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MATURITY, SPAWNING, AND FECUNDITY OF ATLANTIC CROAKER, *MICROPOGONIAS UNDULATUS*, OCCURRING NORTH OF CAPE HATTERAS, NORTH CAROLINA

The Atlantic croaker, *Micropogonias undulatus*, is an important inshore, bottom fish ranging from the Gulf of Maine to Bay of Campeche, Mexico (Chao 1978). United States commercial landings have reached 50,000 metric tons (t) in recent years (Gutherz et al. 1975; McHugh 1977), though dramatic declines in landings have occurred; at least in the area from Cape Hatteras, N.C., to Cape Cod, Mass. (Joseph 1972). White and Chittenden (1977) have postulated the existence of an abrupt change in life histories and population dynamics of Atlantic croaker and other species whose ranges traverse Cape Hatteras. They showed differences in spawning times, size at maturity, maximum size and age, and total annual mortality rates of Atlantic croakers from north and south of Cape Hatteras and speculated the differences may result from different temperature regimes.

Few studies exist on reproduction of Atlantic croaker occurring north of Cape Hatteras. Wallace (1940) studied size at maturity and sexual development of fish from Chesapeake Bay and ocean waters off Virginia and North Carolina. Welsh and Breder (1923) reported size and age at maturity based on collections from Massachusetts to Florida. Occurrence of larval stages and gonad development indicated that spawning occurred from July through December and peaked during October and November (Welsh and Breder 1923; Hildebrand and Schroeder 1928; Wallace 1940). Haven (1957) and Chao and Musick (1977) found indications from juvenile length frequencies of late winter or early spring spawning. The only report of fecundity was that a 395 mm female contained approximately 180,000 eggs (Hildebrand and Schroeder 1928).

This paper presents size at maturity, spawning times as indicated by ovarian development, and fecundity observations of the Atlantic croaker population north of Cape Hatteras.

Methods

All fish were collected during seven National Marine Fisheries Service bottom-trawl surveys of the continental shelf from Cape Hatteras to Block Island, R.I., during 1973-76 (Table 1). The survey design and sampling methods were described by Grosslein (1969). Atlantic croakers were captured each year between lat. 39°00′ N (Cape May, N.J.) and 35°15′ N (Cape Hatteras) in depths from 7 to 131 m.

Subsamples of approximately 25 fish, representative of the length frequency of each catch, were frozen whole for laboratory examination. Each fish was weighed (grams), measured (millimeters total length, TL), sexed, and its maturity stage was determined using the sexual development classification and criteria of Wallace (1940).

TABLE 1.—Summary of Atlantic croaker data collected between Cape May, N.J., and Cape Hatteras, N.C., during 1973-76.

Collection no.	Dates	No. of observations	Number used in probit analysis	
			Males	Females
1	9-16 Oct. 1973	556	245	286
2	27-30 Sept. 1974	699	324	258
3	16-18 Sept. 1975	79	31	28
4	30 Oct.-6 Nov. 1975	607	204	145
5	14-17 Dec. 1975	122	—	—
6	6-17 Oct. 1976	438	84	103
7	18 Dec. 1976	16	—	—
Total		2,517	888	820

Ovaries in development stage 4 from 1973 and 1974 cruises were exsected, weighed (±0.01 g), and preserved in a modified Gilson's fluid (Simpson 1951) for subsequent fecundity estimation.

Egg counts for fecundity estimation were made by a method similar to Bagenal's (1957), but modified as follows. After 4-6 wk preservation the ovaries were washed over a 1.0 mm mesh screen which permitted all the eggs to pass through it but retained the ovarian tissue. After repeated washings and decanting the eggs were diluted in water to a known volume, randomly stirred, and three 10 ml aliquots, each containing from 200 to 400 eggs, were extracted and the eggs counted using a microscope. To test the accuracy of the sampling method two aliquots were extracted from an egg batch, counted, and replaced until 20 aliquots were counted. The mean and standard deviation (SD) of all counts was 255 and 38.3, and the coefficient of variation (CV) was 15.0%. For the means of three samples the SD was 20.4 and the CV was 8.7%. The mean egg number of the three aliquots times the total dilution volume divided by the aliquot volume was used to estimate fecundity.

