UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

EARLY DEVELOPMENT, SPAWNING, GROWTH, AND OCCURRENCE OF THE SILVER MULLET (*Mugil curema*) ALONG THE SOUTH ATLANTIC COAST OF THE UNITED STATES

BY WILLIAM W. ANDERSON

FISHERY BULLETIN 119

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 57

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1957

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 20 cents

ABSTRACT

A school of spawning silver mullet (*Mugil curema*) was encountered off the lower Florida coast in April 1954, near the 20-fathom line. Running-ripe females and ripe males were captured and the eggs fertilized. A developmental series of eggs is described; unfertilized eggs averaged 0.82 mm. in diameter and fertilized eggs 0.90 mm. Hatching occurred about 40 hours after fertilization. Newly hatched larvae were about 1.7 mm. long. The larvae were maintained for 32 hours after hatching and to a size of 2.5 mm. A series of larvae is illustrated and described. Larvae 2.5 to 5.0 mm. were taken in plankton tows on the outer Continental Shelf from Florida to North Carolina during spring; a series is figured and described. Dip-net collections from the outer Continental Shelf and in the Gulf Stream contained silver mullet 6 to 25 mm. long. The seine collections in the Georgia coastal areas provided specimens about 20 to 120 mm. long. Development is described through the late juvenile stage.

Spawning appears associated with the outer Continental Shelf and probably occurs from late March until September, with the peak during April, May, and June.

Young silver mullet grow rapidly (about 17 mm. a month) in Georgia waters from April to November. They apparently leave Georgia waters during late fall and early winter when the waters are rapidly cooling.

CONTENTS

EARLY DEVELOPMENT, SPAWNING, GROWTH, AND OCCURRENCE OF THE SILVER MULLET (*Mugil curema*) ALONG THE SOUTH ATLANTIC COAST OF THE UNITED STATES

By William W. Anderson, Fishery Research Biologist

The biology, chemistry, and physical oceanography of the waters adjacent to the coast of the United States from Cape Hatteras, N. C., to lower Florida are little known. Collections by the Fish and Wildlife Service motor vessel *Theodore N. Gill* provided basic material and data for the study of these conditions as a result of a series of cruises made during 1953 and 1954.

This paper presents the findings on spawning, early development, growth, habits, and occurrence of one species. The data contribute to the tremendous task of determining the identity and biology of the numerous fish larvae, a knowledge of which is prerequisite to the understanding of fish populations in the area.

Opportunity to add to the meager information available on spawning, early life history, growth, habits, and the occurrence in offshore waters of the silver mullet, *Mugil curema* Cuvier and Valenciennes, began off the coast of southern Florida. A school of spawning individuals was located (fig. 1) and several running ripe females and ripe males were taken in dip nets. The eggs were fertilized, and during the next several days a developmental series of eggs and larvae was obtained. This series was carried forward with specimens about 2.5 mm. to 5 mm. long, from material taken in routine plankton tows; dip-net collections provided a series of specimens ranging in length from about 6 to 25 mm. Finally, our seine collections from the outer beaches and estuarine marsh areas in Georgia extended the series to juveniles up to about 120 mm. in length.

The silver mullet is known on the Atlantic coast from Cape Cod to South America, and on the Pacific coast from about Chile to the Gulf of California. Along the Atlantic coast of the United States it is taken in commercially significant quantities only in Florida, where it constitutes about one-twentieth of the total mullet landings of about 30 million pounds annually. The principal fishing gears are gill nets, trammel nets, beach seines, and stop nets (Idyll 1949).

I greatly appreciate the assistance of George A. Rounsefell and Frederick H. Berry for critical review of the manuscript. My special thanks are extended to Jack W. Gehringer for review, also for numerous other aids during the study.

METHODS

Eggs were fertilized in several small culture jars and in a glass aquarium of several gallons' capacity. It was not necessary to strip either the females or males as eggs and milt were running during the handling of the fish. Sea water from the spawning location strained through No. 1 plankton silk was used as the culture medium.

For some unknown reason the eggs in the large aquarium failed to develop, but hatching was accomplished in all of the culture jars. In an effort to carry some of the larvae through at least the end of the yolk-sac period, they were handled in several ways: some were retained without changing water in the original jars in which fertilization took place; some were placed in new water from wherever the ship was at the time; but the majority were removed to fresh jars containing a new supply of strained water from the spawning location. The latter procedure met with the best success. Most of the larvae were dead after 36 hours, but one larva survived for 45 hours.

After fertilization a series of eggs was preserved every 2 hours for the first 12 hours and then every 4 hours until hatching at 40 hours. Larvae were preserved at hatching, and then 4, 10, 16, 23, 32, 42, and 45 hours after hatching. All eggs and larvae were preserved in 5 percent buffered formalin.

Biological, oceanographic, and chemical methods used aboard the *Theodore N. Gill*, general work plan, cruise plans, and objectives are given by Anderson, Gehringer, and Cohen (1956).

NOTE.—Approved for publication February 8, 1957. Fishery Bulletin 119.

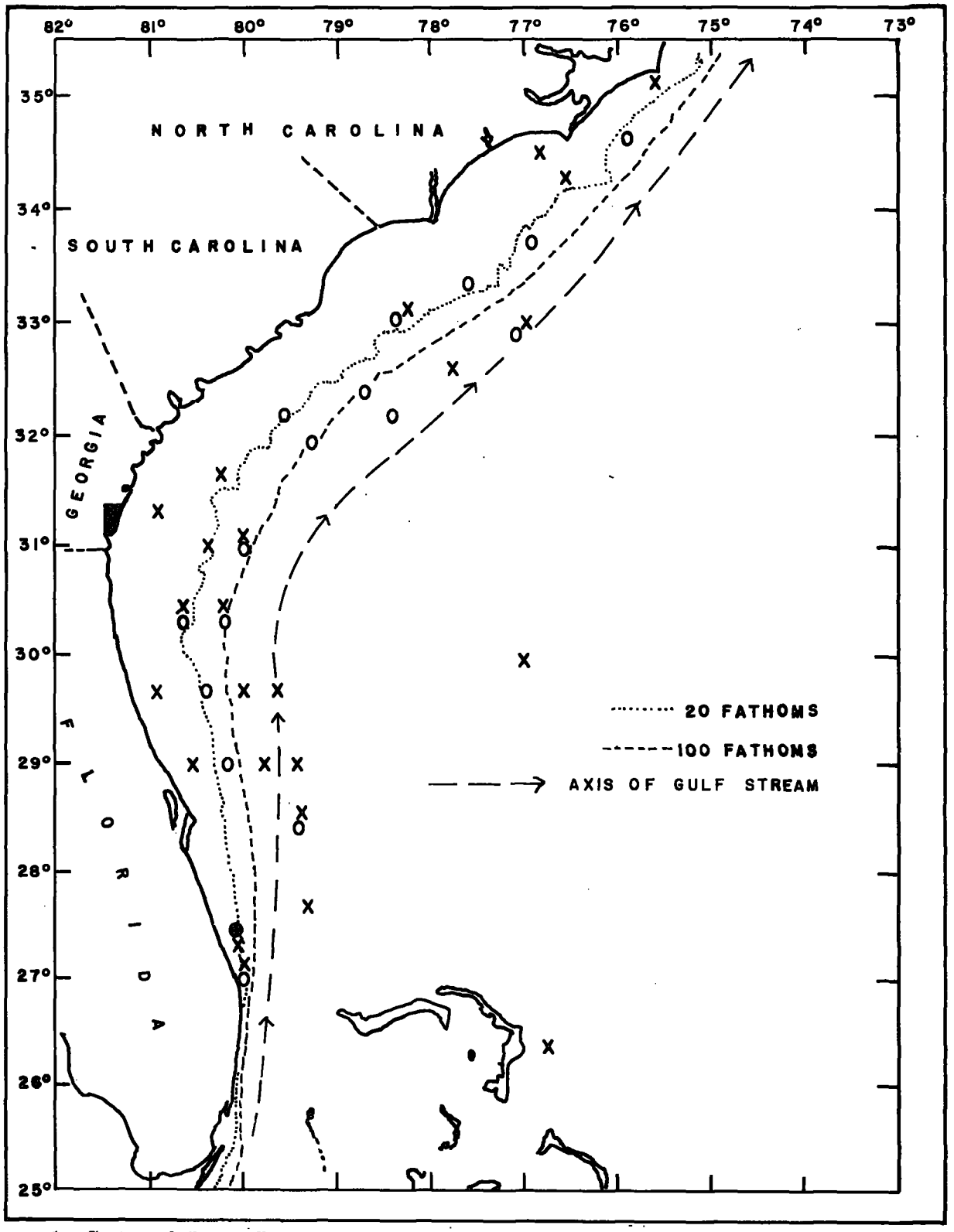

FIGURE 1.—Capture of silver mullet larvae in plankton tows indicated by circles; dip-net collections are shown by x's. (See tables 1 and 2 for occurrence data.) General location of seining shown by blacked-in area on Georgia coast; spawning school of silver mullet indicated by black dot off lower Florida coast near 20-fathom line (*Theodore N. Gill*, station 4).

Seine collections to supplement the material and data collected with the M/V *Theodore N. Gill* in offshore waters have been made on a semimonthly basis since 1953 at three localities in Georgia. One station is on the open ocean beach on St. Simons Island, a second is in the marshy estuarine area behind the barrier islands, and the third is up the Altamaha River at about tidewater limits. Only beach and marsh material are included in this paper.

All descriptions of eggs, larvae, and juveniles are based on preserved material unless otherwise stated.

Measurements of eggs and the larvae up to about 25 mm. in length were made with a stereoscopic microscope and a micrometer eyepiece. The larger specimens were measured with calipers.

Both standard lengths (in small specimens from the tip of the snout to tip of the urostyle) and total lengths (in small specimens from the tip of the snout to tip of the finfold or caudal fin) were determined. For discussions of body proportions only standard lengths were used. In other discussions, larvae less than 7.0 mm. standard length are referred to in total lengths, and those 7.0 mm. and larger in standard lengths (figs. 3 through 16 follow this procedure).

Original measurements were used to construct the curves portraying rates of growth of various body parts, and changes in certain body proportions.

I have followed the general approach used by Ahlstrom and Ball (1954) in presenting the larval development in that sequences of fin formation, body proportions, and pigmentation are discussed. Egg development and yolk-sac larvae are presented separately.

