.e., annual total). These figures are given in the last column in tables 2 through 5. The lines comprising each region are as follows:

| Region | Area | Lines |
|---|---|---|
| 1 | Northern California | 40–77 |
| 2 | Southern California | 80–93 |
| 3 | Northern Baja California | 97–107 |
| 4 | Upper central Baja California | 110–120 |
| 5 | Lower central Baja California | 123–137 |
| 6 | Southern Baja California | 140–157 |

A slightly different approach was used to elucidate the offshore-inshore distribution. Unlike the preceding section, only selected stations on selected lines were used, because the selected data were more quickly and easily handled, and because these particular selected stations had the most regular coverage, having been occupied almost every month throughout the 4 years studied.

Only those lines and stations that are multiples of 10 were used (e.g., lines 40, 50, and 60, but not 63, 67, or 73, and stations 40, 50, and 60, but not 45, 55, or 65), except for the most inshore stations. The standardized numbers of eggs

TABLE 3.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1952*

[Cruise numbers in parentheses. No eggs taken during cruises 5210 and 5211]

| | Jan. (5201) | Feb. (5202) | Mar. (5203) | Apr. (5204) | May (5205) | June (5206) | July (5207) | Aug. (5208) | Sept. (5209) | Annual total | Percent of total for all areas |
|---|---|---|---|---|---|---|---|---|---|---|---|
| North of Point Conception: | | | | | | | | | | | |
| Lines 40–57 | | | | | | 0 | 49 | | | 49 | |
| 60–77 | | | | 0 | 0 | 5,278 | 9,541 | 817 | 0 | 15,636 | |
| Total and percent | | | | 0 | 0 | 5,278 | 9,590 | 817 | 0 | 15,685 | 2.64 |
| Southern California: | | | | | | | | | | | |
| Line 80 | 0 | 161 | 1,993 | 0 | 2,769 | 22,624 | 3,262 | 793 | 0 | 31,602 | |
| 83 | | | | 107 | 6,789 | 9,290 | | | | 16,186 | |
| 85 | 0 | 0 | 0 | | | | 3,108 | 0 | 27 | 3,135 | |
| 87 | | | | 982 | 30,880 | 4,855 | | | | 36,717 | |
| 90 | 0 | 7,625 | 54,153 | 3,075 | 30,302 | 20,144 | 2,013 | 3,034 | 2,262 | 122,608 | |
| 93 | 0 | 0 | 905 | 11,713 | 9,727 | 2,944 | 8,293 | 3,001 | 109 | 36,692 | |
| Total and percent | 0 | 7,786 | 57,051 | 15,877 | 80,467 | 59,857 | 16,676 | 6,828 | 2,398 | 246,940 | 41.64 |
| Northern Baja California: | | | | | | | | | | | |
| Line 97 | 33 | 1,631 | 1,691 | 34,173 | 12,380 | 8,632 | 22,058 | 1,368 | 1,600 | 83,566 | |
| 100 | 1,813 | 11,532 | 12,735 | 26,325 | 10,821 | 4,440 | 4,839 | 0 | 127 | 72,632 | |
| 103 | | | | 10,914 | 24,782 | 1,428 | | 27 | 8 | 37,159 | |
| 105 | 173 | 29,562 | 1,278 | | | | 7,475 | | | 38,488 | |
| 107 | | | | 8,899 | 12,323 | 4,323 | | 15 | 13 | 25,573 | |
| Total and percent | 2,019 | 42,725 | 15,704 | 80,311 | 60,306 | 18,823 | 34,372 | 1,410 | 1,748 | 257,418 | 43.40 |
| Upper central Baja California: | | | | | | | | | | | |
| Line 110 | 0 | 0 | 63 | 18,950 | 26,376 | 4,877 | 751 | 0 | 0 | 51,017 | |
| 113 | | 0 | 325 | 1,350 | 1,944 | 2,672 | 98 | 0 | 0 | 6,389 | |
| 115 | 0 | | | | | | | | | 0 | |
| 117 | | 0 | 61 | 132 | 539 | 2,841 | 140 | 0 | 0 | 3,713 | |
| 120 | 0 | 0 | 1,313 | 1,777 | 4,145 | 523 | 0 | 25 | 0 | 7,783 | |
| Total and percent | 0 | 0 | 1,762 | 22,209 | 33,004 | 10,913 | 989 | 25 | 0 | 68,902 | 11.63 |
| Lower central Baja California: | | | | | | | | | | | |
| Line 123 | 0 | 0 | 1,300 | 527 | 1,978 | 239 | 0 | 0 | 0 | 4,044 | |
| 127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 130 | 0 | 0 | 0 | 93 | 0 | 0 | 0 | 0 | 0 | 93 | |
| 133 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Total and percent | 0 | 0 | 1,300 | 620 | 1,978 | 239 | 0 | 0 | 0 | 4,137 | .69 |
| Southern Baja California: | | | | | | | | | | | |
| Line 140 | | 0 | | | | | | | | 0 | |
| 143 | | 0 | | | | | | | | 0 | |
| 147 | | 0 | | | | | | | | 0 | |
| 150 | | 0 | | | | | | | | 0 | |
| Total and percent | | 0 | | | | | | | | 0 | .00 |
| Grand total | 2,019 | 50,511 | 75,817 | 119,017 | 175,755 | 95,110 | 61,627 | 9,080 | 4,146 | 593,082 | |
| Percent[1] | 0.34 | 8.52 | 12.78 | 20.07 | 29.63 | 16.04 | 10.39 | 1.53 | 0.70 | 100.0 | |

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

(instead of estimates of abundance) for these selected lines and stations were summed by 2-month intervals from February to July. The bimonthly totals for the lines were divided by the bimonthly totals for the entire area to give the bimonthly percentage of eggs found on the line. To estimate the offshore-inshore movements, stations 100 and seaward (offshore) were grouped together, stations 70–90 (intermediate) were grouped together, and stations 60-shore (inshore) were grouped together for each line. The station groups were summed bimonthly and the percentage of the bimonthly total for each of the three station groups was computed (tables 6, 7, 8, and 9). Table 10 presents a comparison of the estimates of relative regional abundance obtained from the standardized numbers of eggs at selected stations on selected lines and the regional distribution based on estimates of abundance using all data. Since the north-south regional distribution indicated by the selected data agreed with the north-south distribution indicated by all the data, no distortion was anticipated in using the selected data to reveal the offshore-inshore distribution.

**TABLE 4.**—*Estimated number (in billions) of jack mackerel eggs in survey area, 1953*

[Cruise numbers in parentheses. No eggs taken during cruises 5301, 5309, 5311, and 5312]

| | Feb. (5302) | Mar. (5303) | Apr. (5304) | May (5305) | June (5306) | July (5307) | Aug. (5308) | Oct. (5310) | Annual total | Percent of total for all areas |
|---|---|---|---|---|---|---|---|---|---|---|
| North of Point Conception: | | | | | | | | | | |
| Lines 40–57 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| 60–77 | -------- | -------- | 12 | 0 | 6,075 | 1,947 | 1,619 | -------- | 9,653 | -------- |
| Total and percent | -------- | -------- | 12 | 0 | 6,075 | 1,947 | 1,619 | -------- | 9,653 | 1.31 |
| Southern California: | | | | | | | | | | |
| Line 80 | 0 | 0 | 3,783 | 22,633 | 3,774 | 5,570 | 288 | -------- | 36,048 | -------- |
| 83 | 0 | 0 | 0 | 2,835 | 5,639 | 5,402 | 0 | 0 | 13,876 | -------- |
| 85 | 0 | 0 | 0 | 152 | 590 | 3,252 | 18 | -------- | 4,012 | -------- |
| 87 | 0 | 0 | 0 | 12,813 | 3,285 | 1,769 | 55 | -------- | 17,922 | -------- |
| 90 | 0 | 0 | 5,512 | 60,199 | 1,241 | 7,016 | 378 | 47 | 74,393 | -------- |
| 93 | 0 | 0 | 1,378 | 14,006 | 12,776 | 10,588 | 91 | 5 | 38,844 | -------- |
| Total and percent | 0 | 0 | 10,673 | 112,638 | 27,305 | 33,597 | 830 | 52 | 185,095 | 25.14 |
| Northern Baja California: | | | | | | | | | | |
| Line 97 | 0 | 0 | 4,327 | 19,550 | 36,880 | 4,556 | 602 | 0 | 65,915 | -------- |
| 100 | 14,348 | 4,508 | 2,700 | 5,664 | 14,660 | 8,939 | 1,232 | 181 | 52,232 | -------- |
| 103 | -------- | -------- | 5,722 | 21,840 | 16,905 | 4,601 | 519 | 0 | 49,587 | -------- |
| 105 | 2,196 | 70,331 | -------- | -------- | -------- | -------- | -------- | -------- | 72,527 | -------- |
| 107 | -------- | -------- | 66,907 | 19,528 | 14,200 | 10,606 | 2,015 | 0 | 113,256 | -------- |
| Total and percent | 16,544 | 74,839 | 79,656 | 66,582 | 82,645 | 28,702 | 4,368 | 181 | 353,517 | 48.02 |
| Upper central Baja California: | | | | | | | | | | |
| Line 110 | 9,585 | 27,732 | 59,051 | 5,847 | 1,228 | 2,250 | 1,122 | 0 | 106,815 | -------- |
| 113 | 5,671 | 738 | 17,658 | 1,376 | 3,412 | 721 | 0 | 0 | 29,576 | -------- |
| 115 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| 117 | 4,239 | 1,964 | 7,505 | 5,090 | 2,324 | 231 | 0 | 0 | 21,353 | -------- |
| 120 | 1,743 | 0 | 3,779 | 12,936 | 247 | 124 | 0 | 0 | 18,829 | -------- |
| Total and percent | 21,238 | 30,434 | 87,993 | 25,249 | 7,211 | 3,326 | 1,122 | 0 | 176,573 | 23.99 |
| Lower central Baja California: | | | | | | | | | | |
| Line 123 | 0 | 0 | 0 | 6,701 | 81 | 0 | 0 | 0 | 6,782 | -------- |
| 127 | 0 | 0 | 0 | 1,974 | 1,022 | 0 | 0 | 0 | 2,996 | -------- |
| 130 | 0 | 0 | 0 | 1,327 | 140 | 0 | 0 | 0 | 1,467 | -------- |
| 133 | 0 | 0 | 0 | 0 | 41 | 0 | 0 | 0 | 41 | -------- |
| 137 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 8 | -------- |
| Total and percent | 0 | 0 | 0 | 10,002 | 1,292 | 0 | 0 | 0 | 11,294 | 1.53 |
| Southern Baja California: | | | | | | | | | | |
| Line 140 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| 143 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| 147 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| 150 | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| Total and percent | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- | -------- |
| Grand total | 37,782 | 105,273 | 178,334 | 214,471 | 124,528 | 67,572 | 7,939 | 233 | 736,132 | -------- |
| Percent[1] | 5.13 | 14.30 | 24.22 | 29.13 | 16.92 | 9.18 | 1.08 | 0.03 | 99.99 | -------- |

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

TABLE 5.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1954*

[Cruise numbers in parentheses. No eggs taken during cruise 5412]

| | Jan. (5401) | Feb. (5402) | Mar. (5403) | Apr. (5404) | May (5405) | June (5406) | July (5407) | Aug. (5408) | Oct. (5410) | Annual total | Percent of total for all areas |
|---|---|---|---|---|---|---|---|---|---|---|---|
| North of Point Conception: | | | | | | | | | | | |
| Lines 40–57 | - | - | - | - | - | 82 | - | - | - | 82 | - |
| 60–77 | - | - | - | 0 | 13, 610 | 7, 697 | 9, 685 | 42 | 0 | 31, 034 | - |
| Total and percent | - | - | - | 0 | 13, 610 | 7, 779 | 9, 685 | 42 | 0 | 31, 116 | 6. 73 |
| Southern California: | | | | | | | | | | | |
| Line 80 | 0 | 0 | 0 | 43 | 14, 898 | 8, 166 | 4, 937 | 0 | 0 | 28, 044 | - |
| 83 | 0 | 0 | 0 | 165 | 25, 822 | 13, 838 | 1, 239 | 31 | 0 | 41, 095 | - |
| 85 | 0 | 0 | 0 | 0 | 3, 185 | 9, 797 | 221 | 0 | 0 | 13, 203 | - |
| 87 | 0 | 0 | 0 | 17, 090 | 11, 430 | 3, 666 | 52 | 25 | 0 | 32, 263 | - |
| 90 | 0 | 0 | 0 | 6, 529 | 3, 894 | 4, 905 | 9, 825 | 1, 596 | 0 | 26, 749 | - |
| 93 | 0 | 0 | 0 | 24, 012 | 3, 822 | 1, 010 | 6, 053 | 874 | 16 | 35, 787 | - |
| Total and percent | 0 | 0 | 0 | 47, 839 | 63, 051 | 41, 382 | 22, 327 | 2, 526 | 16 | 177, 141 | 38. 31 |
| Northern Baja California: | | | | | | | | | | | |
| Line 97 | 0 | 0 | 7, 846 | 22, 602 | 4, 428 | 11, 690 | 1, 632 | 256 | 0 | 48, 454 | - |
| 100 | 0 | 8, 034 | 40, 461 | 21, 729 | 10, 523 | 985 | 7, 289 | 539 | 0 | 89, 560 | - |
| 103 | 0 | 878 | 2, 178 | 7, 505 | 11, 424 | 915 | 0 | 0 | 0 | 22, 900 | - |
| 105 | - | - | - | - | - | - | - | - | - | - | - |
| 107 | 0 | 13, 887 | 1, 220 | 4, 029 | 3, 717 | 1, 998 | 0 | 0 | 0 | 24, 851 | - |
| Total and percent | 0 | 22, 709 | 51, 705 | 55, 865 | 30, 092 | 15, 588 | 8, 921 | 795 | 0 | 185, 765 | 40. 18 |
| Upper central Baja California: | | | | | | | | | | | |
| Line 110 | 148 | 208 | 365 | 6, 451 | 6, 622 | 1, 820 | 2, 978 | 0 | 0 | 18, 592 | - |
| 113 | 0 | 846 | 4, 137 | 4, 301 | 4, 861 | 538 | 70 | 40 | 0 | 14, 793 | - |
| 115 | - | - | - | - | - | - | - | - | - | - | - |
| 117 | 0 | 464 | 0 | 924 | 585 | 2, 011 | 0 | 33 | 0 | 4, 017 | - |
| 120 | 0 | 0 | 208 | 2, 008 | 4, 547 | 4, 671 | 392 | 0 | 0 | 11, 826 | - |
| Total and percent | 148 | 1, 518 | 4, 710 | 13, 684 | 16, 615 | 9, 040 | 3, 440 | 73 | 0 | 49, 228 | 10. 65 |
| Lower central Baja California: | | | | | | | | | | | |
| Line 123 | 0 | 0 | 0 | 124 | 12, 526 | 0 | 0 | 0 | 0 | 12, 650 | - |
| 127 | 0 | 0 | 0 | 915 | 207 | 4 | 0 | 0 | 0 | 1, 126 | - |
| 130 | 0 | 0 | 0 | 2, 160 | 0 | 0 | 0 | 0 | 0 | 2, 160 | - |
| 133 | 0 | 0 | 0 | 2, 984 | 0 | 0 | 0 | 0 | 0 | 2, 984 | - |
| 137 | 168 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 168 | - |
| Total and percent | 168 | 0 | 0 | 6, 183 | 12, 733 | 4 | 0 | 0 | 0 | 19, 088 | 4. 13 |
| Southern Baja California: | | | | | | | | | | | |
| Line 140 | 0 | - | - | - | - | - | - | - | - | - | - |
| 143 | 0 | - | - | - | - | - | - | - | - | - | - |
| 147 | 0 | - | - | - | - | - | - | - | - | - | - |
| 150 | 0 | - | - | - | - | - | - | - | - | - | - |
| Total and percent | 0 | - | - | - | - | - | - | - | - | - | - |
| Grand total | 316 | 24, 317 | 56, 415 | 123, 571 | 136, 101 | 73, 793 | 44, 373 | 3, 436 | 16 | 462, 338 | - |
| Percent [1] | 0. 07 | 5. 26 | 12. 20 | 26. 73 | 29. 44 | 15. 96 | 9. 60 | 0. 74 | 0 | 100. 00 | - |

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

Spawning in 1951 began in February. About 7 percent of the total number of eggs for the season were spawned during this month. Spawning rose to a peak of more than 30 percent of the total in March, and then gradually declined until June, when an increase occurred. Spawning decreased thereafter, being negligible in September. Spawning during February and March was centered about 150 miles offshore in region 2. During the next 2 months spawning was more general and no compact center was observed. Spawning had reached its widest distribution (most of the eggs being taken between lines 60 and 120) in April and May, and the center had moved inshore. During June and July the center was dispersed and offshore.

