DISTRIBUTION, ABUNDANCE, AND AGE AND GROWTH OF THE TOMTATE, *HAEMULON AUROLINEATUM*, ALONG THE SOUTHEASTERN UNITED STATES COAST[1]

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ABSTRACT

Tomtates, *Haemulon aurolineatum*, were widely distributed over sponge-coral habitats throughout the South Atlantic Bight region in depths of 9 to 55 m, although they were occasionally caught in large numbers over sandy bottom habitats. Fish were most common in offshore areas during winter and were not taken in waters of <10°C south of Cape Fear, N.C. Juveniles ($\leq$148 mm TL) were caught in the same geographical areas as adults, but were collected in warmer waters than adults during fall and winter. Spawning occurred during the spring.

Individuals collected by hook and line and trawl were aged by scales and otoliths. Back-calculated mean total lengths were from 103.0 mm at age I, to 280.5 at age IX. The von Bertalanffy growth equation is $l_t = 310\,(1 - \exp - 0.22017\,(t + 1.28))$, where t is age in years, and l_t is total length at age. The oldest fish sampled was age IX, 289 mm TL. Annual total mortality based on catch curves from 1,496 fish landed by the recreational fishery from 1972 to 1978 was 59% (instantaneous total annual mortality = 0.89). We found that the tomtate grows faster, does not live as long, and has a higher natural mortality rate than most other reef fishes previously studied in the South Atlantic Bight.

The tomtate, *Haemulon aurolineatum*, is a small grunt (Haemulidae), which occurs from Cape Cod, Mass., to Brazil, including the Caribbean, Gulf of Mexico, and Central American coast. The species, previously referred to as *Bathystoma rimator*, *B. aurolineatum*, and *Haemulon rimator* (Courtenay 1961), is known vernacularly as xira in Brazil; cuji in Venezuela; rancho, juez, and chankay in Mexico; and mulita, mula, mariquita, and maruca in Puerto Rico.

The tomtate is taken primarily by hook and line off the southeastern United States and by traps, hook and line, and trawl in the more southern areas of its range. Unfortunately, commercial landings of tomtates in the United States are reported in the collective term "grunts," which includes many different species of the family and therefore precludes species identifications that are needed for fishery management. A Soviet-Cuban cooperative fisheries research program on the Campeche Banks revealed the tomtate as the main demersal species caught by trawl from 1962 to 1972 (Sokolova 1969; Sauskan and Olaechea 1974). Also, exploratory trawling off South Carolina found large quantities of tomtates (Wenner et al. 1979a).

Recreational headboat[4] fishermen fishing from North Carolina to Cape Canaveral, Fla., caught an average of 23.2 t (metric tons) of tomtates in 1976 and 1977 (Dixon[5]). This species was the most commonly caught haemuline, although second in weight landed to the white grunt, *Haemulon plumieri*.

In this paper we describe the relative abundance, spatial and temporal distributions, spawning, age, growth, and mortality for tomtates along the southeastern United States.

METHODS

Distribution and Relative Abundance

Eight groundfish survey cruises spanning all four seasons (Table 1) were conducted on the con-

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[4] A boat for hire where anglers are charged on a per person basis.

[5] R. L. Dixon, Southeast Fisheries Center Beaufort Laboratory, NMFS, NOAA, Beaufort, NC 28516, pers. commun. January 1978.

Manuscript accepted September 1981.

TABLE 1.—Groundfish cruises of the RV *Dolphin*.

Cruise	Dates	No. of trawls	No. of tows with tomtates	No. of tomtates
DP-7305	23 Oct. -16 Nov. 1973	86	18	2,075
DP-7402	1 Apr. - 9 May 1974	112	19	442
DP-7403	13 Aug.-19 Sept. 1974	87	14	581
DP-7501	16 Jan. -10 Apr. 1975	92	10	1,212
DP-7503	30 Aug.-19 Sept. 1975	87	20	1,298
DP-7601	12 Jan. - 7 Feb. 1976	86	15	4,005
DP-7603	28 Aug.-21 Sept. 1976	89	15	1,749
DP-7701	17 Jan. - 9 Mar. 1977	93	11	3,260

tinental shelf and upper continental slope between Cape Fear, N.C., and Cape Canaveral, Fla., except in spring 1974 when sampling extended to Cape Hatteras. A preassigned number of stations was selected randomly (Grosslein 1969) with a set number in each of six depth zones (9-18 m; 19-27 m; 28-55 m; 56-110 m; 111-183 m; 184-366 m). Bottom water temperatures were measured at each station with mechanical or expendable bathythermographs.

Thirty-minute trawls were made continuously (day and night) from the RV *Dolphin*, at 6.5 km/h with a towing wire scope of 2.5-3.0:1. The trawl was a 3/4-scale version of a "Yankee No. 36" with a 16.5 m footrope, 11.9 m headrope, and 1.3 cm stretch mesh cod end liner (Wilk and Silverman 1976).

Fork lengths (later converted to total lengths) of all fish collected by trawl were recorded to the nearest centimeter. Frozen fish samples were taken to the laboratory for further investigations.

An index of relative abundance (Musick and McEachran 1972) was calculated for each depth zone by the following expression:

$$\text{Index of Relative Abundance} = \frac{\Sigma \ln (x + 1)}{n_h}$$

where n_h = number of trawls in the hth depth zone, and x = number of individuals for each tow in a given depth zone. Because previous investigators have shown that trawl catches are usually distributed as a negative binomial (Elliott 1971; Taylor 1953), a ln $(x + 1)$ transformation was made on the relative abundance data to permit statistical tests to determine if the differences among habitats within depth zones were significant.

Estimates of biomass standing stock were calculated with both transformed, ln $(x + 1)$, and untransformed data for comparison of the resulting values. The stratified mean catch/tow (Cochran 1977) was calculated by the expression:

$$\bar{y}_{st} = \frac{1}{N} \sum_{h=1}^{k} [N_h \bar{y}_h]$$

where $\bar{y}_{st}$ = stratified mean catch(kg)/tow,
N = total area,
N_h = area of hth depth zone (from planimeter chart measurements),
$\bar{y}_h$ = mean catch/tow in the hth depth zone, and
k = number of zones in the set.

The area of live-bottom habitat in each depth zone (≈14.5%) was estimated from the frequency of occurrence of sponge and coral in catches during 5 yr of bottom trawling with the stratified random sampling design. The areas of sandy-bottom habitats were obtained by subtraction. The estimated population variance of the mean catch(kg)/tow was also calculated by Clark and Brown (1977):

$$S^2 = \frac{1}{N} \sum_{h=1}^{k} [N_h \bar{y}_h^2] - N\bar{y}_{st}^2 + \sum_{h=1}^{k} S_h^2 \left[(N_h - 1) + \frac{(N_h - N)}{N} \frac{(N_h - n_h)}{n_h}\right]$$

where S^2 = estimated population variance, and
S_h^2 = variance of the hth zone.

The mean catch/tow $(\bar{y}_h)$ of the transformed ln $(x + 1)$ data was estimated for each depth zone following the methodology of Bliss (1967):

$$E(\bar{y}_h) = \exp\ (\bar{y}_h + S_h^2/2)$$

where $E(\bar{y}_h)$ = the estimated (retransformed) mean catch(kg)/tow in the hth depth zone, $\bar{y}_h$ and S_h^2, both expressed in logarithmic units, are the zone mean and its variance. The same methodology was applied to obtain the stratified mean catch/tow from transformed data for the whole study area. Biomass estimates were expanded by the area swept method (Rohr and Gutherz 1977), using

$$SS_{tot} = \sum_{h=1}^{k} (\bar{P}_h)\ (A_h)$$

where SS_{tot} = total standing stock,

$\bar{P}_h$ = average population expressed as kilograms per km^2 in the hth depth zone, and
A_h = total area of the hth depth zone.

