ASPECTS OF THE LIFE HISTORY OF THE ATLANTIC CROAKER, *MICROPOGON UNDULATUS*

by

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ABSTRACT

A validated scale method of age determination is described for the Atlantic croaker, *Micropogon undulatus*. Two age classes were generally observed, but only one was abundant. Mean total lengths were 155-165 mm at age I and 270-280 mm at age II based on three methods of growth estimation. Fish matured near the end of their first year of life when they were about 140-170 mm in total length. Spawning occurred from at least September through March but reached a peak in October. Somatic weight-length relationships varied monthly, and changes appeared to be associated with maturation and spawning. Somatic weight reached a maximum in June, and the minimum was observed in March. Maximum somatic weight loss (24%) occurred in March, but no data were obtained from December through February. In estuaries, age 0 croaker appeared to occupy soft-substrate habitat and older fish occurred near oyster reefs. Life spans were only one or two years, and the total annual mortality rate was 96%. The above life history pattern appears similar for croaker found throughout the Carolinean Province. Contrasts are presented to illustrate differences in the life histories of croaker found north and south of Cape Hatteras, N.C.

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INTRODUCTION

The Atlantic croaker, *Micropogon undulatus*, ranges from Cape Cod, Mass. (Welsh and Breder, 1924) to Campeche Bank off Mexico (Hildebrand, 1955). It is potentially a very important protein source because it is one of the most abundant inshore fishes of the northern Gulf of Mexico (Gunter, 1938, 1945; Moore, Brusher, and Trent, 1970; Franks et al., 1972) and the southeastern United States (Haven, 1957; Bearden, 1964; Anderson, 1968).

Much work has been done on this species. However, many aspects of its life history and population dynamics are not clear; because no reliable method of age determination exists and reproduction has not been studied intensively. A few early workers, including Welsh and Breder (1924) and Wallace (1940), attempted to determine croaker age using scales; but criteria for marks were not described and methods were not validated. More recent workers, in general, have not attempted to use hard parts to determine croaker age and growth. The scale method is difficult to apply to croaker (Joseph, 1972), and this may be related to its migratory habits and extended spawning season (Suttkus, 1954). Only Wallace (1940) studied reproduction using a large series of gonads. However, he worked north of Cape Hatteras, N. C. The life history of croaker found north of Cape Hatteras seems quite different from that of individuals in the Carolinean Province (see Briggs, 1974). Studies of the reproduction of croaker found south of Cape Hatteras have been based on few fish (Gunter, 1945; Bearden, 1964) or fish less than 200 mm in length (Hansen, 1970).

This paper describes a validated method of age determination for croaker, their weight-length and girth-length relationships, habitat segregation between age groups, spawning seasonality, somatic weight variation, growth, maximum size, life span, and total annual mortality. Finally, it contrasts the life histories of croaker found north and south of Cape Hatteras.

MATERIALS AND METHODS

Collections were made from commercial shrimp trawlers during 1974 in the Gulf of Mexico off Freeport-Galveston, Tex., Port Aransas, Tex., and Cameron, La. Fish were also collected by trawling in Palacios, Galveston, and Matagorda Bays, Tex., and Cameron Bay, La. Additional fish, hereinafter termed reef fish, were captured by angling with dead shrimp bait (25 mm long) near an oyster bar in Galveston Bay. Collection months are indicated on Fig. 12.

A sample was taken from each trawl catch by shoveling into a 25-liter container small portions of the catch from various areas of the deck. Unusually large fish were arbitrarily selected to obtain older fish to develop an ageing technique. Total length was measured on each croaker. Total and gonad weights and girth at the point of insertion of the dorsal fin were determined for fish over a broad size range during each sampling period. Scales below the lateral line posterior to the pectoral fin were removed from 1,100 fish, were pressed on .5-mm thick plastic slides, and were examined using a scale projector. Scales were examined from small numbers of croaker collected off Mississippi and Fort Pierce, Fla., and in Chesapeake Bay, Va., to judge whether or not our proposed age determination method is valid throughout their geographical range. The gonads of more than 2,000 fish were examined, and ovaries were classified according to Nikolsky (1963) except that Nikolsky's immature and resting stages were combined.

The regressions of somatic, gonad, and total weights, and girth on length were computed to express the best linear or quadratic fit using the Statistical Analysis System (Service, 1972). Total weight-length, somatic weight-length, and girth-length regressions were computed for each month after pooling the data, because F tests (Ostle, 1963, p. 204) indicated that one regression line could be used for all observations.

SPAWNING

Spawning occurred over a protracted period extending at least from September to late March. The regressions of gonad weight on length were not significant during May, June, or July for either sex. The mean gonad weight in this period was 0.10 g and its 95% upper and lower confidence limits were 0.11 and 0.09 g. The regressions of gonad weight on length (Fig. 1) indicate gonad development in each sex began by late August, increased greatly during September, reached a peak in October, declined greatly by November, and remained minimal in March. Similarly, the coefficients of determination of the regression lines (Table 1) show that gonad weight variation in each sex was associated increasingly with length until October and then greatly declined. Therefore, it appears that peak spawning occurred in October. Fish captured in the Gulf and by the reef were in all stages of development during September, as were trawl-caught bay fish in October (Fig. 2). Therefore, spawning apparently began at least by late September, and some individuals finished or had nearly finished spawning at that time. Most spawning occurred during October in agreement with the gonad weight-length analyses, because most fish captured in the Gulf were still immature in September. Most fish captured near the reef and in the Gulf were ripe or spent during October and November. Specimens captured in the Gulf during late March were in a resting stage or nearly spent, so that spawning is apparently completed by late March except for a few individuals.

Maturity was reached at about 140-170 mm in length, and developing fish as small as 136 mm were observed (Fig. 1).

Many aspects of croaker spawning appear similar throughout the Carolinean Province. The prolonged spawning period suggested by our data agrees with frequently reported collections of fish in the 25-40 mm size range from October to June (Pearson, 1929; Gunter, 1945; Suttkus, 1954; Bearden, 1964; Perret, 1966; Hansen, 1970; Parker, 1971; Swingle, 1971; Christmas and Waller, 1973; Hoese, 1973; Gallaway and Strawn, 1974). The apparent peak of spawning after September agrees with Pearson (1929), Hildebrand and Cable (1930), Suttkus (1954), and Bearden (1964), and size at maturity agrees with Pearson (1929), Hildebrand and Cable (1930), Bearden (1964), Roithmayr (1965), Hansen (1970), and Hoese (1973).

The general similarity of croaker reproduction suggests that October 15, which approximates the time of peak spawning, would be appropriate as a defined birth date in warm temperate waters.

SOMATIC WEIGHT VARIATION

Somatic weight-length relationships varied monthly, and these changes appeared to be associated with maturation and spawning. Peak somatic weight occurred during June except in fish smaller than about 140 mm. Somatic weights predicted by the regression equations for each month (Table 2) were compared with predicted weights in June (Fig. 3). The somatic weight of individuals smaller than about 140 mm increased from May to at least September. Fish of about 140-160 mm showed progressive somatic weight loss from June to September-October. The smallest fish greater than 160 mm generally showed the greatest somatic weight loss (or smallest gain); and somatic weight loss, in general, seemed to progressively increase from June to September-October. Somatic weight loss during the fall in fish larger than 140 mm was greatest in September-October just prior to the time of peak spawning. However, somatic weight loss was greatest in March when individuals of 170-250 mm had lost 20-24% of their June weight. The observed somatic weight-length relationships and apparent weight changes in November may be anomalous. Absolute somatic weight decreased in fish smaller than 140 mm, but the percentage weight loss in fish greater than 160 mm was about 5%. Croaker mature at about 140-160 mm, and most fish were small and immature in November. These smaller fish may have just begun to mature for spawning, and their inclusion in the data may have biased the observed pattern in November. This interpretation is supported by the regression coefficients of $\underline{X}$ and $\underline{X}^2$ which were markedly smaller during November than during other months in the period August-March (Table 2).

Somatic weight changes have not been reported for croaker, and additional data from the post-peak spawning period December to February are needed to fully understand their annual cycle of somatic weight change.

Possibly, the percentage of somatic weight loss may be greater in late fall and winter than we observed in March.

AGE DETERMINATION AND GROWTH

General Basis for the Method of Age Determination

Scale marks similar to annuli were distinguished by standard criteria, especially cutting over and differential spacing of circuli. Croaker appear to form two marks on their scales each year except that no mark is formed during their first winter. Some fish form no mark during their first year if October 15 is defined as the birth date of croaker. Even-numbered marks (cold-period marks) form from about December to March, and odd-numbered marks (warm-period marks) form from about May to November. Fish that do not form a mark in their first year would not have mark numbering that corresponds to the typical odd and even system. Cold-period marks were most distinct and were used as "year" marks, although they represent 1-1½ years of growth. Recognition of the first cold-period mark is the basis for our method. Subsequent marks, especially cold-period marks, seem to be easily identified.

Age determination was validated by: 1) establishing the time of year when each mark forms, 2) establishing age through analysis of length frequencies, and 3) showing that modes of back-calculated and observed lengths at each age agree with age determination by length frequencies.