Spawning in 1952 began in January, when less than 1 percent of the total number of eggs were spawned, and rose to a peak of about 30 percent in May. It then declined to less than 1 percent in September and ceased altogether by October. The center of spawning was about 120 miles farther south during February and March than during the same period of 1951. Once again it was in the intermediate area. During April and May, spawning became heavier in region 3 and there was a strong inshore movement. During the final 2 months the spawners were grouped to

TABLE 6.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1951*

[Standard haul totals]

| Line | Offshore stations (100-seaward) | Intermediate stations (90–70) | Inshore stations (60-shore) | Total | Percent |
|---|---|---|---|---|---|
| February-March: | | | | | |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 | 0 |
| 80 | 2,795 | 7,790 | 1,658 | 12,243 | 33.3 |
| 90 | 1,506 | 9,013 | 1,484 | 12,003 | 32.6 |
| 100 | 91 | 955 | 907 | 1,953 | 5.3 |
| 110 | 0 | 477 | 10,053 | 10,530 | 28.6 |
| 120 | 0 | 0 | 74 | 74 | .2 |
| Total | 4,392 | 18,235 | 14,176 | 36,803 | 100.0 |
| Percent | 11.9 | 49.6 | 38.5 | 100.0 | ---------- |
| April-May: | | | | | |
| 60 | 0 | 14 | 0 | 14 | .1 |
| 70 | 1,573 | 27 | 0 | 1,600 | 6.0 |
| 80 | 2,502 | 629 | 160 | 3,291 | 12.4 |
| 90 | 3,430 | 1,832 | 2,976 | 8,238 | 31.0 |
| 100 | 589 | 201 | 7,312 | 8,102 | 30.0 |
| 110 | 647 | 525 | 2,505 | 3,677 | 13.8 |
| 120 | 847 | 309 | 538 | 1,694 | 6.4 |
| Total | 9,588 | 3,537 | 13,491 | 26,616 | 99.7 |
| Percent | 36.0 | 13.3 | 50.7 | 100.0 | ---------- |
| June-July: | | | | | |
| 60 | 1,490 | 222 | 6 | 1,718 | 11.3 |
| 70 | 137 | 2,613 | 1,414 | 4,164 | 27.5 |
| 80 | 40 | 1,100 | 664 | 1,804 | 11.9 |
| 90 | 945 | 284 | 2,399 | 3,628 | 23.9 |
| 100 | 15 | 1,134 | 802 | 1,951 | 12.9 |
| 110 | 0 | 765 | 420 | 1,185 | 7.8 |
| 120 | 0 | 648 | 56 | 704 | 4.6 |
| Total | 2,627 | 6,766 | 5,761 | 15,154 | 99.9 |
| Percent | 17.3 | 44.6 | 38.0 | 99.9 | ---------- |

TABLE 7.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1952*

[Standard haul totals]

| Line | Offshore stations (100-seaward) | Intermediate stations (90–70) | Inshore stations (60-shore) | Total | Percent |
|---|---|---|---|---|---|
| February-March: | | | | | |
| 60 | [1] | [1] | [1] | [1] | [1] |
| 70 | [1] | [1] | [1] | [1] | [1] |
| 80 | 11 | 377 | 0 | 388 | 2.8 |
| 90 | [1] | 6,665 | 0 | 6,665 | 48.5 |
| 100 | [1] | 4,528 | 2,027 | 6,555 | 47.7 |
| 110 | [1] | 4 | 2 | 6 | <0.1 |
| 120 | [1] | 142 | 0 | 142 | 1.0 |
| Total | 11 | 11,716 | 2,029 | 13,756 | 100.1 |
| Percent | 0.1 | 85.2 | 14.7 | 100.0 | ---------- |
| April-May: | | | | | |
| 60 | [1] | 0 | 0 | 0 | 0 |
| 70 | [1] | 0 | 0 | 0 | 0 |
| 80 | 223 | 0 | 0 | 223 | 1.0 |
| 90 | 205 | 3,635 | 4,805 | 8,645 | 37.1 |
| 100 | 82 | 1,724 | 6,107 | 7,913 | 34.0 |
| 110 | [1] | 5,495 | 567 | 6,062 | 26.0 |
| 120 | [1] | 293 | 159 | 452 | 1.9 |
| Total | 510 | 11,147 | 11,638 | 23,295 | 100.0 |
| Percent | 2.2 | 47.8 | 50.0 | 100.0 | ---------- |
| June-July: | | | | | |
| 60 | 5 | 535 | 36 | 576 | 3.6 |
| 70 | 429 | 270 | 0 | 699 | 4.4 |
| 80 | 3,495 | 2,235 | 1,098 | 6,828 | 42.8 |
| 90 | 74 | 3,766 | 950 | 4,790 | 30.0 |
| 100 | 161 | 601 | 1,208 | 1,970 | 12.4 |
| 110 | [1] | 398 | 665 | 1,063 | 6.7 |
| 120 | [1] | 0 | 13 | 13 | .1 |
| Total | 4,164 | 7,805 | 3,970 | 15,939 | 100.0 |
| Percent | 26.1 | 49.0 | 24.9 | 100.0 | ---------- |

[1] Region not occupied.

TABLE 8.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1953*

[Standard haul totals]

| Line | Offshore stations (100-seaward) | Intermediate stations (90–70) | Inshore stations (60-shore) | Total | Percent |
|---|---|---|---|---|---|
| February-March: | | | | | |
| 60 | [1] | [1] | [1] | [1] | [1] |
| 70 | [1] | [1] | [1] | [1] | [1] |
| 80 | [1] | 0 | 0 | 0 | 0 |
| 90 | [1] | 0 | 0 | 0 | 0 |
| 100 | [1] | 1,551 | 4,445 | 5,996 | 51.0 |
| 110 | [1] | 1,138 | 4,399 | 5,537 | 47.1 |
| 120 | [1] | [1] | 228 | 228 | 1.9 |
| Total | ---------- | 2,689 | 9,072 | 11,761 | 100.0 |
| Percent | ---------- | 22.9 | 77.1 | 100.0 | ---------- |
| April-May: | | | | | |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 70 | [1] | 0 | 8 | 8 | <0.1 |
| 80 | 1,149 | 2,452 | 18 | 3,619 | 11.7 |
| 90 | 1,725 | 5,631 | 298 | 7,654 | 24.8 |
| 100 | [1] | 580 | 805 | 1,385 | 4.5 |
| 110 | [1] | 5,437 | 8,721 | 14,158 | 45.8 |
| 120 | [1] | 403 | 3,679 | 4,082 | 13.2 |
| Total | 2,874 | 14,503 | 13,529 | 30,906 | 100.1 |
| Percent | 9.3 | 46.9 | 43.8 | 100.0 | ---------- |
| June-July: | | | | | |
| 60 | [1] | 0 | 96 | 96 | 1.3 |
| 70 | 85 | 116 | 61 | 262 | 3.4 |
| 80 | 21 | 703 | 657 | 1,381 | 18.0 |
| 90 | [1] | 423 | 364 | 787 | 10.3 |
| 100 | 151 | 952 | 3,456 | 4,559 | 59.4 |
| 110 | [1] | [1] | 562 | 562 | 7.3 |
| 120 | [1] | 17 | 10 | 27 | .4 |
| Total | 257 | 2,211 | 5,206 | 7,674 | 100.1 |
| Percent | 3.3 | 28.8 | 67.8 | 99.9 | ---------- |

[1] Region not occupied.

TABLE 9.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1954*

[Standard haul totals]

| Line | Offshore stations (100-seaward) | Intermediate stations (90–70) | Inshore stations (60-shore) | Total | Percent |
|---|---|---|---|---|---|
| February-March: | | | | | |
| 60 | [1] | [1] | [1] | [1] | [1] |
| 70 | [1] | [1] | [1] | [1] | [1] |
| 80 | [1] | 0 | 0 | 0 | 0 |
| 90 | [1] | 0 | 0 | 0 | 0 |
| 100 | [1] | 4,167 | 1,207 | 5,374 | 96.5 |
| 110 | [1] | 0 | 185 | 185 | 3.3 |
| 120 | [1] | 12 | 0 | 12 | 0.2 |
| Total | ---------- | 4,179 | 1,392 | 5,571 | 100.0 |
| Percent | ---------- | 75.0 | 25.0 | 100.0 | ---------- |
| April-May: | | | | | |
| 60 | 43 | 180 | 0 | 223 | 1.7 |
| 70 | [1] | 745 | 40 | 785 | 5.8 |
| 80 | [1] | 2,326 | 19 | 2,345 | 17.4 |
| 90 | [1] | 2,051 | 616 | 2,667 | 19.8 |
| 100 | 987 | 1,206 | 1,151 | 3,344 | 24.8 |
| 110 | [1] | 351 | 3,308 | 3,659 | 27.1 |
| 120 | [1] | 423 | 36 | 459 | 3.4 |
| Total | 1,030 | 7,282 | 5,170 | 13,482 | 100.0 |
| Percent | 7.6 | 54.0 | 38.3 | 99.9 | ---------- |
| June-July: | | | | | |
| 60 | 50 | 816 | 0 | 866 | 11.7 |
| 70 | [1] | 48 | 784 | 832 | 11.3 |
| 80 | 347 | 743 | 936 | 2,026 | 27.5 |
| 90 | [1] | 404 | 1,931 | 2,335 | 31.6 |
| 100 | [1] | 135 | 367 | 502 | 6.8 |
| 110 | [1] | 92 | 302 | 394 | 5.3 |
| 120 | [1] | 270 | 153 | 423 | 5.7 |
| Total | 397 | 2,508 | 4,473 | 7,378 | 99.9 |
| Percent | 5.4 | 34.0 | 60.6 | 100.0 | ---------- |

[1] Region not occupied.

TABLE 10.—*Comparison of estimates of regional distribution using selected stations on selected lines and all data, 1951–54*

| Line | February–March | April–May | June–July | Selected stations Total | Selected stations Percent | All stations (percent) |
|---|---|---|---|---|---|---|
| 1951: | | | | | | |
| 60 | 0 | 14 | 1,718 | 1,732 | [1] 2.20 | 12.13 |
| 70 | 0 | 1,600 | 4,164 | 5,764 | 7.34 | |
| 80 | 12,243 | 3,291 | 1,804 | 17,338 | 22.07 | 22.77 |
| 90 | 12,003 | 8,238 | 3,628 | 23,869 | 30.38 | 31.53 |
| 100 | 1,953 | 8,102 | 1,951 | 12,006 | 15.28 | 16.00 |
| 110 | 10,530 | 3,677 | 1,185 | 15,392 | 19.59 | 14.61 |
| 120 | 74 | 1,694 | 704 | 2,472 | 3.15 | 2.95 |
| Total | | | | 78,573 | 100.01 | 99.99 |
| 1952: | | | | | | |
| 60 | (2) | 0 | 576 | 576 | 1.09 | 2.64 |
| 70 | (2) | 0 | 699 | 699 | 1.32 | |
| 80 | 388 | 223 | 6,828 | 7,439 | 14.04 | 14.78 |
| 90 | 6,665 | 8,645 | 4,790 | 20,100 | 37.93 | 40.95 |
| 100 | 6,555 | 7,913 | 1,970 | 16,438 | 31.02 | 29.31 |
| 110 | 6 | 6,062 | 1,063 | 7,131 | 13.46 | 10.31 |
| 120 | 142 | 452 | 13 | 607 | 1.15 | 2.01 |
| Total | | | | 52,990 | 100.01 | 100.00 |
| 1953: | | | | | | |
| 60 | (2) | 0 | 96 | 96 | 0.19 | 1.31 |
| 70 | (2) | 8 | 262 | 270 | .54 | |
| 80 | 0 | 3,619 | 1,381 | 5,000 | 9.91 | 9.76 |
| 90 | 0 | 7,654 | 787 | 8,441 | 16.77 | 24.34 |
| 100 | 5,996 | 1,385 | 4,559 | 11,940 | 23.72 | 39.07 |
| 110 | 5,537 | 14,158 | 562 | 20,257 | 40.24 | 21.43 |
| 120 | 228 | 4,082 | 27 | 4,337 | 8.62 | 4.09 |
| Total | | | | 50,341 | 99.99 | 100.00 |
| 1954: | | | | | | |
| 60 | (2) | 223 | 866 | 1,089 | 4.12 | 6.73 |
| 70 | (2) | 785 | 832 | 1,617 | 6.12 | |
| 80 | 0 | 2,345 | 2,026 | 4,371 | 16.54 | 24.79 |
| 90 | 0 | 2,667 | 2,335 | 5,002 | 18.92 | 24.01 |
| 100 | 5,374 | 3,344 | 502 | 9,220 | 34.88 | 29.70 |
| 110 | 185 | 3,659 | 394 | 4,238 | 16.03 | 8.09 |
| 120 | 12 | 459 | 423 | 894 | 3.38 | 6.69 |
| Total | | | | 26,431 | 99.99 | 100.01 |

[1] Hundredths of a percent are used so trace amounts of spawning may be indicated (see p. 252).
[2] Region not occupied.

the north in region 2 and were farther offshore in the intermediate area.

Spawning in 1953 began in February and rose to a peak of nearly 30 percent of the total in May, and then declined. Only small numbers of eggs were taken in October. Early spawning was centered in region 3, with a fair amount in region 2. The center of spawning was about 240 miles farther south than the early spawning of 1951, and most of the spawning was inshore. From this center, spawning moved both north and south and somewhat offshore to the intermediate area. During the final 2 months, the center of spawning was again in region 3 and inshore.

The monthly distribution of spawning for 1954 is very similar to that for 1953. Spawning extended from January to October and reached a peak of nearly 30 percent of the total in May. Early spawning was centered in region 3 about 150 miles offshore (intermediate area) and no eggs were taken off California. In the next 2 months the heavier concentrations extended north to region 2 and south to the northern edge of region 4, with some inshore movement. During the final 2 months the center shifted northward to region 2 and inshore. The distribution and relative abundance of jack mackerel eggs for 1951–54 are illustrated in Farris (1958: figs. 3–6).

The remarkable similarity of monthly distribution of spawning in 1952 through 1954 (peak month, May) is illustrated in figure 4. The year

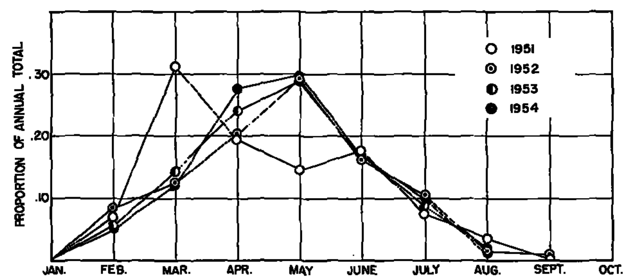


FIGURE 4.—Proportion of annual spawning of jack mackerel, by months, 1951–54.

1951 appears to have been an anomalous year with an early peak of spawning in March. The proportion of spawning that occurred during the peak month of each year, including 1951, was approximately three-tenths of the total for the year. Furthermore, over seven-tenths of the spawning for any year occurred during the first 5 months.

Of the 4 years studied, 1951 had the highest proportion of the annual total number of eggs in region 1. High proportions of the annual total eggs were found in regions 3 and 4 during 1953, with a small proportion being taken in regions 1 and 2.

## BOUNDARIES OF THE SPAWNING AREA

The northern and western boundaries of jack mackerel spawning during August and September were established by expedition *Norpac*, an extensive study of the north Pacific in 1955 conducted by the California Cooperative Oceanic Fisheries Investigations and other agencies (Ahlstrom, 1956: p. 39; Ahlstrom and Kramer, 1957: p. 55). These boundaries may be less certain than the others because the study of the area was more limited in time. The eastern and southern boundaries were established from data collected on regular survey cruises of the California Cooperative Oceanic Fisheries Investigations (Farris, 1958). Spawning areas are approximately bounded by the 26th parallel on the south, the 45th parallel on the north, the coast of North America on the east, and the 150th meridian on the west.

## SOURCES OF ERROR AND BIAS IN SAMPLING EGGS

These data and subsequent interpretations are subject to errors inherent in the collection procedures. The types of error investigated and evaluated were (1) completeness of retention of eggs by the nets; (2) completeness of sampling of the vertical range; (3) sampling error owing to a variable distribution of eggs in space and time; and (4) incomplete sampling of the horizontal range of jack mackerel spawning.

### RETENTION OF EGGS BY THE NETS

The eggs are fully retained by the net once they are in it, because the plankton nets have a stretched mesh of 0.5–0.7 mm. (Ahlstrom, 1953), and the spherical eggs range in diameter from 0.9–1.1 mm (Ahlstrom and Ball, 1954). It would appear, therefore, that no eggs are lost through the mesh of the sampling net.

### SAMPLING OF THE VERTICAL RANGE

Investigation of the vertical distribution of jack mackerel eggs (Ahlstrom, 1959: table 7) with a horizontally towed closing net reveals that most of the eggs occur in the upper 40 meters of water. Jack mackerel eggs have rarely been taken below 100 meters, and never below 140 meters. The bulk of the eggs have occurred above the thermocline. Since plankton hauls are routinely made from a depth of 140 meters, which has always included the thermocline depth, it seems likely that the vertical distribution of jack mackerel eggs is completely sampled.

### VARIABLE DISTRIBUTION OF EGGS

The distribution of jack mackerel eggs is variable with respect to both time and space. An illustrative example is given in figure 5. The standard numbers of jack mackerel eggs for line 97 have been plotted by station for 4 months.

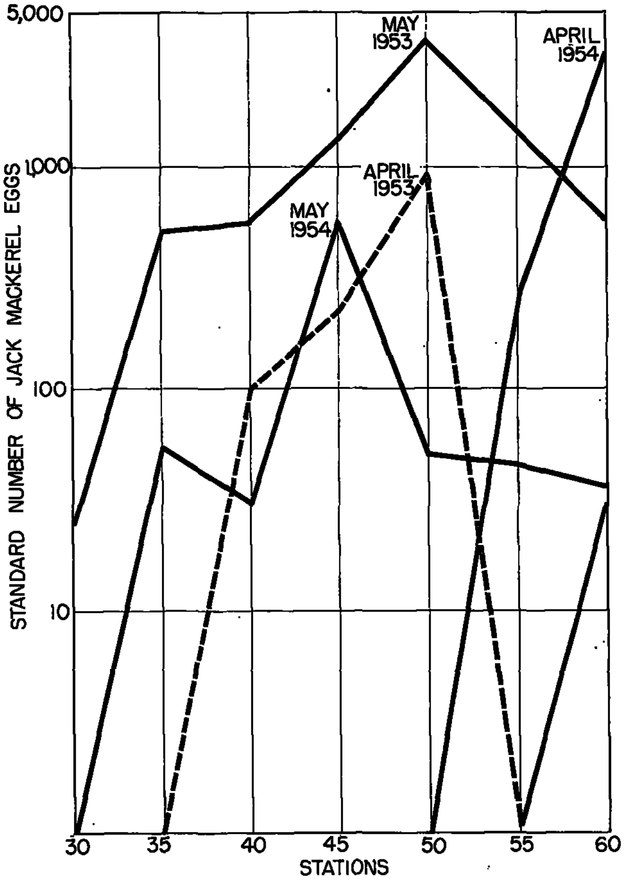


FIGURE 5.—Standard numbers of jack mackerel eggs found on line 97 during 4 months.

The average number of eggs per station by month is given below.

| Year: | *April* | *May* |
|---|---|---|
| 1953 | 181 | 1, 116 |
| 1954 | 762 | 143 |

The average station on line 97 in May 1953 contained six times as many eggs as the average station in the preceding month. Assuming that this change was rectilinear in time, the estimate would be altered considerably, depending on which day of the month the sample was taken.

Spatial variability is indicated by the data for April 1954, in which a change of 1 order of magnitude occurs within 20 miles. There is at least one such combination of adjacent stations having as great a change in the distribution of jack mackerel eggs for each cruise illustrated. The grid of stations occupied is too coarse except for fairly rough estimates of egg abundance. Although more frequent sampling of more closely spaced stations is highly desirable, such sampling cannot be effected, since it would raise the current cost of sampling prohibitively.

The monthly sampling of the California Cooperative Oceanic Fisheries Investigations grid of stations has all but precluded the simple assessment of the error associated with these estimates of abundance. Although the construction of the proper statistical model was not within the scope of this investigation, I was able to make an estimate of the error arising from the practice of linear interpolation of egg numbers in time and space. This calculation was possible because in 1953 and 1954 stations which were only 20 miles apart were occupied, and the samples contained jack mackerel eggs. In 1952, a few stations containing jack mackerel eggs were occupied in late March.