The sweep of the "3/4 Yankee trawl" was 8.748 m (Azarovitz[6]), and 3.241 km was the distance covered during a standard trawl. It should be noted that all estimates were minimum estimates because the sampling efficiency of our gear with regard to tomtates was unknown. Standing stock values calculated for sandy-bottom areas incorporated such a large number of zero catches that the transformation did not normalize the data, so the resulting values should be considered suspect.

Age and Growth

Scales, otoliths, fish lengths, and fish weights were collected from 1,496 tomtates from the recreational headboat fishery operating from North Carolina to Cape Canaveral from 1972 through 1978 and from approximately 100 juvenile fish collected by research trawling off South Carolina. Total fish length was recorded in millimeters and weight in grams.

Scales were removed from beneath the tip of the posteriorly extended pectoral fin, soaked in a one-tenth aqueous solution of phenol, cleaned and mounted dry between two glass slides, and viewed at 40× magnification on a scale projector. Measurements were made and recorded from the scale focus to each annulus and to the scale edge in the anterior field for marginal increment analyses and back-calculating fish length at the time of annulus formation.

Otoliths (sagittae) were removed by making a transverse cut in the cranium with a hacksaw midway between the posterior edge of the orbit and the preopercle. The skull was pried open and the otoliths were removed with forceps, washed in water, and stored dry in labeled vials. Rings were counted by placing the otoliths in a blackened-bottom watch glass and then viewing the structures through a binocular dissecting microscope with the aid of reflected light. Some of the otoliths from large (older) fish were sectioned with a Buchler, Isomet, 11-1180[7] low-speed saw to facilitate aging. Measurements were not recorded from otoliths since these structures were used only as a method of validating age determined by reading scales.

Lengths by age for fish from all years combined were back-calculated from a scale radius-fish length regression. The regression equation was based on the relationship of magnified (40×) scale length to total fish length. Since a majority of the scale measurements were clustered around a relatively narrow size range, we based our regression on a subsample of scale radius and body length measurements. After grouping the measurements into 25 mm body length intervals, we selected approximately 12 from each interval to ensure that the regression provided good representation. The prediction equation took the form $TL = a\ SR^b$; where TL = total length, SR = scale radius, a = intercept, and b = slope. We substituted the means of the distances from the focus to each annulus for SR in the above equation, calculated the mean fish length for the time of each annulus formation, and then calculated mean growth increment for each age group.

Calculation of a theoretical growth curve is useful in modeling of growth in natural populations of fish. Growth parameters such as theoretical maximum attainable size (L_∞), growth coefficient (K), and theoretical time of the beginning of growth (t_0), may be used in constructing population models. The most popular theoretical growth curve, the von Bertalanffy ($l_t = L_\infty(1 - \exp -K(t - t_0))$) was fitted to back-calculated length at age data (Ricker 1975; Everhart et al. 1975). This particular equation also allows us to make comparisons with results obtained by other researchers.

The growth parameter, L_∞, was first derived by fitting a Walford (1946) line: $l_{t+1} = L_\infty (1 - k) + kl_t$ to back-calculated data where l_t = total length at age t, and k = slope of the Walford line. The slope (k) is equal to e^{-k}, thus our first estimate of $K = \ln k$. Preliminary values of L_∞ were obtained by solving the equation $L_\infty = y$-intercept / $(1 - k)$, and by regressing annual growth increment (X) against fish length at the beginning of the incremental period (Y) (Jones 1976). By plotting $\log_e (L_\infty - l_t)$ against t and by using trial values of L_∞ ranging from lower than the prelimi-

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[6] T. Azarovitz, Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, Mass., pers. commun. January 1978.

[7] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

nary values to much greater, we determined the best L_∞ that resulted in the straightest line. The growth coefficient (K) was the slope of this line and was used to solve for t_0:

$$t_0 = \frac{\text{y - intercept of natural log line - } \log_e L_\infty}{K}.$$

We checked the t_0 value to see if it was biased toward younger or older fish by using the equation $t_0 = t(1/K) \ln (1 - l_t/L_\infty)$ for separate ages I-IX (Jones 1976).

Mortality Estimates

We calculated annual total mortality estimates by analyzing catch curves (Beverton and Holt 1957) based on fully recruited age fish and older. If the $\log_e$ of the age frequency in the catch is plotted on age, the slope of the linear descending right limb of the curve is equal to the mean instantaneous total mortality (Z). To calculate mortality rates, we first needed to assign ages to the 1,100 or so unaged fish. We grouped fish of known age by 25 mm length intervals, calculated the percentage of fish of each observed age in each group, and used these percentages to estimate the number of fish of each age for the unaged group (Ricker 1975).

Length-Weight and Fork Length-Total Length Relationships

To calculate length-weight and length conversion relationships fish lengths were subsampled to provide a fairly equal distribution throughout the size range of fish examined during this study. The length-weight relationship was expressed exponentially, whereas the fork length-total length equation was expressed as a simple linear regression.

Spawning

Gonads were examined macroscopically by season to determine the approximate time of spawning. Observations on the development of testes were used collaboratively with measurements recorded from ovaries. Ovaries were weighed to calculate a seasonal gonad index, or the percentage of gonad weight to fish weight.

RESULTS

Distribution and Relative Abundance

Tomtates were collected throughout the South Atlantic Bight (Figs. 1-4). Although most of the continental shelf is sandy "open-shelf habitat" (Struhsaker 1969), the greatest catches of tomtates were directly associated with the irregularly distributed sponge-coral ("live bottom") habitats (as defined by Wenner et al. 1979a). Indices of relative abundance over live-bottom areas were significantly larger ($P<0.01$) than abundance indices from sandy-bottom catches in all seasons and years, except during the cold winter of 1977 (Table 2). Although tomtates occurred in 30-70% of the collections from the sponge-coral habitat, 79.6% of the total number caught during seven cruises, excluding the cold winter of 1977, were at sponge-coral stations (Table 3).

During all seasons, catches of tomtates over sand were infrequent, but occasionally large (Wenner et al. 1979a, b, c, d). Occurrence of tomtates in both sandy-bottom and live-bottom habitats increased the difficulty in biomass estimations. Information from catches over the sponge-coral habitat with the 30-min tows was expanded to preliminary estimates of biomass (Tables 4, 5), although the catch represented a mixed habitat collection of unknown proportions. Standing crop estimates of tomtates from the region between Cape Fear and Cape Canaveral ranged from 1,730 t (minimum catch, summer 1974) to 12,878 t (maximum catch, winter 1976). Although biomass estimates were calculated separately for each depth zone and standing crop estimates were calculated separately for catches from live-bottom and sandy-bottom habitats (Table 6), all estimates represent minimal values because fish availability and vulnerability to the trawl were not considered.

Tomtates, both juvenile (<137 mm TL) and adult, were more abundant in catches in the northern part of the South Atlantic Bight than in catches in the south. During all seasons sampled, between 1973 and 1977, the catch north of lat. 32°32′N, an arbitrary shelf division, was between 59 and 89% of the total catch. The one exception occurred during the cold winter of 1977, when 98% of the total catch (3,192 fish) was made south of lat. 32°30′N at a single station.