Repeated reading suggests our method of age determination is precise. We found 91% agreement between the first reading of scales from 200 fish (112 age 0 and 88 age I) and a second reading three months later.

Characteristics of Scale Markings Used to Determine Age

The first mark is typically a light mark formed in warm periods. It is characterized by cutting over in the lateral field, but it has little or no differential spacing of circuli before and after the mark (Fig. 4). This mark is often difficult to distinguish after the heavier second mark is formed. The typical second mark is formed in cold periods. It is the most diagnostic feature for age determination in croaker, and its recognition is the basis for our method. This mark is characterized by heavy cutting over of circuli and differential spacing of circuli in the lateral field (Fig. 5). Generally, circuli are closely spaced before the second mark and more widely spaced after it. When the first mark is absent or difficult to see, the typical second mark is readily distinguished. The third mark is typically formed in warm periods and is similar to the first mark (Fig. 6). We examined only six fish whose scales had the fourth mark, and its criteria may need modification. However, the fourth mark apparently forms in cold periods and apparently resembles the second mark in having heavy cutting over and differential spacing of circuli (Fig. 6).

The ages of croaker from a broad geographical range seemingly can be determined by our method, although further work is needed to establish this. Scales of fish from Mississippi (Fig. 7), Fort Pierce, Fla. (Fig. 8), and Chesapeake Bay (Figs. 9, 10) showed markings similar to those on scales from Texas fish. Croaker scales from Florida generally had very light cutting over and seemed difficult to read, possibly because the fish were collected in tropical waters of southern Florida where temperature changes are not as extreme as further north. Only six fish from

Texas had scales with four marks. In contrast, scales from some Chesapeake Bay fish had six marks (Fig. 10). Croaker which live south of Cape Hatteras survive only about one or two years (see General Discussion) and therefore tend to have comparatively few marks on their scales. The ages of these fish might be easier to determine than the ages of croaker which live north of Cape Hatteras. The latter croaker apparently survive longer and probably tend to have more marks on their scales.

Times of Mark Formation

The time when each annulus-like mark formed was determined by plotting for each month the distance from the scale margin to the last mark (Fig. 4). Croaker generally appear to form two marks per year. Scales with no marks had the smallest distance between the scale margin and focus in May (Fig. 11). The radius increased from May to October as scales grew during that period. Therefore, apparently no mark is formed during the first winter; and some croakers form no mark during the first year of life if October 15 is defined as their birth date. Scales with one mark had the mark closest to the scale edge in warmer months. In March the mark was far removed from the scale margin, suggesting that the first mark normally forms in warm months. Apparently this mark formed on some fish throughout the period May to at least October. The increment between the scale margin and the mark did not increase with time for the first (or third) mark, but the reason for this is not clear. Scales with two marks showed the last mark closest to the scale margin in March. The increment between this mark and the scale edge progressively increased to June and then remained nearly constant through November. Therefore, the second mark apparently forms during the colder months. Scales with three marks showed the last mark being formed throughout the warm months. Scales with four marks were observed only during March. The increment on these scales suggests that the last mark was formed during winter or spring. However, further data is needed to confirm this.

Our findings on times of mark formation agree with Haven's (1954) suggestion that croaker form one fall mark and one winter mark each year in Chesapeake Bay and with Richards' (1973) computer-simulated findings that the related black drum, _Pogonias cromis_, forms one mark a year until maturity and two marks a year thereafter.

Age Determination and Growth by the Length-Frequency Method

Our length-frequency distributions suggest two croaker year classes occurred off Texas. One age group greatly predominated in the length frequencies of trawl-caught fish from the bay and Gulf during June (Fig. 12). The size range of that age group was primarily about 100-150 mm in the bay and about 120-160 mm in the Gulf. Young-of-the-year first appear in Texas bays about November and increase in size in the bays from about 10-50 mm during January to 30-85 mm in March, 40-100 mm during May, and 70-130 mm in June (Gunter, 1945; Parker, 1971; Gallaway and Strawn, 1974). Therefore, the fish we had captured by trawling during June must be young-of-the-year. After June, these fish grew to about 110-170 mm in August, 120-175 mm in September, and 140-180 mm in October when they reached age I. Similar sizes in October have been recorded by Gunter (1945), Parker (1971), and Gallaway and Strawn (1974). The now age I fish increased in length to about 130-190 mm during November and to about 165-220 mm by March. The large fish caught in June by angling near the reef were about 190-270 mm and apparently were survivors of the young-of-the-year that had become age I on the preceding October 15. These age I+ fish were about 200-310 mm in September when they approached age II. This agrees with Gunter's (1945) size estimates for age II croaker off Texas.

With minor differences, length frequencies reported throughout the Carolinean Province by many workers including Pearson (1929), Hildebrand and Cable (1930), Gunter (1945), Suttkus (1954), Bearden (1964), Miller (1965), Perret (1966), Hansen (1970), Parker (1971), Christmas and Waller (1973), Hoese (1973), and Gallaway and Strawn (1974) show growth and age composition similar to our findings. Growth north of Cape Hatteras seems similar to that in the Carolinean Province. Haven (1957) presented monthly length frequencies of fish he considered young-of-the-year. His fish ranged from about 120-220 mm in October, but the mode was about 175-180 mm.

Agreement of Observed and Back-Calculated Lengths with Length Frequencies

Observed sizes at ages 0, I, and II agree closely with ages determined by length frequencies (Fig. 13). Only age 0 fish were captured in May and age I fish in July, so that graphs are not presented for these months. The frequencies show overlap in size between the various ages each month. This is to be expected, especially in a species having a prolonged spawning season, and makes it impossible to use the length-frequency method to assign age confidently in overlapping size ranges. The observed lengths of age 0 fish in September were primarily 130-170 mm (mean = 151 mm), but they ranged from about 110-220 mm. This age group was about 140-220 mm (mean = 158 mm) during October when they became age I and about 130-220 mm (mean = 172 mm) during November. The observed lengths of age I fish in September were about 200-340 mm with the mean being 253 mm. This age group was about 190-360 mm (mean = 274 mm) in October when they became age II.

Lengths back-calculated to cold-period marks using the regression of total length on scale radius (Fig. 14) reasonably agree with the sizes at age I estimated by length frequencies in October (Fig. 15). Back-calculated lengths were slightly smaller than the sizes at age I+ in March as expected. Back-calculated lengths from age I+ fish were primarily 110-210 mm at age I with a mean length of 165 mm. In agreement, back-calculated lengths from six age II+ fish had a mean of 181 mm at age I and of 270 mm at age II.

Growth estimates based upon the length-frequency method and from observed and back-calculated estimates using the scale method show very close agreement. Mean lengths in October were about 155-165 mm at age I and 270-280 mm at age II, depending upon how age was determined. The extreme back-calculated and observed size ranges found at given ages may be due to the long spawning season and/or prolonged time span when the cold-period mark may form.

HABITAT SEGREGATION BETWEEN AGE GROUPS

At least part of all croaker age groups apparently utilized bays as feeding grounds during the warmer months, but age I and older fish seemed to occupy different habitat than young-of-the-year. Croaker captured by angling near the oyster reef from June to August were about 200-270 mm in length (Fig. 12) and seemed common there. In contrast, trawl-caught bay fish were generally much smaller than 200 mm. Reef and trawl-caught bay individuals were then about age 0 and age I+, respectively. Many other workers, including Reid (1955), Perret (1966), Nelson (1969), Hansen (1970), Parker (1971), Hoese (1973), and Gallaway and Strawn (1974), have also captured few individuals greater than 200 mm long by trawling in bays;

but they captured many small specimens comparable in size to our trawl-caught fish. Therefore, although bait size may have resulted in selection of larger fish near the reef, the two age groups seem to segregate by habitat: young-of-the-year occupied soft substrates and age I and older fish occurred near oyster reefs. This agrees with Harden Jones' (1968) generalization that the feeding grounds of adult fishes are separate from their spawning grounds and nurseries.

Age I and older fish seemed to remain near oyster reefs until they migrated to sea to spawn. Fish caught near oyster reefs were much larger than those caught trawling in the Gulf or bays until September-October (Fig. 12). Specimens larger than 191 mm were not collected in the Gulf until September, which is about when spawning begins in the northern Gulf (Gunter, 1945; Suttkus, 1954, present study). Simmons and Hoese (1959) captured fish less than 175 mm in length throughout the summer as they migrated to the Gulf, but these workers captured fish similar in size to our reef fish only during September.

The larger young-of-the-year began moving to sea by late spring or early summer. Trawl-caught fish in the bay were smaller than those in the Gulf during June (Fig. 12) when modal length for young-of-the-year was about 120 mm in the bay and about 140 mm in the Gulf. Parker (1971) and Franks et al. (1972) suggested that young-of-the-year began moving to sea at about 85-100 mm in length.