The errors arising from stratification in space (i.e., spacing sampling stations 40 miles apart) and time (i.e., spacing sampling cruises 1 month apart) were considered. Standard numbers of eggs for stations 20 miles apart—obtained by linear interpolation of values obtained from stations 40 miles apart—were compared with values actually observed. In like manner, standard numbers of eggs for stations sampled at intervals of one-half month—obtained by linear interpolation of observed values from stations sampled at monthly intervals—were compared with the values actually observed. The differences should be zero if no error arises from linear interpolation through space and time. Since the average difference cannot be expected actually to equal zero, owing to sampling variability, the 95-percent confidence limits for both estimates were computed. These limits should include zero.

The error arising from spacing the sampling stations 40 miles apart was estimated using data from selected stations on selected lines. (Stations having no eggs were not used.) These stations were placed 20 miles apart. An estimated value was given for every other station by a process of linear interpolation of values between the remaining stations which were 40 miles apart. These interpolated values were then compared with the actual number of eggs found at the stations and the difference ($\Delta_i$) calculated. ($\Delta_i$=observed standard number of jack mackerel eggs minus estimated number of jack mackerel eggs.) The deltas were averaged to give $\bar{\Delta}$, the average difference between the observed standard number of jack mackerel eggs and the number calculated by linear interpolation.

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The frequency distribution of $\Delta_i$ was plotted and appeared to be normally distributed (fig. 6).

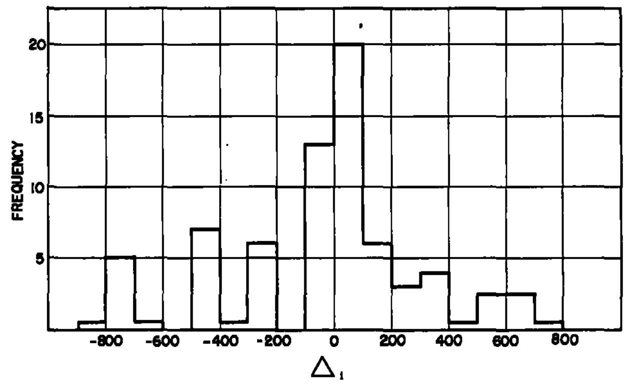


FIGURE 6.—Frequency distribution of $\Delta_i$ (the difference between observed and estimated numbers of jack mackerel eggs).

Therefore $\Delta_i$ was considered to be a normally distributed random variable with mean $\bar{\Delta}$ and variance $s^2$.

| Statistic | Value | Description |
|---|---|---|
| $\bar{\Delta}$ | 7.8 | Average difference. |
| $s^2\Delta_i$ | 518,956 | Variance of the individual differences. |
| $s\Delta_i$ | 720 | Standard deviation of the individual differences. |
| $s\bar{\Delta}$ | 74.2 | Standard deviation of the mean. |
| $n$ | 94 | Number of differences observed. |

$$-137.2 \leq \bar{\Delta} \leq 152.8$$

The average difference is close to zero. The wide confidence limits indicate the high variability associated with any one observation.

The $\Delta_i$ were compared with the size of each $i$th haul to determine whether the differences were related to population size (fig. 7). No relation was evident and it was concluded that the $\Delta_i$ were not related to population size.

The error arising from stratification in time was estimated by considering the standard numbers of jack mackerel eggs taken at selected stations during cruises spaced about 2 weeks apart (March, late March, and April, 1952). By linear interpolation of the number of eggs taken at a station between the March and April occupancies, an estimate of the number of eggs that should occur at the station during the late March occupancy was obtained. This estimated number was then

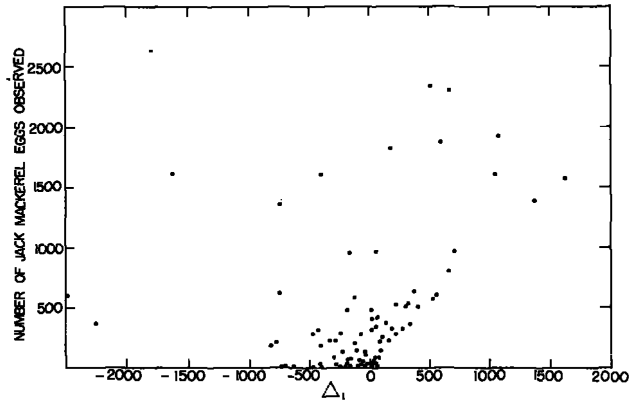


FIGURE 7.—Relation of $\Delta_i$ (the difference between observed and estimated numbers of jack mackerel eggs) and the number of eggs observed at the $i$th station.

compared with the number actually observed and the difference ($\Delta_i$) noted. ($\Delta_i$=the standard number of jack mackerel eggs estimated by linear interpolation minus the number actually observed.) The differences were averaged to give a mean difference ($\bar{\Delta}$) between the estimated number of eggs and the actual number of eggs. The average difference ($\bar{\Delta}$) was minus 11, with a variance of 3370. The 95-percent confidence limits on $\bar{\Delta}$ are minus 47 to plus 25.

Although the individual errors arising from the practice of linear interpolation of jack mackerel eggs in time and space were high and variable, the average error tended toward zero. I concluded that for a large number of samples (i.e., interpolations) the error arising from linear interpolation of the number of eggs in time and space was negligible.

A further indication of irregularities in the spatial and/or temporal distribution would be the nonconcurrence of eggs and larvae in the sampling areas. In table 11 the occurrences of eggs and larvae, by regions, are compared. In region 1,

TABLE 11.—*Occurrences of jack mackerel eggs and larvae, by month and region, 1952–54*

| Date | Region 1[1] | | | Region 2 | | | Region 3 | | | Region 4 | | | Region 5 | | | Region 6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Stations occupied | Stations with eggs | Stations with larvae | Stations occupied | Stations with eggs | Stations with larvae | Stations occupied | Stations with eggs | Stations with larvae | Stations occupied | Stations with eggs | Stations with larvae | Stations occupied | Stations with eggs | Stations with larvae | Stations occupied | Stations with eggs | Stations with larvae |
| **1952:** | | | | | | | | | | | | | | | | | | |
| January | ------ | ------ | ------ | 28 | 0 | 0 | 19 | 3 | 1 | 22 | 0 | 0 | 25 | 0 | 0 | ------ | ------ | ------ |
| February | ------ | ------ | ------ | 27 | 5 | 3 | 20 | 7 | 0 | 30 | 0 | 0 | 18 | 0 | 0 | 14 | 0 | 0 |
| March | ------ | ------ | ------ | 25 | 4 | 6 | 20 | 8 | 12 | 25 | 7 | 11 | 21 | 1 | 3 | ------ | ------ | ------ |
| April | 18 | 0 | 0 | 37 | 14 | 12 | 31 | 24 | 26 | 36 | 17 | 13 | 33 | 5 | 10 | ------ | ------ | ------ |
| May | 23 | 0 | 0 | 50 | 31 | 28 | 43 | 35 | 37 | 40 | 30 | 25 | 31 | 5 | 7 | ------ | ------ | ------ |
| June | 34 | 4 | 3 | 58 | 36 | 42 | 58 | 34 | 42 | 42 | 21 | 18 | 30 | 3 | 3 | ------ | ------ | ------ |
| July | 46 | 14 | 4 | 38 | 31 | 22 | 32 | 27 | 25 | 36 | 9 | 11 | 27 | 0 | 2 | ------ | ------ | ------ |
| August | 15 | 2 | 1 | 22 | 10 | 8 | 17 | 3 | 9 | 30 | 1 | 0 | 15 | 0 | 0 | ------ | ------ | ------ |
| September | 21 | 0 | 0 | 22 | 6 | 8 | 17 | 5 | 3 | 19 | 0 | 0 | 15 | 0 | 0 | ------ | ------ | ------ |
| October | 18 | 0 | 0 | 21 | 0 | 1 | 15 | 0 | 2 | 19 | 0 | 0 | 15 | 0 | 0 | ------ | ------ | ------ |
| November | 18 | 0 | 0 | 22 | 0 | 0 | 16 | 0 | 0 | 21 | 0 | 0 | 14 | 0 | 0 | ------ | ------ | ------ |
| December | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Total | 193 | 20 | 8 | 350 | 137 | 130 | 288 | 146 | 157 | 320 | 85 | 78 | 244 | 14 | 25 | 14 | 0 | 0 |
| **1953:** | | | | | | | | | | | | | | | | | | |
| January | ------ | ------ | ------ | 34 | 0 | 0 | 20 | 0 | 0 | 16 | 0 | 0 | 13 | 0 | 0 | 13 | 0 | 0 |
| February | ------ | ------ | ------ | 35 | 0 | 1 | 17 | 2 | 4 | 24 | 8 | 5 | 19 | 0 | 0 | ------ | ------ | ------ |
| March | ------ | ------ | ------ | 36 | 0 | 3 | 17 | 9 | 13 | 29 | 11 | 12 | 31 | 0 | 1 | ------ | ------ | ------ |
| April | 20 | 1 | 0 | 61 | 9 | 8 | 41 | 30 | 21 | 38 | 31 | 18 | 35 | 0 | 0 | ------ | ------ | ------ |
| May | 30 | 0 | 0 | 63 | 41 | 23 | 38 | 35 | 22 | 37 | 28 | 21 | 35 | 8 | 10 | ------ | ------ | ------ |
| June | 26 | 18 | 2 | 56 | 31 | 20 | 43 | 33 | 34 | 40 | 19 | 23 | 31 | 11 | 9 | ------ | ------ | ------ |
| July | 24 | 9 | 2 | 38 | 21 | 15 | 20 | 14 | 8 | 21 | 8 | 5 | 19 | 0 | 0 | ------ | ------ | ------ |
| August | 19 | 6 | 1 | 38 | 11 | 5 | 20 | 8 | 3 | 21 | 3 | 2 | 20 | 0 | 0 | ------ | ------ | ------ |
| September | ------ | ------ | ------ | 18 | 0 | 1 | ------ | ------ | ------ | 24 | 0 | 0 | ------ | ------ | ------ | ------ | ------ | ------ |
| October | ------ | ------ | ------ | 18 | 2 | 8 | 16 | 2 | 6 | 21 | 0 | 4 | 14 | 0 | 1 | ------ | ------ | ------ |
| November | ------ | ------ | ------ | 19 | 0 | 0 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| December | ------ | ------ | ------ | 28 | 0 | 0 | 17 | 0 | 0 | 21 | 0 | 0 | 16 | 0 | 0 | ------ | ------ | ------ |
| Total | 119 | 34 | 5 | 444 | 115 | 79 | 249 | 133 | 111 | 292 | 108 | 90 | 233 | 19 | 21 | 13 | 0 | 0 |
| **1954:** | | | | | | | | | | | | | | | | | | |
| January | 2 | 0 | 0 | 42 | 0 | 0 | 22 | 0 | 0 | 27 | 1 | 0 | 23 | 1 | 2 | 18 | 0 | 0 |
| February | 2 | 0 | 0 | 37 | 0 | 0 | 24 | 11 | 3 | 31 | 5 | 4 | 22 | 0 | 1 | ------ | ------ | ------ |
| March | 2 | 0 | 0 | 35 | 0 | 0 | 32 | 15 | 19 | 48 | 8 | 19 | 36 | 0 | 0 | ------ | ------ | ------ |
| April | 18 | 0 | 0 | 51 | 16 | 13 | 39 | 29 | 26 | 52 | 24 | 19 | 38 | 8 | 15 | ------ | ------ | ------ |
| May | 19 | 8 | 2 | 54 | 33 | 23 | 42 | 34 | 34 | 52 | 25 | 29 | 38 | 9 | 8 | ------ | ------ | ------ |
| June | 36 | 13 | 9 | 48 | 31 | 20 | 39 | 25 | 34 | 51 | 17 | 22 | 35 | 1 | 6 | ------ | ------ | ------ |
| July | 19 | 8 | 6 | 37 | 13 | 11 | 20 | 9 | 9 | 22 | 6 | 3 | 20 | 0 | 1 | ------ | ------ | ------ |
| August | 22 | 1 | 2 | 39 | 10 | 13 | 19 | 6 | 8 | 22 | 2 | 0 | 20 | 0 | 0 | ------ | ------ | ------ |
| September | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| October | 2 | 0 | 0 | 38 | 2 | 1 | 22 | 0 | 0 | 23 | 0 | 0 | 20 | 0 | 1 | ------ | ------ | ------ |
| November | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| December | ------ | ------ | ------ | 36 | 0 | 0 | 16 | 0 | 0 | 26 | 0 | 0 | 19 | 0 | 0 | 18 | 0 | 0 |
| Total | 122 | 30 | 19 | 417 | 105 | 81 | 275 | 129 | 133 | 354 | 88 | 96 | 271 | 19 | 34 | 36 | 0 | 0 |

[1] See page 253.

there are more occurrences of eggs than of larvae, while in region 5, the converse is true. This may indicate southern transport of the larvae by the California Current.

The high proportion of stations occupied in region 2 at which eggs or larvae were taken is a further indication (see also tables 3, 4, and 5) that this is the region of maximum spawning activity.

A comparison of total occurrences of eggs with total occurrences of larvae is interpreted as indicative of a distribution more regular than that encountered for other pelagic eggs and larvae (e.g., sardines).

### SAMPLING OF THE HORIZONTAL RANGE OF SPAWNING

To determine the proportion of the total annual spawning which might be missed by failure to extend the sampling far enough seaward, the proportion of eggs taken beyond stations 90 (the usual seaward extent of sampling) was computed (see column 100—seaward in tables 6, 7, 8, and 9). This areal proportion was multiplied by the proportion of annual spawning that occurred during the appropriate 2-month interval (tables 2, 3, 4, and 5) to give a bimonthly estimate of the proportion of annual spawning which might be missed by failure to extend the sampling sufficiently seaward (table 12). It would appear that at least 21 percent of the annual spawning has occurred seaward of stations 90, and that a portion of the eggs has been missed in those years when monthly sampling was not extended beyond that point.

TABLE 12.—*Proportion of jack mackerel spawning occurring seaward of station 90, by 2-month intervals, 1951–54*

| Month | 1951 | 1952 | 1953 | 1954 |
|---|---|---|---|---|
| February–March | 0.05 | (1) | (1) | (1) |
| April–May | .12 | 0.01 | 0.05 | 0.04 |
| June–July | .04 | .07 | .01 | .01 |
| Annual total | .21 | .08 | .06 | .05 |

1 Region not occupied.

Data from the previously mentioned *Norpac* indicate that the proportion of eggs spawned in northern waters (north of line 40) may be between 1 and 2 percent of the annual total. This proportion is minimal, since spawning occurs in periods other than that covered by *Norpac*. This estimate was determined by estimating the total spawning in the region for the period August–early September (8,655 billion eggs) and comparing that figure with the estimated number of eggs spawned in 1954 (464,452 billion) and 1951 (874,322 billion). It is therefore inferred that an appreciable amount of annual spawning may occur west of stations 90 but a lesser amount takes place north of line 40.

## EFFECTS OF TEMPERATURE ON SPAWNING

Temperature may have at least two effects on the jack mackerel. It influences the rate at which the eggs develop (see p. 250), and it may well govern when and where the adults spawn.

To determine the effect of temperature on the spawning jack mackerel, temperatures at 10-meter depths were tabulated by 0.5° C. intervals for all stations where jack mackerel eggs were taken in 1951 through 1954 (table 13). The temperature at this depth is generally representative of the strata in which jack mackerel eggs are most abundant. These data were examined also for seasonal effect by dividing the year into an early (January–May) and a late (June–December) period. The effect of temperature on the size of haul was also examined by dividing the samples into two categories: hauls containing 1–100 eggs and hauls containing 101 eggs and more.

A seasonal trend toward higher spawning temperatures in the late summer with a greater temperature range was indicated (table 14 and figure 8). The data were then tabulated by

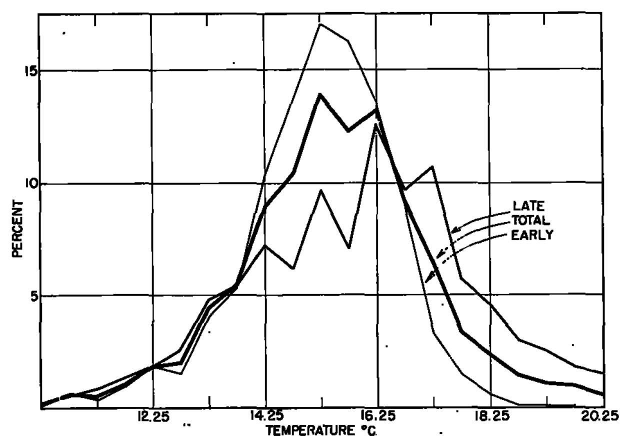


FIGURE 8.—Percentage of early (January-May) stations, of late (June–December) stations, and of the total stations having jack mackerel eggs, shown by 0.5° C. temperature intervals measured at 10-meter depth.