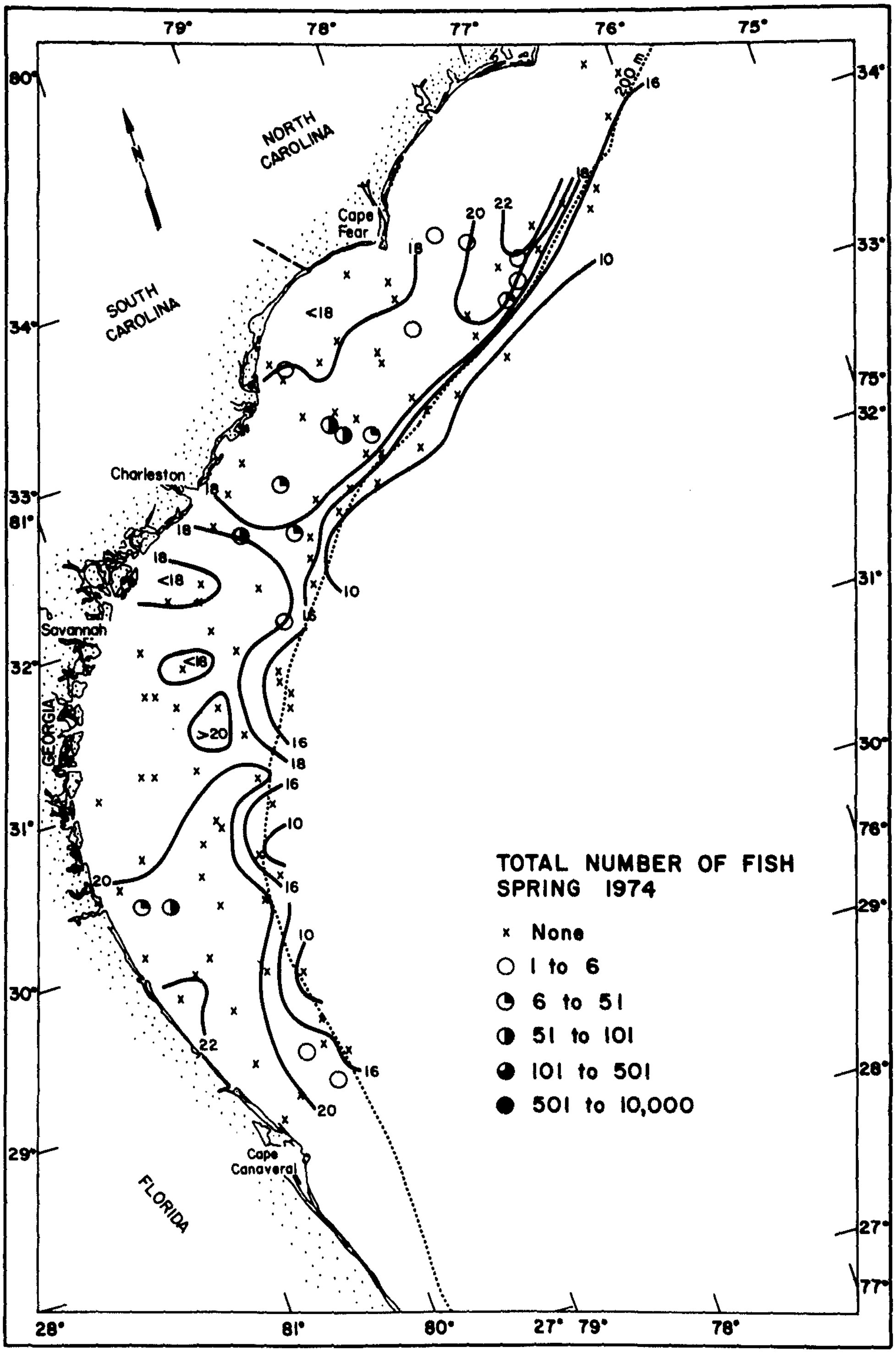

FIGURE 1.—Spatial distribution and catch per tow of tomtates between Cape Fear and Cape Canaveral, 1 April-9 May 1974.

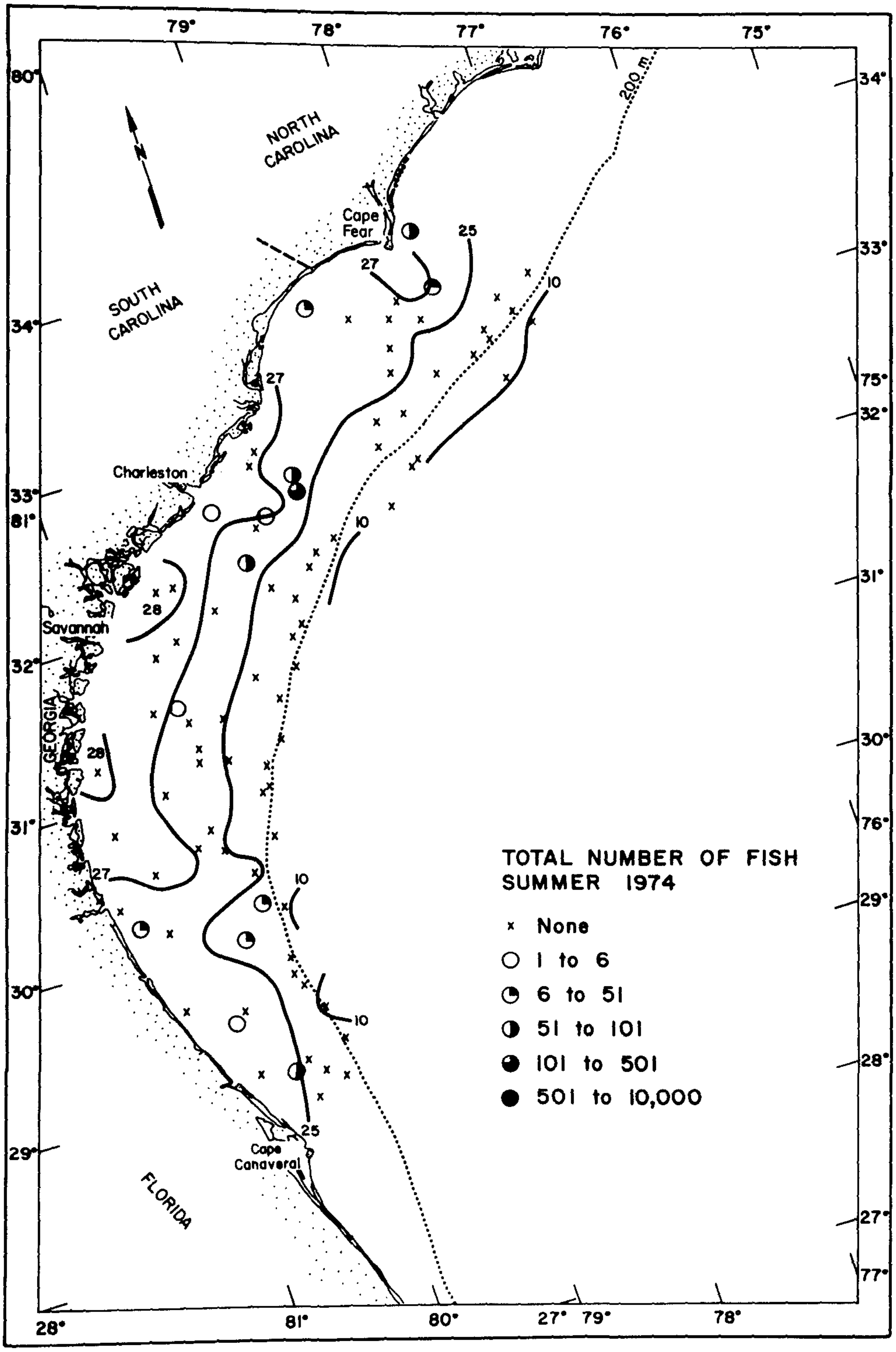

FIGURE 2.—Spatial distribution and catch per tow of tomtates between Cape Fear and Cape Canaveral, 13 August-19 September 1974.

