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Distribution, growth, and availability of juvenile croaker, Micropogon undulatus, in Virginia

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DISTRIBUTION, GROWTH, AND AVAILABILITY OF JUVENILE CROAKER, *MICROPOGON UNDULATUS*, IN VIRGINIA[1]

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INTRODUCTION

The shore fisheries of Virginia have long produced an important part of the nation's seafood supply. The principal fishing gears, the pound net and the haul seine, take a variety of fishes, of which the most important is the croaker, *Micropogon undulatus*. Prior to World War II from one-quarter to one-half of the landings of food fishes in Virginia consisted of croakers, and the catch reached a maximum in 1945 when more than 55 million pounds were landed (Fig. 1). Since that time the croaker catch has decreased precipitously, and in 1952, the latest year for which records are available, less than four million pounds were delivered to Virginia ports.

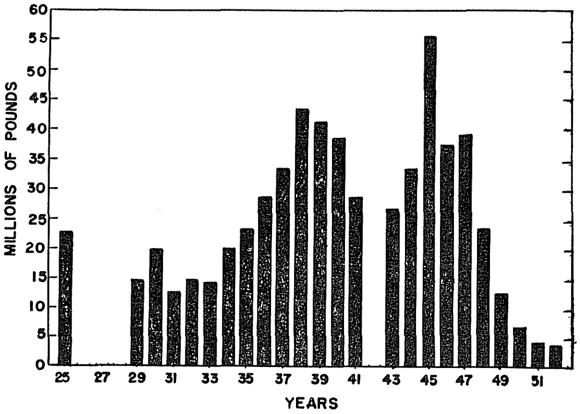

FIG. 1. Total weight of croakers landed in Virginia by all commercial gears from 1925 to 1952, inclusive. Data from U. S. Fish and Wildlife Service Statistical Digests.

Commercial fishing for croakers within Chesapeake Bay extends from March or April until the middle of October. The best catches usually are made in spring and fall, when the fish are migrating. In winter, all but the young leave the Bay, and offshore they continue to be caught by otter trawls. It is not known whether extensive migrations occur during the winter months, but some southward movement seems likely. Of 188 adults tagged in the ocean off Virginia in 1949[2] only two were recovered, both south of Cape Hatteras.

Little is known of the life history of the croaker. Spawning, it is believed, occurs in fall and winter, probably near the entrance of the Bay. Pearson (1941) took larval and postlarval croakers from

[1] Contributions from the Virginia Fisheries Laboratory, No. 68.

[2] In cooperation with the U. S. Fish and Wildlife Service and the Chesapeake Biological Laboratory, Solomons, Maryland.

1.5 to 15 millimeters long in plankton nets near the mouth of Chesapeake Bay in September 1929 and from July to October 1930 inclusive. Raney and Massmann (1953) found young, 20 to 30 millimeters long, in tidal fresh waters of the Pamunkey River in March 1949, and Massmann (1954) reported small young in four Virginia rivers (James, Rappahannock, Pamunkey, and Mattaponi) in spring. Welsh and Breder (1923) observed that the young, ranging from 10 to 100 millimeters, appear to spend the first winter in the deeper water of the larger bays and inlets, and stated they occurred in January from the Severn River in Maryland to Hampton Roads and Cape Charles. These young were most abundant in deep water between the mouths of the Potomac and Choptank Rivers. Hildebrand and Schroeder (1928) took many young, ranging from 10 to 120 millimeters, in the deeper parts of the Bay in the colder months. Wallace (1940), surveying juveniles in the upper Bay in the winters of 1938, 1939, and 1940, found them only in water 24 meters or more in depth, between Kent Point and the mouth of the Potomac River.

Since scattered sampling had suggested that the estuaries tributary to Chesapeake Bay were important nursery grounds, an investigation of the distribution, seasonal movements, and growth of young croakers was inaugurated in 1951. The York River and its tributary, the Pamunkey, and a station (714H) in Chesapeake Bay immediately off the mouth of the York were selected for intensive study, because they are close to the Laboratory. In addition two surveys of the James and Rappahannock Rivers were made and station 716Q near the mouth of Chesapeake Bay was visited several times. Locations of sampling stations are shown in Figure 2.