DEVELOPMENT OF THE EGG

The pelagic eggs of the silver mullet are spherical in shape and contain single, large oil globules. In unfertilized eggs (fig. 2a) the yolk appears as an unsegmented opaque mass with little, if any, perivitelline space. The oil globule is pale yellow and located at the top of the yolk mass. The surface of the eggshell has a finely scratched or etched appearance. A series of 10 unfertilized eggs ranged in diameter from 0.77 to 0.86 mm., with an average of 0.82 mm.; and the diameter of the oil globules ranged from 0.27 to 0.32 mm., with an average of 0.30 mm.

Two hours after fertilization (fig. 2b) the eggs had reached the 32-blastomere stage and had developed a perivitelline space ranging from 0.04 to 0.12 mm. wide. A series of 10 eggs at this stage ranged in diameter from 0.86 to 0.92 mm., with an average of 0.90 mm.; and had oil globules with diameters ranging from 0.27 to 0.32 mm. and averaging 0.30 mm. The small increase in average diameter of the egg appears to result from absorption of water with an accompanying expansion of the eggshell and development of the perivitelline space. From this stage of development until hatching the diameters of the eggs and oil globules maintain about the same range of sizes and averages. The perivitelline space and yolk mass vary as the embryo develops and some of the yolk material is used up (fig. 2, c to i).

Four hours after fertilization (fig. 2c) the blastodisc was well formed and berrylike in appearance. The segmentation cavity was present 8 hours after fertilization (fig. 2d), and the embryonic shield was well advanced in 12 hours (fig. 2e).

The embryo was well differentiated 16 hours after fertilization (fig. 2f). The optical vesicles are well defined, eight somites are visible, and the blastopore is closed. The tail has not begun to separate from the yolk, which at this stage has a granular appearance. Irregular lines of pigment spots are present on the dorsal surface of the embryo, one on each side of the notochord, extending from just behind the head onto the tail section.

At 24 hours after fertilization (fig. 2, g, h) pupils have developed in the large eyes, 24 myomeres are discernible, and the tail has started to separate from the yolk mass which remains granular in appearance. Melanophores in the rows of pigment spots on the dorsal surface of the embryo (one row each side of center line) are now more closely set and extend from just back of the eyes to that portion of the tail which is free from the yolk mass. A few scattered melanophores appear on the sides of the embryo.

After 32 hours (fig. 2i) the embryo has a well-developed finfold and the tail free for about one-third the length of the body. In addition to the dorsal rows of pigment spots, melanophores are present on the ventral aspect of the embryo and are more numerous on the sides of the body.

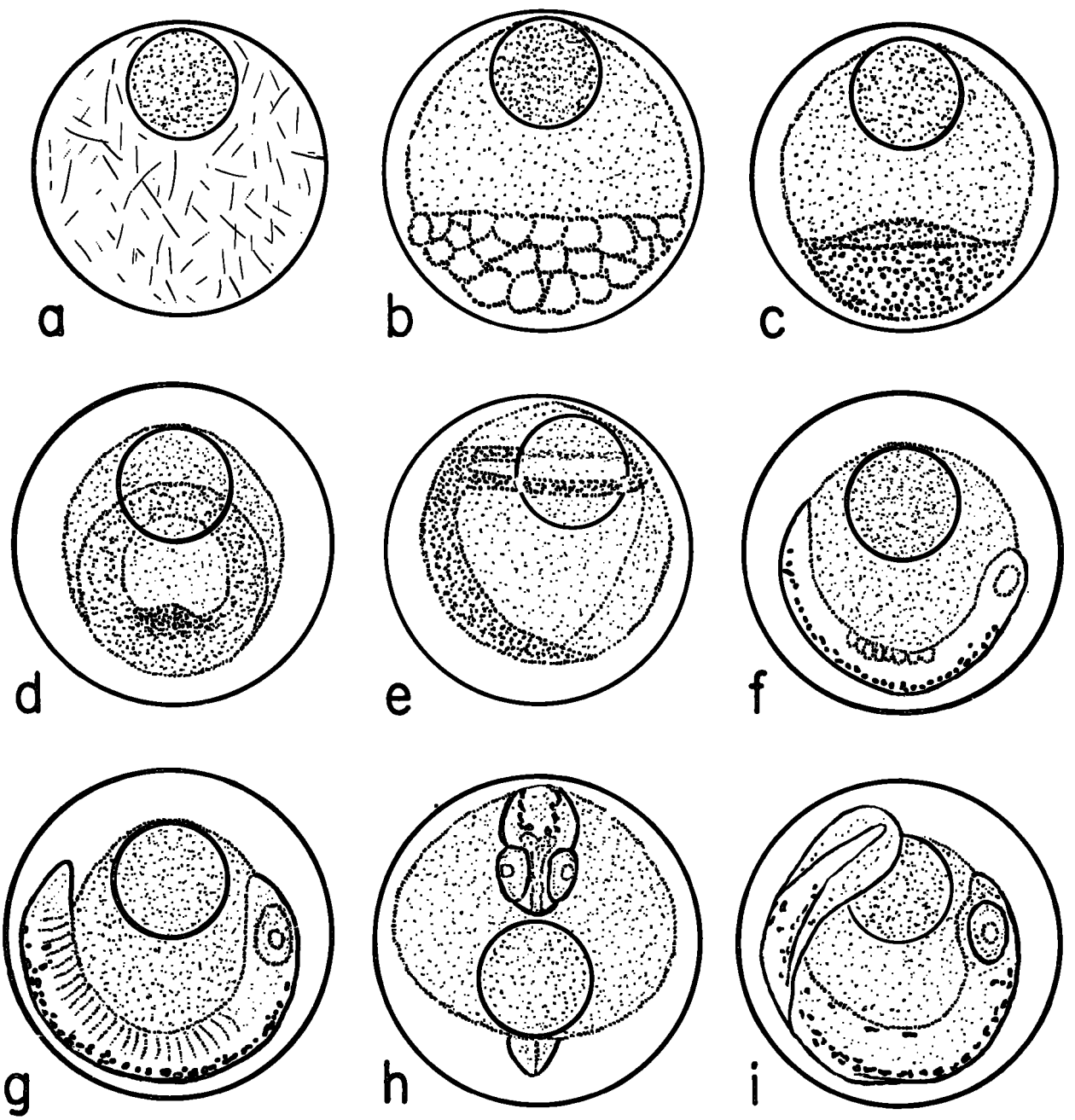

FIGURE 2.—Various stages of development of silver mullet eggs: a, unfertilized eggs; b, 2 hours after fertilization (32 blastomeres); c, 4 hours after fertilization (blastodisc well formed, cells small); d, 8 hours after fertilization (segmentation cavity forming); e, 12 hours after fertilization (early embryo); f, 16 hours after fertilization (embryo); g, 24 hours after fertilization (lateral view of embryo); h, 24 hours after fertilization (top view of embryo); i, 32 hours after fertilization (lateral view of embryo).

YOLK-SAC LARVAE

Hatching began 40 hours after fertilization, and no increase in number of larvae was evident after 42 hours. The larvae floated at the surface, and movement consisted largely of occasional jerking actions. Only 3 newly hatched larvae were preserved, and these had a size range of 1.63 to 1.76 mm. total length, and an average of 1.69 mm.

The larvae hatch in an undeveloped state, lacking a mouth and fins, and without pigment in the eyes (fig. 3). The large oil globule is located, in a large part, in the posterior half of the yolk sac. Pigmentation consists of ventral rows of pigment spots, in addition to the dorsal rows, and a few scattered melanophores on the sides of the body and head.

Four hours after hatching (fig. 4) the body had lengthened (11 specimens ranged in total length from 1.74 to 2.15 mm., an average of 1.89 mm.) and there was considerable shrinking of the yolk mass; the finfold was more developed and beginning to constrict in the caudal region. Pigmentation remained essentially the same. At 16 hours (fig. 5) there was a further increase in length (7 specimens ranged in total length from 2.30 to 2.47 mm., an average of 2.36 mm.), the yolk mass was much reduced, the finfold had reached its maximum development, and no basic change in pigmentation had occured.

The larvae were dying rapidly after 32 hours, and it was apparent none would survive much longer. Consequently 6 of the more active ones were preserved at this stage (ranging in total length from 2.49 to 2.68 mm. and averaging 2.56 mm.). Other than this increase in length, a smaller yolk mass, and minute pectoral fin buds; these larvae were similar to those at 16 hours after hatching, and are not figured.

All larvae were dead 45 hours after hatching, and the last to die appeared to have been infected by fungus. For this reason I have not considered specimens older than 32 hours. The developmental series is continued with material from plankton tows.

Two specimens from the plankton material, both 2.56 mm. total length and from the same tow, indicate that the yolk-sac larva begins a rapid transition at about 2.5 mm. total length. In the least developed of the specimens (fig. 6), the larval hump has disappeared and small pectoral buds are evident. The oil globule has shrunk, but remains comparatively large, and the yolk mass has decreased. The mouth is not differentiated, and the eyes have no pigment. Body pigmentation remains essentially the same, irregular dorsal and ventral rows of pigment spots with a few scattered melanophores on body and head. The finfold is more constricted in the caudal region. The second 2.56-mm. specimen (fig. 7) has a distinct head, and the mouth has developed. The eyes are pigmented, and the pectoral fin has enlarged into a fleshy-based, fan-shaped fin

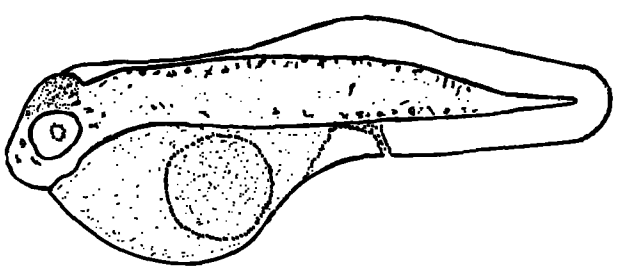

FIGURE 3.—Newly hatched larva, 1.76 mm.

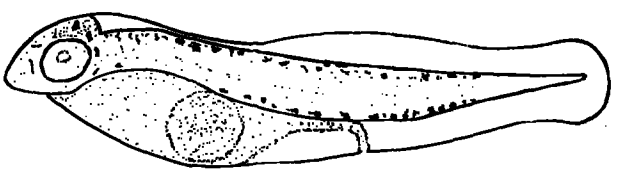

FIGURE 4.—Yolk-sac larva, 2.15 mm.

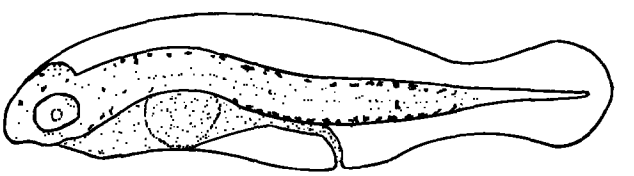

FIGURE 5.—Yolk-sac larva, 2.47 mm.