TABLE 13.—*Temperature distribution at 10 meters of stations having jack mackerel eggs, by season and size of sample, 1951–54*

[In 0.5° C. intervals]

| Temperature | 1951 | | | 1952 | | | 1953 | | | 1954 | | | Total | | | Percent of total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Early | Late | Total | Early | Late | Total | Early | Late | Total | Early | Late | Total | Early | Late | Total | |
| 1-100 eggs: | | | | | | | | | | | | | | | | |
| 10.00-10.49 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 2 | 0.2 |
| 10.50-10.99 | 0 | 2 | 2 | 0 | 0 | 0 | 4 | 1 | 5 | 1 | 0 | 1 | 5 | 3 | 8 | 1.1 |
| 11.00-11.49 | 1 | 2 | 3 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 5 | 7 | 1.0 |
| 11.50-11.99 | 2 | 1 | 3 | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 6 | 6 | 6 | 12 | 1.7 |
| 12.00-12.49 | 3 | 4 | 7 | 1 | 1 | 2 | 4 | 4 | 8 | 0 | 1 | 1 | 8 | 10 | 18 | 2.5 |
| 12.50-12.99 | 3 | 2 | 5 | 1 | 5 | 6 | 2 | 4 | 6 | 1 | 0 | 1 | 7 | 11 | 18 | 2.5 |
| 13.00-13.49 | 9 | 5 | 14 | 3 | 4 | 7 | 1 | 5 | 6 | 2 | 4 | 6 | 15 | 18 | 33 | 4.6 |
| 13.50-13.99 | 10 | 3 | 13 | 7 | 2 | 9 | 6 | 7 | 13 | 1 | 3 | 4 | 24 | 15 | 39 | 5.5 |
| 14.00-14.49 | 6 | 6 | 12 | 4 | 3 | 7 | 7 | 5 | 12 | 10 | 6 | 16 | 27 | 20 | 47 | 6.6 |
| 14.50-14.99 | 4 | 3 | 7 | 4 | 6 | 10 | 5 | 5 | 10 | 11 | 3 | 14 | 24 | 17 | 41 | 5.7 |
| 15.00-15.49 | 10 | 11 | 21 | 13 | 7 | 20 | 10 | 10 | 20 | 17 | 6 | 23 | 50 | 34 | 84 | 11.7 |
| 15.50-15.99 | 15 | 11 | 26 | 6 | 5 | 11 | 4 | 6 | 10 | 13 | 1 | 14 | 38 | 23 | 61 | 8.5 |
| 16.00-16.49 | 17 | 17 | 34 | 11 | 15 | 26 | 8 | 10 | 18 | 17 | 9 | 26 | 53 | 51 | 104 | 14.5 |
| 16.50-16.99 | 14 | 8 | 22 | 8 | 14 | 22 | 4 | 4 | 8 | 13 | 12 | 25 | 39 | 38 | 77 | 10.7 |
| 17.00-17.49 | 9 | 12 | 21 | 2 | 20 | 22 | 1 | 6 | 7 | 8 | 6 | 14 | 20 | 44 | 64 | 9.0 |
| 17.50-17.99 | 6 | 6 | 12 | 1 | 3 | 4 | 1 | 5 | 6 | 0 | 6 | 6 | 8 | 20 | 28 | 3.9 |
| 18.00-18.49 | 5 | 3 | 8 | 0 | 5 | 5 | 0 | 5 | 5 | 0 | 7 | 7 | 5 | 20 | 25 | 3.5 |
| 18.50-18.99 | 1 | 6 | 7 | 0 | 1 | 1 | 0 | 3 | 3 | 0 | 6 | 6 | 1 | 16 | 17 | 2.4 |
| 19.00-19.49 | 0 | 2 | 2 | 0 | 1 | 1 | 0 | 5 | 5 | 0 | 2 | 2 | 0 | 10 | 10 | 1.4 |
| 19.50-19.99 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 6 | 7 | 1 | 10 | 11 | 1.5 |
| 20.00-20.49 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 2 | 0 | 4 | 4 | 0 | 7 | 7 | 1.0 |
| 20.50-20.99 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 2 | .2 |
| Total | 115 | 106 | 221 | 61 | 96 | 157 | 59 | 93 | 152 | 99 | 86 | 185 | 334 | 381 | 715 | 99.7 |
| 101+ eggs: | | | | | | | | | | | | | | | | |
| 10.00-10.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10.50-10.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.00-11.49 | 0 | 0 | 0 | .0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11.50-11.99 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 2 | 3 | .4 |
| 12.00-12.49 | 2 | 1 | 3 | 1 | 0 | 1 | 3 | 0 | 3 | 0 | 0 | 0 | 6 | 1 | 7 | 1.0 |
| 12.50-12.99 | 1 | 2 | 3 | 0 | 1 | 1 | 2 | 0 | 2 | 2 | 2 | 4 | 5 | 5 | 10 | 1.5 |
| 13.00-13.49 | 4 | 2 | 6 | 5 | 5 | 10 | 2 | 2 | 4 | 6 | 2 | 8 | 17 | 11 | 28 | 4.1 |
| 13.50-13.99 | 7 | 8 | 15 | 2 | 2 | 4 | 6 | 3 | 9 | 3 | 5 | 8 | 18 | 18 | 36 | 5.3 |
| 14.00-14.49 | 19 | 11 | 30 | 8 | 1 | 9 | 13 | 6 | 19 | 14 | 6 | 20 | 54 | 24 | 78 | 11.4 |
| 14.50-14.99 | 14 | 3 | 17 | 25 | 10 | 35 | 21 | 6 | 27 | 24 | 2 | 26 | 84 | 21 | 105 | 15.4 |
| 15.00-15.49 | 29 | 3 | 32 | 8 | 7 | 15 | 25 | 11 | 36 | 23 | 4 | 27 | 85 | 25 | 110 | 16.2 |
| 15.50-15.99 | 23 | 4 | 27 | 22 | 7 | 29 | 24 | 8 | 32 | 22 | 1 | 23 | 91 | 20 | 111 | 16.3 |
| 16.00-16.49 | 20 | 9 | 29 | 14 | 6 | 20 | 7 | 8 | 15 | 13 | 3 | 16 | 54 | 26 | 80 | 11.7 |
| 16.50-16.99 | 6 | 6 | 12 | 7 | 9 | 16 | 5 | 4 | 9 | 13 | 2 | 15 | 31 | 21 | 52 | 7.6 |
| 17.00-17.49 | 1 | 4 | 5 | 2 | 6. | 8 | 2 | 8 | 10 | 1 | 3 | 4 | 6 | 21 | 27 | 4.0 |
| 17.50-17.99 | 1 | 3 | 4 | 1 | 7 | 8 | 1 | 5 | 6 | 0 | 0 | 0 | 3 | 15 | 18 | 2.6 |
| 18.00-18.49 | 0 | 4 | 4 | 0 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 8 | 8 | 1.2 |
| 18.50-18.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | .3 |
| 19.00-19.49 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 5 | 5 | .7 |
| 19.50-19.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | .1 |
| 20.00-20.49 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 2 | .3 |
| 20.50-20.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 127 | 61 | 188 | 95 | 64 | 159 | 112 | 71 | 183 | 121 | 32 | 153 | 455 | 228 | 683 | 100.1 |

TABLE 14.—*Summary: Distribution of temperatures at 10 meters of stations having jack mackerel eggs, by season and size of sample, 1951–54*

[In 0.5°C. intervals]

| Temperature | Early season | | | | Late season | | | | Season total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1-100 eggs | 101+ eggs | Total | Percent of total | 1-100 eggs | 101+ eggs | Total | Percent of total | 1-100 eggs | 101+ eggs | Total | Percent of total |
| 10.00-10.49 | 1 | 0 | 1 | 0.1 | 1 | 0 | 1 | 0.2 | 2 | 0 | 2 | 0.1 |
| 10.50-10.99 | 5 | 0 | 5 | .6 | 3 | 0 | 3 | .5 | 8 | 0 | 8 | .6 |
| 11.00-11.49 | 2 | 0 | 2 | .3 | 5 | 0 | 5 | .8 | 7 | 0 | 7 | .5 |
| 11.50-11.99 | 6 | 1 | 7 | .9 | 6 | 2 | 8 | 1.3 | 12 | 3 | 15 | 1.1 |
| 12.00-12.49 | 8 | 6 | 14 | 1.8 | 10 | 1 | 11 | 1.8 | 18 | 7 | 25 | 1.8 |
| 12.50-12.99 | 7 | 5 | 12 | 1.5 | 11 | 5 | 16 | 2.6 | 18 | 10 | 28 | 2.0 |
| 13.00-13.49 | 15 | 17 | 32 | 4.1 | 18 | 11 | 29 | 4.8 | 33 | 28 | 61 | 4.4 |
| 13.50-13.99 | 24 | 18 | 42 | 5.3 | 15 | 18 | 33 | 5.4 | 39 | 36 | 75 | 5.4 |
| 14.00-14.49 | 27 | 54 | 81 | 10.3 | 20 | 24 | 44 | 7.2 | 47 | 78 | 125 | 8.9 |
| 14.50-14.99 | 24 | 84 | 108 | 13.7 | 17 | 21 | 38 | 6.2 | 41 | 105 | 146 | 10.4 |
| 15.00-15.49 | 50 | 85 | 135 | 17.1 | 34 | 25 | 59 | 9.7 | 84 | 110 | 194 | 13.9 |
| 15.50-15.99 | 38 | 91 | 129 | 16.3 | 23 | 20 | 43 | 7.1 | 61 | 111 | 172 | 12.3 |
| 16.00-16.49 | 53 | 54 | 107 | 13.6 | 51 | 26 | 77 | 12.6 | 104 | 80 | 184 | 13.2 |
| 16.50-16.99 | 39 | 31 | 70 | 8.9 | 38 | 21 | 59 | 9.7 | 77 | 52 | 129 | 9.2 |
| 17.00-17.49 | 20 | 6 | 26 | 3.3 | 44 | 21 | 65 | 10.7 | 64 | 27 | 91 | 6.5 |
| 17.50-17.99 | 8 | 3 | 11 | 1.4 | 20 | 15 | 35 | 5.7 | 28 | 18 | 46 | 3.3 |
| 18.00-18.49 | 5 | 0 | 5 | .6 | 20 | 8 | 28 | 4.6 | 25 | 8 | 33 | 2.4 |
| 18.50-18.99 | 1 | 0 | 1 | .1 | 16 | 2 | 18 | 3.0 | 17 | 2 | 19 | 1.4 |
| 19.00-19.49 | 0 | 0 | 0 | 0 | 10 | 5 | 15 | 2.5 | 10 | 5 | 15 | 1.1 |
| 19.50-19.99 | 1 | 0 | 1 | .1 | 10 | 1 | 11 | 1.8 | 11 | 1 | 12 | .9 |
| 20.00-20.49 | 0 | 0 | 0 | 0 | 7 | 2 | 9 | 1.5 | 7 | 2 | 9 | .6 |
| 20.50-20.99 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | .3 | 2 | 0 | 2 | .1 |
| Total | 334 | 455 | 789 | 100.0 | 381 | 228 | 609 | 100.0 | 715 | 683 | 1,398 | 100.1 |

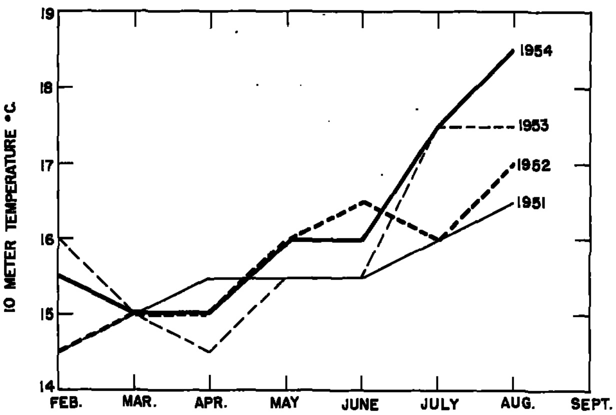


FIGURE 9.—Monthly median temperatures at 10 meters, at which jack mackerel eggs were spawned.

monthly intervals and the median temperatures at 10 meters computed for each month. The monthly median temperatures are shown in figure 9 and indicate that spawning generally occurs at lower temperatures in spring than in late summer. The within-year median temperature shift is greater than the between-year temperature variation (see below).

The data from table 13 are summarized in tables 15 and 16. A difference in optimum spawning temperature between small hauls (1–100 eggs) and large hauls (101 eggs and more) is noted (fig. 10). The reason for the difference is that a large proportion of the large hauls were taken during the peak of the season (April and May), and have therefore a more restricted temperature distribution.

The early, late, and annual distributions of temperature at a depth of 10 meters, by 0.5° C. increments, for all stations occupied in 1951–54 are given in table 17. These differ from the distribution of temperatures at which jack mackerel were taken in two ways: their temperature range is greater, and they show less tendency to cluster about a central value.

TABLE 15.—*Summary: Distribution of temperatures at 10 meters of stations having jack mackerel eggs, by size of sample, 1951–54*

[In 0.5° C. intervals]

| Temperature | 1-100 eggs | 101+ eggs | Total samples | Percent of total |
|---|---|---|---|---|
| 10.00–10.49 | 2 | 0 | 2 | 0.1 |
| 10.50–10.99 | 8 | 0 | 8 | .6 |
| 11.00–11.49 | 7 | 0 | 7 | .5 |
| 11.50–11.99 | 12 | 3 | 15 | 1.1 |
| 12.00–12.49 | 18 | 7 | 25 | 1.8 |
| 12.50–12.99 | 18 | 10 | 28 | 2.0 |
| 13.00–13.49 | 33 | 28 | 61 | 4.4 |
| 13.50–13.99 | 39 | 36 | 75 | 5.4 |
| 14.00–14.49 | 47 | 78 | 125 | 9.0 |
| 14.50–14.99 | 41 | 105 | 146 | 10.4 |
| 15.00–15.49 | 84 | 110 | 194 | 13.9 |
| 15.50–15.99 | 61 | 111 | 172 | 12.3 |
| 16.00–16.49 | 104 | 80 | 184 | 13.2 |
| 16.50–16.99 | 77 | 52 | 129 | 9.2 |
| 17.00–17.49 | 64 | 27 | 91 | 6.5 |
| 17.50–17.99 | 28 | 18 | 46 | 3.3 |
| 18.00–18.49 | 25 | 8 | 33 | 2.4 |
| 18.50–18.99 | 17 | 2 | 19 | 1.4 |
| 19.00–19.49 | 10 | 5 | 15 | 1.1 |
| 19.50–19.99 | 11 | 1 | 12 | .9 |
| 20.00–20.49 | 7 | 2 | 9 | .6 |
| 20.50–20.99 | 2 | 0 | 2 | .1 |
| Total | 715 | 683 | 1,398 | 100.2 |

TABLE 16.—*Average temperatures at 10 meters during jack mackerel spawning, by season and size of sample, 1951–54*

| Sample size and spawning season | Mean | Median | Mode |
|---|---|---|---|
| 1951: | | | |
| 1–100 eggs: | | | |
| Early | 15.5 | 15.5 | 16.0 |
| Late | 15.8 | 16.0 | 16.0 |
| Annual average | 15.7 | 15.5 | 16.0 |
| 101+ eggs: | | | |
| Early | 15.2 | 15.0 | 15.0 |
| Late | 15.4 | 15.0 | 14.0 |
| Annual average | 15.3 | 15.0 | 15.0 |
| 1952: | | | |
| 1–100 eggs: | | | |
| Early | 15.3 | 15.0 | 15.0 |
| Late | 16.0 | 16.0 | 17.0 |
| Annual average | 15.7 | 16.0 | 16.0 |
| 101+ eggs: | | | |
| Early | 15.3 | 15.0 | 14.5 |
| Late | 15.9 | 15.5 | 14.5 |
| Annual average | 15.6 | 15.5 | 14.5 |
| 1953: | | | |
| 1–100 eggs: | | | |
| Early | 14.5 | 14.5 | 15.0 |
| Late | 15.9 | 15.5 | 16.0 |
| Annual average | 15.3 | 15.0 | 15.0 |
| 101+ eggs: | | | |
| Early | 15.1 | 15.0 | 15.0 |
| Late | 16.1 | 15.5 | 15.0 |
| Annual average | 15.5 | 15.0 | 15.0 |
| 1954: | | | |
| 1–100 eggs: | | | |
| Early | 15.5 | 16.0 | 16.0 |
| Late | 16.6 | 16.5 | 16.5 |
| Annual average | 16.0 | 16.0 | 16.0 |
| 101+ eggs: | | | |
| Early | 15.2 | 15.0 | 14.5 |
| Late | 15.2 | 15.0 | 14.0 |
| Annual average | 15.2 | 15.0 | 15.0 |
| All years: | | | |
| 1–100 eggs: | | | |
| Early | 15.2 | 15.5 | 16.0 |
| Late | 16.0 | 16.0 | 16.0 |
| Annual average | 15.7 | 15.5 | 16.0 |
| 101+ eggs: | | | |
| Early | 15.2 | 15.0 | 15.5 |
| Late | 15.7 | 15.0 | 15.0 |
| Annual average | 15.4 | 15.5 | 15.5 |

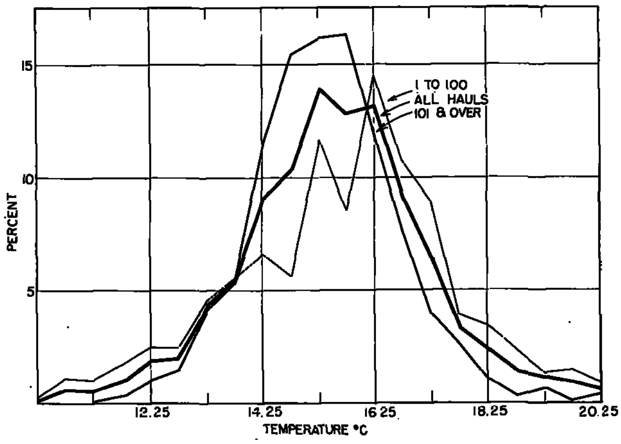


FIGURE 10.—Percentage of stations having jack mackerel eggs, grouped by 0.5° C. temperature intervals measured at 10-meter depth for stations with hauls of 1–100 eggs, with hauls of 101 eggs and more, and for all stations where eggs were taken.

All jack mackerel data were then combined for each year and the mean, median, and modal temperatures at 10 meters were computed (table 18). The mean and median temperatures for the 4 years are remarkably constant (15.5° C.) with about 60 percent of the annual spawning occurring within 1° of the median and mean. Less than 40 percent of all the stations occupied during the spawning season (February through July) had temperatures within 1° of 15.5° C. (table 19). The constancy of annual temperature medians and means would indicate a sharp temperature optimum for spawning were it not for the within-year temperature shift. The within-year temperature shift suggests that a physiological temperature optimum for jack mackerel is a function of many environmental factors, such as condition of the fish and availability of food, to mention two possibilities. Furthermore, if temperature is the controlling factor, spawning should occur more or less uniformly throughout the area having the optimum temperature. A temperature of 15.5° C. is usually present in the waters off California or Baja California, but spawning occurs only during spring and summer. This may indicate that the length of day has some regulatory effect on spawning.