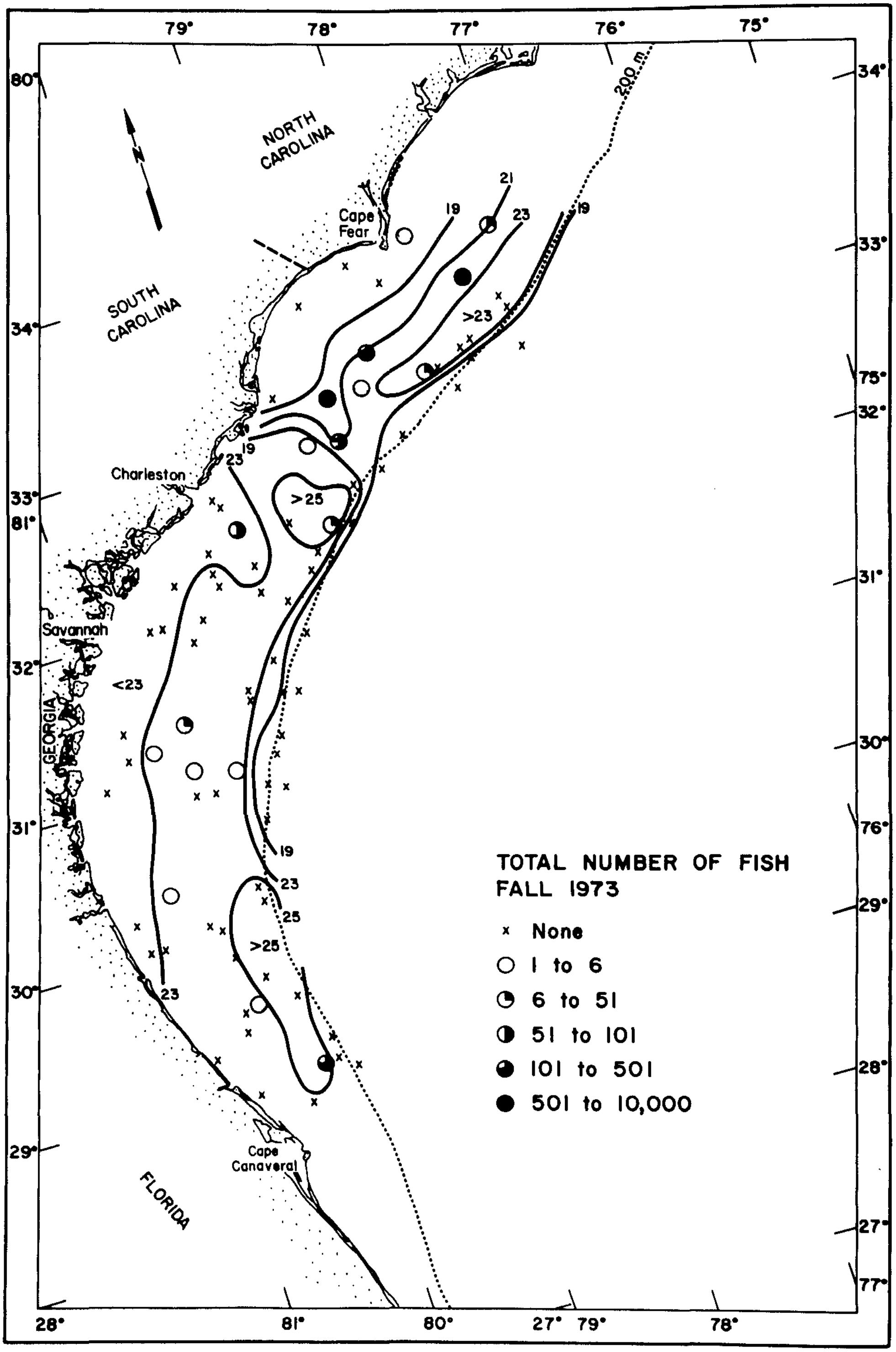

FIGURE 3.—Spatial distribution and catch per tow of tomtates between Cape Fear and Cape Canaveral, 23 October-16 November 1973.

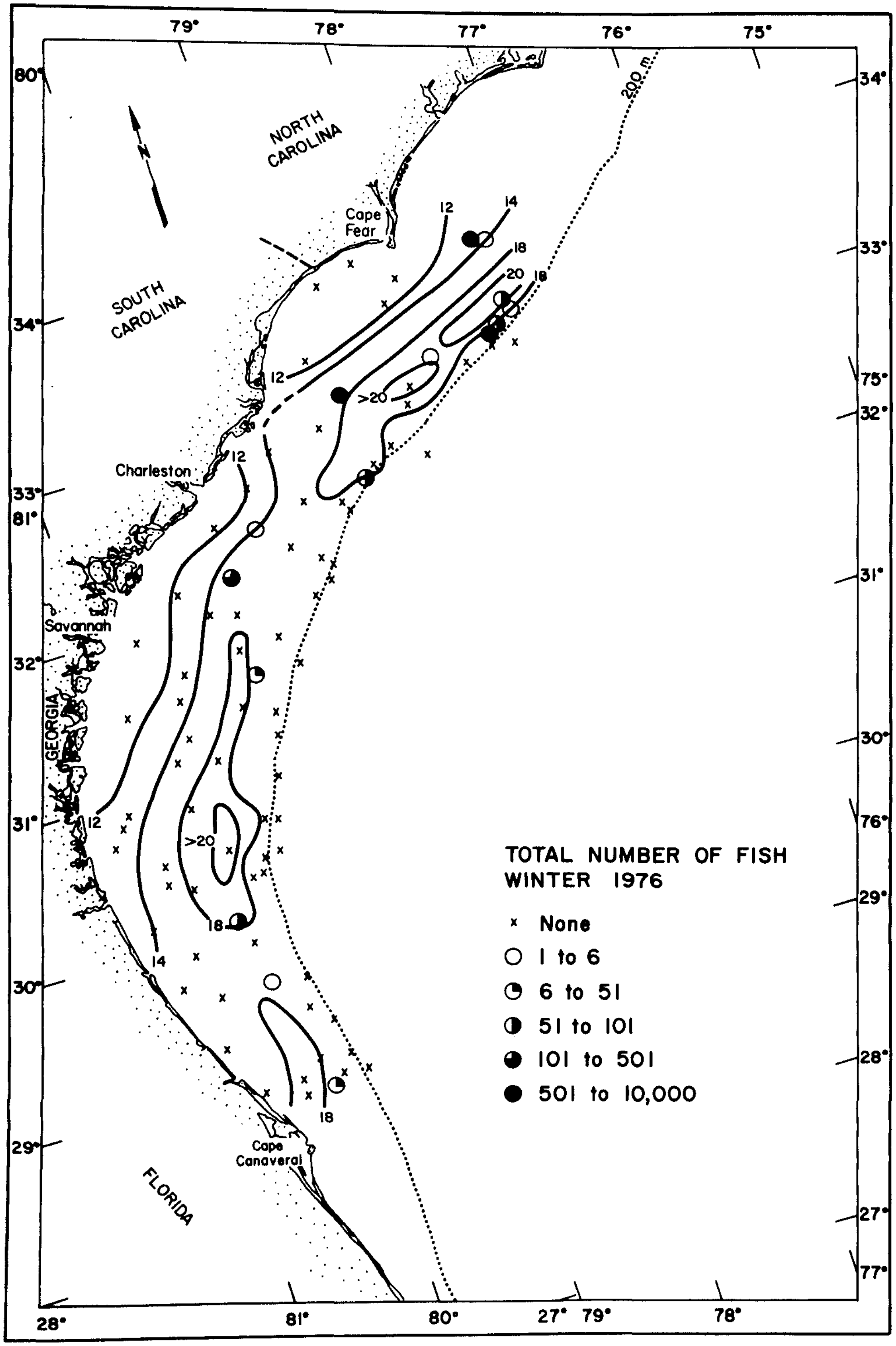

FIGURE 4.—Spatial distribution and catch per tow of tomtates between Cape Fear and Cape Canaveral, 12 January-7 February 1976.