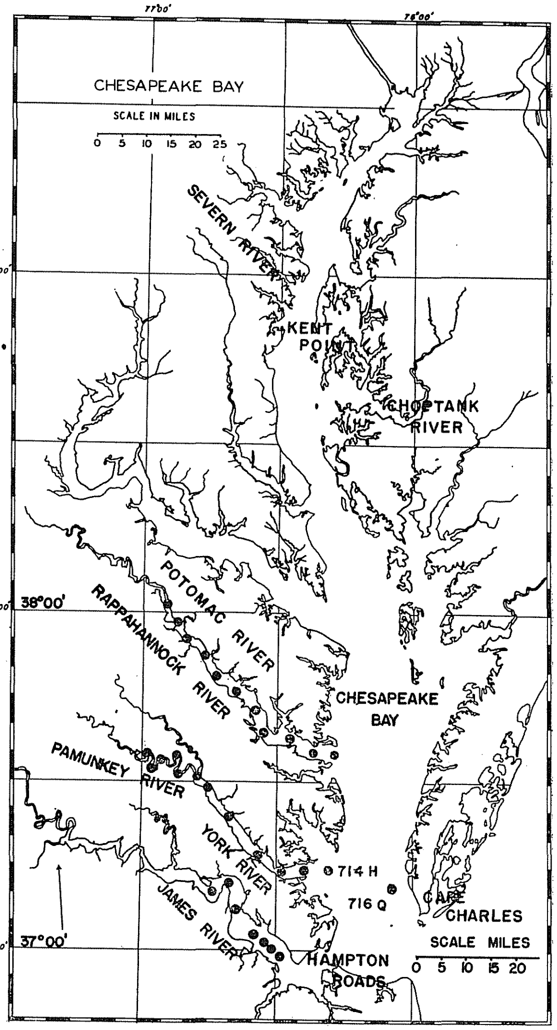

FIG. 2. The region covered by the survey. Sampling stations are shown by black circles.

METHODS

Stations spaced at approximately five and one-half mile intervals were numbered according to the system adopted by the Chesapeake Bay Institute (1949). Bay stations are designated by three numbers indicating latitude, followed by a letter or letters indicating east-west position. River stations are preceded by the letters J for the James, Y for the York, P for the Pamunkey, R for the Rappahannock, and the numbers represent the distances in nautical miles above the river mouth. Shallow-water stations occupied occasionally near established stations are not shown. The station in Chesapeake Bay at the mouth of the York River, all stations in the York River, and the lower two in the Pamunkey, were sampled monthly or bimonthly. Only rarely was it impossible to visit all these stations during the month. The upper three stations in the Pamunkey River were visited occasionally.

The sampling gear was an otter trawl about eight feet wide at the mouth with quarter-inch bar (half-inch stretched) mesh. Hauls were limited to periods of five to fifteen minutes and each was timed. Duplicate tows were made occasionally. The speed of the vessel was regulated as closely as possible by adjusting the engine speed, and it was determined that the velocity was about 3.2 knots. Tows were made parallel to the banks of the estuary. Surface and bottom water samples were taken at the end of each haul with a bucket and a Kemmerer water bottle respectively. Temperatures were recorded, and salinities measured with a stem hydrometer and corrected to 15°C.

All croakers captured were measured from the tip of the snout to the posterior border of the caudal fin to the nearest millimeter. The older croakers were separated from the young of the year on the basis of length. All samples gathered during a month at a single station were combined to derive measures of availability and average length. Since all hauls were not of equal duration, the length-frequency distributions for each of the nine stations were weighted so that the monthly effort was equal at each. The percentage length-frequency distributions for each month were computed from these pooled weighted frequencies (Figs. 3-5).

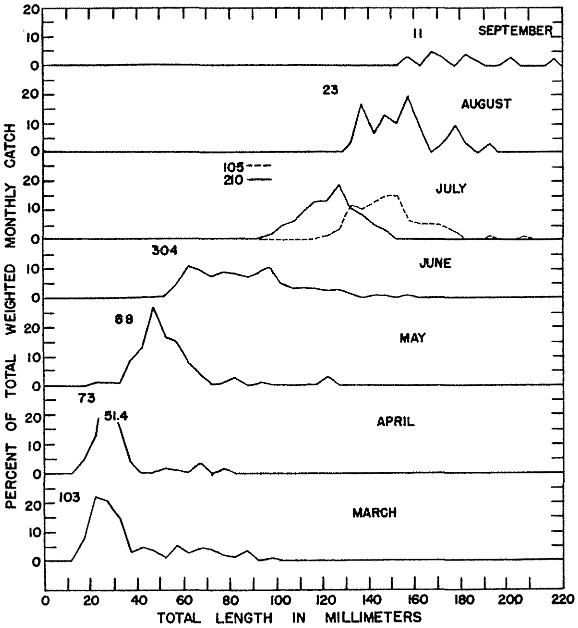

FIG. 3. Length frequencies of 0 age-group croakers captured in a small one-quarter inch mesh trawl from March through September 1952, at nine stations in the York River and its tributary, the Pamunkey. The dotted line shown in July represents those captured in a large three-quarter inch mesh trawl at station 716Q. Numbers indicate the actual number of fish captured each month.

Statistical Treatment of Data

Effect of Towing Direction upon the Catch

To investigate the possibility that hauls made with or against the current may capture different numbers of fish, fifteen pairs of tows were examined (Table I). As is common in biological data, the frequency distribution of catches was not normal, and some adjustment was necessary before the analysis of variance could be applied. The values were transformed according to the expression $\sqrt{n + 0.5}$, where n was the original catch per unit of effort. Statistical analysis showed that the difference between upstream and downstream hauls was no greater than would be expected by chance, for the variance ratio (F) did not differ significantly from unity (Table II). Between stations, however, highly significant heterogeneity was demonstrated ($F = 28.55$, $F_{0.01} = 3.70$).