TABLE 17.—*Summary: Distribution of temperatures at 10 meters, by season, at stations occupied, 1951–54*

[In 0.5° C. intervals]

| Temperature | 1951 | | | 1952 | | | 1953 | | | 1954 | | | Total for all years | Percent of total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Early | Late | Total | Early | Late | Total | Early | Late | Total | Early | Late | Total | | |
| 8.00–8.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0.02 |
| 8.50–8.99 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | .04 |
| 9.00–9.49 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 1 | 4 | 0 | 1 | 1 | 6 | .11 |
| 9.50–9.99 | 1 | 3 | 4 | 3 | 1 | 4 | 8 | 3 | 11 | 2 | 1 | 3 | 22 | .40 |
| 10.00–10.49 | 2 | 8 | 10 | 5 | 11 | 16 | 7 | 4 | 11 | 2 | 6 | 8 | 45 | .83 |
| 10.50–10.99 | 6 | 4 | 10 | 7 | 9 | 16 | 10 | 5 | 15 | 2 | 3 | 5 | 46 | .85 |
| 11.00–11.49 | 12 | 10 | 22 | 6 | 20 | 26 | 18 | 9 | 27 | 7 | 6 | 13 | 88 | 1.62 |
| 11.50–11.99 | 13 | 7 | 20 | 5 | 14 | 19 | 37 | 5 | 42 | 13 | 6 | 19 | 100 | 1.84 |
| 12.00–12.49 | 18 | 9 | 27 | 19 | 21 | 40 | 52 | 12 | 64 | 19 | 11 | 30 | 161 | 2.96 |
| 12.50–12.99 | 13 | 7 | 20 | 31 | 26 | 57 | 59 | 21 | 80 | 35 | 14 | 49 | 206 | 3.79 |
| 13.00–13.49 | 36 | 15 | 51 | 35 | 31 | 66 | 59 | 21 | 80 | 46 | 16 | 62 | 259 | 4.76 |
| 13.50–13.99 | 50 | 19 | 69 | 49 | 20 | 69 | 78 | 37 | 115 | 64 | 21 | 85 | 338 | 6.22 |
| 14.00–14.49 | 50 | 33 | 83 | 59 | 27 | 86 | 72 | 42 | 114 | 93 | 30 | 123 | 406 | 7.48 |
| 14.50–14.99 | 42 | 30 | 72 | 70 | 31 | 101 | 75 | 36 | 111 | 94 | 29 | 123 | 407 | 7.49 |
| 15.00–15.49 | 71 | 49 | 120 | 62 | 46 | 108 | 60 | 54 | 114 | 94 | 43 | 137 | 479 | 8.71 |
| 15.50–15.99 | 66 | 51 | 117 | 61 | 35 | 96 | 65 | 41 | 106 | 96 | 39 | 135 | 454 | 8.35 |
| 16.00–16.49 | 63 | 52 | 115 | 53 | 50 | 103 | 35 | 50 | 85 | 61 | 65 | 126 | 429 | 7.89 |
| 16.50–16.99 | 53 | 45 | 98 | 43 | 50 | 93 | 29 | 38 | 67 | 43 | 54 | 97 | 355 | 6.53 |
| 17.00–17.49 | 47 | 43 | 90 | 30 | 57 | 87 | 21 | 43 | 64 | 31 | 56 | 87 | 328 | 6.03 |
| 17.50–17.99 | 36 | 49 | 85 | 24 | 39 | 63 | 21 | 39 | 60 | 15 | 39 | 54 | 262 | 4.82 |
| 18.00–18.49 | 21 | 45 | 66 | 7 | 41 | 48 | 6 | 33 | 39 | 18 | 55 | 73 | 226 | 4.16 |
| 18.50–18.99 | 9 | 40 | 49 | 8 | 33 | 41 | 8 | 28 | 36 | 11 | 36 | 47 | 173 | 3.16 |
| 19.00–19.49 | 3 | 30 | 33 | 4 | 30 | 34 | 7 | 29 | 36 | 11 | 18 | 29 | 132 | 2.41 |
| 19.50–19.99 | 6 | 29 | 35 | 12 | 18 | 30 | 2 | 16 | 18 | 5 | 37 | 42 | 125 | 2.30 |
| 20.00–20.49 | 0 | 18 | 18 | 5 | 13 | 18 | 1 | 12 | 13 | 0 | 31 | 31 | 80 | 1.47 |
| 20.50–20.99 | 1 | 21 | 22 | 5 | 17 | 22 | 2 | 9 | 11 | 1 | 11 | 12 | 67 | 1.23 |
| 21.00–21.49 | 2 | 10 | 12 | 3 | 15 | 18 | 4 | 8 | 12 | 1 | 10 | 11 | 53 | .98 |
| 21.50–21.99 | 1 | 8 | 9 | 2 | 11 | 13 | 5 | 4 | 9 | 1 | 5 | 6 | 37 | .68 |
| 22.00–22.49 | 2 | 8 | 10 | 1 | 6 | 7 | 0 | 5 | 5 | 0 | 5 | 5 | 27 | .50 |
| 22.50–22.99 | 0 | 8 | 8 | 0 | 3 | 3 | 0 | 4 | 4 | 0 | 6 | 6 | 21 | .39 |
| 23.00–23.49 | 0 | 6 | 6 | 1 | 6 | 7 | 0 | 0 | 0 | 0 | 3 | 3 | 16 | .29 |
| 23.50–23.99 | 0 | 9 | 9 | 0 | 4 | 4 | 0 | 3 | 3 | 0 | 8 | 8 | 24 | .44 |
| 24.00–24.49 | 0 | 8 | 8 | 0 | 6 | 6 | 0 | 1 | 1 | 0 | 0 | 0 | 15 | .27 |
| 24.50–24.99 | 0 | 8 | 8 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | .16 |
| 25.00–25.49 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 3 | .06 |
| 25.50–25.99 | 0 | 8 | 8 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 2 | 12 | .22 |
| 26.00–26.49 | 0 | 8 | 8 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 10 | .18 |
| 26.50 and over | 0 | 15 | 15 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 17 | .31 |
| Total | 624 | 717 | 1,341 | 611 | 692 | 1,303 | 744 | 619 | 1,363 | 765 | 669 | 1,434 | 5,441 | 99.95 |

TABLE 18.—*Annual mean, median, and modal temperatures at which spawning occurred, 1951–54*

[At 10 meters; in °C.]

| Year | Median and mean temperature | Percent spawning within 1° of median | Mode |
|---|---|---|---|
| 1951 | 15.5 | 58 | 16.3 |
| 1952 | 15.5 | 65 | 16.3 |
| 1953 | 15.5 | 60 | 15.3 |
| 1954 | 15.5 | 63 | 15.3 |

TABLE 19.—*Summary: Distribution of temperatures at 10 meters, at all stations occupied, February through July, 1951–54*

[In 0.5°C. intervals]

| Temperature | 1951 | | 1952 | | 1953 | | 1954 | |
|---|---|---|---|---|---|---|---|---|
| | Total | Percent | Total | Percent | Total | Percent | Total | Percent |
| 8.00–8.49 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.10 |
| 8.50–8.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9.00–9.49 | 0 | 0 | 1 | 0.12 | 4 | 0.44 | 1 | .10 |
| 9.50–9.99 | 2 | 0.27 | 4 | .49 | 10 | 1.10 | 3 | .30 |
| 10.00–10.49 | 7 | .95 | 13 | 1.60 | 10 | 1.10 | 8 | .81 |
| 10.50–10.99 | 7 | .95 | 11 | 1.35 | 15 | 1.65 | 5 | .51 |
| 11.00–11.49 | 10 | 1.36 | 20 | 2.46 | 25 | 2.74 | 12 | 1.21 |
| 11.50–11.99 | 16 | 2.18 | 16 | 1.97 | 40 | 4.39 | 19 | 1.92 |
| 12.00–12.49 | 20 | 2.72 | 34 | 4.18 | 61 | 6.70 | 25 | 2.53 |
| 12.50–12.99 | 16 | 2.18 | 37 | 4.55 | 63 | 6.92 | 38 | 3.84 |
| 13.00–13.49 | 35 | 4.76 | 50 | 6.15 | 61 | 6.70 | 51 | 5.16 |
| 13.50–13.99 | 50 | 6.80 | 50 | 6.15 | 86 | 9.34 | 63 | 6.38 |
| 14.00–14.49 | 61 | 8.30 | 60 | 7.37 | 79 | 8.66 | 92 | 9.30 |
| 14.50–14.99 | 46 | 6.26 | 87 | 10.70 | 76 | 8.34 | 92 | 9.30 |
| 15.00–15.49 | 77 | 10.49 | 75 | 9.23 | 87 | 9.55 | 102 | 10.31 |
| 15.50–15.99 | 76 | 10.35 | 67 | 8.24 | 77 | 8.35 | 105 | 10.62 |
| 16.00–16.49 | 80 | 10.90 | 76 | 9.35 | 49 | 5.38 | 97 | 9.81 |
| 16.50–16.99 | 61 | 8.30 | 69 | 8.49 | 41 | 4.50 | 79 | 7.99 |
| 17.00–17.49 | 48 | 6.53 | 53 | 6.52 | 43 | 4.72 | 62 | 6.27 |
| 17.50–17.99 | 35 | 4.76 | 32 | 3.94 | 29 | 3.18 | 32 | 3.24 |
| 18.00–18.49 | 36 | 4.90 | 18 | 2.22 | 15 | 1.65 | 35 | 3.54 |
| 18.50–18.99 | 17 | 2.31 | 12 | 1.48 | 17 | 1.87 | 25 | 2.53 |
| 19.00–19.49 | 5 | .68 | 6 | .74 | 11 | 1.21 | 16 | 1.62 |
| 19.50–19.99 | 10 | 1.36 | 8 | .98 | 3 | .33 | 15 | 1.52 |
| 20.00–20.49 | 5 | .68 | 3 | .37 | 4 | .44 | 7 | .71 |
| 20.50–20.99 | 5 | .68 | 3 | .37 | 3 | .33 | 2 | .20 |
| 21.00–21.49 | 3 | .41 | 2 | .25 | 1 | .11 | 0 | 0 |
| 21.50–21.99 | 1 | .14 | 4 | .49 | 1 | .11 | 1 | .10 |
| 22.00–22.49 | 4 | .54 | 1 | .12 | 0 | 0 | 0 | 0 |
| 22.50–22.99 | 1 | .14 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23.00–23.49 | 0 | 0 | 1 | .12 | 0 | 0 | 1 | .10 |
| 23.50–23.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24.00–24.49 | 1 | .14 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24.50–24.99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25.00–25.49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Turner (1948: p. 351) says, "The reproductive rhythms of the female, as in the male, are influenced by numerous factors in the external environment as well as by physiologic factors conditioning the internal environment." Since little is known about the internal factors governing the spawning of fishes, no comprehensive explanation for the variation in the distribution of spawning jack mackerel can be given at this time. It is concluded that temperature is important, but not the controlling factor in spatial-temporal distribution of spawning jack mackerel.

## SURVIVAL OF THE LARVAE

The method used by Ahlstrom (1954b) to determine the survival of larvae has been retained so that interspecific comparisons might more easily be made for fish occupying the area surveyed by the California Cooperative Oceanic Fisheries Investigations. All larvae of a species were withdrawn from a station sample and measured. The measurements are grouped into size classes and adjusted by the standard haul factor (p. 250). These standardized counts are integrated over time and space (p. 251) and adjusted for growth. The products are summed for the year to give an estimate of abundance of the size class. The decline in abundance of successively larger size classes provides an estimate of survival.

### REGIONAL ESTIMATES OF ABUNDANCE OF LARVAE

The regional estimates of abundance by size class for jack mackerel larvae are given in table 20 for 1952, table 21 for 1953, and table 22 for 1954. These tables are summarized in tables 23 and 24, and the annual estimates of abundance and survival are given in table 25. It will be noted that the curves shown in figure 11 derived from this table are very similar, suggesting that the number of larvae surviving a 30-day period has

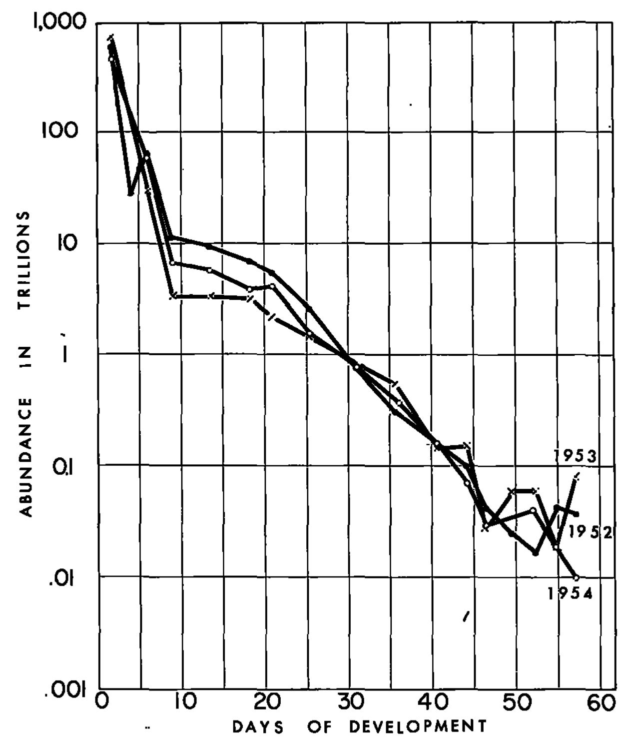


FIGURE 11.—Abundance curves of jack mackerel larvae to age 57 days, 1952–54.

been relatively constant. In 1952, of the 593 trillion eggs estimated to have been spawned, only 780 billion larvae are estimated to have survived at the end of 30 days. In 1953, 736 trillion eggs were estimated to have been spawned and 850 billion larvae are estimated to have survived, while in 1954, 462 trillion eggs were estimated to have been spawned with 830 billion larvae the estimated survivors at the end of the first month of life. This indicates an average survival (for the first month of life) of a little more than 1 larva per 1,000 eggs spawned.

TABLE 20.—*Regional distribution of jack mackerel larvae, by month and size class, 1952*

[In billions]

| Area and month | 2.0 mm. | 2.5 mm. | 3.0 mm. | 3.5 mm. | 4.0 mm. | 4.5 mm. | 5.0 mm. | 5.75 mm. | 6.75 mm. | 7.75 mm. | 8.75 mm. | 9.75 mm. | 10.75 mm. | 11.75 mm. | 12.75 mm. | 13.75 mm. | 14.75 mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northern California (lines 40–77): | | | | | | | | | | | | | | | | | |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 550 | 561 | 1,537 | 29 | 36 | 38 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 242 | 1,246 | 1,541 | 107 | 57 | 9 | 48 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 834 | 1,807 | 3,078 | 136 | 93 | 47 | 60 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80–93): | | | | | | | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 311 | 230 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 2,156 | 3,068 | 2,334 | 468 | 258 | 261 | 103 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 134 | 1,287 | 2,916 | 1,026 | 2,337 | 1,351 | 1,429 | 409 | 33 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 3,130 | 8,654 | 8,116 | 841 | 582 | 183 | 145 | 17 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 |
| June | 1,640 | 2,727 | 5,355 | 778 | 1,206 | 926 | 766 | 252 | 71 | 15 | 0 | 0 | 8 | 0 | 0 | 0 | 0 |
| July | 285 | 2,145 | 2,591 | 1,098 | 391 | 704 | 668 | 553 | 235 | 95 | 7 | 0 | 0 | 25 | 0 | 0 | 0 |
| August | 307 | 761 | 1,250 | 24 | 30 | 0 | 0 | 38 | 9 | 0 | 12 | 14 | 0 | 0 | 17 | 0 | 0 |
| September | 480 | 503 | 140 | 7 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 8,443 | 19,375 | 22,717 | 4,242 | 4,827 | 3,425 | 3,111 | 1,302 | 348 | 122 | 19 | 14 | 16 | 25 | 17 | 0 | 0 |
| Northern Baja California (lines 97–107): | | | | | | | | | | | | | | | | | |
| January | 0 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 363 | 2,825 | 3,599 | 1,361 | 425 | 205 | 15 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 7,089 | 6,478 | 3,749 | 383 | 960 | 292 | 551 | 325 | 82 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 3,374 | 6,506 | 6,944 | 577 | 7 | 168 | 359 | 70 | 28 | 11 | 0 | 8 | 0 | 0 | 0 | 0 | 0 |
| June | 83 | 510 | 2,930 | 629 | 505 | 284 | 254 | 204 | 147 | 83 | 16 | 0 | 5 | 0 | 0 | 0 | 0 |
| July | 1,962 | 3,612 | 7,523 | 2,103 | 1,241 | 1,238 | 379 | 277 | 50 | 36 | 103 | 58 | 0 | 0 | 0 | 0 | 37 |
| August | 27 | 1,284 | 2,365 | 283 | 189 | 77 | 51 | 16 | 9 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 |
| September | 0 | 68 | 151 | 73 | 264 | 205 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 15 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 12,898 | 21,324 | 27,261 | 5,409 | 3,591 | 2,469 | 1,641 | 914 | 316 | 158 | 119 | 66 | 11 | 0 | 0 | 0 | 37 |
| Upper central Baja California (lines 110–120): | | | | | | | | | | | | | | | | | |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 112 | 236 | 300 | 421 | 284 | 99 | 58 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 |
| April | 5,410 | 3,510 | 5,393 | 161 | 56 | 19 | 22 | 33 | 32 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 628 | 985 | 1,465 | 634 | 396 | 338 | 185 | 138 | 11 | 17 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 258 | 1,534 | 127 | 49 | 37 | 45 | 20 | 5 | 23 | 0 | 0 | 0 | 0 | 0 | 20 | 0 |
| July | 0 | 152 | 138 | 78 | 59 | 130 | 86 | 18 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 6,038 | 4,905 | 8,642 | 1,236 | 860 | 945 | 622 | 308 | 117 | 40 | 31 | 0 | 15 | 0 | 0 | 43 | 0 |
| Lower central Baja California (lines 123–137): | | | | | | | | | | | | | | | | | |
| March | 0 | 49 | 48 | 8 | 34 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 0 | 448 | 1,179 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 |
| May | 83 | 25 | 441 | 50 | 45 | 21 | 45 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 122 | 97 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 83 | 644 | 1,765 | 123 | 79 | 50 | 45 | 10 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 |
| Grand total | 28,296 | 48,055 | 63,463 | 11,146 | 9,450 | 6,936 | 5,479 | 2,587 | 781 | 320 | 169 | 102 | 42 | 25 | 17 | 43 | 37 |

The slope of the abundance curve is not constant. Survival during the first 9 days is very low but after this initial period, it is better. The inconsistency in the estimates of larvae older than 40 days is most likely due to sample variation. These estimates are made from small numbers of observations and have therefore a large error associated with them.

Although these data are in some respects quite limited, they are comparable with the survival data collected by Sette (1943) for Atlantic mackerel and Ahlstrom (1954b) for Pacific sardine.