MAXIMUM SIZE AND AGE, LIFE SPAN, AND MORTALITY RATE

Croaker in the Carolinean Province are typically small and have a short life span and high mortality rate. Most fish we collected were less than 200 mm in length and the largest was 357 mm. The largest croaker generally observed in warm-temperate water have been less than 300 mm in length (Hildebrand and Cable, 1930; Reid, 1955; Bearden, 1964; Miller, 1965; Perret, 1966; Nelson, 1969; Hansen, 1970; Parker, 1971; Swingle, 1971; Hoese, 1973; Gallaway and Strawn, 1974), although some workers captured fish as large as 330-380 mm (Pearson, 1929; Gunter, 1945, 1950; Suttkus, 1954; Christmas and Waller, 1973; Franks et al., 1972). Rivas and Roithmayr (1970) found a 668 mm specimen, but this is exceptional.

Our length frequencies suggest two year classes occurred, but only one was abundant. This agrees with other reported length frequencies from warm-temperate waters (see references cited in section on Age Determination and Growth by the Length-Frequency Method). Therefore, the typical croaker life span in warm-temperate water appears to be only one or two years. Age II+ fish captured in March were the oldest fish we examined in agreement with other estimated maximum ages from the Carolinean Province (Gunter, 1945; Suttkus, 1954; Bearden, 1964; Nelson, 1969; Hansen, 1970; Hoese, 1973). Fish associated with oyster reefs are larger and a year older than trawl-caught bay or Gulf fish during the summer. However, the abundance of these age I croaker must be small compared to abundance of age 0 croaker, because the geographical area occupied by oyster reefs is comparatively small.

Croaker have a high total annual mortality rate as their short life span suggests. We found only six age II+ fish in 1123 aged. Greatest mixing of age groups probably coincides with fall spawning in the Gulf. We observed 11 age 1+ and 250 age 0+ fish in random samples from trawl catches made September 25-27, 1974, so that the total annual mortality rate was about 96%. This must approximate the total annual mortality rate throughout the Carolinean Province because maximum sizes and ages, length frequencies, and life spans appear similar throughout this area.

TOTAL WEIGHT-LENGTH AND GIRTH-LENGTH RELATIONSHIPS

Total weight-length and length-girth regression relationships are self-explanatory and are summarized in Fig. 16.

GENERAL DISCUSSION

Many aspects of the life history of Atlantic croaker in the Carolinean Province appear different than those of fish found in cold-temperate waters north of Cape Hatteras except that the growth rates appear similar. In general, our data and the literature cited in pertinent sections of this paper agree that in warm-temperate waters: 1) peak spawning occurs about October but the spawning season is long and lasts from about September to at least March, 2) maturity is reached at about 140-180 mm in length as the fish approach age I, 3) two year classes appear in the length frequencies but one greatly predominates, 4) most fish are about 200 mm or less in length and maximum size is about 300-350 mm, 5) life span is about 1-2 years and maximum age is about two years, 6) most fish live only to about age I, and 7) total annual mortality rate is about 95%. In contrast, fish living north of Cape Hatteras generally: 1) have a spawning season (August-December) that is shorter and starts and ends earlier (Welsh and Breder, 1924; Hildebrand and Schroeder, 1928; Wallace, 1940; Pearson, 1941), 2) have their peak spawning probably in August or September because Pearson (1941) captured croaker less than 15 mm in length primarily in September, 3) reach maturity when greater than 200 mm in length as they approach at least age II (Welsh and Breder, 1924; Wallace, 1940; Haven, 1954), and 4) have large average size [258 mm according to Haven (1959)] and a maximum size of 500 mm or greater (Hildebrand and Schroeder, 1928; Gunter, 1950). Maturity is reached about one year later in cold-temperate waters and typical sizes are much larger, although growth rates appear similar. Maximum age is probably about 2-4 years north of Cape Hatteras in agreement with non-validated ages determined by Welsh and Breder (1924) and Wallace (1940). If these are true, the total annual mortality rate must be lower north of Cape Hatteras.

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FIGURES

FIGURE 1. Gonad weight-length regressions for Atlantic croaker by sex and month. The length of each line shows the observed size range.

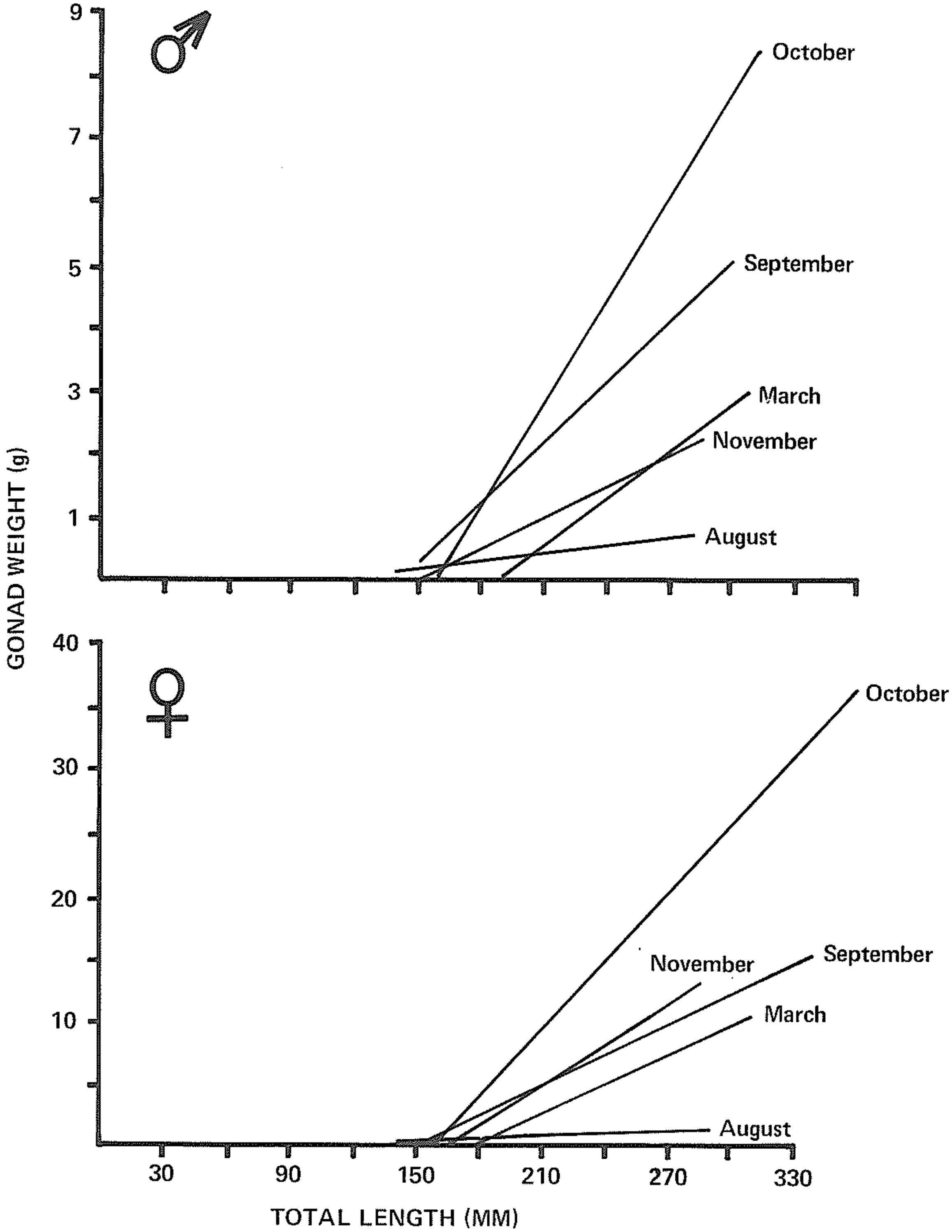

9
7
5
3
1
October
September
March
November
August
40
30
20
10
October
November
September
March
August
30
90
150
210
270
330
TOTAL LENGTH (MM)
GONAD WEIGHT (g)

FIGURE 2. Gonad condition of Atlantic croaker by months and areas. The ordinate represents percent of the sample. Gonad conditions on the abcissa are: immature or resting (1), maturation (2), maturity (3), reproduction (4), and spent (5).