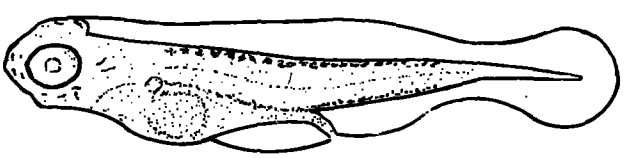

FIGURE 6.—Yolk-sac larva, 2.56 mm.

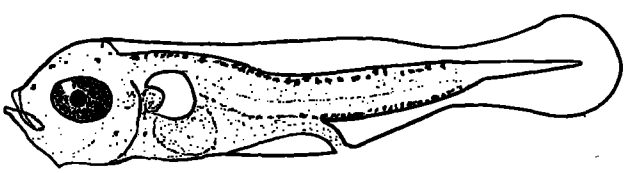

FIGURE 7.—Yolk-sac larva, 2.56 mm.

423182 O—57——2

without rays. The oil globule is still visible, but the yolk mass has been largely absorbed. Pigmentation is basically unchanged. Thickening of the head and of the body anterior of the anus is very noticeable. I believe the yolk-sac stage ends at about this period of development.

DEVELOPMENT FROM LARVAL TO JUVENILE STAGES

Development from about 3.5 to 110 mm. is included as larval, early juvenile, and juvenile. A developmental series is illustrated in figures 8 to 16. Each set of characters will be discussed separately and development briefly outlined.

DEVELOPMENT OF FINS

Caudal.—A fully developed caudal fin has 14 principal rays (of which 12 are branched) and 14 to 17 secondary rays. For details of caudal skeleton of *M. curema*, see Hollister 1937.

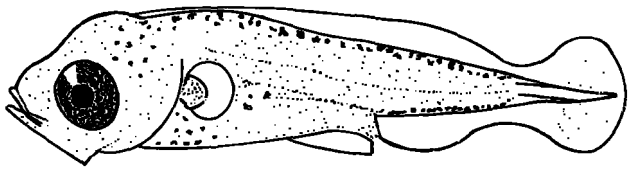

FIGURE 8.—Larva, 3.7 mm

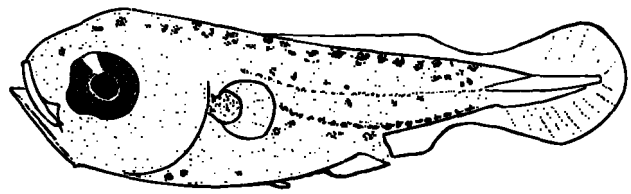

FIGURE 9.—Larva, 4.0 mm.

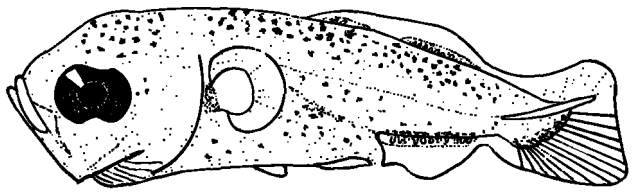

FIGURE 10.—Larva, 4.7 mm.

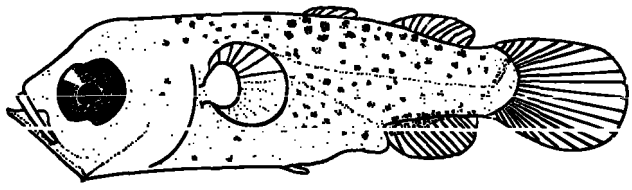

FIGURE 11.—Larva, 5.3 mm.

At about 3.7 mm. total length (fig. 8) there is no indication of development of the caudal fin other than a deeper constriction of the finfold in the caudal region. A thickening is evident on the ventral side of the urostyle at about 4.0 mm. total length, but no true rays have formed (fig. 9). At about 4.7 mm. total length (fig. 10), 14 rays have developed ventrally which will be the principal caudal rays, the urostyle has tipped upward, and the fin shape has changed. The caudal has developed a well-rounded form at about 5.3 mm. total length (fig. 11), the urostyle has reached its maximum flexing, and about 23 rays are visible. The fin is much broadened at about 7.0 mm. standard length (fig. 12), and 25 or 26 rays are present. A full complement of rays (14 principal and 15 secondary) is visible at about 14.5 mm. (fig. 13), although none of the principal rays are branched; and the fin has begun to fork. Branching of the 12 principal rays (2 principal rays do not branch) has occured by 25 mm. standard length, and forking seems complete by 110 mm. (figs. 14, 15, and 16).

Dorsals.—When fully developed the first dorsal has 4 spines, and the second dorsal has 1 spine and 8 branched rays.

The dorsal bases are first evident and developing rays visible in both fins when the larvae are about 4.7 mm. total length (fig. 10). The 4 spines of the first dorsal and the 1 spine and 8 soft rays of the second dorsal are quite evident at about 5.3 mm. total length (fig. 11). The last ray of the second dorsal is branched by 14.5 mm. standard length, 7 of the 8 soft rays are branched by 25 mm., and all are branched by 50 mm. Final fin shape is reached when the juveniles are between 50 and 110 mm. long (figs. 13, 14, 15, and 16).

Anal.—The fully developed anal fin has 3 spines and 9 branched soft rays.

Developing rays and the anal base are first evident in larvae about 4.7 mm. total length (fig. 10). The full complement of rays (12) is present in larvae about 5.3 mm. total length (fig. 11). The two spines are discernible and the last ray has branched by a larvae size of about 14.5 mm. (fig. 13). (Young silver mullet have 2 spines and 10 soft rays, rarely II, 9: the third spine develops from the first ray which starts as a segmented ray and fuses into a spine when the fish is

about 30 to 40 mm. long, and I consider the larval period to end at this time.) The last 9 rays are branched in specimens about 25 mm. long (fig. 14). Final fin shape is reached in juveniles between 50 and 110 mm. long (figs. 15 and 16).

Pectorals.—The pectoral fin buds are first evident in yolk-sac larvae about 2.5 mm. total length, but the first rays do not develop until the larvae are about 5.3 mm. total length, when about 5 or 6 rays are present in the upper part of the fin. The number of rays increases to about 10 by a larval size of 7.0 mm. standard length, and the full complement (15 to 17) is reached by a larval size of 14.5 mm. Ray development and changes in fin shape at various larval and juvenile sizes are demonstrated in figures 6 to 16.

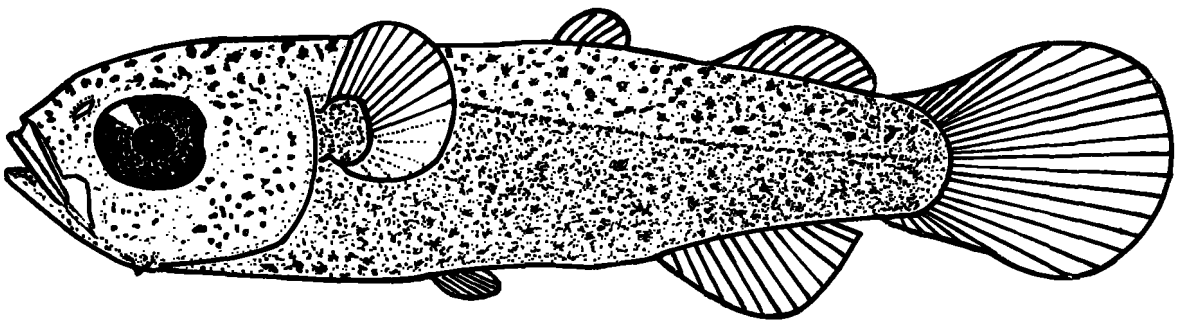

FIGURE 12.—Larva, 7.0 mm.

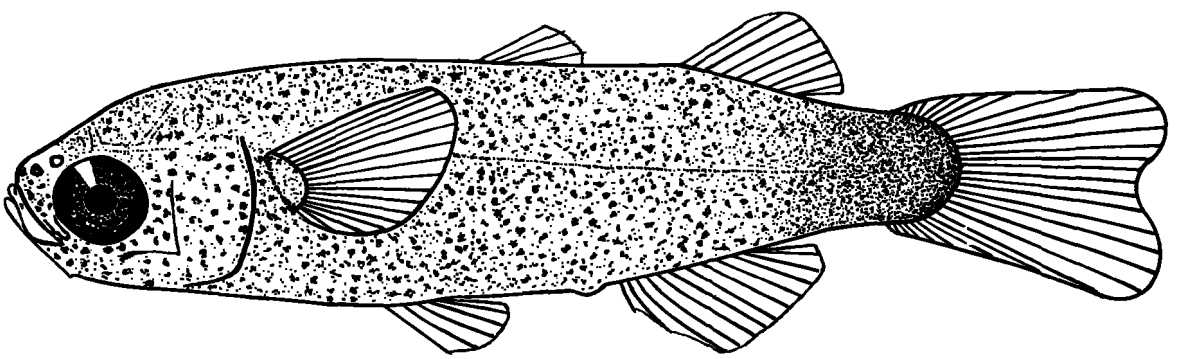

FIGURE 13.—Larva, 14.5 mm.

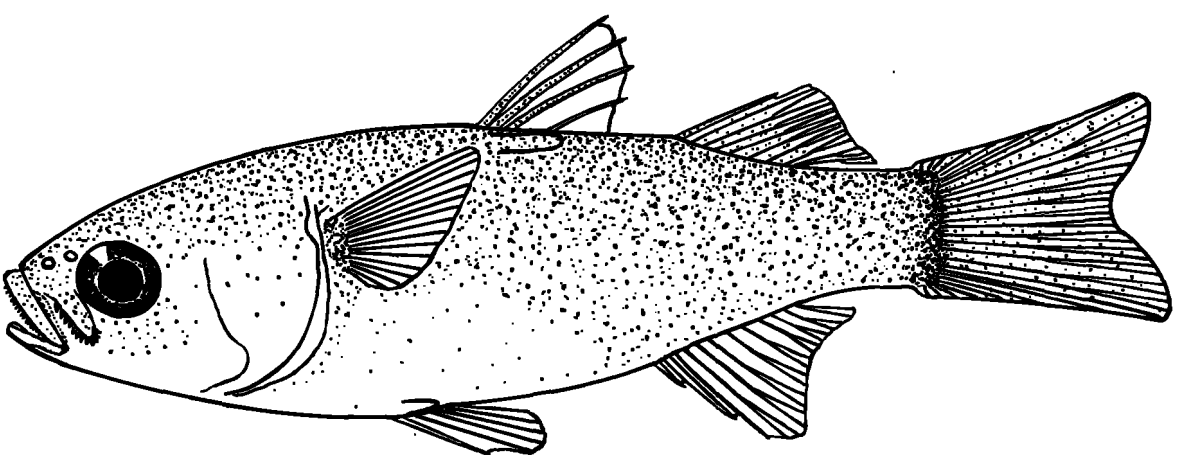

FIGURE 14.—Larva, 25.5 mm.