TABLE 21.—*Regional distribution of jack mackerel larvae, by month and size class, 1953*

[In billions]

| Area and month | 3.0 mm. | 3.5 mm. | 4.0 mm. | 4.5 mm. | 5.0 mm. | 5.75 mm. | 6.75 mm. | 7.75 mm. | 8.75 mm. | 9.75 mm. | 10.75 mm. | 11.75 mm. | 12.75 mm. | 13.75 mm. | 14.75 mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northern California (lines 40-77): | | | | | | | | | | | | | | | |
| June | 316 | 66 | 75 | 0 | 0 | 0 | 0 | 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 175 | 51 | 40 | 40 | 15 | 17 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 555 | 117 | 115 | 40 | 15 | 17 | 10 | 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80-93): | | | | | | | | | | | | | | | |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 2,846 | 113 | 11 | 11 | 0 | 4 | 50 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 |
| April | 1,067 | 515 | 252 | 126 | 0 | 0 | 0 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 |
| May | 5,017 | 620 | 426 | 211 | 55 | 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 2,086 | 125 | 410 | 362 | 491 | 360 | 181 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 883 | 114 | 51 | 315 | 27 | 261 | 68 | 0 | 20 | 22 | 0 | 0 | 30 | 0 | 59 |
| August | 32 | 0 | 0 | 0 | 36 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 11,931 | 1,487 | 1,150 | 1,025 | 609 | 705 | 301 | 57 | 30 | 55 | 0 | 0 | 48 | 0 | 59 |
| Northern Baja California (lines 97-107): | | | | | | | | | | | | | | | |
| February | 2,712 | 274 | 161 | 17 | 0 | 0 | 0 | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 996 | 223 | 697 | 971 | 409 | 69 | 69 | 11 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| April | 1,512 | 89 | 87 | 96 | 87 | 23 | 17 | 12 | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| May | 1,249 | 188 | 261 | 346 | 138 | 155 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 3,621 | 358 | 280 | 337 | 488 | 206 | 208 | 41 | 62 | 0 | 7 | 0 | 0 | 0 | 0 |
| July | 213 | 22 | 70 | 8 | 18 | 20 | 6 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 151 | 0 | 64 | 10 | 46 | 18 | 20 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 10,454 | 1,154 | 1,620 | 1,785 | 1,186 | 491 | 405 | 118 | 68 | 16 | 7 | 0 | 0 | 0 | 0 |
| Upper central Baja California (lines 110-120): | | | | | | | | | | | | | | | |
| February | 183 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 680 | 58 | 145 | 155 | 267 | 186 | 15 | 69 | 0 | 6 | 0 | 14 | 0 | 0 | 0 |
| April | 864 | 62 | 9 | 6 | 37 | 4 | 8 | 16 | 0 | 16 | 0 | 0 | 0 | 0 | 0 |
| May | 1,224 | 57 | 140 | 78 | 29 | 24 | 64 | 16 | 0 | 0 | 0 | 8 | 0 | 0 | 0 |
| June | 2,446 | 292 | 104 | 51 | 30 | 14 | 24 | 40 | 35 | 15 | 0 | 16 | 0 | 20 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 23 | 13 | 0 | 0 |
| August | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 104 | 0 | 0 | 0 | 0 | 18 | 0 | 40 | 13 | 44 | 21 | 0 | 0 | 0 | 22 |
| Total | 5,501 | 478 | 398 | 290 | 374 | 246 | 136 | 181 | 48 | 81 | 21 | 61 | 13 | 20 | 22 |
| Lower central Baja California (lines 123-137): | | | | | | | | | | | | | | | |
| May | 463 | 16 | 12 | 8 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 646 | 60 | 18 | 20 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1,109 | 76 | 36 | 28 | 7 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grand total | 29,550 | 3,312 | 3,319 | 3,168 | 2,191 | 1,468 | 852 | 557 | 146 | 152 | 28 | 61 | 61 | 20 | 81 |

TABLE 22.—*Regional distribution of jack mackerel larvae, by month and size class, 1954*

[In billions]

| Month and area | 3.0 mm. | 3.5 mm. | 4.0 mm. | 4.5 mm. | 5.0 mm. | 5.75 mm. | 6.75 mm. | 7.75 mm. | 8.75 mm. | 9.75 mm. | 10.75 mm. | 11.75 mm. | 12.75 mm. | 13.75 mm. | 14.75 mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northern California (lines 40-77): | | | | | | | | | | | | | | | |
| May | 269 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 2,061 | 210 | 150 | 141 | 108 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 578 | 0 | 222 | 57 | 0 | 67 | 116 | 164 | 97 | 46 | 0 | 0 | 41 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 2,908 | 210 | 372 | 198 | 108 | 84 | 169 | 164 | 97 | 46 | 0 | 0 | 41 | 0 | 0 |
| Southern California (lines 80-93): | | | | | | | | | | | | | | | |
| April | 4,099 | 241 | 77 | 84 | 63 | 9 | 15 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 6,549 | 525 | 130 | 59 | 31 | 29 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 21,445 | 3,122 | 3,371 | 2,146 | 2,491 | 1,034 | 478 | 222 | 22 | 13 | 0 | 0 | 0 | 0 | 0 |
| July | 455 | 0 | 0 | 0 | 0 | 37 | 16 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 39 | 4 | 5 | 15 | 10 | 5 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 133 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 32,720 | 3,892 | 3,583 | 2,304 | 2,595 | 1,114 | 528 | 227 | 36 | 13 | 0 | 0 | 0 | 0 | 0 |
| Northern Baja California (lines 97-107): | | | | | | | | | | | | | | | |
| February | 175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 2,424 | 185 | 97 | 371 | 555 | 85 | 9 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 5,022 | 707 | 353 | 456 | 278 | 88 | 45 | 30 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 4,566 | 428 | 203 | 102 | 78 | 38 | 21 | 16 | 21 | 0 | 26 | 0 | 0 | 0 | 0 |
| June | 2,704 | 301 | 303 | 79 | 194 | 103 | 42 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 741 | 14 | 17 | 0 | 0 | 6 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 61 | 31 | 18 | 0 | 9 | 11 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 10 |
| Total | 15,693 | 1,666 | 991 | 1,008 | 1,114 | 331 | 124 | 58 | 31 | 0 | 31 | 0 | 0 | 0 | 10 |
| Upper central Baja California (lines 110-120): | | | | | | | | | | | | | | | |
| February | 820 | 37 | 15 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 2,437 | 214 | 321 | 139 | 84 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 1,058 | 76 | 235 | 64 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 1,312 | 373 | 125 | 39 | 139 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 1,710 | 162 | 96 | 60 | 92 | 12 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 27 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 7,364 | 901 | 792 | 324 | 319 | 17 | 7 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lower central Baja California (lines 123-137): | | | | | | | | | | | | | | | |
| January | 198 | 17 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| April | 270 | 19 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| May | 70 | 0 | 0 | 0 | 8 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 74 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 612 | 90 | 10 | 0 | 14 | 2 | 5 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| Grand total | 59,297 | 6,759 | 5,748 | 3,834 | 4,150 | 1,518 | 833 | 484 | 164 | 72 | 31 | 0 | 41 | 0 | 10 |

TABLE 23.—*Regional distribution of jack mackerel larvae, by size class, 1952–54*

[In billions]

| Year and region | 3.0 mm. | 3.5 mm. | 4.0 mm. | 4.5 mm. | 5.0 mm. | 5.75 mm. | 6.75 mm. | 7.75 mm. | 8.75 mm. | 9.75 mm. | 10.75 mm. | 11.75 mm. | 12.75 mm. | 13.75 mm. | 14.75 mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1952: | | | | | | | | | | | | | | | |
| Northern California (lines 40-77) | 3,078 | 136 | 93 | 47 | 60 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80-93) | 22,717 | 4,242 | 4,827 | 3,425 | 3,111 | 1,302 | 348 | 122 | 19 | 14 | 16 | 25 | 17 | 0 | 0 |
| Northern Baja California (lines 97-107) | 27,261 | 5,409 | 3,591 | 2,469 | 1,641 | 914 | 316 | 157 | 119 | 66 | 11 | 0 | 0 | 0 | 37 |
| Upper central Baja California (lines 110-120) | 8,642 | 1,236 | 860 | 945 | 622 | 308 | 117 | 40 | 31 | 0 | 15 | 0 | 0 | 43 | 0 |
| Lower central Baja California (lines 123-137) | 1,765 | 123 | 79 | 50 | 45 | 10 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 |
| Total | 63,463 | 11,146 | 9,450 | 6,936 | 5,479 | 2,587 | 781 | 319 | 169 | 102 | 42 | 25 | 17 | 43 | 37 |
| 1953: | | | | | | | | | | | | | | | |
| Northern California (lines 40-77) | 555 | 117 | 115 | 40 | 15 | 17 | 10 | 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80-93) | 11,931 | 1,487 | 1,150 | 1,025 | 609 | 705 | 301 | 57 | 30 | 55 | 0 | 0 | 48 | 0 | 59 |
| Northern Baja California (lines 97-107) | 10,454 | 1,154 | 1,620 | 1,785 | 1,186 | 491 | 405 | 118 | 68 | 16 | 7 | 0 | 0 | 0 | 0 |
| Upper central Baja California (lines 110-120) | 5,501 | 478 | 398 | 290 | 374 | 246 | 136 | 181 | 48 | 81 | 21 | 61 | 13 | 20 | 22 |
| Lower central Baja California (lines 123-137) | 1,109 | 76 | 36 | 28 | 7 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 29,550 | 3,312 | 3,319 | 3,168 | 2,191 | 1,468 | 852 | 557 | 146 | 152 | 28 | 61 | 61 | 20 | 81 |
| 1954: | | | | | | | | | | | | | | | |
| Northern California (lines 40-77) | 2,908 | 210 | 372 | 198 | 108 | 84 | 169 | 164 | 97 | 46 | 0 | 0 | 41 | 0 | 0 |
| Southern California (lines 80-93) | 32,720 | 3,892 | 3,583 | 2,304 | 2,595 | 1,114 | 528 | 227 | 36 | 13 | 0 | 0 | 0 | 0 | 0 |
| Northern Baja California (lines 97-107) | 15,693 | 1,666 | 991 | 1,008 | 1,114 | 331 | 124 | 58 | 31 | 0 | 31 | 0 | 0 | 0 | 10 |
| Upper central Baja California (lines 110-120) | 7,364 | 901 | 792 | 324 | 319 | 17 | 7 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lower central Baja California (lines 123-137) | 612 | 90 | 10 | 0 | 14 | 2 | 5 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| Total | 59,297 | 6,759 | 5,748 | 3,834 | 4,150 | 1,548 | 833 | 484 | 164 | 72 | 31 | 0 | 41 | 0 | 10 |

TABLE 24.—*Percentage of each size class of jack mackerel larvae, occurring in each region, 1952–54*

| Year and region | 3.0 mm. | 3.5 mm. | 4.0 mm. | 4.5 mm. | 5.0 mm. | 5.75 mm. | 6.75 mm. | 7.75 mm. | 8.75 mm. | 9.75 mm. | 10.75 mm. | 11.75 mm. | 12.75 mm. | 13.75 mm. | 14.75 mm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1952: | | | | | | | | | | | | | | | |
| Northern California (lines 40–77) | 4.9 | 1.2 | 1.0 | 0.7 | 1.1 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80–93) | 35.8 | 38.0 | 50.9 | 49.4 | 56.7 | 50.2 | 44.8 | 38.1 | 10.9 | 13.7 | 39.0 | 100.0 | 100.0 | 0 | 0 |
| Northern Baja California (lines 97–107) | 43.1 | 48.6 | 37.8 | 35.6 | 30.0 | 35.2 | 40.5 | 49.4 | 71.0 | 65.1 | 26.7 | 0 | 0 | 0 | 100.0 |
| Upper central Baja California (lines 110–120) | 13.6 | 11.1 | 9.1 | 13.6 | 11.3 | 11.8 | 14.7 | 12.5 | 18.1 | 0 | 34.3 | 0 | 0 | 100.0 | 0 |
| Lower central Baja California (lines 123–137) | 2.8 | 1.1 | 0.8 | 0.7 | 0.8 | 0.4 | 0 | 0 | 0 | 21.2 | 0 | 0 | 0 | 0 | 0 |
| Total | 100.2 | 100.0 | 99.6 | 100.0 | 99.9 | 99.6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1953: | | | | | | | | | | | | | | | |
| Northern California (lines 40–77) | 1.8 | 3.5 | 3.5 | 1.3 | 0.7 | 1.1 | 1.2 | 36.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern California (lines 80–93) | 40.4 | 44.8 | 34.6 | 32.4 | 27.8 | 48.0 | 35.4 | 10.3 | 20.4 | 35.9 | 0 | 0 | 79.4 | 0 | 72.6 |
| Northern Baja California (lines 97–107) | 35.4 | 34.9 | 48.8 | 56.3 | 54.1 | 33.4 | 47.5 | 21.1 | 46.5 | 10.3 | 26.3 | 0 | 0 | 0 | 0 |
| Upper central Baja California (lines 110–120) | 18.6 | 14.4 | 11.9 | 9.2 | 17.0 | 16.8 | 15.9 | 32.5 | 32.9 | 53.8 | 73.7 | 100.0 | 20.6 | 100.0 | 27.4 |
| Lower central Baja California (lines 123–137) | 3.8 | 2.3 | 1.1 | 0.9 | 0.3 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 100.0 | 99.9 | 99.9 | 100.1 | 99.9 | 99.9 | 100.0 | 100.0 | 99.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1954: | | | | | | | | | | | | | | | |
| Northern California (lines 40–77) | 4.9 | 3.1 | 6.5 | 5.2 | 2.6 | 5.4 | 20.3 | 34.1 | 59.2 | 64.5 | 0 | 0 | 100.0 | 0 | 0 |
| Southern California (lines 80–93) | 55.2 | 57.4 | 62.4 | 60.1 | 62.6 | 72.1 | 63.4 | 47.0 | 22.0 | 17.7 | 0 | 0 | 0 | 0 | 0 |
| Northern Baja California (lines 97–107) | 26.4 | 24.6 | 17.3 | 26.2 | 26.9 | 21.4 | 14.9 | 11.7 | 18.8 | 0 | 100.0 | 0 | 0 | 0 | 100.0 |
| Upper central Baja California (lines 110–120) | 12.4 | 13.3 | 13.8 | 8.4 | 7.7 | 1.0 | 0.7 | 7.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lower central Baja California (lines 123–137) | 1.0 | 1.3 | 0.2 | 0 | 0.3 | 0.1 | 0.6 | 0 | 0 | 17.8 | 0 | 0 | 0 | 0 | 0 |
| Total | 99.9 | 99.7 | 100.2 | 99.9 | 100.1 | 100.0 | 99.9 | 100.0 | 100.0 | 100.0 | 100.0 | 0 | 100.0 | 0 | 100.0 |

TABLE 25.—*Annual estimates of abundance and survival of jack mackerel eggs and larvae, 1952–54*

[In billions]

| Category | Duration (days) | Average age (days) | Size range (mm.) | 1952 | | 1953 | | 1954 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Abundance | Survival per 100,000 eggs | Abundance | Survival per 100,000 eggs | Abundance | Survival per 100,000 eggs |
| Eggs | 3.6 | 1.8 | ---------- | 593,100 | ---------- | 736,100 | ---------- | 462,300 | ---------- |
| Larvae: | | | | | | | | | |
| 2.0 mm | 1.0 | 4.1 | 1.90– 2.25 | 28,300 | 4,711 | ---------- | ---------- | ---------- | ---------- |
| 2.5 mm | 1.0 | 5.1 | 2.26– 2.75 | 48,100 | 8,109 | ---------- | ---------- | ---------- | ---------- |
| 3.0 mm | 1.0 | 6.1 | 2.76– 3.25 | 63,500 | 10,706 | 29,500 | 4,007 | 59,300 | 12,827 |
| 3.5 mm | 4.8 | 9.0 | 3.26– 3.75 | 11,100 | 1,871 | 3,300 | 448 | 6,800 | 1,470 |
| 4.0 mm | 4.2 | 13.5 | 3.76– 4.25 | 9,400 | 1,548 | 3,300 | 448 | 5,700 | 1,232 |
| 4.5 mm | 3.7 | 17.4 | 4.26– 4.75 | 6,900 | 1,163 | 3,200 | 434 | 3,800 | 821 |
| 5.0 mm | 3.3 | 21.0 | 4.76– 5.25 | 5,500 | 927 | 2,200 | 298 | 4,100 | 886 |
| 5.75 mm | 5.9 | 25.5 | 5.26– 6.25 | 2,600 | 438 | 1,500 | 203 | 1,500 | 324 |
| 6.75 mm | 5.0 | 31.0 | 6.26– 7.25 | 780 | 131 | 850 | 115 | 830 | 179 |
| 7.75 mm | 4.3 | 35.7 | 7.26– 8.25 | 320 | 53 | 560 | 76 | 480 | 97 |
| 8.75 mm | 3.8 | 39.4 | 8.26– 9.25 | 170 | 28 | 150 | 20 | 160 | 34 |
| 9.75 mm | 3.5 | 43.3 | 9.26–10.25 | 100 | 16 | 150 | 20 | 71 | 15 |
| 10.75 mm | 3.1 | 46.7 | 10.26–11.25 | 42 | 7 | 28 | 3 | 30 | 6 |
| 11.75 mm | 2.9 | 49.7 | 11.26–12.25 | 25 | 4 | 60 | 8 | ---------- | ---------- |
| 12.75 mm | 2.6 | 52.4 | 12.26–13.25 | 17 | 2 | 60 | 8 | 41 | 8 |
| 13.75 mm | 2.4 | 54.9 | 13.26–14.25 | 43 | 7 | 20 | 2 | ---------- | ---------- |
| 14.75 mm | 2.3 | 57.2 | 14.26–15.25 | 37 | 6 | 81 | 11 | 10 | 2 |

## GROWTH RATE OF LARVAE

The growth rate of jack mackerel larvae was obtained by direct observation of material taken from station 70 on line 97 (97.70) during March of 1957 (Farris, 1959). Eggs were taken from the sea with a plankton net, sorted according to developmental stage, placed in jars of fresh sea water, and observed daily until they hatched. After hatching the larvae were measured daily until they died. No attempt was made to feed the fish. The measurements were averaged daily and plotted as log average length against days (fig. 12). Such a plot suggested that growth during the first 3 days was more rapid than for the next 4 days. The yolk sac was absorbed and the eyes became pigmented on the sixth day of larval life. The growth rates for the first 3 days (section A) and for the following 4 days (section B) were then compared by regression analysis (table 26), where $X$=days past hatching, $Y$=length in millimeters, $\log Y=a+bX$, $s_b$=standard deviation of slope, and $s_{y/x}$=standard deviation of sample points

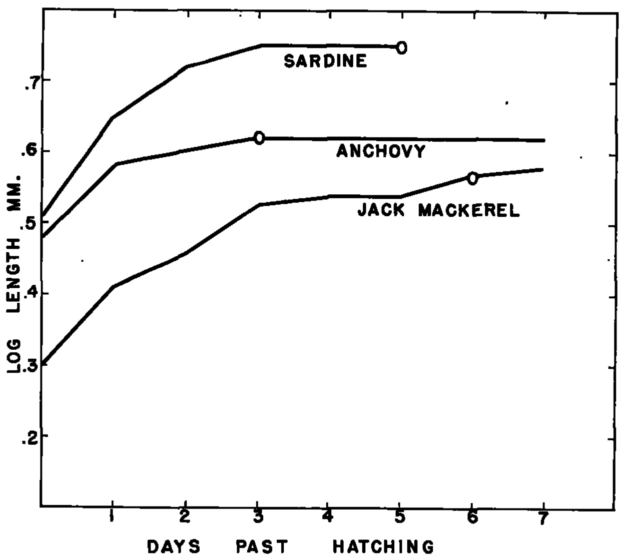


FIGURE 12.—Growth curves of jack mackerel, Pacific sardine, and northern anchovy. (Open circles indicate complete absorption of the yolk.)

from the line. The comparison of the two slopes indicated that the initial relative growth rate is about five times that of the later relative growth rate.