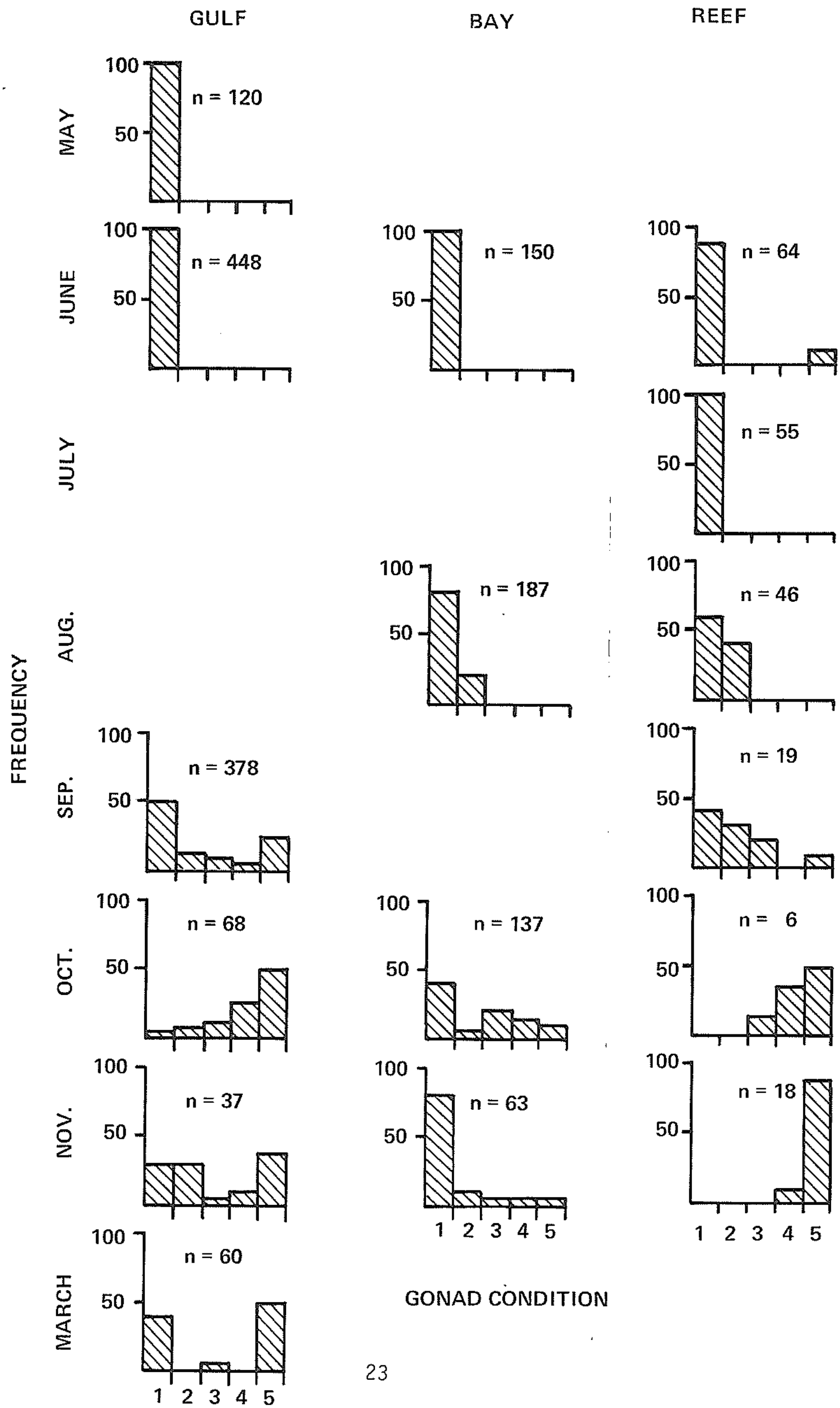
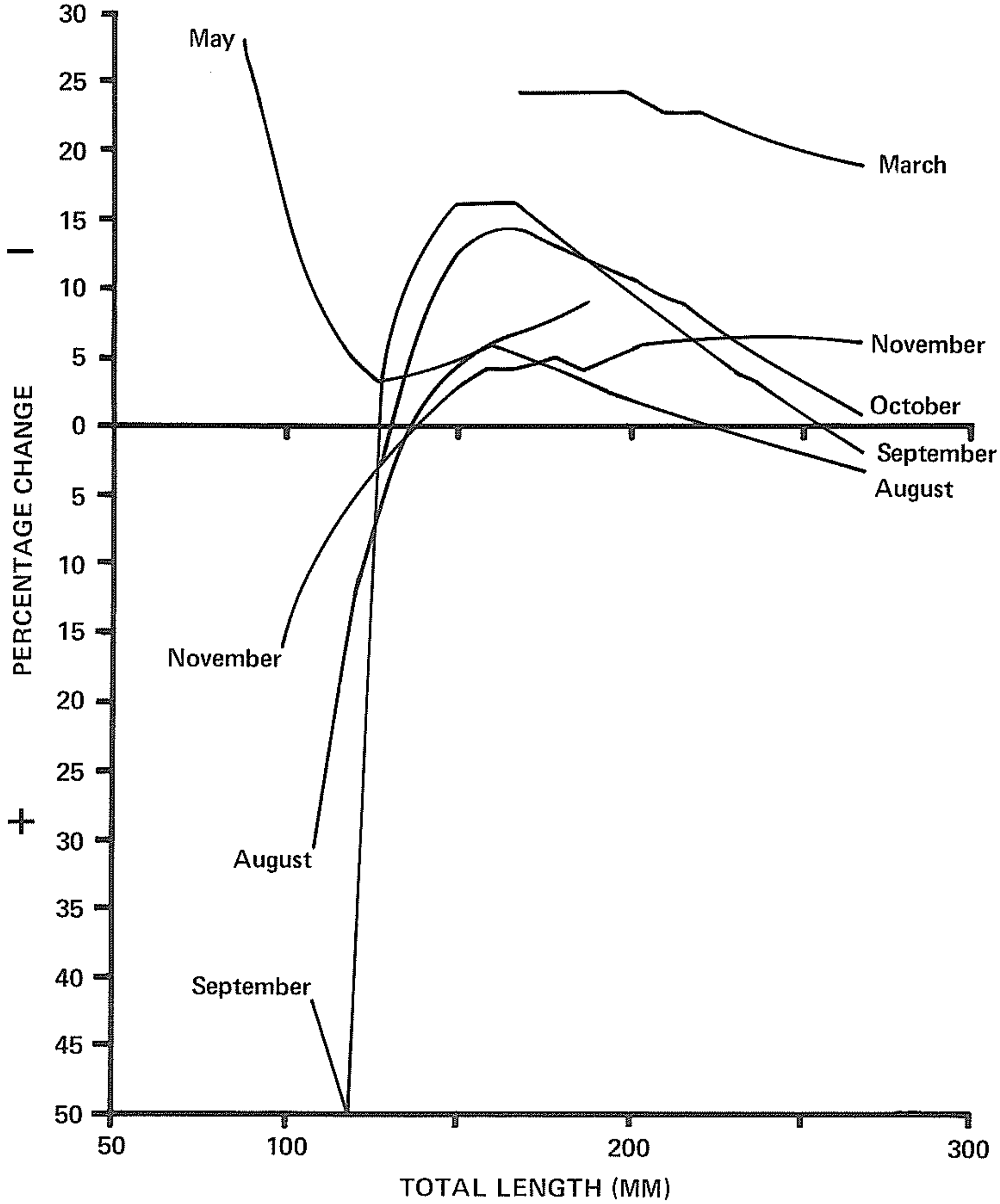

GULF
BAY
REEF
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
MARCH
FREQUENCY
n = 120
n = 448
n = 150
n = 64
n = 55
n = 187
n = 46
n = 378
n = 19
n = 68
n = 137
n = 6
n = 37
n = 63
n = 18
n = 60
100
50
1 2 3 4 5
GONAD CONDITION

FIGURE 3. Monthly somatic weight changes in Atlantic croaker. The lengths of the curves represent observed size ranges.



30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
–
+
PERCENTAGE CHANGE
May
March
November
October
September
August
November
August
September
50
100
200
300
TOTAL LENGTH (MM)

FIGURE 4. Scale from a 190 mm croaker showing mark 1. This fish was approaching age I when it was captured off Texas in September. The axis depicted shows how measurements were made to determine when each mark formed.

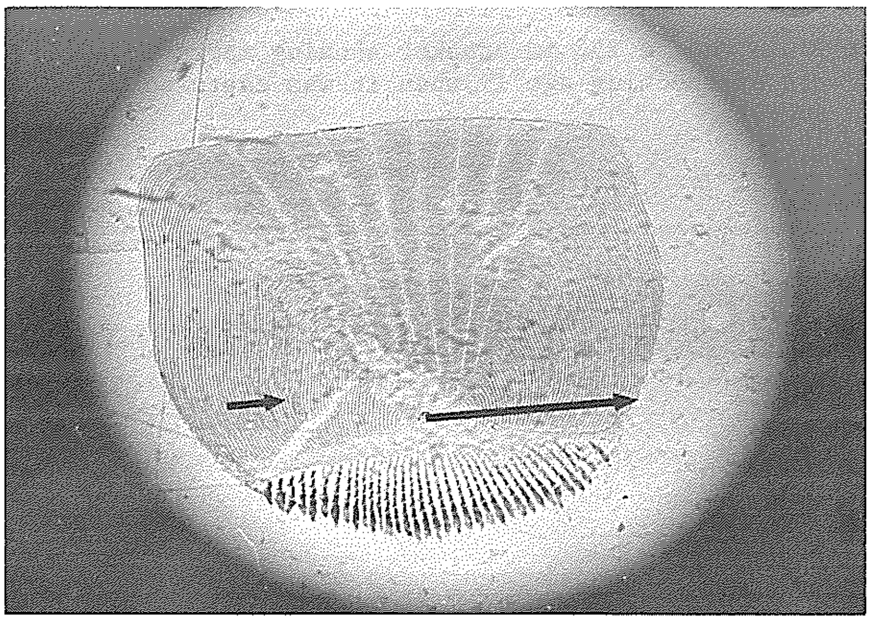


FIGURE 5. Scale from a 255 mm croaker showing marks 1 and 2. This fish was approaching age II when it was captured off Texas in August.