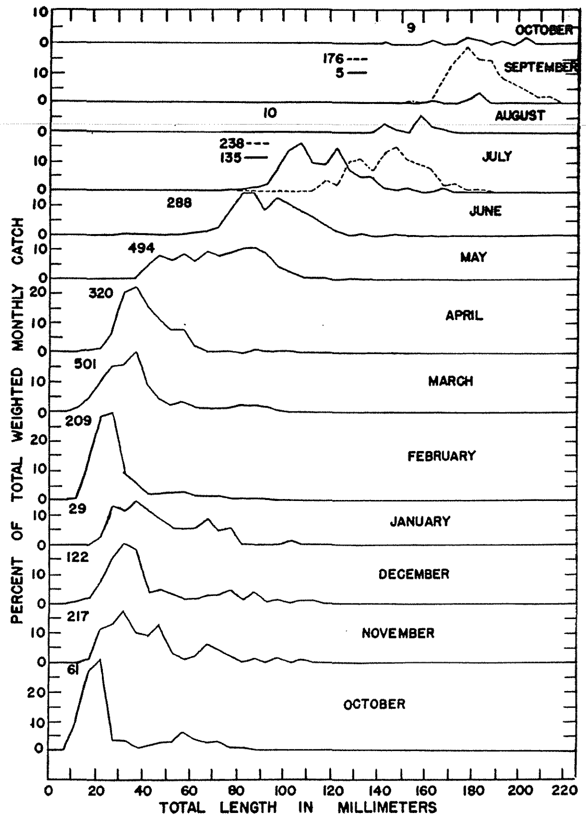

FIG. 4. Length frequencies of 0 age-group croakers captured in a small one-quarter inch mesh trawl from October 1952 through October 1953, at nine stations in the York River and its tributary, the Pamunkey. The dotted lines shown in July and September 1953 represent those captured in a large three-quarter inch mesh trawl in the lower river in July and at station 716Q in September. Numbers indicate the actual number of fish captured each month. Smaller young of the year present during September and October of 1953, shown in Figure 5, are not included here.

Reliability of Single Hauls as Estimates of Availability

The analysis above suggests also that a single five- or ten-minute haul provides an efficient estimate of the availability of young croakers at any station. Records of additional pairs of hauls, for which the direction of towing was not recorded, are available to test this question more effectively. These data (Table III), transformed as before, were added to the previous observations, and the analysis of variance was repeated. As shown in Table IV, the differences between successive hauls at the same station could easily have arisen by chance. The catches made at the different stations, however, were drawn from a population

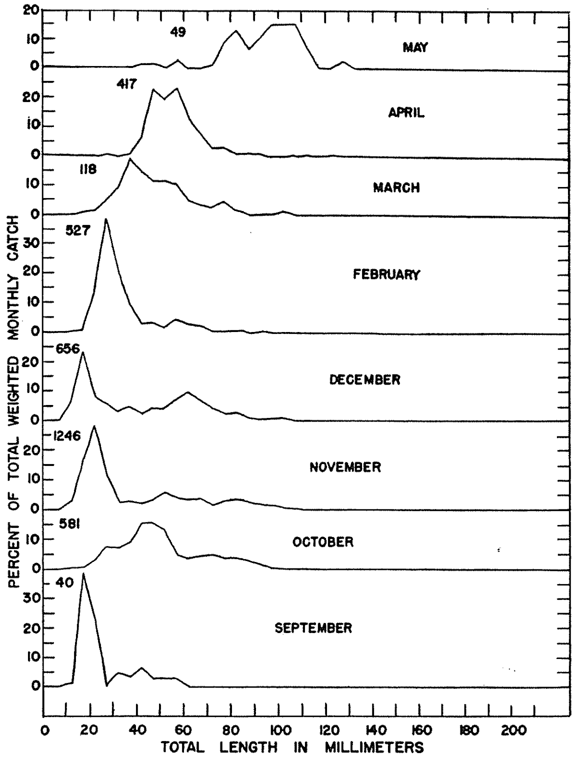

FIG. 5. Length frequencies of 0 age-group croakers captured in a small one-quarter inch mesh trawl from September 1953 through May 1954, at nine stations in the York River and its tributary, the Pamunkey. Numbers indicate the actual number of fish captured each month. Larger croakers present during September and October 1953, shown in Figure 4, are not included here.

TABLE I. Availability of young croakers in paired hauls with and against the current

Station number	Date	Duration of Hauls in Minutes		Number of Croakers		Catch Per 10-Minute Haul	
		Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream
714H.....	16:VII:53	10	10	1	1	1.0	1.0
Y11......	15:VII:53	11	15	3	10	2.7	6.7
Y24......	15:VII:53	9	8	9	8	10.0	10.0
Y28......	20:X:53	10	5	114	42	114.0	84.0
P33......	17:XI.53	10	10	10	6	10.0	6.0
P39......	17:XI:53	5	5	39	52	78.0	104.0
Y18......	16:XII:53	15	5	28	14	18.7	28.0
Y24......	22:XII:53	21	11	28	20	13.3	18.2
Y0.......	8:II:54	5	10	1	0	2.0	0.0
Y24......	8:II:54	9	9	64	141	71.1	156.7
Y28......	8:II:54	14	6	181	101	129.3	168.3
Y24......	10:III:54	10	8	18	5	18.0	6.2
Y24......	27:IV:54	17	10	2	2	1.2	2.0
Y28......	27:IV:54	11	8	45	27	40.9	33.8
Y28......	28:IV:54	15	7	2	3	1.3	4.3

highly heterogeneous with respect to availability ($F = 34.6$, $F_{0.01} = 2.66$).