TABLE 2.—*t*-test and chi-square results of comparisons between numbers of tomtates in catches over live-bottom and sandy-bottom habitats.

Seasons	*t*-test of $\frac{\Sigma \ln (x+1)}{n}$	df	χ^2 test of $\frac{\Sigma x}{n}$	df
Fall 1973	3.75**	65	14.79**	1
Spring 1974	4.70**	85	15.69**	1
Summer 1974	4.15**	66	24.73**	1
Winter 1975	2.83**	68	93.36**	1
Summer 1975	8.18**	66	69.46**	1
Winter 1976	8.77**	67	350.41**	1
Summer 1976	11.04**	67	193.32**	1
Winter 1977	1.59n.s.	70	40.42**	1

** = significant at 0.01 level; n.s. = nonsignificant at 0.05 level.

TABLE 3.—Catches of tomtates associated with collections within the "live bottom"-sponge/coral habitats.

	Live bottom stations		Tomtate catch	
Cruise date	*N*	% with tomtates	Total number	% from live bottom
Fall 1973	10	39	2,075	29.6
Spring 1974	11	42	442	55.7
Summer 1974	14	50	581	76.2
Winter 1975[1]	9	30	1,212	78.4
Summer 1975	18	70	1,298	98.2
Winter 1976	11	53	4,005	97.6
Summer 1976	8	53	1,749	91.7
Winter 1977[2]	11	55	3,260	1.5
Average		50		79.6

[1] Sampling season prolonged into spring.
[2] Unusually cold winter, data omitted from average.

TABLE 4.—Mean catch/tow ($\bar{y}_h$) values for trawl-caught tomtates on untransformed and transformed [ln (kg + 1)] data by depth and habitat zone for summer 1974. Bliss' (1967) estimation of the mean was applied to the transformed values.

Depth (m)	Habitat	$\bar{y}_h$ biomass (kg/tow) untransformed	$\bar{y}_h$ biomass (kg/tow) transformed	Area of zone (km^2)	No. of tows
9-18	live	5.272	12.981	2,622	2
	sand	0.324	0.163	15,461	14
19-27	live	6.804	6.804	2,730	1
	sand	0.218	0.101	16,100	18
28-55	live	3.991	5.196	3,794	5
	sand	0.000	0.000	22,367	14
56-110	live	1.285	1.120	692	6
	sand	0.000	0.000	4,083	8

TABLE 5.—Mean catch/tow ($\bar{y}_h$) values for trawl-caught tomtates on untransformed and transformed [ln (kg + 1)] data by depth and habitat zone for winter 1976. Bliss' (1967) estimation of the mean was applied to the transformed values.

Depth (m)	Habitat	$\bar{y}_h$ biomass (kg/tow) untransformed	$\bar{y}_h$ biomass (kg/tow) transformed	Area of zone (km^2)	No. of tows
9-18	live	0.000	0.000	2,622	2
	sand	0.000	0.000	15,461	15
19-27	live	104.848	110.616	2,730	3
	sand	0.000$^+$	0.000$^+$	16,100	13
28-55	live	5.450	5.465	3,794	2
	sand	0.133	0.130	22,367	19
56-110	live	2.675	3.163	692	4
	sand	0.001	0.001	4,083	11

TABLE 6.—Minimum standing crop estimates of tomtates in the South Atlantic Bight during summer 1974 and winter 1976. All values should be expanded by 10^2; units are in metric tons. LCL and UCL = lower and upper 90% confidence limits, respectively.

	Untransformed			Transformed		
	Mean($\overline{Y}$st)	LCL	UCL	Mean($\overline{Y}$st)	LCL	UCL
Summer 1974						
sand bottom	3.00	0.02	5.98	2.53	1.05	4.19
live bottom	17.08	7.14	27.02	21.39	8.46	48.36
total area	20.08			23.92		
Winter 1976						
sand bottom	1.05	0.23	1.87	1.02	0.39	1.70
live bottom	108.86	13.39	204.34	127.76	46.71	342.13
total area	109.91			128.78		

Tomtates were collected at depths ranging from 13 to 91 m. The greatest relative abundance of both juveniles and adults in the South Atlantic Bight was consistently within the three shallowest (<55 m) depth zones (Fig. 5). The depth distributions of juveniles and adults indicated a slight shift offshore during winter but did not indicate major seasonal movements of fish within the South Atlantic Bight region. During winters (1975-77), tomtates were not collected in the nearshore (9-18 m) zone. In summer 1976, only adults were caught in the deep 56-110 m depth zone. During fall 1973 and winter 1977, only juveniles were collected in the 56-110 m depth zone, while in winter 1976, juveniles were much more abundant than adults in this depth zone.

Tomtates were collected at bottom temperatures from 10.3° to 28.1°C, but were seldom caught at temperatures <13°C. Differences in thermal distributions of juvenile (≤148 mm TL) and adult tomtates in the South Atlantic Bight indicated separate thermal preferences. During fall (1973) and winter (1976), the proportion of juveniles to adults in the total catch increased at

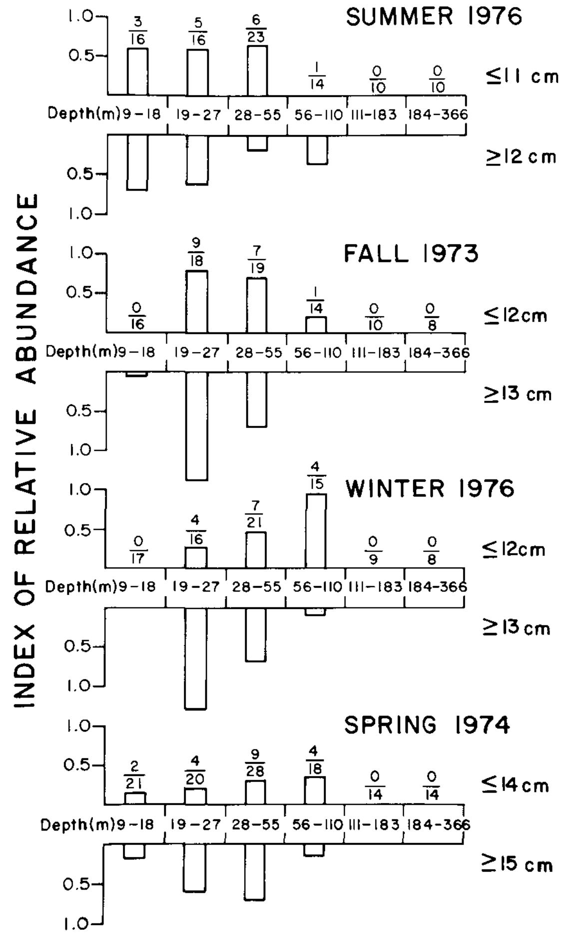

FIGURE 5.—Index of relative abundance for tomtates by depth zone during four seasons (juveniles above the axis, adults below: fraction numerator = number of trawls with tomtates; denominator = total number of trawls in depth zone).

higher temperature intervals (Fig. 6). Young tomtates (20-63 mm) have previously been collected during December in the Florida Keys at a water temperature of 16.2°C (Springer and Woodburn 1960). During summer (1975), juveniles were collected only in the coolest thermal zone (24.0°-27.9°C), while during spring (1974), both juveniles and adults were collected in the same thermal interval (16.0°-23.9°C).