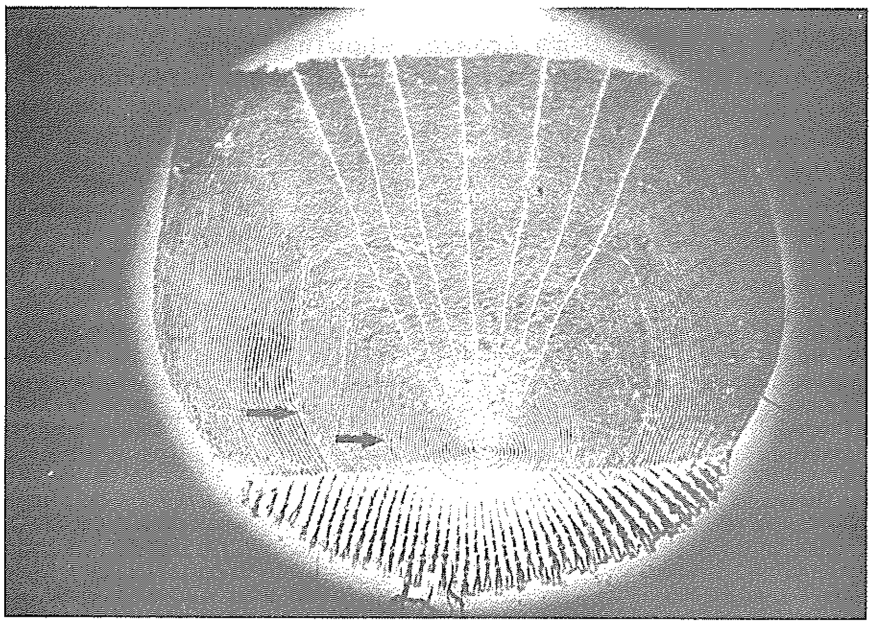


FIGURE 6. Scale from a 310 mm croaker showing marks 2, 3, and 4. This was an age II+ fish captured off Texas in March.

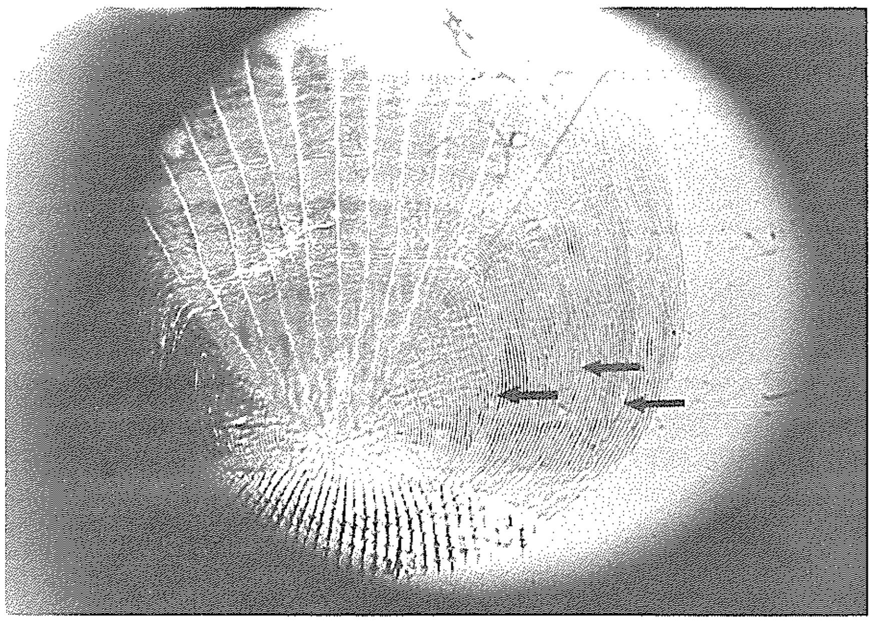


FIGURE 7. Scale from a 260 mm croaker showing marks 1 and 2. This fish was approaching age II when it was captured off Mississippi in August.

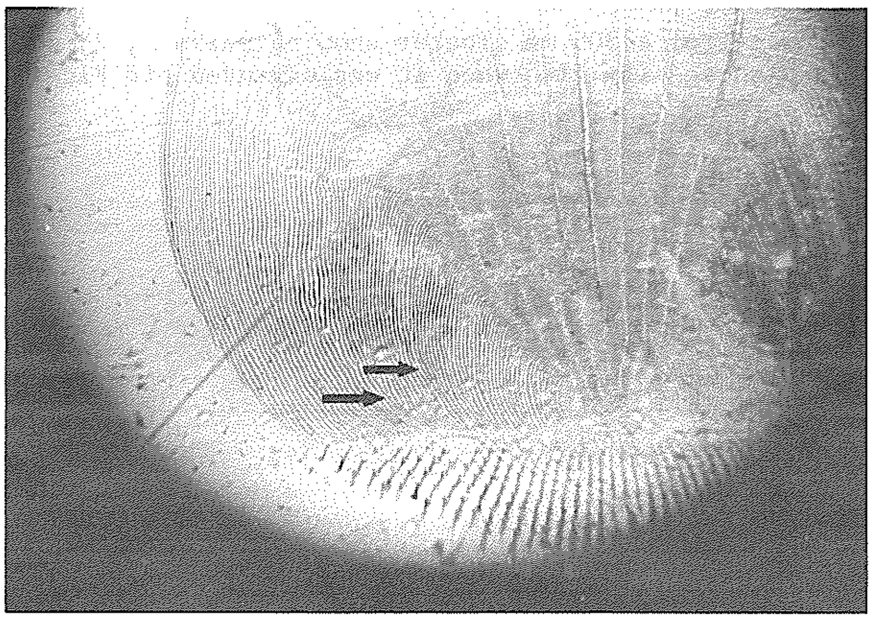


FIGURE 8. Scale from a 305 mm croaker showing marks 1, 2, 3, and 4. This was an age II+ fish when it was captured off Florida in March.

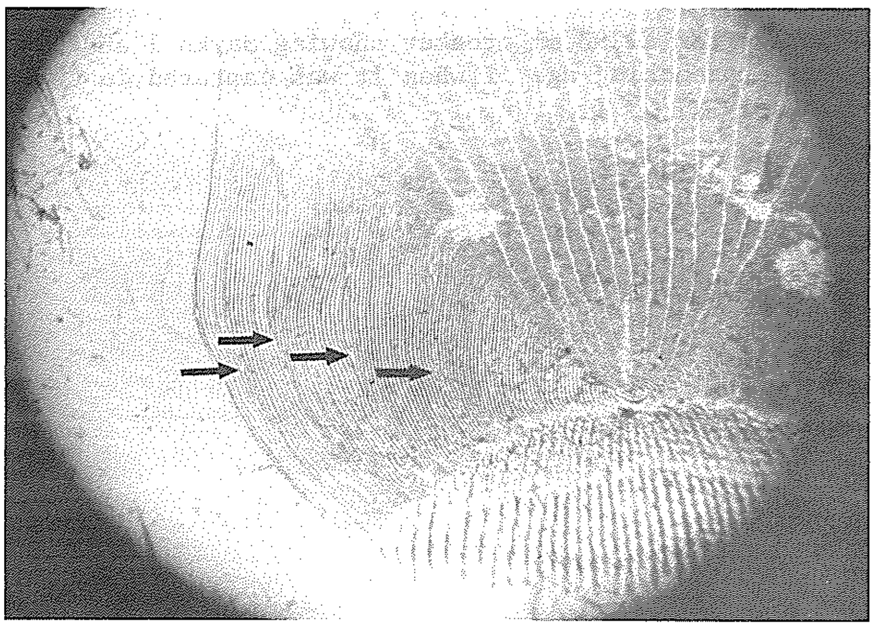


FIGURE 9. Scale from a 293 mm croaker showing marks 1 and 2. This fish was approaching age II when it was captured in Chesapeake Bay in July.

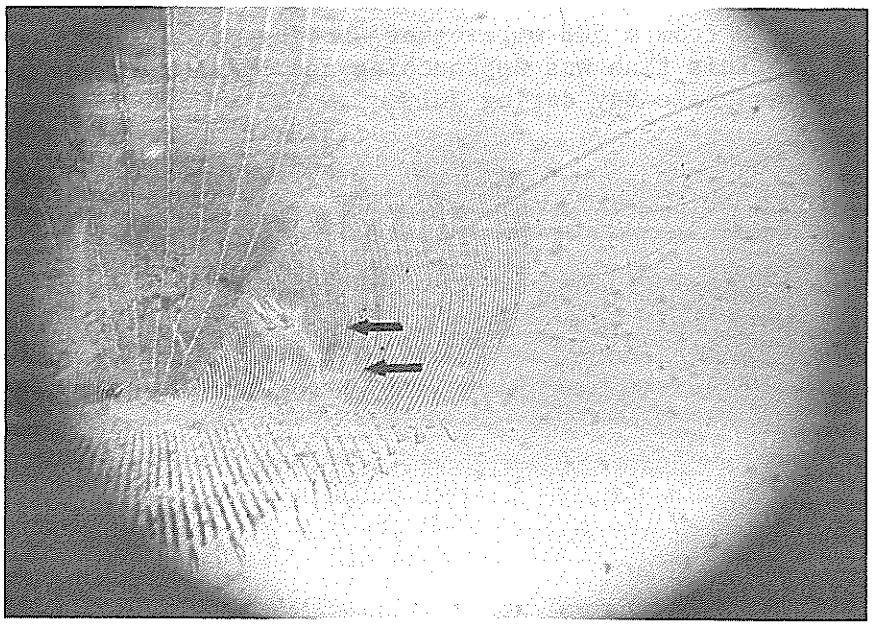


FIGURE 10. Scale from a 508 mm croaker showing marks 1, 2, 3, 4, 5, and 6. This fish was approaching age IV when it was captured in Chesapeake Bay during July.