This analysis confirms the previous evidence that single tows give a reasonable estimate of the availability of young croakers at a given station at a given time. The highly significant heterogeneity

TABLE II. Analysis of variance of the availability of young croakers in hauls made with and against a current

Source of variation	Sum of squares	Degrees of freedom	Variance estimate	Variance ratio
Direction of haul.....	0.90	1	0.90	.....
Stations.....	399.76	14	28.55	28.55
Interaction..	14.01	14	1.00	.....

TABLE III. Availability of young croakers in paired hauls at various stations

Station number	Date	Duration of Hauls in Minutes		Numbers of Croakers		Catch Per 10-Minute Haul	
		Haul 1	Haul 2	Haul 1	Haul 2	Haul 1	Haul 2
P39......	12:II:53	8	5	2	1	2.5	2.0
Y24......	19:VI:53	10	7	110	41	110.0	58.6
Y28......	19:VI:53	5	5	47	33	94.0	66.0
Y28......	15:VII:53	10	7	4	2	4.0	2.9
P33......	15:VII:53	10	10	22	20	22.0	20.0
Y0.	17:VIII:53	15	10	2	2	1.3	2.0
Y24......	17:XI:53	10	8	390	341	390.0	426.2
Y18......	8:II:54	12	12	10	19	8.3	15.8
'	8:II:54	9	8	1	0	1.1	0.0
P33......	28:IV:54	9	8	232	96	257.8	120.0

TABLE IV. Analysis of variance of the availability of young croakers in paired hauls at various stations

Source of variation	Sum of squares	Degrees of freedom	Variance estimate	Variance ratio
Paired hauls.	0.23	1	0.23	.....
Stations.....	1153.97	24	48.08	34.59
Interaction..	33.27	24	1.39	.....

demonstrated for stations, however, indicates that real differences in availability exist between stations.

Reliability of Single Hauls as Estimates of Mean Length

It is of interest also to test whether single hauls of short duration provide a reliable estimate of the size distribution of croakers at each station. For this test there are available eleven paired hauls in which each catch included at least 20 croakers. These data are not particularly applicable to treatment by analysis of variance because some of the samples obviously were not drawn from populations homogeneous with respect to length. It is apparent by inspection, however, that the estimates of mean length derived from each haul of a pair are similar, and this close correspondence is illustrated in Figure 6.

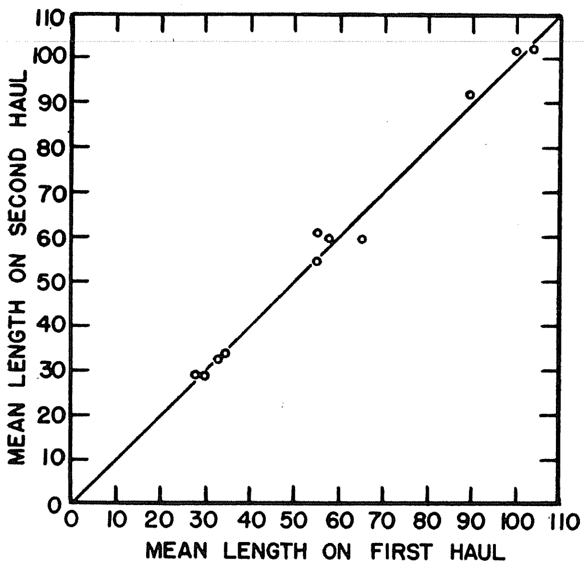

FIG. 6. Mean lengths of croakers taken in duplicate hauls at the same station.

HYDROGRAPHIC CONDITIONS

In the shallow waters of Chesapeake Bay and its estuaries water temperatures are influenced strongly by air temperatures and are highest during July, August, and September and lowest during December, January, and February. Bottom temperatures in the York and Pamunkey Rivers usually fluctuated between 25°C and 30°C in summer, and between 4°C and 8°C in winter.

Salinities decreased rather regularly upriver, and were lowest in March, April, and May and highest in September, October, November, and December, as illustrated by Hewatt and Andrews (1954). The bottom waters nearly always contained more salt than the upper layers. Table V shows the observed ranges in salinity at the bottom in the York River system during the period of this investigation.

TABLE V. Depths and observed range of bottom salinity at York and Pamunkey River stations, March 1952 to April 1954

Station number	Depth range in feet	Bottom salinity range in 0/00
714H	36 - 43	29.5 - 17.6
Y0	39 - 65	29.9 - 19.1
Y5	20 - 25	22.7 - 14.0
Y11	28 - 40	23.5 - 14.7
Y18	34 - 39	22.0 - 11.1
Y24	33 - 35	22.1 - 5.8
Y28	19 - 22	15.3 - 2.9
P33	22 - 34	10.2 - 0.0
P39	22 - 25	5.8 - 0.0
P42*	19 - 23	0.0 - 0.0
P46*	14 - 24	0.8 - 0.0
P52*	5 - 15	0.3 - 0.0

*Sampled only occasionally during survey.