TABLE 26.—*Regression statistics for the relative growth rate of jack mackerel larvae*

| | $a$ | $b$ | $s_b$ | $s_{y/x}$ | $\bar{X}$ | $\bar{Y}$ |
|---|---|---|---|---|---|---|
| Section A: days 1 through 3 | 0.328 | 0.067 | 0.0091 | 0.0616 | 1.3 | 0.614 |
| Section B: days 4 through 8 | .486 | .013 | .0017 | .0184 | 3.1 | .687 |

The relative growth rates of the other two species (Pacific sardine, *Sardinops caerulea*, and northern anchovy, *Engraulis mordax*) illustrated in figure 12 are similar to the growth rate shown for jack mackerel. In addition, the relative growth rate of the sardine as determined by direct observation ($b=0.018$) is in good agreement with the relative growth rate ($b=0.019$) determined by Ahlstrom (1954b) using an indirect method (Farris, 1959: p. 33). Ahlstrom, working with preserved material, was able to follow length-frequency modes through time.

Although growth has been described by two log curves instead of one, either would have served as well for estimating survival. The abundance of a size class is given by the following equation:

$$C=\sum_{i=1}^{n}\frac{c_i'w_it_i}{d_i}$$

where

$C$=estimate of total abundance of larvae of size class

$c_i'$=standard number of larvae belonging to the size class at the $i$th station

$w_i$=area factor proportional to area of the $i$th station

$t_i$=time factor equal to one-half the time from preceding ocupancy plus one-half the time to succeeding occupancy

$d_i$=duration of size category in days, i.e., the number of days used by larvae to grow from the lower-size boundary to the upper-size boundary of the size class

$n$=number of stations considered.

The effects of 1- and 2-phase growth on mortality estimates were compared by recomputing estimates of abundance for sardines given by Ahlstrom (1954b: p. 133). In recomputing abundance of yolk-sac larvae, the formula used was—Duration of size category (days)=

$$\frac{\log l''-\log l'}{0.081},$$

where 0.081 is the log increase in length per day of the larvae, $l'$ is the lower boundary of the size-class interval, and $l''$ is the upper boundary of the size-class interval. The duration of size category for the remaining size categories of larvae is given by—

$$\frac{\log l''-\log l'}{0.018}.$$

The results of the recomputation are given in table 27 under the heading "double phase," and may be compared with Ahlstrom's figures. The slight differences in average age for given size may be due to shrinkage of the larvae upon preservation in formalin.

Since relative growth rates derived from laboratory observations on the first 5 days in the life of a sardine could be extrapolated and reconciled with field observations, it was assumed that the extrapolation could be made for jack mackerel, too.

An analysis of successive length-frequency diagrams has not been used because the time interval between successive cruises is too great for the estimation of a rapid growth rate. Secondly, any changes in the survival of larvae between cruises would influence the length frequencies; hence the changes would alter the estimation of the growth parameter and thereby alter the estimates of annual survival. A growth rate derived from direct observation has the advantage of being independent of variation in survival.

TABLE 27.—*Estimates of abundance of young sardine, using single phase and double phase growth curves, 1950*

[Single phase after Ahlstrom (1954b)]

| Category | Size range (mm.) | Duration (days) | Average age (days) | Estimated abundance |
|---|---|---|---|---|
| Single phase: | | | | |
| Egg | ------------ | 3.0 | 1.5 | 285,676 |
| Yolk-sac larvae | 2.26–4.25 | 3.5 | 4.8 | 11,850 |
| Larvae: | | | | |
| 4.75 mm | 4.26–5.25 | 4.8 | 8.9 | 10,778 |
| 5.75 mm | 5.26–6.25 | 3.9 | 13.2 | 5,590 |
| 6.75 mm | 6.26–7.25 | 3.3 | 16.8 | 6,197 |
| 7.75 mm | 7.26–8.25 | 2.9 | 20.0 | 5,931 |
| 8.75 mm | 8.26–9.25 | 2.6 | 22.7 | 4,834 |
| 9.75 mm | 9.26–10.25 | 2.3 | 25.1 | 3,738 |
| 10.75 mm | 10.26–11.25 | 2.1 | 27.3 | 2,880 |
| Double phase: | | | | |
| Egg | ------------ | 3.0 | 1.5 | 285,676 |
| Yolk-sac larvae: | | | | |
| 3.25 mm | 2.26–4.25 | 1.9 | 3.9 | 21,829 |
| 4.75 mm | 4.26–5.25 | 5.1 | 7.5 | 10,144 |
| Larvae: | | | | |
| 5.75 mm | 5.26–6.25 | 4.2 | 12.1 | 5,191 |
| 6.75 mm | 6.26–7.25 | 3.5 | 15.9 | 5,843 |
| 7.75 mm | 7.26–8.25 | 3.1 | 19.2 | 5,548 |
| 8.75 mm | 8.26–9.25 | 2.7 | 22.1 | 4,655 |
| 9.75 mm | 9.26–10.25 | 2.4 | 24.7 | 3,582 |
| 10.75 mm | 10.26–11.25 | 2.2 | 27.0 | 2,749 |

The regression statistics of section A (table 26) were used to estimate the duration of the various size categories of jack mackerel through the 3.0-mm. size class and the regression statistics of section B for all size classes thereafter. The duration of the size category (in days) through the 3.0-mm. size category is given by—

$$\frac{\log l''-\log l'}{0.067},$$

where $l''$ is the upper boundary of the size class, and $l'$ is the lower boundary.

The duration of the size category (in days) for all remaining size categories is given by—

$$\frac{\log l''-\log l'}{0.013}.$$

The average age for any size category is given by summing the duration of size class for shorter size classes and adding one-half the duration of the size category under consideration. For example, the average age of the 4.5-mm. size category is obtained by summing the durations for categories, eggs through 4.0 (15.6) and adding one half of 3.7. The average age is 17.4 days.

The coincidence of the absorption of the yolk-sac and the inflection of the survival curve is tentatively interpreted as follows:

Basic mortality rates of pelagic fish eggs and yolk-sac larvae are high owing to factors intrinsic to the eggs and inherent in the species; most of those which are unfit have died before absorbing their yolk or die shortly thereafter; the survivors beyond the critical stage now survive at a higher rate because they have successfully negotiated the change in nutrition (i.e., from yolk to copepod eggs and nauplii). A more comprehensive exposition of this hypothesis is given by Farris (1960).

## SOURCES OF ERROR AND BIAS IN SAMPLING LARVAE

In the section on sources of error in egg sampling, some of the more obvious sources of error and bias were examined. These same sources of error were examined in sampling procedures for larvae. In addition, the avoidance of the net by the larvae might be added as a source of error.

### RETENTION OF LARVAE BY THE NETS

Incomplete retention by the net of some small size classes of larvae becomes a serious problem. Estimates of abundance were made for the 2.0- and 2.5-mm. size classes of larvae in 1952 (table 25). These estimates are lower than the estimated abundance of the 3.0-mm. size-class larvae, indicating that the smaller size classes were undersampled. Larvae less than 3.0 mm. in length, meeting the mesh head on, are able to pass through and do not appear in our collections in proportion to their true abundance. Estimates for these size classes were not made in 1953 and 1954.

Figure 4, from Ahlstrom and Ball (1954) suggests that the head depth may be 10 to 20 percent greater than the body depth at the pectoral. If this is so, the maximum depth of the 3.0-mm. larvae is greater than the maximum mesh opening of the sampling net (0.55 mm. after shrinking and 0.7 mm. before shrinking). As the larvae grow longer, their bodies grow increasingly deep and they are therefore retained within the sampling net. Evidence that larvae 3.0 mm. and longer would be retained once they are in the plankton net is given in table 28.

TABLE 28.—*Standard length and body depth at pectoral of jack mackerel larvae*

[Measurements in millimeters]

| Average standard length | Average depth at pectoral |
|---|---|
| 2.8 [1] | 0.46 [1] |
| 3.2 | 0.62 |
| 3.8 | 0.82 |
| 4.2 | 1.03 |
| 4.8 | 1.23 |

[1] Data from Ahlstom and Ball (1954, p. 215–216).

## SAMPLING OF THE VERTICAL RANGE

The vertical distribution of larvae was examined for both the total range and quantitative diurnal differences in abundance at different depths. The data (table 29, after Ahlstrom, 1959: p. 119) indicate that almost all the larvae were found above 100 meters and that no larvae were found below 140 meters. Since net hauls are routinely made from a 140-meters depth, the net passes through the entire water column which can be expected to contain jack mackerel larvae.

The possibility of quantitative day-night differences (because of diurnal vertical migration) was analyzed by examining the vertical distribution of samples taken during the day and at night. These comparable day-night series were completed for several stations. The 2-, 8-, and 19-meter strata contain proportionally more larvae when sampled in the day than at night. The data indicate that there may be some slight tendency for the larvae to migrate to the surface during the day; however, it is more likely that there was a change in the water being sampled at station 94.80 (5403) between the day and night series. Both sardine and anchovy larvae are known to be distributed somewhat deeper in the daytime (negative phototaxis) than at night (Ahlstrom, 1959), as are many species of plankton organisms, so that a positive phototaxis would need to be better documented than is possible from our data. No definite diurnal variation in vertical distribution is evidenced.

TABLE 29.—*Standard number of jack mackerel larvae taken in day and night hauls, by depths*

[Stations in parentheses; after Ahlstrom, 1959]

| Depth range (m.) | Average depth (m.) | Day hauls: Cruise 4106 (94.37) | Cruise 4106 (94.47) | Cruise 5206 (90.28) | Cruise 5305 (93.50) | Cruise 5403 (94.80) | Total larvae taken | Percent of total | Night hauls: Cruise 4106 (94.37) | Cruise 4106 (94.47) | Cruise 5206 (90.28) | Cruise 5305 (93.50) | Cruise 5403 (94.80) | Total larvae taken | Percent of total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2–3 | 2 | 0 | 0 | 0 | 0 | 92 | 92 | 42.8 | 0 | 0 | 12 | 0 | 26 | 38 | 42.7 |
| 6–10 | 8 | 0 | 0 | 2 | 0 | 86 | 88 | 40.9 | 0 | 0 | 13 | 4 | 0 | 17 | 19.1 |
| 16–21 | 19 | 0 | 0 | 0 | 0 | 24 | 24 | 11.2 | 0 | 4 | *0 | 0 | 5 | 9 | 10.1 |
| 24–31 | 28 | 0 | 0 | *0 | 0 | 2 | 2 | .9 | *0 | *3 | 0 | 0 | 7 | 10 | 11.2 |
| 33–45 | 41 | *1 | *0 | 0 | 2 | 2 | 5 | 2.3 | 0 | 0 | 1 | 0 | 6 | 7 | 7.9 |
| 46–60 | 56 | 0 | 0 | 0 | 0 | 2 | 2 | .9 | 0 | 0 | 0 | 0 | 8 | 8 | 9.0 |
| 63–79 | 72 | 0 | 0 | 0 | 0 | 2 | 2 | .9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 92–112 | 105 | 0 | 0 | 0 | *0 | *0 | 0 | 0 | 0 | 0 | 0 | *0 | *0 | 0 | 0 |
| 127–150 | 138 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200–239 | 215 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 276–291 | 285 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1 | 0 | 2 | 2 | 210 | 215 | 99.9 | 0 | 7 | 26 | 4 | 52 | 89 | 100.0 |

*Region of the thermocline.

## VARIABLE DISTRIBUTION OF LARVAE

The difficulties in assessing the variability of these estimates have previously been discussed in the section on sources of error in sampling eggs. Since the proper statistical model is not known at this time, no good estimate of error can be given. It was shown in the case of eggs that for a large number of interpolations in space and time the error tended toward zero. The error of the estimates of abundance for the larvae is probably as great as the error of the estimates for egg abundance, and very likely it is even greater. This may be particularly true for the estimates of abundance of the older size categories which are based on fewer than 10 observations.

## SAMPLING OF THE HORIZONTAL RANGE

It was shown that incomplete sampling of the entire range of jack mackerel spawning introduced an error of at least 21 percent of the estimated total egg population. This error appears to be reduced for the estimates of larvae. A very small proportion of the 30-day and older larvae is taken seaward of stations 90 (tables 30, 31, and 32). These tables were constructed using the standard numbers of jack mackerel larvae (6.75 mm size-class) for all stations sampled during the year. The data were grouped by 2-month intervals about selected sampling lines and further grouped to reflect the offshore-inshore distribution of the larvae as was done with the eggs (see p. 253). The data seem to indicate that almost all the 30-day-old larvae are to be found in an area bounded by line 80 on the north, line 110 on the south, stations 90 on the west, and the coast on the east. Some larvae are found both to the north and south of the main area. This area is far more restricted than that exhibited by the distribution of the eggs (see above).

TABLE 30.—*Relative north-south, inshore-offshore distribution of 6.75-mm. (30-day old) jack mackerel larvae, by 2-month intervals, 1952*

[Standard haul totals]

| Lines | Stations: 100-seaward | Stations: 90–70 | Stations: 60-shore | Total | Percent |
|---|---|---|---|---|---|
| February–March: | | | | | |
| 60 | (1) | (1) | (1) | (1) | (1) |
| 70 | (1) | (1) | (1) | (1) | (1) |
| 80 | 0 | 0 | 0 | 0 | 0 |
| 90 | (1) | 0 | 0 | 0 | 0 |
| 100 | (1) | 0 | 0 | 0 | 0 |
| 110 | (1) | 2.7 | 8.3 | 11.0 | 100.0 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 0 | 2.7 | 8.3 | 11.0 | 100.0 |
| Percent | 0 | 24.5 | 75.5 | 100.0 | ---------- |
| April–May: | | | | | |
| 60 | (1) | 0 | 0 | 0 | 0 |
| 70 | (1) | 0 | 0 | 0 | 0 |
| 80 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 9.4 | 0 | 9.4 | 16.8 |
| 100 | 0 | 19.2 | 8.2 | 27.4 | 48.9 |
| 110 | (1) | 9.0 | 10.2 | 19.2 | 34.3 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 0 | 37.6 | 18.4 | 56.0 | 100.0 |
| Percent | 0 | 67.2 | 32.8 | 100.0 | ---------- |
| June–July: | | | | | |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 | 0 |
| 80 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 42.4 | 53.3 | 95.7 | 45.4 |
| 100 | 0 | 47.1 | 54.9 | 102.0 | 48.4 |
| 110 | (1) | 3.6 | 5.9 | 9.5 | 4.5 |
| 120 | (1) | 3.1 | 0 | 3.1 | 1.5 |
| Total | 0 | 96.2 | 114.1 | 210.3 | 99.8 |
| Percent | 0 | 45.7 | 54.3 | 100.0 | ---------- |

[1] Region not occupied.

TABLE 31.—*Relative north-south, inshore-offshore distribution of 6.75-mm. (30-day old) jack mackerel larvae, by 2-month intervals, 1953*

[Standard haul totals]

| Lines | Stations: 100-seaward | Stations: 90–70 | Stations: 60-shore | Total | Percent |
|---|---|---|---|---|---|
| February–March: | | | | | |
| 60 | (1) | (1) | (1) | (1) | (1) |
| 70 | (1) | (1) | (1) | (1) | (1) |
| 80 | 4.9 | 0 | 0 | 4.9 | 16.2 |
| 90 | (1) | 0 | 3.8 | 3.8 | 12.5 |
| 100 | (1) | 8.4 | 8.1 | 16.5 | 54.5 |
| 110 | (1) | 0 | 5.1 | 5.1 | 16.8 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 4.9 | 8.4 | 17.0 | 30.3 | 100.0 |
| Percent | 16.2 | 27.8 | 56.0 | 100.0 | ---------- |
| April–May: | | | | | |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 70 | (1) | 0 | 0 | 0 | 0 |
| 80 | 0 | 0 | 0 | 0 | 0 |
| 90 | 0 | 0 | 0 | 0 | 0 |
| 100 | (1) | 5.9 | 18.4 | 24.3 | 31.6 |
| 110 | (1) | 0 | 52.6 | 52.6 | 68.5 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 0 | 5.9 | 71.0 | 76.9 | 100.1 |
| Percent | 0 | 7.7 | 92.3 | 100.0 | ---------- |
| June–July: | | | | | |
| 60 | (1) | 0 | 0 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 | 0 |
| 80 | 0 | 12.1 | 3.0 | 15.1 | 6.9 |
| 90 | (1) | 35.2 | 36.8 | 72.0 | 32.9 |
| 100 | 0 | 32.6 | 18.6 | 51.2 | 23.3 |
| 110 | (1) | 11.8 | 58.9 | 70.7 | 32.2 |
| 120 | (1) | 0 | 10.3 | 10.3 | 4.7 |
| Total | 0 | 91.7 | 127.6 | 219.3 | 100.0 |
| Percent | 0 | 41.8 | 58.2 | 100.0 | ---------- |

[1] Region not occupied.

There are several possible explanations for the relatively restricted distribution of jack mackerel larvae. Four interactions of ocean current and fish survival are discussed as possible explanations of the observed distribution.

*Uniform current flow, differential survival.*—In this model, it is assumed that the southerly flowing California Current has a uniform velocity, i.e., it has no eddies or countercurrents, and the larvae have a differential survival. The eggs spawned in some part of the Current will survive at a much higher rate over those deposited in other parts. Under the conditions of this model, the older larvae (survivors) would occur in regions south of the one in which they were spawned, never north of the spawning region. If the current, though of uniform velocity, is very slow, the southward displacement will be slight and therefore very hard to measure.

*Uniform current flow, uniform survival.*—If the California Current flowing south contained larvae which survived equally well in any part of the current, one would expect the older larvae to

TABLE 32.—*Relative north-south, inshore-offshore distribution of 6.75-mm. (30-day old) jack mackerel larvae, by 2-month intervals, 1954*

[Standard haul totals]

| Lines | Stations 100-seaward | Stations 90–70 | Stations 60-shore | Total | Percent |
|---|---|---|---|---|---|
| February-March: | | | | | |
| 60 | (1) | (1) | (1) | (1) | (1) |
| 70 | (1) | (1) | (1) | (1) | (1) |
| 80 | 0 | 0 | 0 | 0 | 0 |
| 90 | (1) | 0 | 0 | 0 | 0 |
| 100 | (1) | 5.3 | 0 | 5.3 | 100.0 |
| 110 | (1) | 0 | 0 | 0 | 0 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 0 | 5.3 | 0 | 5.3 | 100.0 |
| Percent | 0 | 100.0 | 0 | 100.0 | ---------- |
| April-May: | | | | | |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 70 | (1) | 0 | 0 | 0 | 0 |
| 80 | (1) | 4.5 | 0 | 4.5 | 8.4 |
| 90 | (1) | 3.0 | 6.2 | 9.2 | 17.1 |
| 100 | 0 | 3.2 | 8.7 | 11.9 | 22.1 |
| 110 | (1) | 5.9 | 15.8 | 21.7 | 40.1 |
| 120 | (1) | 0 | 6.6 | 6.6 | 12.3 |
| Total | 0 | 16.6 | 37.3 | 53.9 | 100.0 |
| Percent | 0 | 30.8 | 69.2 | 100.0 | ---------- |
| June-July: | | | | | |
| 60 | 0 | 3.0 | 0 | 3.0 | 1.5 |
| 70 | (1) | 10.5 | 0 | 10.5 | 5.1 |
| 80 | 2.8 | 7.7 | 49.8 | 60.3 | 29.5 |
| 90 | (1) | 54.8 | 56.0 | 110.8 | 54.2 |
| 100 | (1) | 2.9 | 13.8 | 16.7 | 8.2 |
| 110 | (1) | 0 | 3.1 | 3.1 | 1.5 |
| 120 | (1) | 0 | 0 | 0 | 0 |
| Total | 2.8 | 78.9 | 122.7 | 204.4 | 100.0 |
| Percent | 1.4 | 38.5 | 60.1 | 100.0 | ---------- |

[1] Region not occupied.

occur always to the south of the spawning area. If one considers the special conditions of low current velocity and high larval mortality, a sampling problem becomes apparent. Consider: A small subarea $X$ on the periphery of the spawning area contains a thousand eggs. At the end of a month, one larva has survived. Subarea $Y$ in the center of the spawning area contains a million eggs. Under conditions of uniform survival a thousand larvae would survive at the end of a month. The sampler has a much better chance of obtaining larvae from subarea $Y$ than from subarea $X$. The failure in obtaining month-old larvae from peripheral areas would lead to a conclusion of better survival in the center of the spawning area, though in fact, survival was uniform over the entire area.