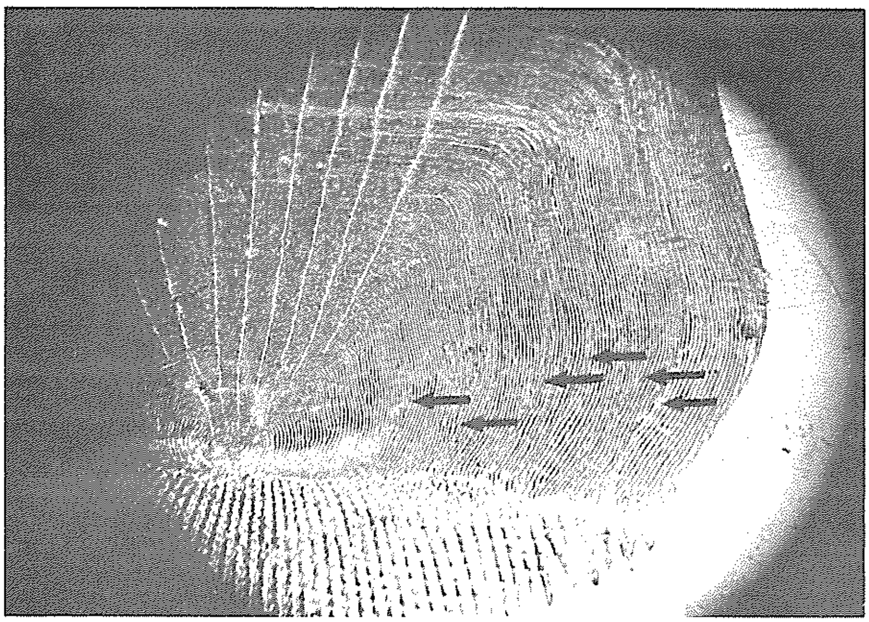
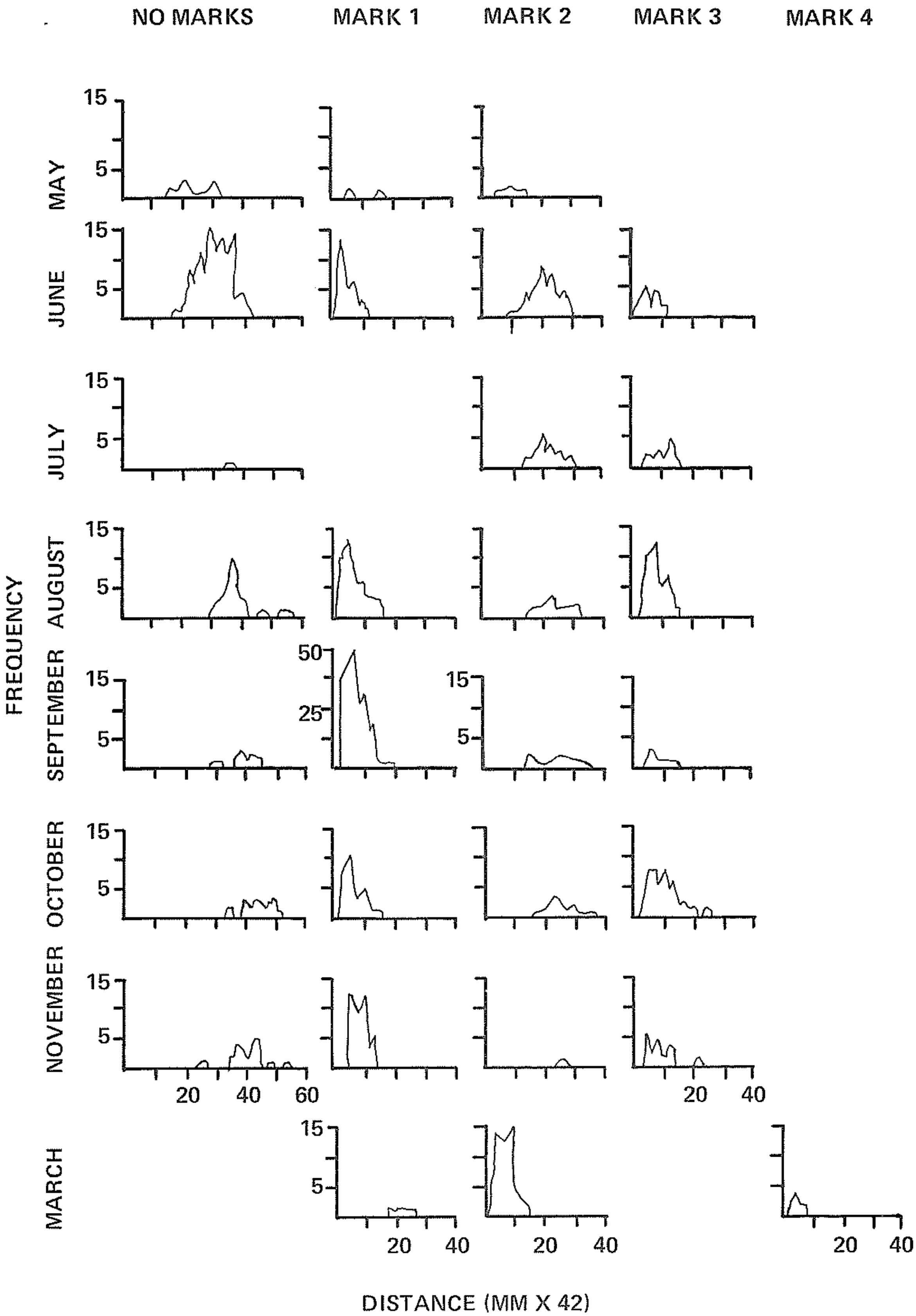
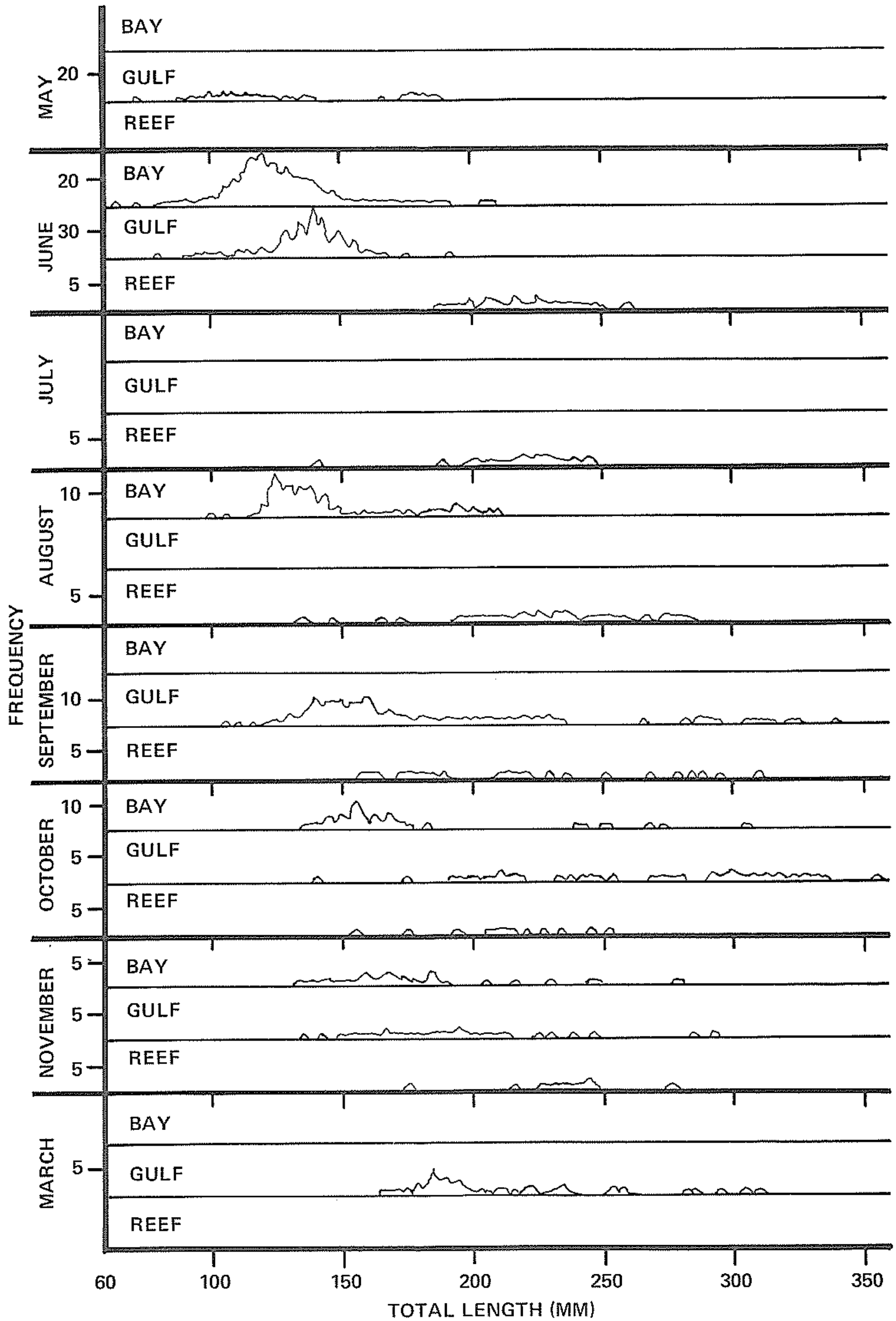


FIGURE 11. Distance from scale margin to the last mark or to the focus if no marks were present.