Tomtates may avoid water temperatures of <10°C. Fish were never caught at <10.3°C during any season, even at five sponge-coral stations in areas where large numbers were caught at >10°C during the previous winter (Fig. 7).

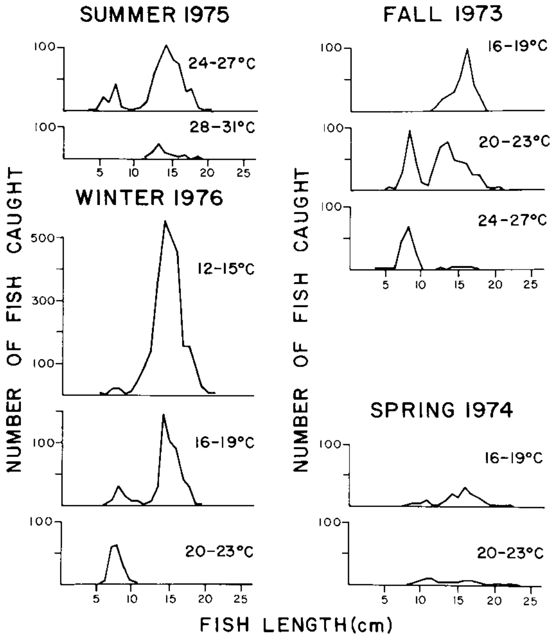

FIGURE 6.—Length-frequency distributions (TL) of tomtates by bottom water temperature interval (4°C).

Age and Growth

Validity of Rings as Annuli

Both scales and otoliths were used to age tomtates. Approximately 75% (397 of 529) of the scale samples and 85% (177 of 208) of the otoliths were legible. Since tomtates have been aged by reading scales (Sokolova 1969), we did not try specifically to validate the methods presented here. Several findings, however, pursuant to the goals of this paper, indicate that rings on tomtate scales and otoliths are true annuli. Close examination of otoliths from young-of-year tomtates, collected by trawl, clearly show the formation of one ring per year, and that the first ring (annulus) forms between the fall and spring collection periods.

The mean length of fish progressively increased as the number of scale or otolith rings increased and otoliths and scales agreed closely (Table 7). For instance, if aged by scales, age-I fish averaged 135.4 mm TL; age-II, 181.9; age-III, 203.3; age-IV, 220.0; age-V, 234.5; age-VI, 255.7; and age-VII, 265.8. If aged by otoliths, age-I fish averaged 134.3 mm TL; age-II, 164.7;

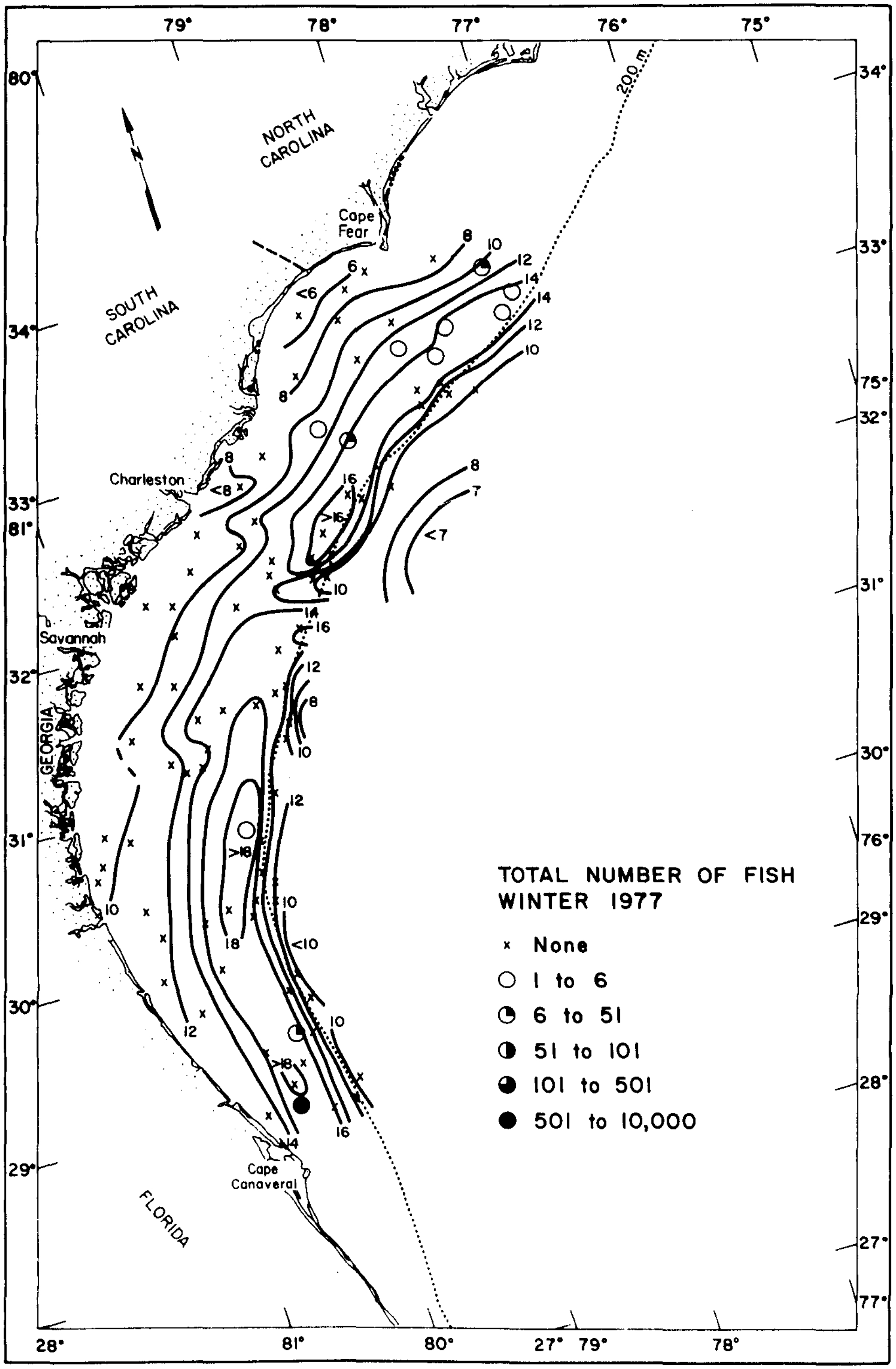

FIGURE 7.—Spatial distribution and catch per tow of tomtates between Cape Fear and Cape Canaveral during the cold winter of 1977.

TABLE 7.—Comparison of mean empirical length-age data obtained by reading tomtate scales and otoliths.