Ventrals.—The ventral fin buds are first evident at a larval size of about 4.0 mm. total length. Rays are visible by 7.0 mm. standard length, and 1 spine and 5 rays are present by a larval size of 14.5 mm. (figs. 9 to 13).

BODY PROPORTIONS

As occurs in many fish, the greatest changes in body proportions of the silver mullet take place between hatching and a length of 4 to 5 mm.

The head length, eye diameter, and body depth (at pectoral) all increase at a rapid rate during the initial period; slow down when the larvae are between about 5 and 25 mm. long; and stabilize at a constant rate from 25 mm. to adult size. These relations are demonstrated in figures 17, 18, and 19. The slight upward shifts in the regression lines for head length and body depth (at pectoral), which occur in fish about 25 to 30 mm. long, take place at the time the young mullet leave the open ocean and move to beach and estuarine habitats. I believe that a greater abundance of food available on these inshore nursery grounds results in an initial rapid growth reflected in these body parts. Young mullet, between 20 and 25 mm. long, from the open ocean appear thin and never seem to have full bellies, whereas young mullet taken from the estuarine areas usually have stomachs somewhat distended.

The distances from snout to insertion of first dorsal fin, snout to insertion of second dorsal fin, and snout to insertion of anal fin increase at a remarkably uniform rate from a larval size of 3–4 mm. to adults. These relations are given in figures 20 and 21.

Jacot (1920, p. 223) said that the development of *M. curema* was much as in *M. cephalus* but without a definite silvery stage and with a constant rate of development of the various parts and of the individual. However, Jacot's smallest specimens were 20 mm. long, and he gives no other measurements.

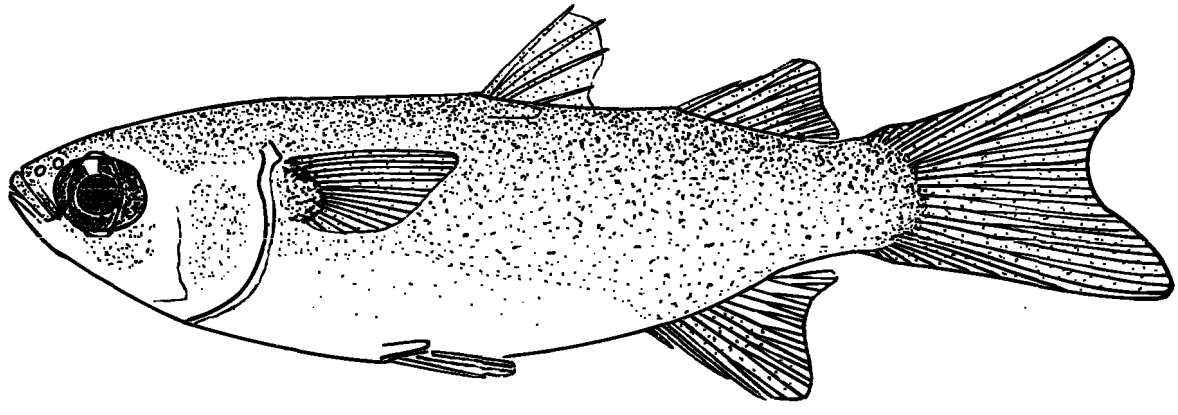

FIGURE 15.—Juvenile, 50.0 mm.

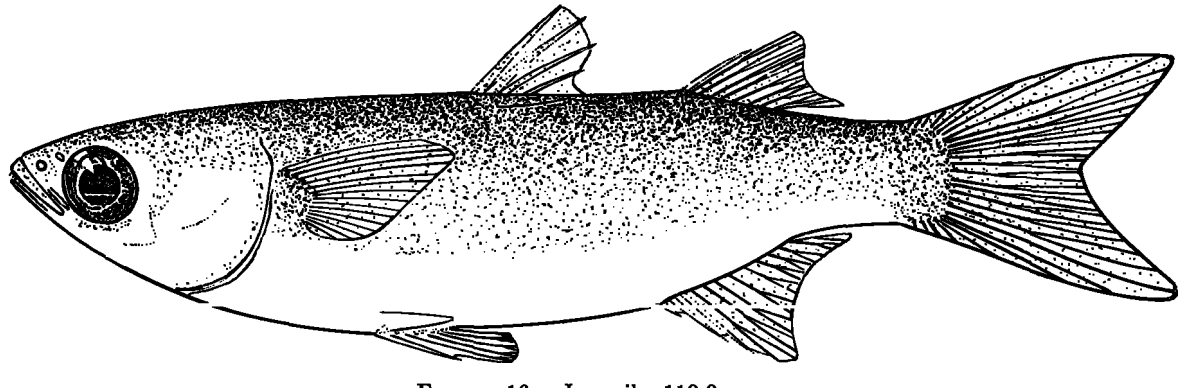

FIGURE 16.—Juvenile, 110.0 mm.

PIGMENTATION

Pigmentation of the embryo and of the larvae through the yolk-sac stage has been described and illustrated. At about 3.7 mm. total length, the pigmentation continues to consist essentially of pigment spots along the dorsal and ventral aspects, with scattered melanophores on the head, sides of body, and throat (fig. 8). Development of pigmentation from this stage is a process of intensification and spreading onto the head and sides of the body, so that by a larval size of about 14.5 mm. the specimens are so densely covered by large and small pigment spots as to appear almost black (this is especially intense on the caudal peduncle). No pigment is present on any of the fins during this period. The development of

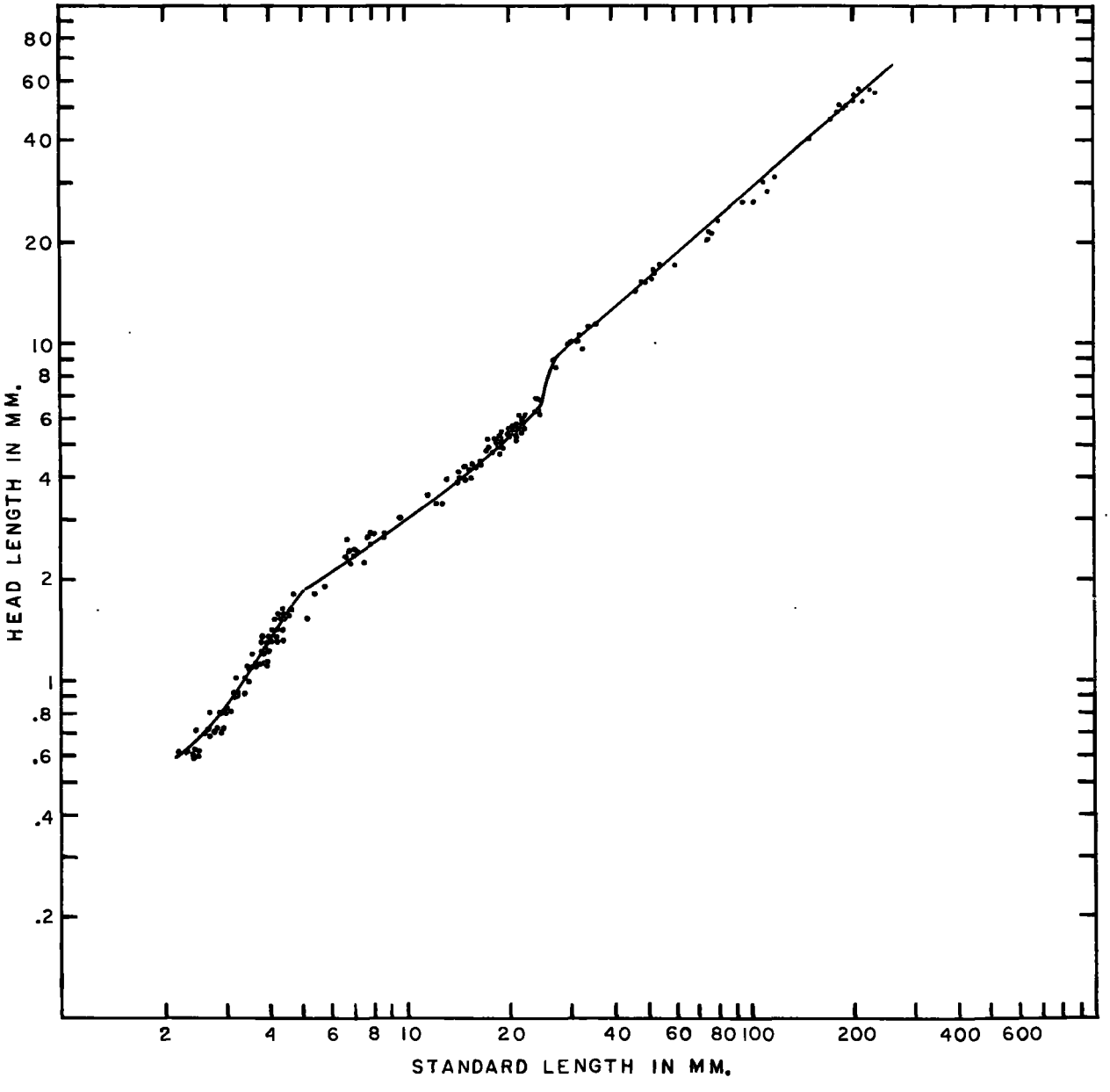

FIGURE 17.—Relation of head length to standard length.[1]

[1] Specimens below 25 mm. long are plankton and dip-net material from open ocean; those 27 to 122 mm. are seine material from marsh and beach areas and those 151 mm. and larger are the specimens from the spawning school.

pigmentation between larvae lengths of 3.7 and 14.5 mm. is illustrated in figures 8 to 13.