Estimates of length at maturity (length at which 50% are mature = L_{50}) were calculated using probit analysis (Finney 1971). Samples used in this analysis were collected from September to November (Table 1; cruises 1-4, 6) which minimizes the affects of seasonal growth on length at maturity. The proportion of mature fish for each centimeter group was calculated for each year by sex. Table 2 shows the proportion mature by centimeter group for the interval between 0 and 100% mature. The proportions were transformed to probits (Fisher and Yates 1964) and the iterative method was used to calculate the weighted linear regression equation, $Y = a + b\,X$, by least squares for the logarithm (base 10) of length (X) and the probit (Y). Chi-square tests indicated no significant ($\chi^2_{0.01}$) heterogeneous deviations from the regression lines; therefore, the regression coefficients were used to determine L_{50}. The variance of L_{50} was estimated as:

$$V(L_{50}) = \frac{1}{b^2}\left[\frac{1}{\Sigma nw} + \frac{\left(L_{50} - \frac{\Sigma nwx}{\Sigma nw}\right)^2}{\Sigma nw\left(x - \frac{\Sigma nwx}{\Sigma nw}\right)^2}\right]$$

where n is the number of observations at each centimeter group, w is the weighting coefficient (Z^2/PQ) (Finney 1971, table II) for probit (Y), and x is the logarithm (base 10) of the length.

In order to test for differences in L_{50} between sexes and between years, z-values (Natrella 1966) were calculated using the equation:

$$z = \frac{L_{50_1} - L_{50_2}}{\sqrt{V(L_{50_1}) + V(L_{50_1})}}\ .$$

TABLE 2.—Percentage mature used in probit analysis by total length group for male (M) and female (F) Atlantic croaker collected in 1973-76. N = number of specimens, L_{50} = length at 50% mature, V(L_{50}) = variance of L_{50}, and χ^2 = for goodness of fit of probit regression line.

Total length (cm)	1973		1974		1975		1976	
	M	F	M	F	M	F	M	F
16							0	
17		0			0		17	0
18	0	10	0		16	0	13	31
19	17	29	9	0	18	10	67	70
20	69	45	36	10	37	33	89	80
21	90	86	47	23	32	28	91	85
22	94	84	56	35	47	30	90	83
23	89	78	65	47	50	27	100	71
24	92	86	85	74	47	43		94
25	97	94	95	93	78	69		100
26	100	97	98	97	77	79		
27		100	100	100	90	82		
28					93	100		
29					100			
N	245	286	324	258	235	173	84	103
L_{50}	19.17	19.81	21.57	22.70	22.35	23.27	18.71	18.52
V(L_{50})	0.0190	0.0191	0.0357	0.0283	0.0376	0.0356	0.0438	0.0234
χ^2	15.82	13.82	5.11	3.97	7.07	12.16	4.09	8.66
df	7	9	8	7	11	9	6	7

Results and Discussion

Length at Maturity

The matrix of z-values is shown in Table 3. Highly significant ($z>2.33$, $P\leq0.01$) differences were found between sexes within years for 1975 and 1976 and between years for each sex except 1973 and 1976 males and 1974 and 1975 females. This indicates that L_{50} for males and females was greater in 1974 and 1975 than in 1973 and 1976. The greatest difference was found between 1975 and 1976 when L_{50} decreased approximately 4.8 cm for females and 3.6 cm for males.

Significant long-term changes in L_{50} have occurred since Wallace's (1940) studies of Chesapeake Bay croakers. The smallest mature female he observed during 1938-40 was 27.5 cm, indicating a L_{50} of at least 30 cm. His collections were made during July and August; therefore, due to additional growth during early fall, 30 cm is an underestimation of L_{50} for comparison with my results obtained from September-November.