SPAWNING

The spawning grounds of *Micropogon undulatus* are not known. As already stated, previous workers have concluded that some spawning occurs near the mouth of Chesapeake Bay. Our observations confirm this conclusion, for although there is no direct evidence that spawning takes place within the Bay, very small postlarval croakers are encountered in considerable numbers in fall and winter in the lower part of the Bay and in the estuaries (Figs. 3-5).

Welsh and Breder (1923) and Hildebrand and Schroeder (1928) reported that the breeding season extends from August to December. Recent information shows that the season is more protracted, for postlarvae have been taken in the Bay from September to April inclusive. Some spawning may occur in almost all months of the year, for Pearson (1941) found small young near the mouth of the Bay in late July. In southern waters spawing seems to cover a long period, for Hildebrand and Cable (1930) reported larval croakers in the vicinity of Beaufort, North Carolina, from September to May. Pearson (1929) took larvae and young along the Texas coast and indicated that spawning extended from October to February with a peak in November. Gunter (1945) working in the same area took small young during a similar period, from October through March. Suttkus (1955) believed the bulk of spawning in Lake Pontchartrain, La. occurred from late October through November, December, and January.

Distinct length-frequency modes are shown in each of the three years in fall and winter (Figs. 3-5). This probably indicates that although the spawning season is protracted, most spawning takes place during a relatively restricted period.

Occasionally there were indications of a second mode, suggesting two spawning maxima, perhaps in spring and fall.

GROWTH

As illustrated in Figures 4 and 5, no appreciable growth seems to occur throughout the late fall and winter. Indeed, the mean length seems to decrease for a time, but this apparent decrease probably is caused by the continual recruitment of larvae and mortality or reduction in availability of the larger young. Rapid growth apparently begins in March or April, and by August the modal length of the few captured is about 155 to 160 millimeters. This measure of the growth rate is only relative, for it is probable that some of the larger fish escaped the gear.

Supplementary tows by W. H. Massmann with a three-quarter inch mesh trawl in July 1952 and 1953, were made in the vicinity of stations Y0, 714H and 716Q. These tows captured larger juveniles than were obtained in the regular series of tows at all established stations. This size difference is possibly due to a gradation in length of croakers up and down river which is intensified by gear selectivity. In September 1953, tows made at station 716Q with the large mesh net captured a homogeneous group of fish, ranging in length from about 150 to 220 millimeters, with a mode at 175 to 180 millimeters. Since most members of this year class had left the rivers for the lower Bay at this season it is believed that this group exhibits the length distribution attained at approximately one year of age. The few fish that remain in the rivers by September, some of which have been captured with the smaller net, also fall within this length range.

Pearson (1929) stated that young croakers in Texas, when approximately a year old, in fall, reach a total length of about 150 millimeters. Gunter (1945) indicated that in October in the same general area the yearlings ranged from 103 to 173 millimeters with a mode at 135 millimeters. Suttkus (1955) found that the modal lengths of year-old croakers in Lake Pontchartrain, La. were 140 to 149 millimeters in October 1953, and 110 to 119 millimeters in October 1954, with a total range from 90 to 200 millimeters. Welsh and Breder (1923) reported an average length of 150 millimeters at one year of age in Florida. Hildebrand and Cable (1930) caught year-old fish in October, near Beaufort, North Carolina, ranging in length from 98 to 194 millimeters with an average length of 143 millimeters. Welsh and Breder (1923) examined the scales of a small series of croakers from New Jersey waters and concluded that growth in northern waters is about the same as in the south.

Local Size Variations

There was considerable variability in the length distribution of juvenile croakers captured at different stations. Usually the smaller croakers were more abundant upriver, and there was a gradual increase in average length toward the Bay. Such gradients were observed throughout the survey except during certain months near the spawning period. To illustrate these differences, the weighted length-frequencies of the 1952 year class, for each month with the exception of August and September when only a few were captured, were combined into two groups. The first included all stations from 714H through Y24, and the second from Y28 through P39 (Fig. 7). In October 1952 the lower York River contained only small croakers, less than 25 millimeters in length, whereas considerable numbers of larger fish were present in the upper river. In November the size distribution of croakers in both parts of the river was similar, with small fish predominating, but some of fairly large size. By December the larger fish were almost completely lacking in the upper river, and although a group of small croakers remained downstream, these also were larger, on the average, than those in the upper part of the York and its tributaries. From January to July 1953 inclusive, the average length was considerably less upriver than down, although from March 1953 to late summer both groups steadily increased in length. Gunter (1945) showed that in Gulf coast waters the smaller fish were usually found in the freshest water. Suttkus (1955) reported differences in mean length of croakers at different stations in Lake Pontchartrain, La. which he attributed to grouping.

Local and Seasonal Variations in Availability

Most of the 0 age-group croakers taken in this survey came from the relatively deep waters of the river channels from stations Y11 to P33 inclusive (Fig. 8). Above and below these limits, some young croakers were taken, but average availability was much lower. Regions of intermediate and low salinity, from zero to 18 parts per thousand, seemed to be preferred.