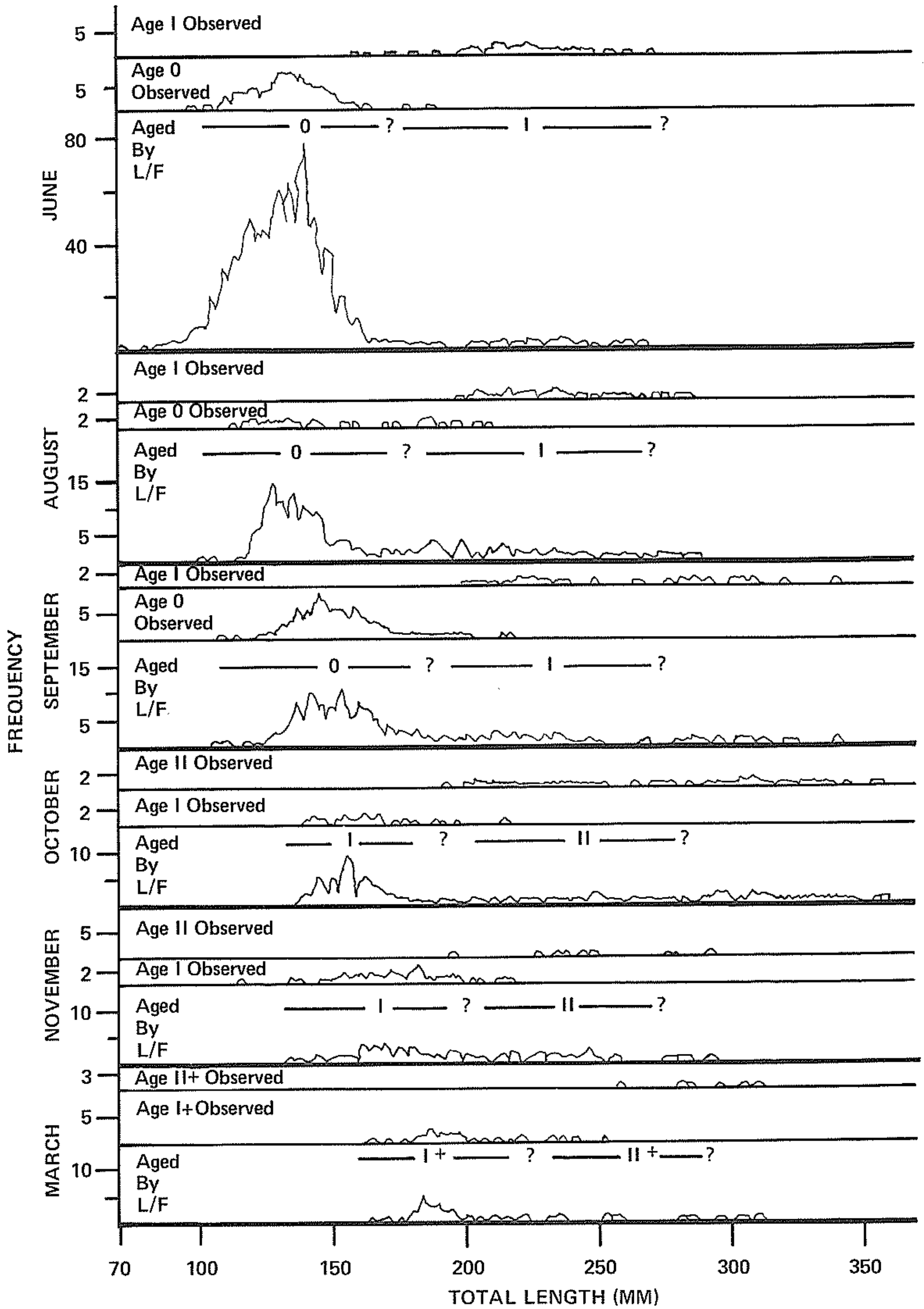
NO MARKS
MARK 1
MARK 2
MARK 3
MARK 4
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
MARCH
FREQUENCY
15
5
50
25
20
40
60
DISTANCE (MM X 42)

FIGURE 12. Length frequencies of Atlantic croaker in each area each month. Frequencies are moving averages of three.



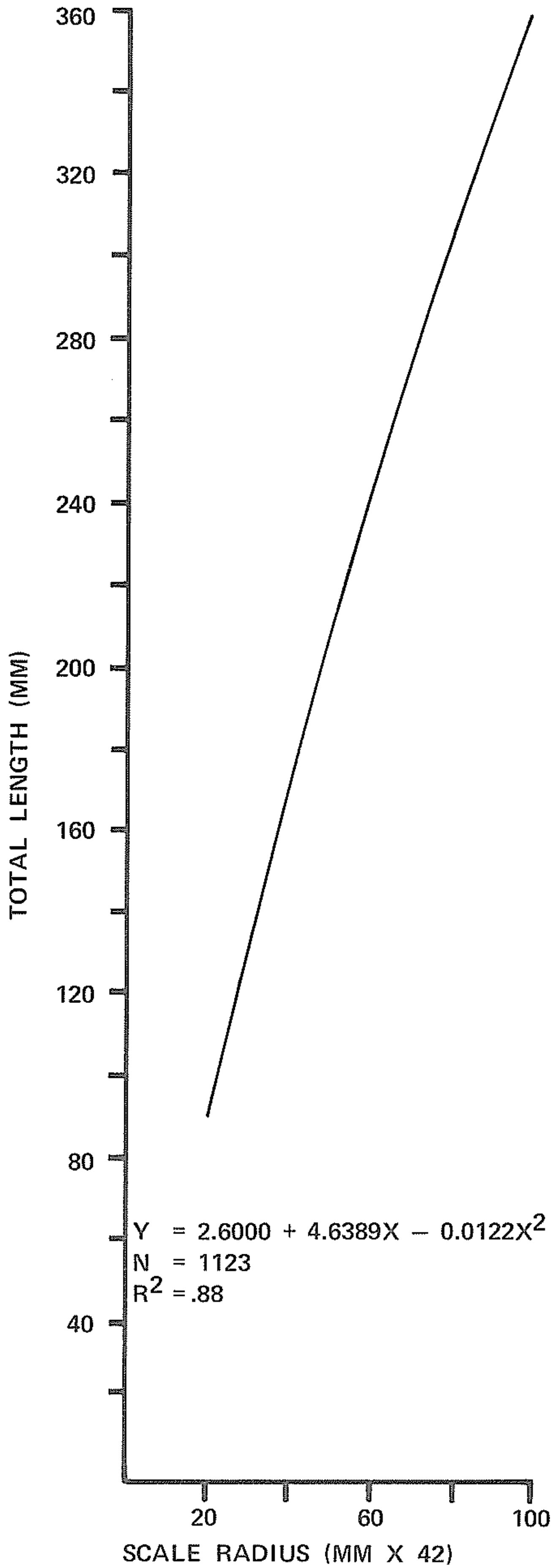
MAY
BAY
GULF
REEF
20
JUNE
BAY
GULF
REEF
20
30
5
JULY
BAY
GULF
REEF
5
AUGUST
BAY
GULF
REEF
10
5
FREQUENCY
SEPTEMBER
BAY
GULF
REEF
10
5
OCTOBER
BAY
GULF
REEF
10
5
5
NOVEMBER
BAY
GULF
REEF
5
5
5
MARCH
BAY
GULF
REEF
5
60
100
150
200
250
300
350
TOTAL LENGTH (MM)

FIGURE 13. Length compositions comparing observed ages with ages determined by the length-frequency method. Frequencies are moving averages of three.