Spawning

The percentage frequencies of maturity stages indicate spawning commenced at least as early as the beginning of September, peaked during October, and ended by late December. The maturity stages and sample years were combined for analysis (Table 4). The percentage of ripe ovaries remained high during September and October, then dropped to a low level in November. No ripe females were found in December. As would be expected the percentage of spawned fish (partially spent, spent, and resting) increased during the sampling period and indicated spawning was nearly completed by mid-December. Because of difficulty in assigning a specific maturity stage to testes and since ovarian development was the best indicator of spawning, males were not analyzed.

The beginning of the spawning season was not sampled; however, an examination of Wallace's (1940) maturity stage data for July and August showed that over 50% of the ovaries were developing (stages II and III) and <10% were ripe (stage IV). The remainder was classified as resting (stage I). Wallace made additional collections in November which showed that ovaries were either partially spent (stage VI) or spent (stage VII). His findings support this study, indicating that spawning commenced about mid-August and was completed by the end of December.

The presence of small juveniles (20-40 mm TL) during April and May have led to speculations of different spawning populations and a spring spawning peak. Chao and Musick (1977) apparently detected a modal group "entering" the York River in May and suggested they may represent

TABLE 3.—Matrix of z-values (Natrella 1966) and significance for differences in L_{50} (length at which 50% of specimens were mature) of male (M) and female (F) Atlantic croaker collected in 1973-76.

	1973		1974		1975		1976	
	M	F	M	F	M	F	M	F
1973 M		0.196	7.269**	16.214**	9.632**	17.546**	6.937**	5.779**
F				9.058**		7.544**		3.196**
1974 M				4.467**	2.903*	6.367**	6.329**	12.546**
F						1.400		12.122**
1975 M						3.400**	8.055**	15.507**
F								9.972**
1976 M								0.729

*$P\leq0.01$; **$P\leq0.001$.

TABLE 4.—Percentage frequency of maturity stages of female Atlantic croaker collected between Cape May, N.J., and Cape Hatteras, N.C., during 1973-76.

		Sampling interval				
Maturity stage	Wallace's stages (1940)	16-18 Sept. 1975	29 Sept.- 1 Oct. 1974	5-20 Oct. 1973, 1976	30 Oct.- 6 Nov. 1975	14-17 Dec. 1975
Developing	II and III	51	29	23		
Ripe	IV and V	46	51	41	12	
Partially spent	VI	3	7	13	31	10
Spent	VII		11	17	32	28
Resting	I		2	6	25	62
Total		42	286	448	196	51

progeny from a different spawning population. Haven (1957) found 20-30 mm fish during April and concluded the spawning season extended over almost the entire year with a possible spring peak. The apparent 9- or 10-mo spawning season may result from little or no overwinter growth or sampling bias due to differential size distribution or trawl avoidance (Haven 1957; White and Chittenden 1977; Chao and Musick 1977). Maturity observations made during this study showed essentially all adult fish spawned during August through December and it is unlikely a spring spawning peak would occur from the Atlantic croaker population north of Cape Hatteras.

Fecundity

Fecundity ranged from 100,800 to 1,742,000 for fish from 196 to 390 mm TL. Preliminary plots of fish length versus fecundity indicated a curvilinear relationship and plots of fish weight and ovary weight versus fecundity appeared linearly related. Therefore, fish length and fecundity were transformed to logarithms (base 10) and least squares regression lines fitted to the data by year using the equation log fecundity = log a + b (log length). Fish weight and ovary weight versus fecundity were related by the linear regression equation $Y = a + bX$ where Y is fecundity and X is either fish weight or ovary weight. Analysis of variance indicated no significant ($P \leq 0.05$) differences in variance about the regression between years for each of fecundity versus length, weight or ovary weight. Analysis of covariance was used to test for between years differences in fecundity relationship. No significant ($P = 0.01$) difference was indicated; therefore, regression equations were calculated for pooled data. Scatter diagrams and fitted lines are shown in Figures 1-3.