	Scales				Otoliths				
Age group	*N*	Mean TL (mm)	Range in length (mm)	SD	*N*	Mean TL (mm)	Range in length (mm)	SD	Difference in means (mm)
0	22	84.7	50-142	28.1	54	89.8	50-142	29.9	5.1
1	9	135.4	109-171	25.6	23	134.3	80-157	21.5	1.1
2	45	181.9	153-206	13.3	43	164.7	150-185	9.7	17.2
3	81	203.0	180-221	9.6	16	197.1	161-212	14.7	5.9
4	134	220.0	195-238	10.5	19	213.0	193-227	11.1	7.0
5	66	234.5	208-257	11.3	12	232.2	226-242	4.1	2.3
6	28	255.7	245-268	6.3	9	253.1	240-262	6.5	2.6
7	5	265.8	260-272	5.5	1	267.0	—	—	1.2
8	4	277.0	270-280	5.0					
9	3	286.7	282-289	4.0					
Total	397								

age-III, 197.1; age-IV, 213.0; age-V, 232.2; age-VI, 253.1; and age-VII, 267.0 mm.

The relative length frequencies of the measured distance from the focus of the scale to each ring progressively increased with the number of rings. Significant features of the plotted curves were the occurrence of one mode for each ring, the consistent location of a specific mode on the *X*-axis for fish of different ages, the increased overlap for each additional ring, and the progressive decrease in the distance between modes for each successive year, indicating less linear growth each year as the fish ages.

Growth

There was relatively little difference in the mean annual increments of fish aged by scales and those of fish aged by otoliths (Table 7). Annual growth increments for fish aged by scales for ages I-V were: I-II, 46.5 mm; II-III, 21.1 mm; III-IV, 17.0 mm; and IV-V, 14.5 mm. After age V, growth appears to be more irregular, probably a result of the relatively small sample sizes for ages VI, VII, VIII, and IX (Table 7).

Lengths by age for fish from all years were back-calculated from a scale radius-fish length regression. The prediction equation was

$$TL = 1.7489\ SR^{0.9572};\ r = 0.93 \text{ and } N = 103,$$

where TL = total length, and SR = scale radius. By substituting the means of the distances from the focus to each annulus for SR in the above equation, we were able to calculate the mean fish length at the time of each annulus formation, and the mean annual growth increment for each age (Table 8).

The von Bertalanffy equation was used to describe theoretical growth. The growth parameters L_∞ and K were first calculated by fitting a Walford (1946) line to back-calculated data. The equation was $l_{t+1} = 90.833 + 0.6747_{l_t}$, $r = 0.982$. Our first estimate of K was l_n 0.6747 or 0.3935. This value was used to obtain L_∞ by solving the equation $L_\infty = y\text{-intercept} / (1 - k)$. The initial value for L_∞ of 289, and the subsequent value of 285.7 obtained by regressing annual growth increment (X) against fish length at the beginning of the incremental period (Y) (Jones 1976),

TABLE 8.—Calculated total lengths (millimeters) of 346 tomtates aged by scales.

		Mean calculated total length at end of year								
Observed age	*N*	1	2	3	4	5	6	7	8	9
I	9	103.7								
II	45	108.1	173.0							
III	75	102.5	171.1	199.1						
IV	123	102.6	168.4	198.8	214.1					
V	56	101.0	167.8	200.7	216.7	226.7				
VI	26	102.2	165.5	198.8	221.1	235.7	245.1			
VII	5	99.6	165.3	200.9	224.4	240.8	251.3	258.8		
VIII	4	105.3	171.7	195.5	215.1	228.6	242.0	252.1	260.8	
IX	3	102.5	170.6	200.9	222.1	237.7	253.0	264.5	273.5	280.5
Total	346									
Weighted mean		103.0	169.3	199.3	216.0	230.4	246.2	258.0	266.2	280.5
Increment		103.0	66.3	30.0	16.7	14.4	15.8	11.8	8.2	14.3
No. calculations		346	337	292	217	94	38	12	7	3

seemed low. Therefore, we plotted $\log_e (L_\infty - l_t)$ against t by using trial values of L_∞ ranging from 285 to 310 mm. The straightest line resulted from L_∞ of 310 mm. The slope of the line, −0.22017, was selected as the growth coefficient (K) and was used to obtain t_0 (−1.28). Our best estimate of the equation describing the theoretical growth of tomtates is

$$l_t = 310\,(1 - \exp - 0.22017(t + 1.28)).$$

Observed, back-calculated, and theoretical lengths at age are presented in Table 9.

TABLE 9.—Total lengths of tomtates at age (observed, back-calculated, and theoretical).

Age	Length at age (mm)		
	Observed	Back-calculated	Theoretical
1	135.4	103.0	122.4
2	181.9	169.3	159.4
3	203.0	199.3	189.2
4	220.0	216.0	213.1
5	234.5	230.4	232.2
6	255.7	246.2	247.6
7	265.8	258.0	259.9
8	277.0	266.2	269.8
9	286.7	280.5	277.8

Mortality Estimates

By age IV, tomtates are fully recruited to the hook and line fishery, the only important method of harvesting this species off the southeastern United States. Instantaneous mortality (Z) estimates were obtained by analyzing catch curves of fish aged IV and older (Fig. 8). The mean total annual mortality estimate for 1972 through 1978 was 59% ($Z = 0.887$). By year, instantaneous mortality rates were 1974, 0.669; 1975, 1.035; 1976, 1.017; 1977, 1.041; and 1978, 0.972. Too few fish were sampled from the fishery in 1972 and 1973 to construct catch curves. The instantaneous mortality rate(s) for tomtates was higher than those previously obtained for white grunt, $Z = 0.65$ (Manooch 1976), or for red porgy, $Z = 0.58$ (Manooch and Huntsman 1977).

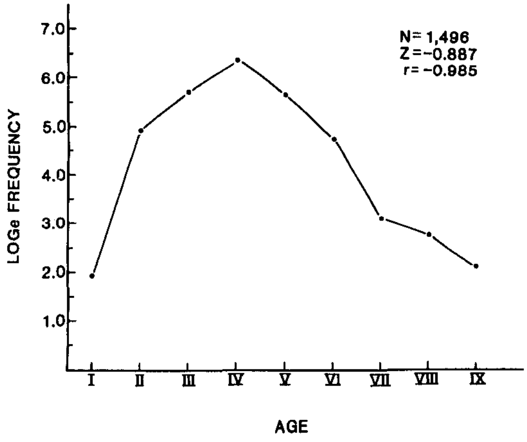

FIGURE 8.—Catch curve for tomtates caught by hooked line off the southeastern United States, 1974-77.

Length-Weight and Fork Length-Total Length Relationships

Fish ranging from 52 to 280 mm TL were used to calculate a length-weight relationship. The equation

$$W = 0.0000086L^{3.0905},\ r = 0.996 \text{ and } N = 70,$$

where W = weight in grams and L = total length in millimeters, describes this relationship. The equation $TL = -1.8196 + 1.1540\ FL$, $r = 0.99$ and $N = 100$ was derived to convert lengths.

Spawning

Indirect evidence indicates that tomtates of the South Atlantic Bight spawn primarily in April and May. Running ripe males and partly spent females were caught in April 1979 (28-42 m; 16.4°-19.4°C), while a major decrease in mean ovarian weight and maximum ovary weight of mature females occurred after the spring (April 1974) sampling period (Table 10). Throughout the year, many (>38%) of the females sampled each season were in the maturing and ripe condition. The presence of juveniles (33-90 mm TL; mode 80 mm) in bottom trawl collections during summer, and the progressive increase in modal fish lengths in length-frequency distributions

TABLE 10.—Gonad condition of adult tomtates (>15 cm TL) from the South Atlantic Bight.