Station P39 marked the upriver range of appreciable numbers of young, for in nine hauls at P42, P46, and P52 croakers were captured only three times. Croakers were taken at station P52 on only one occasion, but this indicates that they may range occasionally far upriver from their usual haunts. Raney and Massmann (1953) sampled extensively with various types of gear over the navigable section of the Pamunkey River, but captured no croakers above station P52. At stations P33 and P39 croakers occasionally were abundant in water containing no measurable amounts of salt by titration. On one such occasion 145 fish were captured in a 15-minute tow at station P39. The occurrence of small croakers in low salinity or fresh water is not unusual and has been noted by Welsh and Breder (1923), Gunter (1942), Raney and Massmann (1953), and Massmann (1954).

Trawl hauls in shoal water (eight to ten feet) from station Y18 to P52 indicated that young, though often present, were not as abundant as in

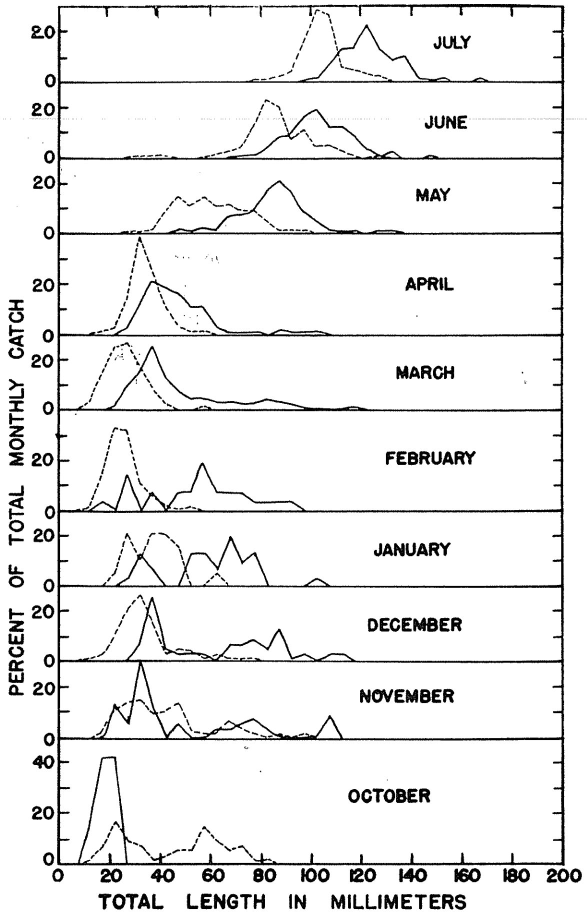

FIG. 7. Length frequencies of all 0 age-group croakers taken in the upper (broken line) and lower (solid line) regions of the York River system from October 1952 through July 1953.

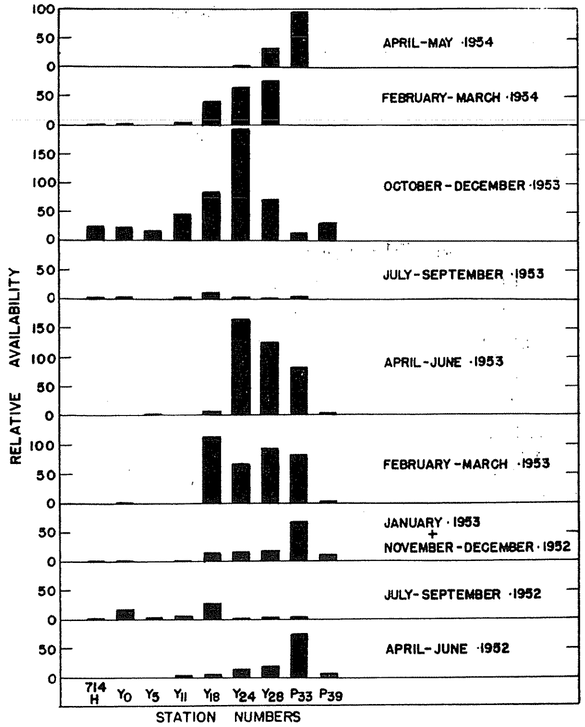

FIG. 8. Relative availability of 0 age-group croakers in the York River and its tributary, the Pamunkey, all stations combined.

the main channel. In the lower river from 714H to Y11 hauls in shoal water captured none. Suttkus (1955) obtained somewhat similar results, obtaining greater numbers from the deep channels than from the shallow flats.

Small croakers apparently seldom move in close to the shore line. Many hundreds of seine hauls were made along the shore in the survey area, at times when young of the year were known to be abundant offshore. These captured young on only two occasions, according to records on file at the Virginia Fisheries Laboratory. The absence of young croakers from the shore zone in Virginia waters is at variance with the results obtained along the Texas Gulf coast, where Pearson (1929) obtained thousands in a small minnow seine. Suttkus (1955) obtained small croakers in seines in all months except November and December.