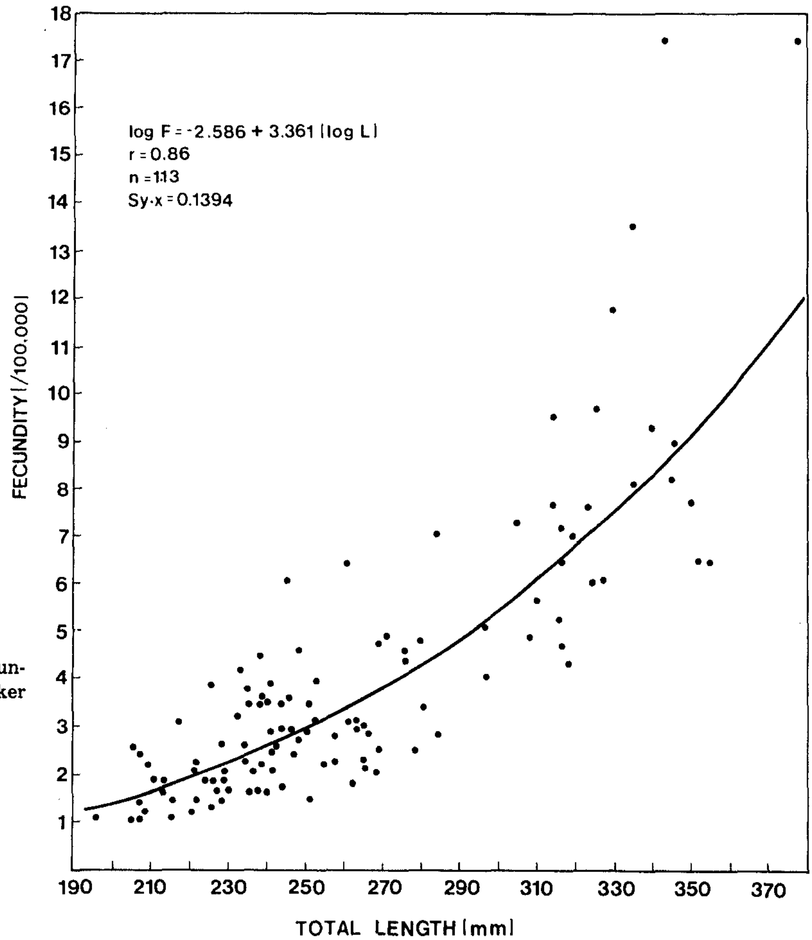

FIGURE 1.—Relationship between fecundity and total length for Atlantic croaker collected in 1973 and 1974.