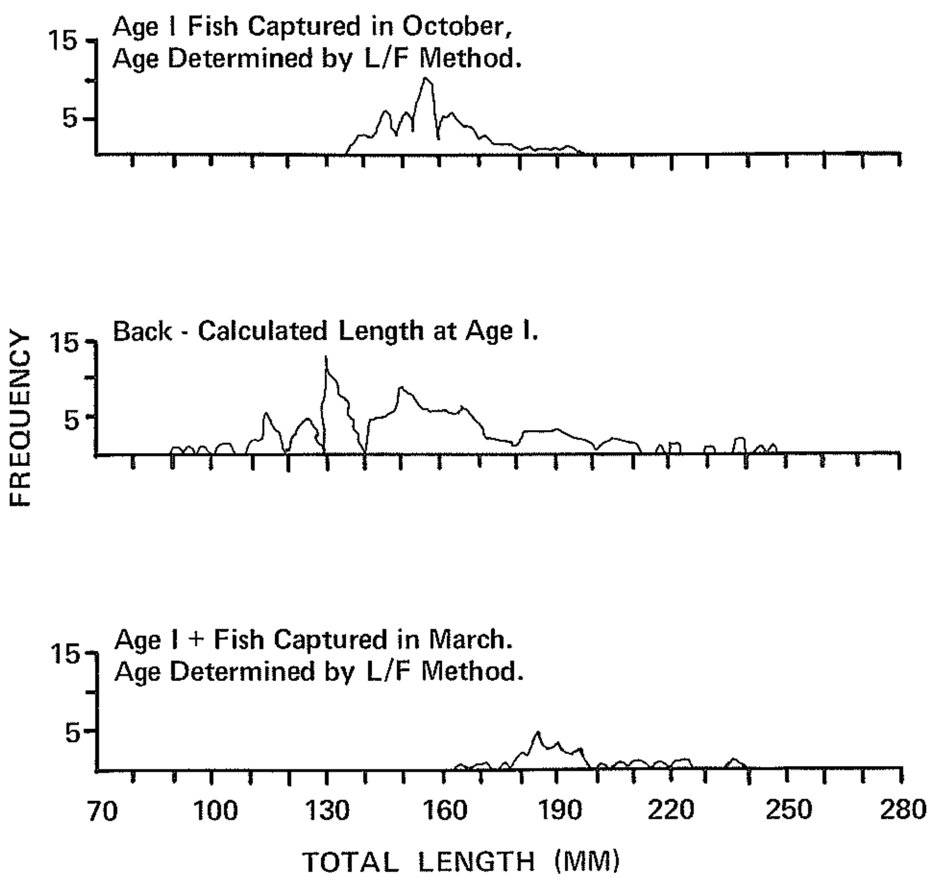
FREQUENCY
JUNE
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
MARCH
Age I Observed
Age 0 Observed
Aged By L/F
0 ? I ?
Age II Observed
I ? II ?
Age II+ Observed
Age I+ Observed
I+ ? II+ ?
70 100 150 200 250 300 350
TOTAL LENGTH (MM)

FIGURE 14. Body length-scale radius relationship for Atlantic croaker. The length of the curve represents the observed size range.



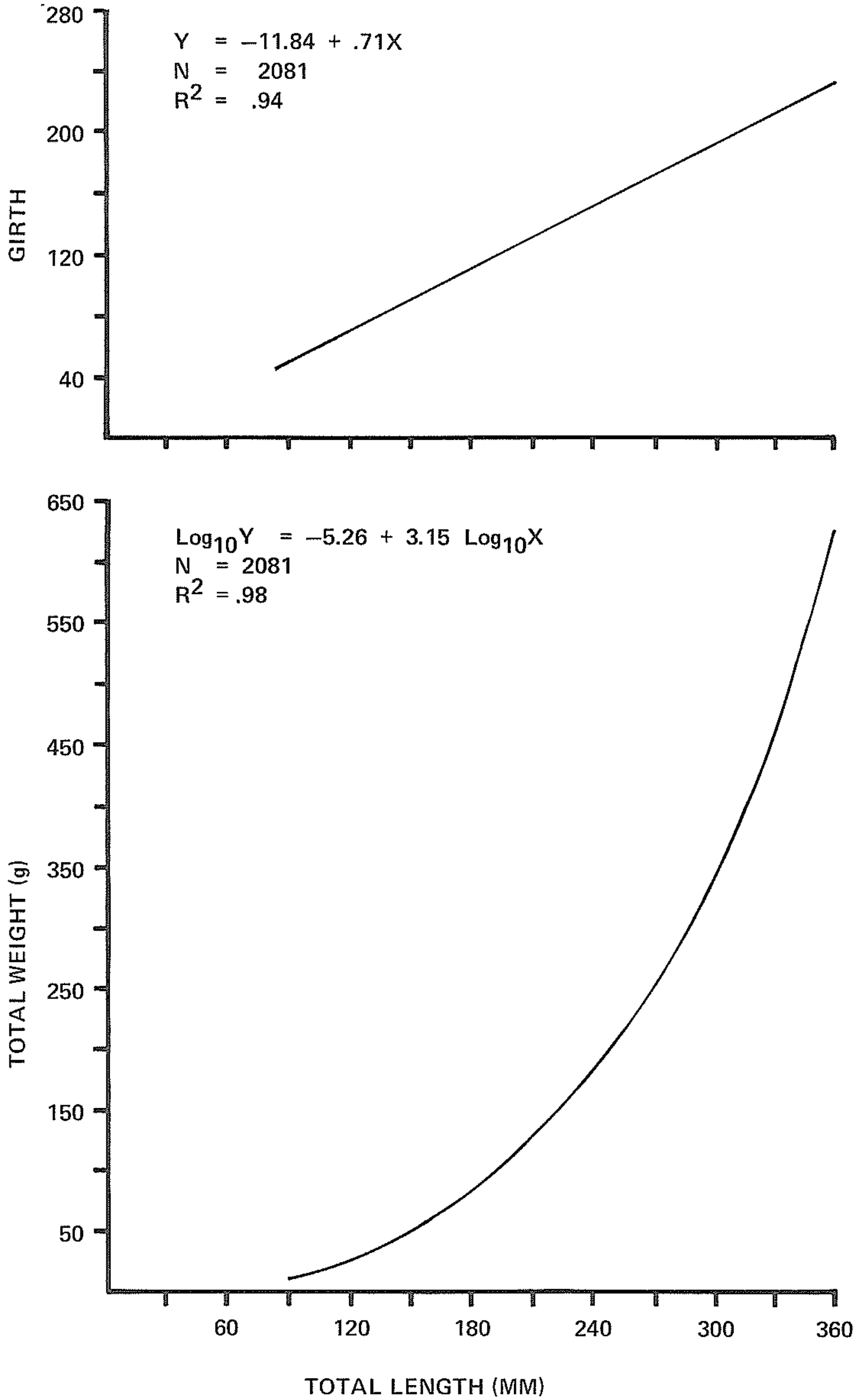
360
320
280
240
200
160
120
80
40
TOTAL LENGTH (MM)
Y = 2.6000 + 4.6389X − 0.0122X²
N = 1123
R² = .88
20
60
100
SCALE RADIUS (MM X 42)

FIGURE 15. Back-calculated length frequencies at age I and length frequencies (L/F) of age I fish in October and age I+ fish in March. Frequencies are moving averages of three.



Age I Fish Captured in October,
Age Determined by L/F Method.
Back - Calculated Length at Age I.
Age I + Fish Captured in March.
Age Determined by L/F Method.
FREQUENCY
15
5
70
100
130
160
190
220
250
280
TOTAL LENGTH (MM)

FIGURE 16. Girth-length and total weight-length relationships for Atlantic croaker. The lines include the observed size ranges. The total weight-length relationship was transformed from a $\log_{10}$ to an arithmetic scale.


Y = −11.84 + .71X
N = 2081
R2 = .94
GIRTH
280
200
120
40
Log10Y = −5.26 + 3.15 Log10X
N = 2081
R2 = .98
TOTAL WEIGHT (g)
650
550
450
350
250
150
50
60
120
180
240
300
360
TOTAL LENGTH (MM)

TABLES

TABLE 1. Analyses for the regressions of gonad weight (g) on total length (mm) for each sex and month. All regressions were significant at α = .0001.

	MALES			FEMALES		
Month	Sample Size	R^2	Equation	Sample Size	R^2	Equation
August	67	.46	Y=-0.389+0.004X	92	.47	Y=-0.426+0.004X
September	108	.68	Y=-4.737+0.033X	286	.63	Y=-11.920+0.080X
October	64	.73	Y=-8.804+0.055X	154	.67	Y=-27.135+0.177X
November	46	.32	Y=-2.782+0.018X	69	.28	Y=-15.570+0.097X
March	35	.43	Y=-3.785+0.021X	41	.32	Y=-13.359+0.077X

TABLE 2. Analyses for the regressions of somatic weight (g) on total length (mm) for each month. All regressions were significant at α = .0001.

Month	Sample Size	R^2	Equation
May	120	.99	$Y = 39.5303 - 0.8538X + 0.0057X^2$
June	686	.99	$Y = 71.1692 - 1.3371X + 0.0076X^2$
August	299	.99	$Y = 120.4035 - 1.9159X + 0.0092X^2$
September	501	.97	$Y = 158.9511 - 2.3706X + 0.0103X^2$
October	265	.98	$Y = 148.7089 - 2.2016X + 0.0097X^2$
November	162	.91	$Y = 73.4739 - 1.2980X + 0.0072X^2$
March	93	.99	$Y = 132.7087 - 1.8537X + 0.0080X^2$