By the time young silver mullet have reached a length of 25 mm., the pigmentation has decreased in intensity. The specimens have a peppered appearance, with lighter pigmented areas appearing on the lower part of the head and belly, and a scattering of pigment spots on the dorsal and caudal fins (fig. 14). Juveniles at a length of about 50 mm. have so few pigment spots on the belly that it is beginning to appear white, and pigment is present on the anal fin (fig. 15). Juveniles 110 mm. long are heavily pigmented on the dorsal surface of the body to about the midline, where the intensity of color decreases rapidly so that the lower third of the body from head to caudal fin is silvery or white; head pigmentation is largely on the dorsal surface, but patches of

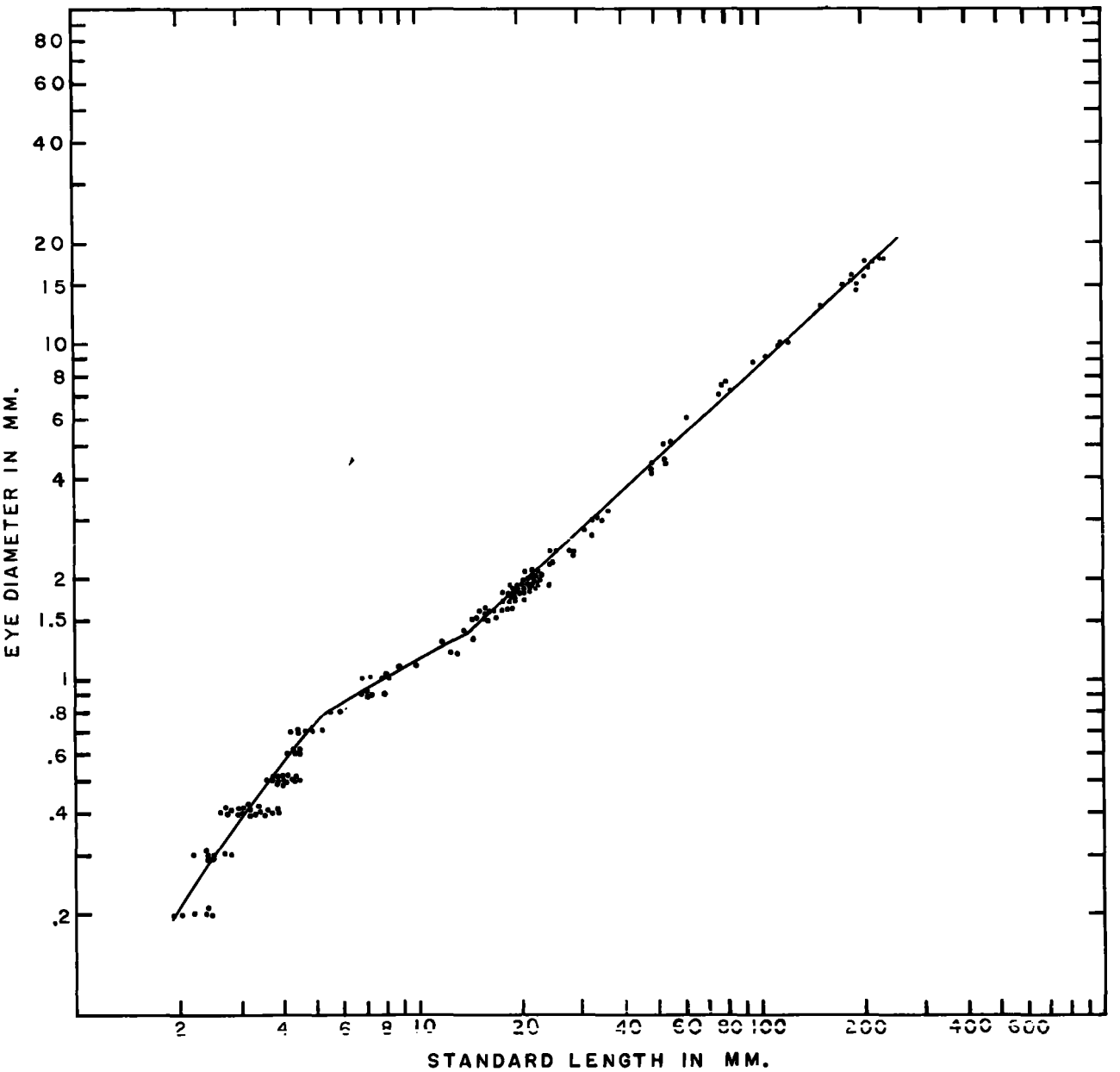

FIGURE 18.—Relation of eye diameter to standard length.[2]

[2] See footnote 1, p. 405.

pigment are present under the eyes and on the opercles; and all of the fins have pigmentation (fig. 16). At this size both freshly caught and preserved specimens appear blue-black on the dorsal surface grading to silvery white bellies.

Jacot (1920) observed that *M. curema* does not go through a definite silvery stage such as occurs in *M. cephalus*. (His smallest specimens were 20 mm.)

SCALES, PREORBITAL, AND TEETH

Scales.—A detailed account of scale development and characters in young of both *M. curema* and *M. cephalus* was given by Jacot (1920).

Preorbital.—The serrated or toothed preorbital bone (common to all Mugilidae) becomes visible when larvae are between 7 and 14 mm. long. There is wide variation in the number and size of the serrations.

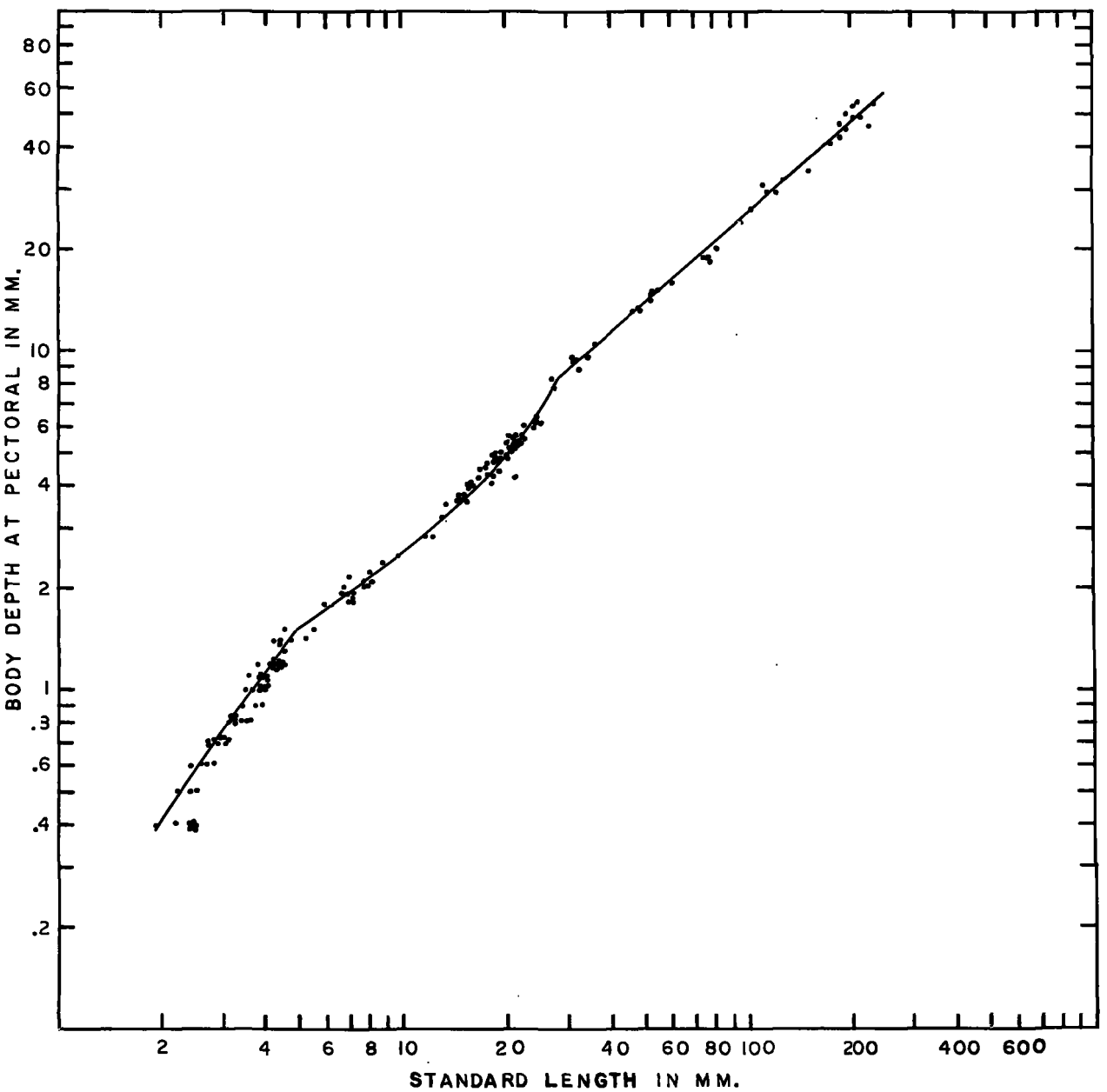

FIGURE 19.—Relation of body depth at pectoral to standard length.[3]

[3] See footnote 1, p. 405.

Teeth.—Schultz (1946, p. 389) states with regard to teeth in *Mugil*, "the teeth in the lower lip are setiform or ciliform, partly embedded or conspicuous; teeth in upper lip similar. The outer row of teeth in both lips is usually more prominent, with simple tips, and if inner rows occur these are either bifid or trifid, at least on adults (apparently the teeth in certain species of this genus become bifid or even trifid in large adults)." He further stated, "In this genus I find that in small specimens of certain species the teeth have simple tips, but later the inner teeth have bifid tips and in the largest adults some possess trifid tips. The teeth of the outer row usually have simple tips, but in some large specimens these are bifid too."