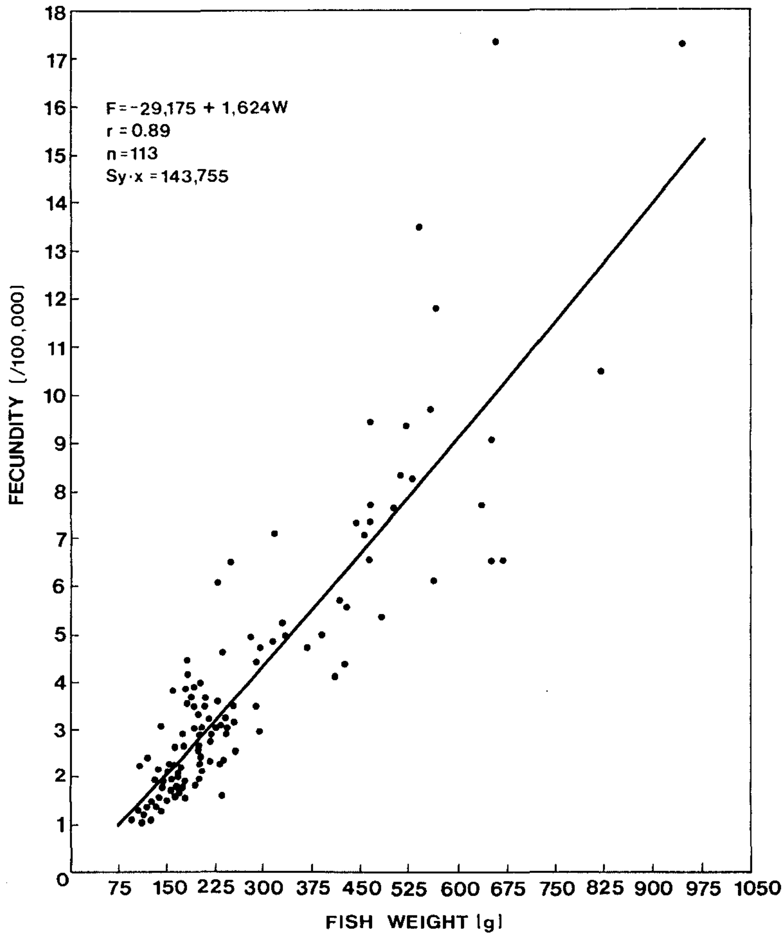

FIGURE 2.—Relationship between fecundity and fish weight for Atlantic croaker collected in 1973 and 1974.

The correlation coefficients for the relationships of fecundity to length, weight, and ovary weight show ovary weight was most closely associated with the variation of fecundity. Unless the ovaries are selected, however, ovary weight is the least reliable predictor of fecundity. It is the most variable parameter and, unless ovaries are collected at the penultimate development stage, the relationship of ovary weight and fecundity will vary seasonally. Fish weight will also vary seasonally and, when ovary weight is included with fish weight, some autocorrelation is present. For general prediction of fecundity, length appears to be the most reliable measure.

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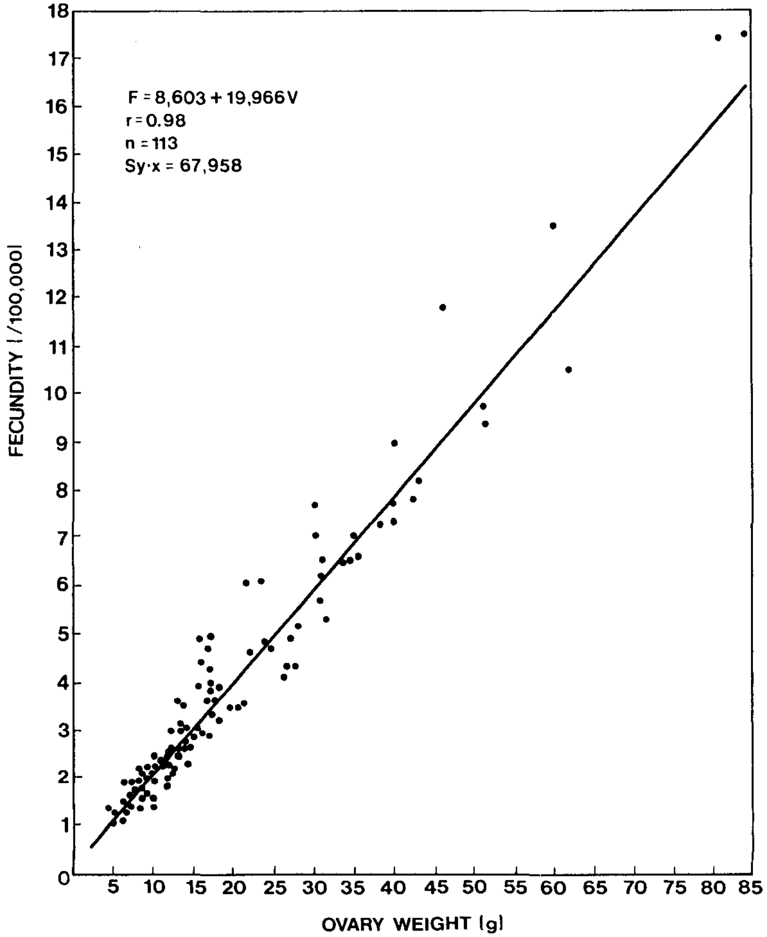

FIGURE 3.—Relationship between fecundity and ovary weight for Atlantic croaker collected in 1973 and 1974.

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