Small croakers were not found near the surface. During the spawning seasons of 1952 and 1953, plankton nets (25 meshes to the inch) were set in the York and Pamunkey Rivers at the surface and bottom, using the method described by Massmann (1952). Twenty-five sets at the surface captured none, but 218 were obtained in thirty-five sets of the same gear at the bottom. Similar results were obtained by Wallace (1940) who made bottom-trawl hauls and surface and bottom plankton tows in the upper Chesapeake Bay in winter and found small croakers only in water deeper than 24 meters. Pearson (1941) captured larval and young croakers near the mouth of the Bay in later summer and fall at the surface but most frequently at the bottom. Hildebrand and Cable (1930) in extensive plankton collections near Beaufort, North Carolina, found young croakers most frequently near the bottom.

Seasonally, the availability of young croakers in the York River reached a maximum in late winter and spring and a minimum in late summer and fall. The location of maximum availability in the river shifted during the course of this investigation (Fig. 8) but the shift did not seem to be primarily seasonal in nature. Major seasonal shifts in length distribution occur, associated with the upstream movement of the current year's brood in fall and winter, and the gradual return movement toward the lower Bay and ocean during late spring, summer, and early fall.

Distribution and Availability in Other Virginia Rivers

Lack of personnel and facilities restricted this investigation chiefly to the York River system, and it was not possible to broaden the surveys to cover Chesapeake Bay and its major tributaries adequately. However, detailed surveys of the James and Rappahannock Rivers were made in March and June 1953.

Catches in the three rivers were compared by calculating the catch per ten-minute tow in five-mile stretches of river (Table VI). In both months the catch per unit of effort was highest in the York and least in the James River. As in the York River system, the availability of young croakers is greatest in the James and Rappahannock in the region of intermediate salinity. Differences in mean length of fish, similar to those found in the York, were also observed in the James and Rappahannock, although the gradients were not as well-defined due to the smaller numbers of fish captured.

Table VI. Relative availability of young croakers in the York, James and Rappahannock Rivers in 1953

Station intervals in miles above mouth of river	Number of Croakers Per Ten-Minute Tow					
	March			June		
	Rappahannock	York	James	Rappahannock	York	James
0 - 4	1.0	0.7	...	0.0	5.5	...
5 - 9	0.0	0.0	...	0.0	0.0	...
10 - 14	...	0.0	0.0	0.0	1.8	5.0
15 - 19	0.0	219.0	4.0	3.0	19.0	0.0
20 - 24	9.4	103.3	5.7	16.2	88.8	5.0
25 - 29	37.6	157.5	...	9.0	80.0	6.0
30 - 34	32.2	0.0	0.0	11.0	72.7	19.0
35 - 39	0.0	0.0	...	6.7	1.0	...
40 - 44	0.0	...	...	30.0	...	...
45 - 49	...	...	...	1.3	...	...

Absolute Abundance

The catch per standard trawl haul provides only a relative measure of the availability of young croakers. In May 1952 an attempt was made, by a continuous marking and recovery program, to estimate the abundance of juvenile croakers in a stretch of the Pamunkey River. In 41 hauls of the trawl, 2,537 apparently uninjured croakers were caught and marked by removing the pelvic fins. Only one marked fish was recovered, and this provided an estimate of about 7.5 million for the total population in the area.

Injuries induced by the trawl or by handling during the marking operation were unavoidable. The marked fish were held in large tubs of river water for a time until mortality seemed to have ceased. There is no good evidence, however, that further mortality did not occur after release, and the population estimate probably should be considered maximal.

Since an estimate based on one recovery is not accurate, it did not seem worth while to compute the area of bottom in this sector of the river. Nevertheless, it is suggested that the York River is an important nursery ground, for the total numbers of young in the York River system at this time must have been many times the computed amount.

Discussion and Conclusions

The distribution and availability of young croakers in the York River system and certain other tributaries of Chesapeake Bay was investigated by regular surveys with a small-meshed otter trawl. It was established that single hauls of ten minutes' duration or less, whether they were made with or against the surface current, provided good estimates of availability and length distribution.

For the following reasons it is believed that spawnings of significant magnitude do not occur within Chesapeake Bay: (1) croakers smaller than ten millimeters in length have never been caught in these waters; (2) we have examined many thousands of adult croakers from the commercial catch, at all times of the fishing season, and have yet to find a fully-ripe or recently-spent female; (3) in other regions croakers apparently spawn in the ocean off the coast, and not in the shallow bays and sounds, as stated by Hildebrand and Cable (1930) for North Carolina, and Pearson (1929) for the Gulf of Mexico.

Spawning probably occurs in the ocean near the mouth of Chesapeake Bay, as shown by Pearson (1941). The spawning season is long, may extend over almost the entire year, and it is possible that two maxima occur.

The sampling gear was quite selective, and the exact rate of growth of young croakers is not known. A modal length of 175 to 180 millimeters probably is reached by the end of the first year, and this is confirmed by the appearance of young croakers of about this size in pound-net catches in the fall.

During most of the year, the average length of young croakers in the estuaries at any instant decreases steadily from the mouth toward the source. In late fall this may not be true, for at this time the recently-hatched postlarvae or young are moving up from the ocean, while those born earlier are already well upstream. It is postulated that, during the succeeding spring and summer, as they grow, the larger fish gradually acquire the power and the incentive to move slowly downriver again. This return migration is very gradual, and the cycle is not complete until after the brood from the next year's spawning begins to ascend the estuaries.