Teeth develop in young silver mullet at about

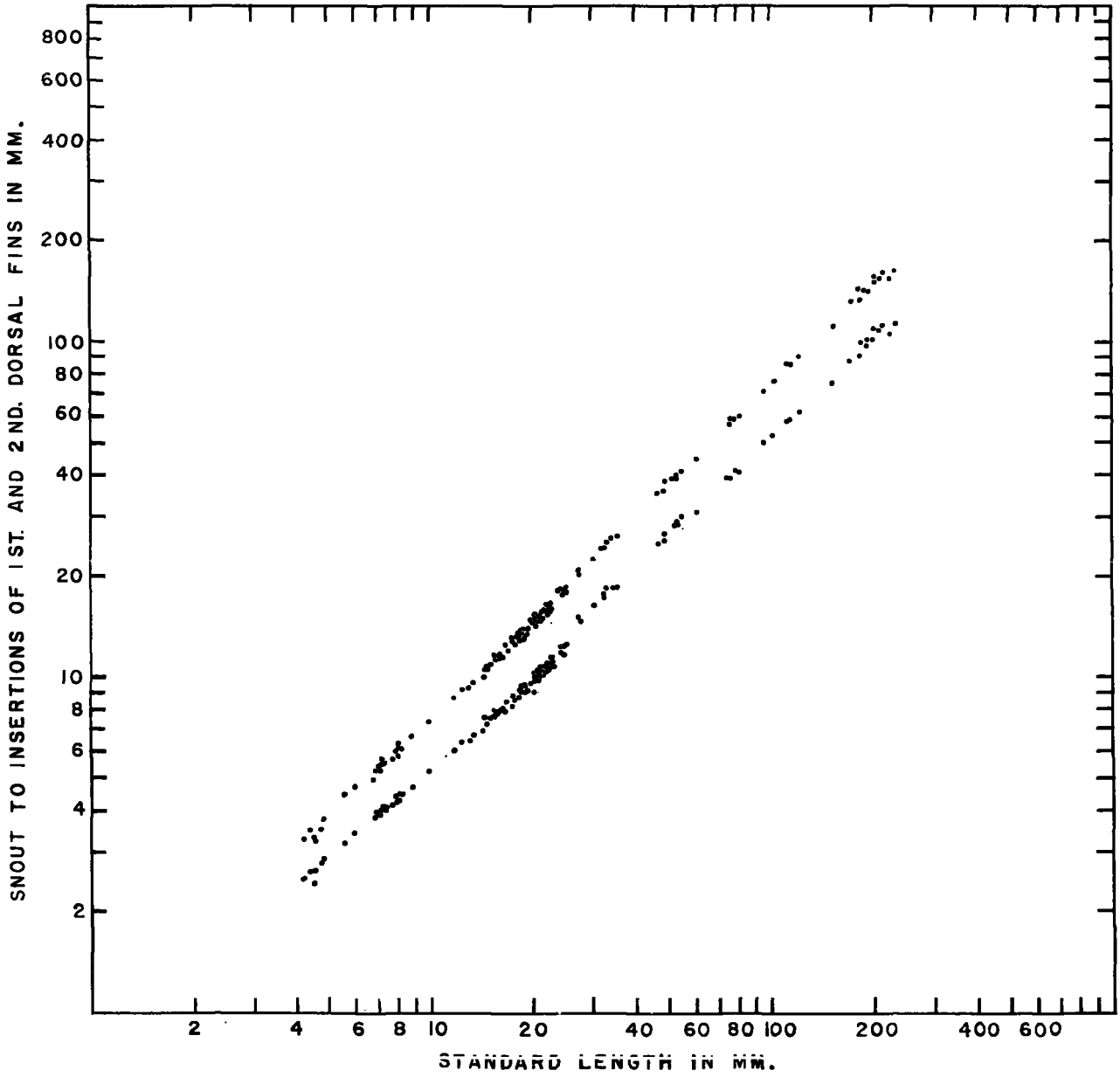

FIGURE 20.—Relation of the distances from snout to insertions of first (lower line) and second (upper line) dorsal fins to standard length.[4]

[4] See footnote 1, p. 405.

20 mm. standard length. In stained material of this size the teeth of the upper lip are in a single series, have simple tips, and number about 12 to 15 on each half of the lip (about half protrude from the fleshy lip). There are no teeth in the lower jaw. At about 30 mm. the teeth in the single row in the upper lip are larger, number about 30 to 35 in each half of the lip, all protrude from the lip, and have simple tips that curve inward. The lower lip has a single row of simple-tipped teeth which are smaller than those of the upper lip. These point straight outward from the thin lip edge, number about 30 on each half of the lip, but barely protrude beyond the lip edge.

In specimens about 50 mm. long the simple-tipped teeth in the single row in the upper lip number about 30 on each half of the lip, but now appear to have flattened tips which are bent

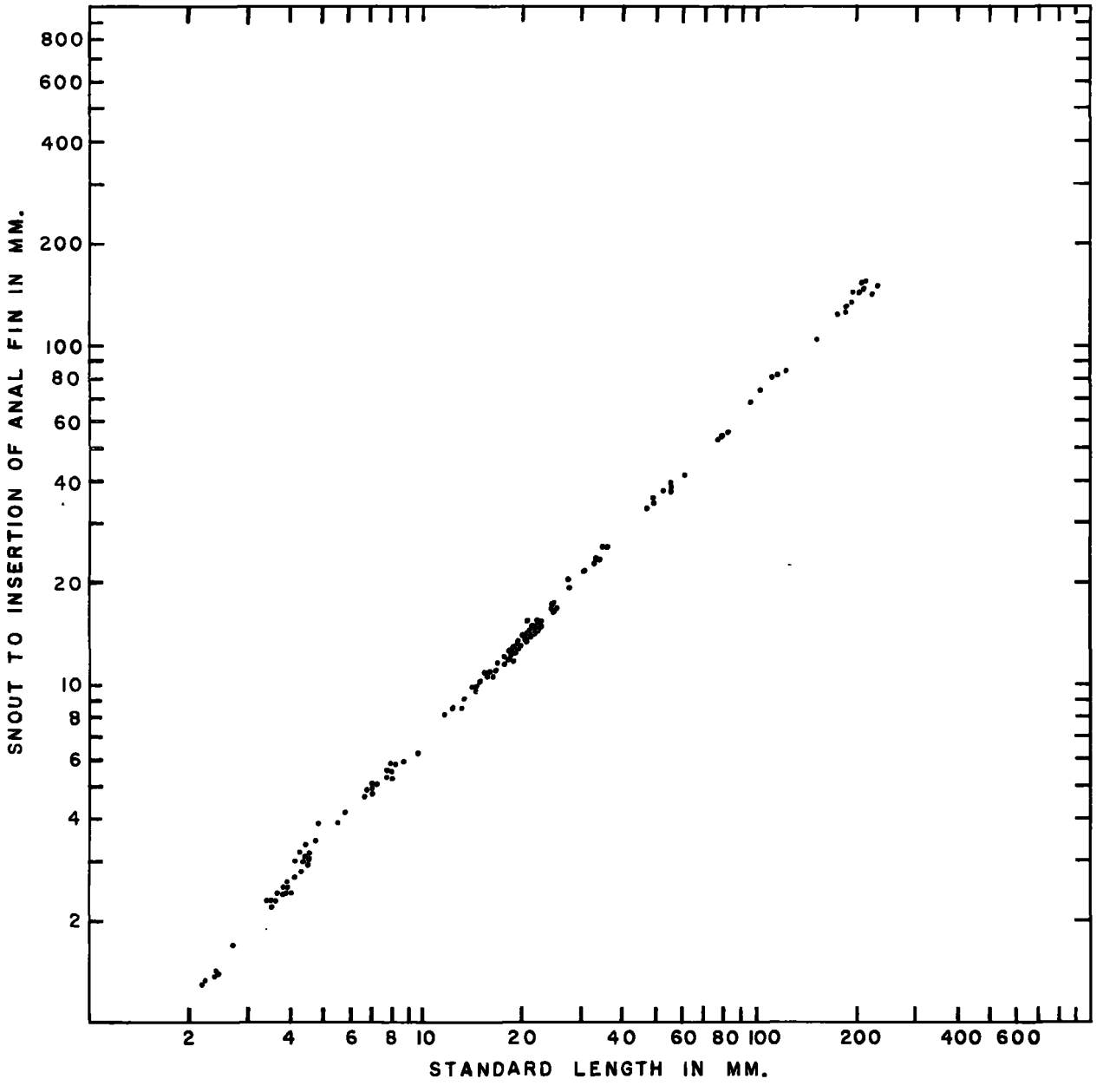

FIGURE 21.—Relation of distance from snout to insertion of anal fin to standard length.[5]

[5] See footnote 1, p. 405.

sharply inward (having a resemblance to a leaf rake). The simple-tipped teeth in the single row of the lower lip are close set, number about 50 in each half of the lip, but still barely protrude from the thin-edged lip.

At about 100 mm. length there are two rows of teeth in the upper lip. The larger teeth in the outer row number about 50 to 55 on each side and have simple tips which are somewhat flattened and incurved. The teeth of the inner row are much smaller than those of the outer row, have simple tips, and number about 30 in each half of the lip. The simple-tipped teeth in the single row in the lower lip are very close set, number about 75 to 80 in each half of the lip, point forward from the thin-edged lip, but do not protrude much beyond the margin of the lip.

GROWTH

Although the sampling program was not planned specifically for this study, growth of mullet may be estimated for Georgia from material from the seine collections. Three growth lines are indicated in figure 22. The first is in reference to the earliest spawned group which appears first on Georgia beaches late in April (earliest record is April 22). Assuming that from 3 to 4 weeks were required for larvae to reach a standard length of 17 to 24 mm., I relate the April recruits to spawning in late March or early April. From April to October the growth can be followed from the upper limits of the size ranges (after October larger juveniles appear to move out of the area). This growth, computed from time of hatching, apparently progresses at a rate of about 17 mm. per month, so that juvenile fish about 120 mm. long late in October would have been spawned about April 1 and are about 7 months old.

Hildebrand and Schroeder (1928, p. 197) state that *M. curema* in southern waters has an average length of about 10 inches (250 mm.) and a maximum length of about 14 inches (350 mm.). As the mature individuals taken from the spawning school off the Florida coast averaged 189 mm. for the males, 209 mm. for the females, and about 198 mm. for males and females combined, they apparently were relatively young fish. If we extend the growth line of about 17 mm. per month beyond October and to a size of 200 mm., it seems quite reasonable that silver mullet at the end of their first year reach a length around 200 mm., and may be maturing at that age.

The second growth line on figure 22 relates to a group of young from later spawning which is present in the beach and marsh areas in August (this represents the last major recruitment). Starting at 20-mm. length and applying the 17 mm. per month growth rate, this group could be expected to reach a size of about 105 mm. in December.

The third growth line relates to the latest spawned stragglers which are about 20 to 30 mm. long in October and reach a size of about 70 mm. by December (fig. 22).

The effects of winter water temperatures on growth of silver mullet in Georgia cannot be followed since the young appear in April when the water temperatures have warmed and apparently leave this coast when waters cool in late fall and early winter (table 5).

SPAWNING

Little has been published on the spawning habits of the silver mullet. Based on presence of the young (20 mm. and up) in estuarine waters of North Carolina, Jacot (1920, p. 226) suggested a rather protracted spawning period of mid-April to mid-August with a peak about May.