*Differential current flow, uniform survival.*—Under conditions of this model, the California Current would have an average transport to the south, but some parts of the water would move faster than others, and eddy currents would be present. The larvae, although surviving at a uniform rate, would not appear to do so because of the postulated concentrating mechanisms. A high proportion of the larvae would be found in the eddies.

*Differential current flow, differential survival.*—Using this model, it is virtually impossible to predict the distribution of the older larvae, as that distribution depends on the special conditions of the current and survival.

Since the average flow, as determined from dynamic topography of the California Current, is slow (about 0.2 knot) and since it contains water flowing both slower and faster accompanied by eddies, no definite conclusion may be reached concerning differential survival, although survival appears to be better in some regions (table 33).

TABLE 33.—*Annual regional summary of distribution of jack mackerel eggs and month-old larvae, 1952–54*

[Survival at the end of 1 month is given for each region]

| Year and region | Eggs (billions) | Percent of total | Larvae [1] (billions) | Percent of total | Survival per 100,000 eggs |
|---|---|---|---|---|---|
| 1952: | | | | | |
| 1 | 15,685 | 2.64 | 0 | 0 | 0 |
| 2 | 246,940 | 41.64 | 348 | 44.8 | 1.4 |
| 3 | 257,418 | 43.40 | 316 | 40.5 | 1.2 |
| 4 | 68,902 | 11.63 | 115 | 14.7 | 1.7 |
| 5 | 4,137 | 0.69 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 |
| Total | 593,082 | 100.00 | 779 | 100.0 | ---------- |
| 1953: | | | | | |
| 1 | 9,653 | 1.31 | 10 | 1.2 | 1.0 |
| 2 | 185,095 | 25.14 | 301 | 35.4 | 1.6 |
| 3 | 353,517 | 48.02 | 405 | 47.5 | 1.1 |
| 4 | 176,573 | 23.99 | 136 | 15.9 | .8 |
| 5 | 11,294 | 1.53 | 0 | 0 | 0 |
| 6 | ---------- | ---------- | ---------- | ---------- | ---------- |
| Total | 736,132 | 99.99 | 852 | 100.0 | ---------- |
| 1954: | | | | | |
| 1 | 31,116 | 6.73 | 169 | 20.3 | 5.4 |
| 2 | 177,141 | 38.31 | 527 | 63.4 | 3.0 |
| 3 | 185,765 | 40.18 | 124 | 14.9 | .7 |
| 4 | 49,228 | 10.65 | 6 | .7 | .1 |
| 5 | 19,088 | 4.13 | 5 | .6 | .3 |
| Total | 462,338 | 100.00 | 831 | 99.9 | ---------- |

[1] 6.75-mm. size class; estimated to be 1 month old.

## AVOIDANCE OF NET

When Ahlstrom (1954b) computed the mortality of sardines, he found that a correction was necessary to account for the larvae which dodged the sampling net. He demonstrated dodging in a relative way by examining the ratio of average number of sardine larvae per night haul (when presumably the larvae cannot see the net) to the average number of larvae per day haul. When he computed the night/day ratio for each size class he found that the ratio increased with size. The

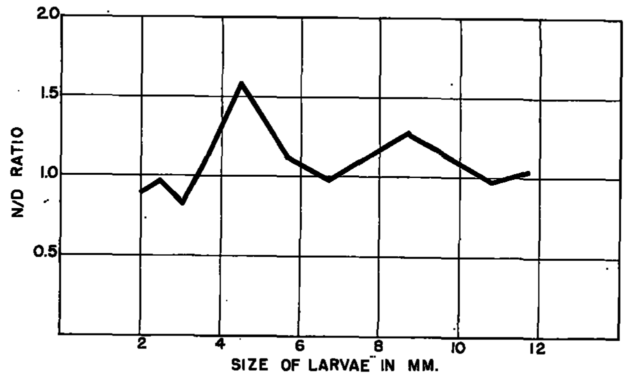


FIGURE 13.—Ratio of the average number of jack mackerel larvae per night haul to the average number taken per day (N/D), by size class, 1952–54.

implication was that as the larvae grew larger and stronger they were better able to dodge the net. This increase in ratio with size is true not only of the sardine, but also of the anchovy, the hake, the Pacific mackerel, et cetera (Ahlstrom, personal communication; Bridger, 1956).

It is, indeed, surprising to find that jack mackerel do not behave in this manner. All jack mackerel data for 3 years have been combined in figure 13. The N/D ratio for the 7.75-mm. size class has been deleted because one of the samples, which was unusually large, prevented comparison of this size class with the other size classes. A least-squares line has been fitted to the data $Y=a+bX$, where $X$=size in millimeters and $Y=N/D$ ratio. The regression statistics are $a=1.06$; $b=0.006$; $s_{y/x}=0.196$; $\overline{X}=6.0$; $\overline{Y}=1.10$; $s_b=0.057$.

The slope of the regression is not significantly different from zero. The interpretation placed on these data is that jack mackerel do not dodge the net despite their apparent ability to do so. The eyes are pigmented and presumably functional about the time the yolk is absorbed (at approximately 3.5 mm.), and larvae at yolk-sac absorption are capable of movement. Ahlstrom (personal communication) believes that jack mackerel larvae can swim as well as the sardine larvae.

## SUMMARY

The distribution and abundance of jack mackerel eggs is described for 4 years, 1951 through 1954. The early survival of jack mackerel larvae is described for 1952, 1953, and 1954. The data were obtained from monthly cruises during which an average of 150 stations was occupied.

Jack mackerel spawned in an area bounded by the 26th parallel on the south, the 45th parallel on the north, the west coast of North America on the east, and the 150th meridian on the west. Most of the spawning occurred in a more restricted area, the boundaries of which varied from year to year. Eggs were mainly confined to the upper 40 meters of water.

Spawning usually began in February, reached a peak in May, and ceased by October. The peak of spawning in 1951, which occurred in March, is considered abnormally early.

The temperature coefficient for the rate of egg development was derived by a regression of log hours of development on temperature in degrees centigrade. Jack mackerel eggs kept under controlled temperature conditions (in an incubator) hatched at the time predicted by the derived temperature coefficient.

The estimates of egg abundance for 1951, 1952, 1953, and 1954 are $8.7\times10^{14}$, $5.9\times10^{14}$, $7.4\times10^{14}$, and $4.6\times10^{14}$, respectively.

The survival at the end of a 30-day period for 1952, 1953, and 1954 was 131, 112, and 179 larvae per 100,000 eggs spawned, respectively. The variation was considered insignificant. An increase in survival rate during the second week of larval life was noted.

The relative growth rate of jack mackerel larvae was approximated from observations on laboratory populations. The relative growth during the first 3 days is more rapid by a factor of 5 than the relative growth of the succeeding 4 days. The onset of the slower growth is correlated in time with yolk-sac absorption.

An area which is bounded by line 80 on the north, line 110 on the south, stations 90 on the west, and the coast of California and Baja California on the east has been shown to contain almost all the month-old larvae.

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## APPENDIX

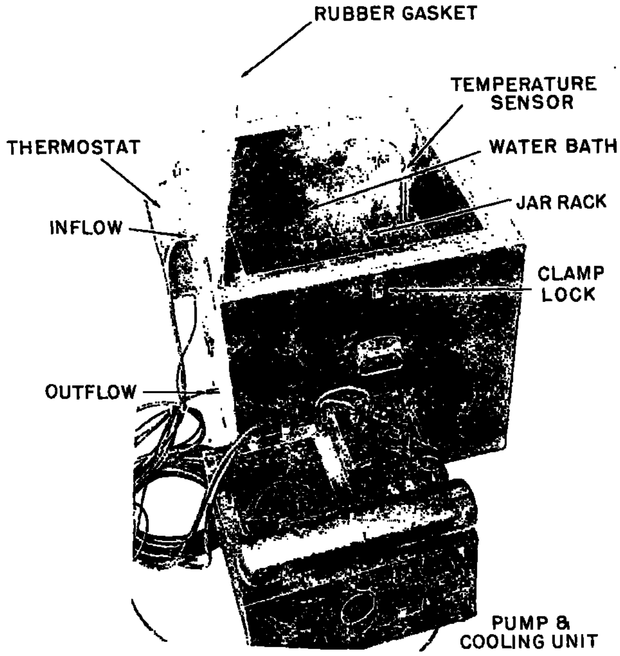
### A. FISH EGG INCUBATOR

**Description**

When estimating the total abundance of pelagic fish eggs it is necessary to know the rate of development. Since this parameter varies with temperature it has been customary in the past to compute a regression of log hours of development against temperature in tenths of a degree centigrade. This indirect method, while very accurate, is extremely laborious and time consuming. A more direct method was desired, and with this need in mind, an incubator was designed for use at sea.

Since most of the biological material is taken well offshore, and since hatching times are relatively short, it is necessary to work at sea. Some of the many technical problems that are peculiar to sea work and their solutions are described here.

The pitch and roll of ships cause delicate equipment to be damaged quite easily, and the need for sturdy construction is readily apparent. Instruments such as this one should be portable, since they have a limited use and cannot be left aboard research vessels indefinitely. A compromise between sturdy construction and portability of an egg incubator was effected by resorting to a double-box construction, using marine plywood. The temperature-sensing and temperature-control devices were of a mechanical nature. A heavy duty, stainless steel sensing element enclosing a mercury column was employed. The mercury column activated a mechanical linkage in the thermostat, which in turn opened and closed an electrical switch. The circulating pump and cooling device were remote from the incubator itself, but connected by garden hoses (appendix fig. 1). The




APPENDIX FIGURE 1.—Fish egg incubator.

separation of units contributed to the portability of the instrument.

Corrosion from the salt air which attacks most metals was controlled by using a synthetic resin paint on all exposed parts of the incubator. Other structures were concealed in corrosion resistant housings.

Temperature control (± 0.2° C. of selected temperature) was obtained by using the main water mass in the water bath as a heat reservoir. As the water mass warmed, the change in temperature was recorded by the sensing element and the water routed through the cooling mechanism. It was believed that temperature changes in the incubation chambers were small, because the main water mass was so large, by comparison, that a large amount of heat would have to be transferred before any appreciable temperature change in the incubation chambers would occur.

The eggs were incubated in pint or quart mason fruit jars. The pint jars had glass tops held in place by a spring clamp; the quart jars were wide-mouthed and equipped with plastic lids.

**Procedure for use**

While the vessel is still at the dock, the incubator and cooling mechanism are secured to the deck. The water bath is filled with fresh water (which causes less corrosion in the cooling system than salt water) and the circulating and cooling motors are started. Operability of the thermostat is checked.

Once the vessel is in the collecting area, the thermostat is set so that the water in the water bath assumes the same temperature as the sea. Later on, at the time the biological sample is received, a bathythermograph reading is taken and the thermostat adjusted. The fruit jars are filled with sea water from the area and the samples placed in them. A small air space is left at the top of the jars to aid aeration of the sample. The jars are then placed in the jar rack and locked into place. From then on the operation is automatic, although temperature readings should be taken frequently to assure that the incubator is operating properly.

**General specifications**

The outside dimensions of the incubator were 32 inches by 32 inches by 35 inches deep. The inside dimensions, the perimeter of the water bath, were 26 inches by 26 inches by 26 inches. Both the inside and outside boxes were made of ⅝-inch marine plywood fastened together with brass screws. The space between the boxes was filled with an insulating material. The inside box was lined with copper sheeting that had been soldered at the joints and was therefore watertight. The jar rack also was made of copper. The individual chambers of the bottle rack were 4 inches square and accommodated either pint or quart wide-mouthed jars.

The copper lining was pierced by three holes: one for inflowing water, one for outflowing water, and one for the temperature-sensing element.

The lid was fastened by two heavy metal strap hinges and three clamp locks. A sponge-rubber gasket prevented leakage.

The water in the water bath was circulated by a Jabsco pump and cooled by a Temprite cooler. The temperature control was maintained by a Partlow thermostat. Two ¼-inch plastic garden hoses with brass fittings connected the pump and cooler with the water bath. All exposed surfaces were painted with green plastic paint.

## B. STAGING SCHEME OF JACK MACKEREL EGGS

*Stage I.*—Unfertilized eggs or fertilized eggs before cell division.

*Stage II.*—Begins when the first cell becomes visible on the yoke and ends at the completion of blastodisk formation (at about the 256-cell stage).

*Stage III.*—Starts at the completion of blastodisk formation and terminates when the germ ring has migrated to its greatest diameter (half-way up the egg).

*Stage IV.*—Begins as the germ ring moves upward over the greatest diameter and ends when the germ ring lies over the oil globule, prior to blastopore closure.

*Stage V.*—Begins at blastopore closure and terminates when the tail bud starts to separate from the yolk.

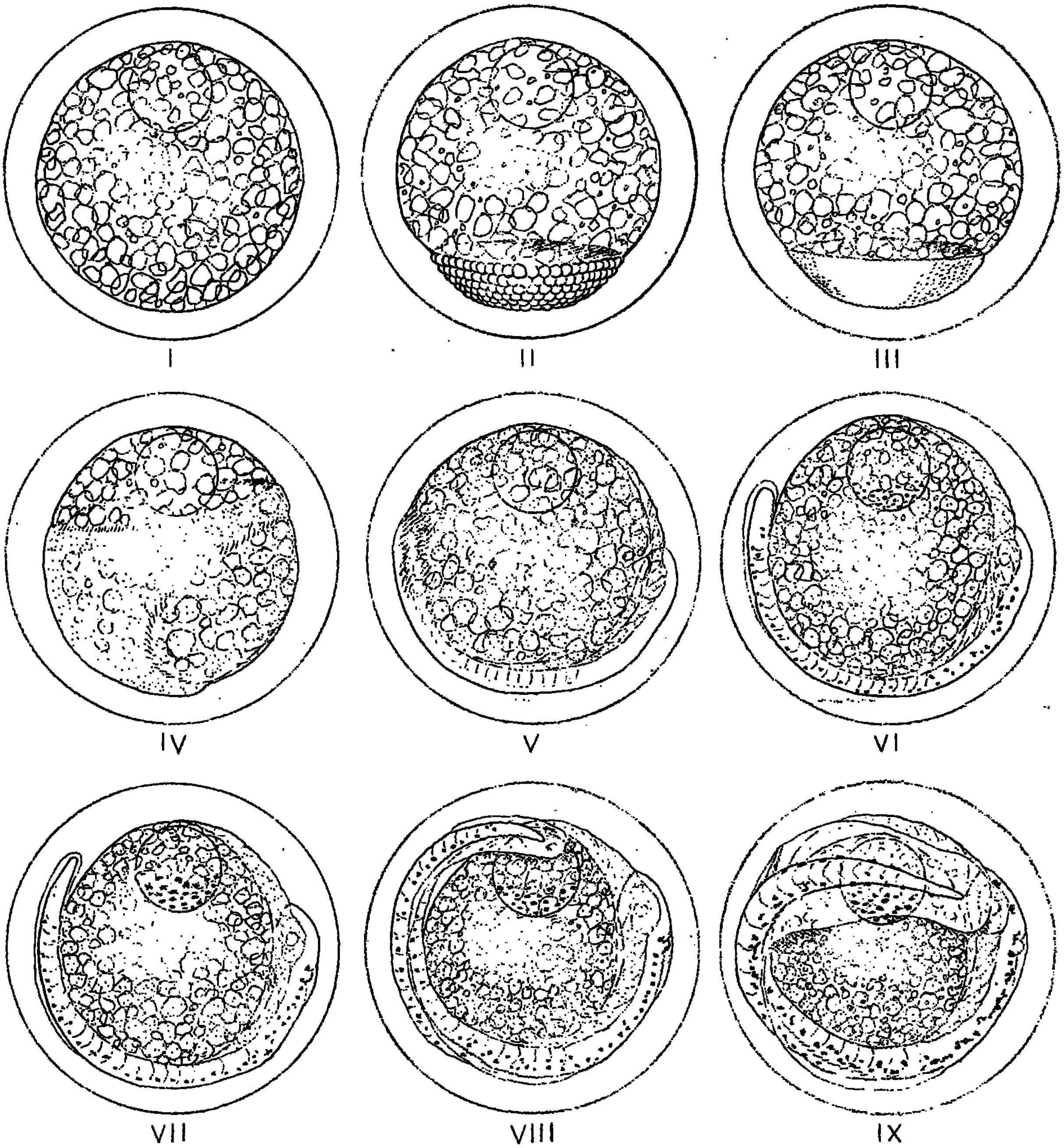
*Stage VI.*—Begins when the tail bud becomes free of the yolk and ends when the caudal one-eighth of the body is free of the yolk.

*Stage VII.*—Begins when the caudal one-eighth of the body is free of the yolk and ends when the caudal one-quarter of the body is free of the yolk. A finfold is visible.

*Stage VIII.*—Begins when the caudal one-quarter of the body is free of the yolk and the tip of the tail approaches the chin. The tail portion of the embryo begins to rotate out of the embryonic plane and the finfold is moderately wide.

*Stage IX.*—This stage is characterized by the tip of the tail laterally approaching the head. The oil globule comes to lie in the anteroventral portion of the yolk sac. The finfold is wide and fully formed. This stage terminates when the embryo hatches.

*Disintegrate.*—Includes all jack mackerel eggs whose internal structure is such that staging is impossible.




APPENDIX FIGURE 2.—Stages of jack mackerel egg development.

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