During the spring and summer most of the young croakers are concentrated midway up the estuary in the region bounded by water containing a trace of salt and water of about 18 $^0/_{00}$ salinity. For the most part they are confined to the bottom waters of the relatively deep channels, and although some may venture into the adjacent shoal water, almost never are they observed or captured near shore, and never in the surface layers.

It is difficult to believe that postlarval and young croakers, which must be feeble swimmers at best, migrate actively from the mouth of Chesapeake Bay to the regions 60 or more miles from the supposed spawning area where young of this size are abundant. Wallace (1940) believed that the young, which he obtained in the upper Bay in waters 24 meters or deeper, were carried up Chesapeake Bay by currents of relatively saline water moving up the Bay along the bottom. The existence of such currents was first suggested by Cowles (1930), postulated again by Newcombe, Horne, and Shepherd (1939), and demonstrated by Pritchard (1951, 1952a, 1952b, 1952c).

Pritchard (1951) observed that if young croakers were to favor depths of 20 feet or more, they could be carried up the Bay by the current, which in Chesapeake Bay has a net velocity of about 0.2 to 0.4 knots. In the James River the net upriver velocity was observed to vary from 0.12 to 0.17 knots (Pritchard 1952a).

The vertical distribution of density in the York River system is such that a similar pattern of circulation must exist. Thus, the young croakers, living as they do near the bottom, could be transported passively upstream. At a velocity of 0.2 knots, a drifting postlarva could be carried from the mouth of the Bay to West Point, a distance of about 60 miles, in twelve and a half days. The most conclusive evidence that such transport occurs is the actual presence of young croakers in the estuary far from their spawning area. It is evident that if young croakers are carried passively upstream there should be a sharp decrease in abundance as the current weakens or disappears. The two-layered circulation system cannot exist in the absence of salt, and as the salinity approaches zero the availability of young croakers actually does decline. Spasmodic occurrences in apparently fresh water may be associated with the occasional upstream movement of isolated patches of water containing some salt. Dr. Pritchard (personal communication) has stated that such a phenomenon is probable.

The gradient in size of croakers in the estuaries might be explained in several ways. If the growth rate were to vary with salinity, then the slowest-growing, and hence the smallest fish, would be found farthest upriver. If the larger young were less resistant to lowered salinity, then the gradient might be caused by a differential mortality with respect to size. If, as they grow, the young are increasingly able to resist transport upstream, and can, in addition, make headway over the bottom against the current, the observed size distribution would also come about. Experiments, to be reported elsewhere, have shown that there is an increasing ability with size to stem currents.

The first explanation does not seem probable because, as illustrated in Figure 7, the rates of increase in mean length with time in the upper and lower parts of the river are about equal. The second does not seem reasonable because there are presumably no barriers to prevent the fish from avoiding adverse conditions, and no dead or dying young have been observed. The third and last explanation seems to fit best the known physical and biological factors, and it is here offered as a hypothesis. The movements of the larger fish able to resist transport are probably complex, but the net result is a slow movement downriver with increasing size, until the year-class vacates the estuary in fall.

As is usual in studies based primarily on observations in nature, more questions are raised than answered. One of the most vital problems is the importance of the Bay and its estuaries as a nursery ground. Evidence has been presented that many millions of young croakers enter the York River. Millions, or even billions more may be living and growing in the other major estuaries, and in the Bay itself, which cover an area many times as great. How many of these young croakers are there in the Bay, and what proportions of them survive to enter the fisheries or to produce later broods? Are there pronounced changes in the circulation pattern, produced by unfavorable winds, for example, that may seriously affect the transport of postlarvae into the Bay and estuaries? Are estuarine waters the important nursery areas, or do most of the croakers that supply the commercial fisheries in the Bay come from nursery grounds on the continental shelf? These, and many other questions, must be answered before the dynamics of croaker populations are really understood.

Summary

1. Indirect evidence, based on maturation of the gonads in adults, and the distribution of post-larvae, suggests that *Micropogon undulatus* spawns in the ocean, not far from the entrance to Chesapeake Bay, from late summer through the winter and spring.

2. Growth is slow in winter, increases rapidly in March or April, and by fall a modal length of 175 to 180 millimeters is reached.

3. The circulation pattern in Chesapeake Bay and its estuaries is such that the newly-hatched croakers can be carried to the upper limits of salt water intrusion in a few days. Here they congregate, gradually shifting downstream again as they grow.

4. At any given time, the smallest fish are found farthest up the estuaries, and the mean length increases steadily toward the Bay.

5. By the end of the first summer, when the next year's brood is about to hatch and be carried to the estuarine nursery grounds, the brood of the previous year has almost entirely vacated the area.

6. During their first year of life, the juveniles seem to favor waters of relatively low salinity, for the most part ranging from zero to 18 parts per thousand. Occasionally, fairly large numbers are found in water that has no appreciable trace of salt.

7. Croakers remain near the bottom even at very early stages.

8. A rough estimate of abundance in a restricted area suggests that many millions of young croakers spend most of their first year in the upper parts of the estuaries. Perhaps it is here that clues to their fluctuations in abundance should be sought.

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