TABLE 1.—*Numbers of larvae of the silver mullet*, M. curema, *at various sizes taken in plankton tows on* Gill *cruises 2, 3, and 6*

Cruise No.	Station No.	Date	Position		Number of larvae		
			N. Lat.	W. Long.	2 to 5 mm.	5.1 to 7 mm.	7.1 to 10 mm.
2	3	Apr. 23, 1953	27° 01′	80° 04′	2		
2	14	Apr. 25, 1953	29° 01′	80° 08′	1		
2	19	Apr. 26, 1953	29° 39′	80° 23′	5		
2	25	Apr. 26, 1953	30° 20′	80° 35′	4		
2	26	Apr. 27, 1953	30° 20′	80° 12′	15		
2	31	Apr. 27, 1953	31° 00′	79° 59′	2		
2	42	May 5, 1953	31° 57′	79° 18′	5		
2	43	May 6, 1953	32° 12′	79° 33′	8		
2	48	May 6, 1953	32° 23′	78° 43′	1		
2	49	May 6, 1953	32° 12′	78° 25′	3		1
2	54	May 7, 1953	33° 03′	78° 21′	7	1	
2	59	May 8, 1953	33° 22′	77° 37′			1
2	61	May 8, 1953	32° 53′	77° 04′	3	1	
2	63	May 8, 1953	33° 15′	76° 23′	1		
2	65	May 9, 1953	33° 42′	76° 55′	11		
2	75	May 10, 1953	34° 39′	75° 53′	2		
3	8	July 26, 1953	28° 18′	79° 26′		1	
6	3	Apr. 25, 1954	27° 00′	80° 03′	1		
6	14	Apr. 27, 1954	29° 00′	80° 10′	1		

At *Gill* regular station 4 off the southern Florida coast near the 20-fathom line (fig. 1), between the hours of 2200 and 2315 on April 25, 1954, thou-

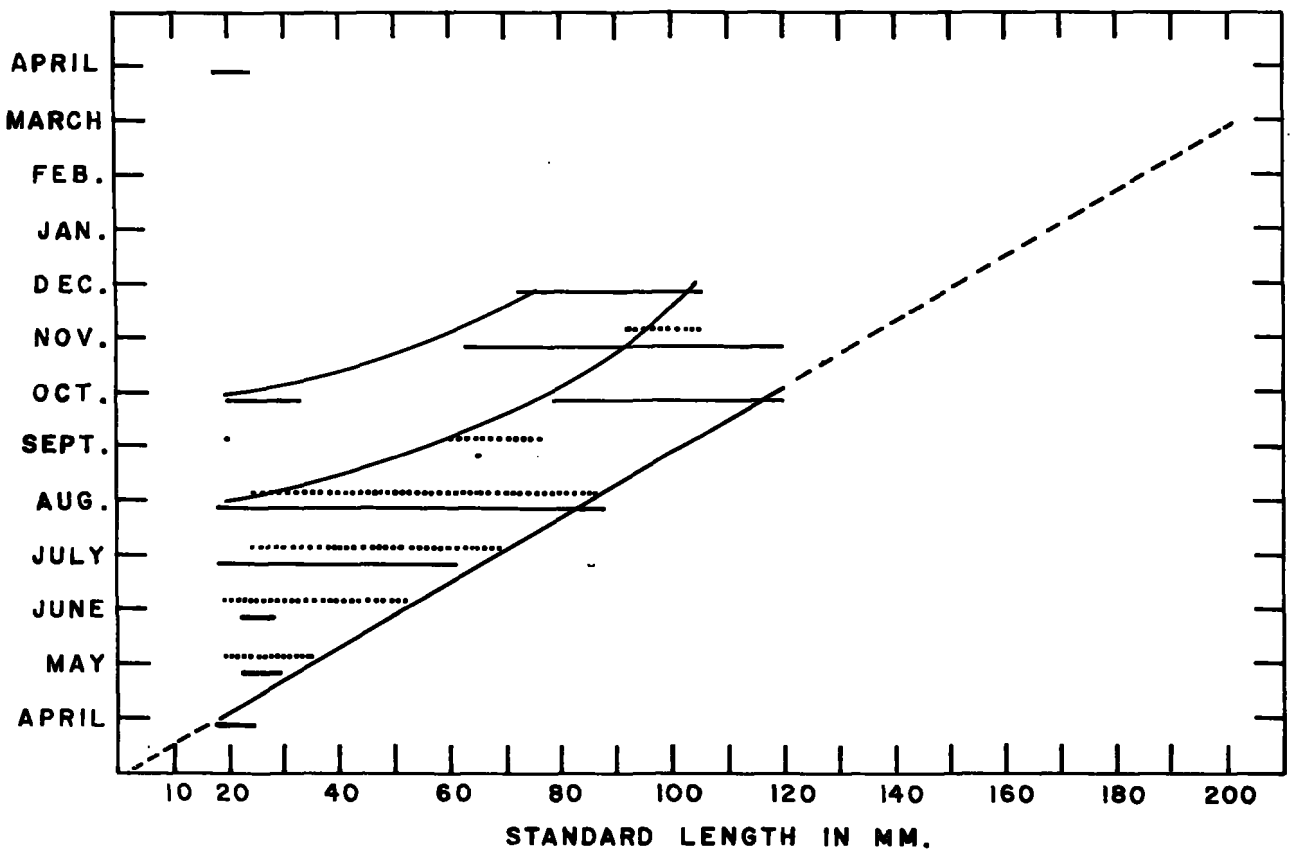

FIGURE 22.—Monthly size ranges of young silver mullet, *M. curema*, taken from two seine locations in Georgia (horizontal solid line is St. Simons Beach, and horizontal dotted line is Sapelo Marsh). Data of March 1953 to January 1956: the size ranges represent the smallest to the largest specimens taken during any given month in this period. When only a few isolated specimens are involved they are indicated by a single black dot (see table 3 for occurrence data). Three growth lines are indicated; the first (lower) relates to young, starting at about 20 mm. length, in April; the second (middle) relates to young, starting at about 20 mm. length, in August; and the third (upper) relates to young, starting at about 20 mm. length, in October.

TABLE 2.—*Numbers of larvae of the silver mullet,* M. curema, *at various sizes taken by dip netting on* Gill *cruises 1 through 9 (none were caught on cruises 1, 5, and 9)*

Cruise No.	Station No.	Date	Position		Number of larvae				
			N. Lat.	W. Long.	6 to 10 mm.	10.1 to 15 mm.	15.1 to 20 mm.	20.1 to 25 mm.	Over 25 mm.
2	Spc. 5	Apr. 17, 1953	30° 00′	77° 00′				1	
2	Std. Sta	Apr. 19, 1953	28° 19′	76° 44′				1	
2	3	Apr. 23, 1953	27° 01′	80° 04′		1	2	1	
2	13	Apr. 24, 1953	29° 00′	80° 33′				1	
2	20 to 21	Apr. 26, 1953	29° 40′	80° 57′				1	
2	25	Apr. 26, 1953	30° 20′	80° 35′		1	3		
2	31	Apr. 27, 1953	31° 00′	79° 59′			1		
2	35	May 4, 1953	31° 21′	80° 55′				1	
2	37	May 5, 1953	31° 38′	80° 14′		1		1	
2	54	May 7, 1953	33° 03′	78° 21′	2				
2	61	May 8, 1953	32° 53′	77° 04′	7				
2	Cape Hatteras	May 11, 1953	35° 13′	75° 32′			9	5	
3	Std. Sta	July 23, 1953	26° 21′	76° 46′					1
3	3	July 25, 1953	27° 00′	80° 03′		1	3		
3	25	July 28, 1953	30° 20′	80° 35′			1		
3	26	July 29, 1953	30° 18′	80° 12′		1	2		
3	69	Aug. 11, 1953	34° 32′	76° 49′				11	
3	70	Aug. 12, 1953	34° 18′	76° 32′				1	
4	7	Oct. 13, 1953	27° 40′	79° 18′		1			
4	8	Oct. 13, 1953	28° 18′	79° 26′	1				
4	15	Oct. 14, 1953	29° 00′	79° 48′	1				
4	26	Oct. 15, 1953	30° 17′	80° 11′			1		
4	32	Oct. 16, 1953	31° 00′	80° 23′			1		
4	52	Oct. 26, 1953	32° 34′	77° 48′				2	
6	4	Apr. 25, 1954	27° 20′	80° 03′		1	1		
6	16	Apr. 27, 1954	29° 00′	79° 26′				1	
7	17	Jun. 25, 1954	29° 38′	79° 36′	1				
8	8	Sept. 12, 1954	28° 17′	79° 28′		1			
8	18	Sept. 13, 1954	29° 40′	80° 00′	1				

sands of mullet were around the vessel. On occasions paired fish were observed swimming side by side, but in general there was just a dense mass of fish milling and splashing at the surface. These fish were very difficult to catch with a dip net, but 12 specimens were captured (6 males and 6 females), which proved to be silver mullet, *Mugil curema*. Standard lengths of the males were 151, 176, 186, 189, 203, and 228 mm.; and of the females, 194, 195, 202, 210, 217, and 234 mm. All of the females were running eggs, and all the males were running milt; in fact the specimens could not be handled without eggs or milt streaming from them. This was a spawning school.

Plankton tows were taken February 16 to March 7, 1953, during cruise 1; and April 22 to May 14, 1953, cruise 2; July 16 to August 12, 1953, cruise 3; October 7 to November 12, 1953, cruise 4; January 21 to February 23, 1954, cruise 5; also, April 15 to April 28, 1954, cruise 6, a partial cruise. Collections were examined and yielded silver mullet larvae as shown in table 1 (no larvae were taken on cruises 1, 4, and 5); specimens were largely early stage larvae under 5 mm. long. Locations of capture are illustrated in figure 1.

All silver mullet material taken by dip netting on *Gill* cruises 1 through 9 is shown in table 2, and locations of capture are illustrated on figure 1. These specimens ranged from about 6 to 25 mm. in length.

TABLE 3.—*Occurrence of young silver mullet* (M. curema) *in seine collections of two areas in Georgia*

[Arranged to show dates and approximate abundance; size ranges illustrated in figure 22]

Date	Sapelo Marsh	Date	St. Simons Beach
	Number		*Number*
May 6, 1953	11	Apr. 22, 1953	9.
May 9, 1955	Many	Apr. 25, 1955	1.
May 18, 1954	Many	May 4, 1954	4.
May 20, 1953	Many	May 18, 1954	3.
May 24, 1955	Many	May 24, 1955	Many.
June 3, 1954	Many	June 3, 1953	1.
June 4, 1953	Many	June 9, 1955	20.
June 9, 1955	7	July 3, 1953	1.
June 17, 1954	Many	July 21, 1953	3.
June 18, 1953	Many	July 21, 1954	7.
June 22, 1955	Many	Aug. 5, 1955	4.
July 3, 1953	14	Aug. 11, 1953	2.
July 6, 1954	15	Aug. 19, 1955	1.
July 8, 1955	22	Aug. 26, 1953	6.
July 21, 1953	2	Sept. 9, 1953	1.
July 21, 1954	23	Oct. 5, 1955	15.
July 22, 1955	12	Oct. 14, 1955	1.
Aug. 5, 1955	18	Oct. 29, 1954	1.
Aug. 6 1954	1	Nov. 3, 1955	41.
Aug. 19, 1954	4	Nov. 16, 1955	Many.
Aug. 19, 1955	8	Dec. 2, 1955	2.
Aug. 26, 1953	1	Dec. 19, 1955	3.
Sept. 6, 1955	3		
Sept. 9, 1953	3		
Nov. 3, 1955	3		
Nov. 16, 1955	2		

From lower Florida to North Carolina, early-stage larvae (2 to 5 mm.) were captured near the 20-fathom line and offshore to about the axis of the Gulf Stream, with the location of capture most frequently between the 20- and 100-fathom

lines on the outer Continental Shelf; none were taken on the inner Continental Shelf (fig. 1). These facts, together with the location of a spawning school of mullet near the 20-fathom curve off the lower Florida coast, are strong evidence that the spawning of the silver mullet occurs at sea over the outer Continental Shelf from Florida to North Carolina.

That the spawning season for silver mullet extends from late March or early April until September with peak spawning during April, May, and June is evident from several types of data: (1) No larvae were found in plankton tows from February 16 to March 7, 1953 (cruise 1); early stage larvae were taken in plankton tows from April 22 to May 14, 1953 (cruise 2); and one larva was found in plankton tows from July 16 to August 12, 1953 (cruise 3); (2) young silver mullet 20 to 25 mm. long were dip netted as early as April 17 off the lower Florida coast, and a very few under 10 mm. in length were dip netted as late as October (table 2); (3) the earliest date young silver mullet were taken along Georgia beaches by seine was April 22 (these ranged in length from 17 to 24 mm.); and some specimens from 20 to 30 mm. long were taken in October, although scarce after August (fig. 22 and table 3). Assuming a minimum of 3 weeks and a maximum of 4 weeks for the larvae to reach a size of about 20 mm. after hatching, the extreme dates of spawning I have suggested are reasonable. Peak spawning of April to June is evident from numbers of young dip netted and seined during periods that would yield young from spawning during these 3 months (tables 2 and 3, and fig. 22).

Spawning of the silver mullet begins with the rise of water temperatures in early spring. In table 4 we see that during late February and early March the surface temperatures over the Continental Shelf in general averaged under 20° C., but exceeded 20° C. during April and May. Perhaps rising temperatures stimulated spawning activity and are more important than absolute temperatures, since spawning continues into summer when water temperatures are much warmer.

TABLE 4.—*Average surface water temperatures (° C.) and salinities (°/₀₀) for the several sections of the area from Cape Hatteras, N. C., to the Florida Straits for* Gill *cruise 1 (Feb. 10 to Mar. 10, 1953), Gill cruise 2 (Apr. 16 to May 15, 1953), and Gill cruise 3 (July 15 to Aug. 16, 1953)*

[The southern section comprises that part of the area lying between Jupiter Inlet and Jacksonville, Fla.; the central section from Jacksonville, Fla. to the North Carolina-South Carolina boundary; and the northern section from this point north to Cape Hatteras. In general, the inner shelf comprises waters lying between the beach and about halfway from the shoreline to the 100-fathom line (mostly waters less than 10 fathoms deep); the outer shelf, the remaining area out to the 100-fathom line; and offshore, that part of the area from the 100-fathom line to beyond the axis of the Gulf Stream]

Season and locality	Northern		Central		Southern	
	° C.	°/₀₀	° C.	°/₀₀	° C.	°/₀₀
Winter—						
Inner shelf	13.6	34.5	14.1	34.5	19.4	36.2
Outer shelf	19.4	35.9	17.7	36.0	20.7	36.2
Offshore	23.0	36.3	22.8	36.2	24.4	36.2
Spring—						
Inner shelf	20.7	34.4	21.6	34.0	21.7	36.2
Outer shelf	21.7	35.4	22.4	35.6	23.5	36.3
Offshore	25.2	36.2	25.8	36.2	26.5	36.1
Summer—						
Inner shelf	27.7	35.5	28.4	35.1	27.5	35.9
Outer shelf	27.7	35.8	28.2	35.7	27.9	36.0
Offshore	28.3	35.9	29.0	35.9	29.0	35.9

MOVEMENTS AND HABITAT OF LARVAL AND JUVENILE FORMS

From data contained in tables 1, 2, and 3, information presented in figures 1 and 22, and discussions on development and spawning, several facts relating to movements and habitat of larval and juvenile mullet from hatching to a length of about 120 mm. are evident. The larvae spend the first several weeks of their lives in the open ocean as far out as the axis of the Gulf Stream. At a length of about 17 to 25 mm. these larvae move inshore (no silver mullet more than 25 mm. in standard length was taken by dip netting in offshore waters). In Georgia waters (about center of the South Atlantic coast of the United States) these young are taken first on the beaches late in April and then in the marshy estuarine areas in May. Recruitment of young from the ocean continues in volume until August, after which recruitment is erratic and small. The young live and grow in the rich estuarine habitat until October or November at which time they have reached lengths up to 120 mm. At this time the young mullet apparently move from the marshy estuarine areas to the outer beaches. By December they appear to depart from the beach area, and perhaps the Georgia coast, as the species was not taken in the seine collections from January until late April when the young (17 to 25 mm.) appear. Trends in temperature and salinity of the marsh and beach habitat are shown in table 5.

Jacot (1920, p. 223), in regard to young *M. curema* at Beaufort, N. C., states, "At Beaufort they have not been recorded earlier than May

TABLE 5.—*Average monthly temperatures (° C.) and salinities (°/oo) for the two areas in Georgia where seine collections were taken*

[The averages were derived from data obtained at time of seining and cover the period March 1953 to January 1956 (see table 3)]

Month	Sapelo Marsh		St. Simons Beach	
	° C.	°/oo	° C	°/oo
January	12.8	23.1	11.4	28.2
February	15.1	19.7	14.6	30.1
March	20.8	22.1	17.8	30.2
April	23.7	19.7	21.1	28.0
May	26.3	20.2	26.2	29.3
June	29.1	23.4	27.3	32.2
July	31.9	26.3	29.6	33.5
August	30.4	26.8	30.0	32.8
September	27.2	20.7	28.0	31.5
October	22.2	23.1	23.8	28.9
November	19.1	31.2	19.9	31.1
December	12.4	25.6	14.2	31.1

25th, but there is reason to believe that they could be found even as early as late April." He further indicates (fig. 3, p. 203), the smallest specimens normally procurable are 20 to 21 mm. long, and specimens of that size occur until September. In summary, Jacot (1920, p. 227) makes these additional general observations: (1) the young are abundant in the bays and estuaries of our Atlantic coast and develop rapidly; (2) in the fall the young school and migrate south; and (3) after their first year, white mullet are seldom caught north of Florida.

Thus we have the same sudden appearance of the young in the beach and estuarine waters in both North Carolina and Georgia during the spring at a length which is comparable (17 to 25 mm.) and which coincides with the length (25 mm.) above which the young were not taken in dip-net collections at sea. In both North Carolina and Georgia the population of juvenile silver mullet, resulting from the previous spring spawning, seems to disappear from the estuarine and beach areas by late fall or early winter, so that these young are apparently scarce or absent entirely during the winter. It is quite likely that a similar situation exists in South Carolina waters.

Jacot thought the juveniles were migrating south and intimated they were moving to Florida waters. I have no direct evidence to substantiate or refute this theory. The only silver mullet more than 25 mm. long which I have taken in offshore waters along our South Atlantic coast were the mature and spawning fish off the lower Florida coast near the 20-fathom line. It is more logical to assume a southward migration along the Florida coast where a habitat ascribed to mullet in general is available than to assume an offshore movement. My guess is that the exodus of juveniles is hastened by cooling of the waters during the fall, but whether or not temperature is the major controlling factor is not known. Perhaps the young would have migrated eventually regardless of temperature, but we cannot disregard the correlation of their disappearance with rapidly falling water temperatures in our marsh and beach areas during late fall and early winter (table 5). There does not seem to be a population of adult silver mullet in our inshore waters of the Carolinas and Georgia commensurate with the numbers of young there during spring and summer.

LITERATURE CITED

AHLSTROM, ELBERT H., and ORVILLE P. BALL.
1954. Description of eggs and larvae of jack mackerel (*Trachurus symmetricus*) and distribution and abundance of larvae in 1950 and 1951. U. S. Dept. Interior, Fish and Wildlife Service, Fish. Bull., No. 97, vol. 56, pp. 209–245.

ANDERSON, WILLIAM W., JACK W. GEHRINGER, and EDWARD COHEN.
1956. Physical oceanographic, biological, and chemical data, South Atlantic Coast of the United States, M/V *Theodore N. Gill* Cruise 1. U. S. Dept. Interior, Fish and Wildlife Service, Spec. Sci. Rept. Fisheries No. 178, 160 pp.

HIGGINS, ELMER.
1928. Progress in biological inquiries, 1926. U. S. Dept. Commerce, Bureau of Fisheries, Doc. 1029, In Rept. Comm. Fish. for 1927, pp. 517–681.

IDYLL, CLARENCE P.
1949. Stop-netting on the west coast of Florida. State of Florida, Bd. of Cons. Tech. Ser. No. 3, 23 pp.

JACOT, ARTHUR PAUL.
1920. Age, growth and scale characters of the mullets, *Mugil cephalus* and *Mugil curema*. Trans. Am. Microscop. Soc., vol. XXXIX, No. 3, July 1920, pp. 199–229, pls. XX–XXVI, 7 figs.

HILDEBRAND, SAMUEL F., and WILLIAM C. SCHROEDER.
1928. Fishes of Chesapeake Bay. Bull. U. S. Bureau of Fisheries, vol. 43, Part 1, 388 pp.

HOLLISTER, GLORIA.
1937. Caudal skeleton of Bermuda shallow water fishes. II. Order Percomorphi, suborder Percesoces: Atherinidae, Mugilidae, Sphyraenidae. Zoologica, vol. XXII, Part 3, No. 17, pp. 265–279.

SCHULTZ, LEONARD P.
1946. A revision of the genera of mullets, fishes of the family Mugilidae, with descriptions of three new genera. Proc. U. S. Nat. Museum, vol. 96, No. 3204, pp. 377–395.

U. S. GOVERNMENT PRINTING OFFICE: 1957 O—423182