Season	Sex	N	Running ripe %	Mean ovarian wt. (g)	Gonad index[1]	Maximum ovarian wt. (g)
Summer 1974	F	31	5	0.6	0.6	1.7
Fall 1973	F	48	2	0.5	0.5	1.4
Winter 1976	F	36	9	1.3	1.1	8.6
Spring 1979[2]	M	13	77	—	—	—
	F	34	0	4.2	3.4	17.0

[1] Gonad index = (ovary wt./fish wt.) × 100.
[2] Females 77% with hydrated eggs.

through a seasonal cycle (Fig. 9), indicated that these juveniles were spawned in spring.

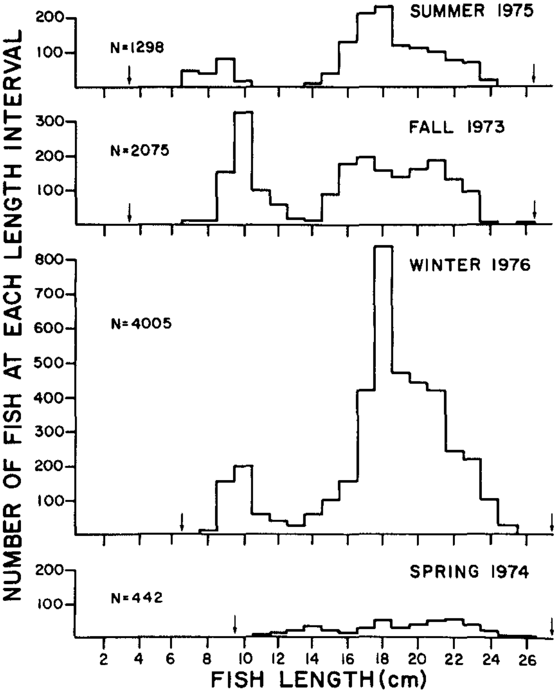

FIGURE 9.—Length-frequency distributions (FL) from the total catch of tomtates between Cape Fear and Cape Canaveral during each of four seasons.

DISCUSSION

Distribution and Abundance

Tomtates are considered abundant in several habitats in and to the south of the South Atlantic Bight, and indicate daily movements between habitats. Within the Bight, tomtates were common over both live-bottom and shelf-edge habitats during earlier (1959-64) exploratory fishing (Struhsaker 1969). Farther south, tomtates were found over broad sandy areas off southern Florida (Craig 1976), near coral stacks in the Tortugas Islands (Longley and Hildebrand 1941), and in grass beds and other open areas in the Bahamas (Bohlke and Chaplin 1968). Tomtates were common from nearshore to the offshore reefs in Florida and were abundant on the shrimp grounds of the Dry Tortugas and the Gulf of Mexico (Courtenay 1961). In the Virgin Islands, changes in distribution with respect to habitat type were associated with feeding behavior. Tomtates feed as individuals or in small schools at night over open sand (Collette and Talbot 1972), and they spend the day on the reef segregated into size groups; juveniles school over the highest part of the reef, while adults hover low between the coral colonies (Smith and Tyler 1972).

Juvenile tomtates may occur in several habitats, either inshore or offshore, which include "live bottom" and rocky outcrops similar to those occupied by adults. Small tomtates (≈33 mm) were abundant over artificial reefs (Parker et al. 1979) and natural ridges in spring through fall off the Carolinas and have been found in the mouths and stomachs of black sea bass in the same areas (Parker[8]). Young tomtates also frequent grass beds (Randall 1968), subtidal mud flats (Reid 1954), and nearshore areas around wharfs (Jordan and Evermann 1896). The presence of young fish among spines of sea urchins (Johnson 1978) suggests that microhabitats may be important to the survival of some early life stages. Juveniles of French grunts, *H. flavolineatum*, and white grunts, *H. plumieri*, form large multispecies schools closely associated with particular coral formations (microhabitats) during the day and follow precise routes (≥100 m) to and from feeding areas (sea grass beds) at night (Ogden and Ehrlich 1977).

Biomass and standing stock calculations for tomtate from groundfish trawling were considered preliminary, minimal estimates. More satisfactory estimates should incorporate information on 1) abundance/biomass sampling conducted completely within a known area of a given habitat type, 2) the correct proportional allocation of a day/night catch factor for each habitat sampled, 3) the vulnerability of tomtate to the sampling gear, and 4) estimates of biomass from untrawlable, rocky outcrop, habitats. Unfortunately, none of the above information is available at present, so our estimates were based upon continuous day/night sampling imposed on the very random nature of sponge-coral habitat distribution. Discrete, short duration trawling completely within the boundaries of the patchy sponge-coral habitats could be directed by pretrawl bottom mapping with underwater TV

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[8] R. O. Parker, Southeast Fisheries Center Beaufort Laboratory, National Marine Fisheries Service, NOAA, Beaufort, NC 28516, pers. commun. January 1978.

(Powles and Barans 1980). This method would allow more accurate quantification of relative abundance differences between habitats and between day and night sampling. Then, a biomass factor could be developed to proportion fish availability to the trawl during daytime collections in sponge-coral habitats and during night in sand bottom habitats. Also, the vulnerability of tomtate, or any groundfish in the South Atlantic Bight, to trawl gear is unknown. Several experiments with a headrope mounted TV system would do much to fill this data gap. Biomass estimates from rocky habitats may have to be extrapolated from nearshore diver counts or offshore TV counts, but many problems remain in the interpretation of these data. In general, a composite estimate of tomtate biomass or standing stock in the South Atlantic Bight should include difficult to obtain fish behavior information.

Tomtate are relatively shallow water (<50 m) groundfish with a more pronounced tendency for annual depth migrations in populations south of the South Atlantic Bight. Tomtates in the Campeche Bank area were most abundant in waters <30 m during all seasons (Sauskan and Olaechea 1974), while tomtates occurred only at depths of <10 m in the Bahamas (Bohlke and Chaplin 1968). Although tomtates remain inshore during winter in Florida (Courtenay 1961), they are not caught by inshore shrimp trawlers off South Carolina (Keiser 1976) and appear to avoid shallow waters (<20 m) north of Florida during winter. There is the possibility that during extremely cold winters, slight migrations (shifts in distribution) southward occur.

In contrast to the results of this study, tomtates of the Campeche Bank move onshore during winter and fall and offshore in spring and summer and are recruited to the fishery in shallow waters, a great distance from the deeper area where spawning takes place (Sauskan and Olaechea 1974). The difference in location of spawning and recruitment and lack of large adult fish over reefs in Florida (Stone et al. 1979) and in commercial trawl catches (Sokolova 1969) suggests separation of juvenile and adult populations, especially south of Florida.

Age and Growth

The fact that scales may be used to accurately determine the age of a warmwater marine fish species is not particularly surprising. Scales have been used to age other reef fishes that occur with tomtates in the South Atlantic Bight. Manooch (1976) found annuli on scales from white grunt collected off the Carolinas; Manooch and Huntsman (1977) aged red porgy, *Pagrus pagrus*, using both scales and otoliths; and Grimes (1978) determined the age of vermilion snapper, *Rhomboplites aurorubens*, by reading scales.

The theoretical parameters derived in this study are compared with those for tomtates from the Campeche Banks, and with cooccurring species in the South Atlantic Bight in Table 11. The Campeche Banks fish did not live as long—5 or 7 yr compared with 9 in the South Atlantic Bight—and had a slightly smaller maximum size (L_∞), 295 mm compared with 310 mm. Consequently, the growth coefficient, although very similar, is slightly higher—0.235 compared with 0.200. With the exception of black sea bass, *Centropristis striata*, sympatric species previously studied in the South Atlantic Bight were longer lived and slower growing (Table 11).

TABLE 11.—Growth parameters for six species of demersal fish.

Common name	Scientific name	Area	Author	M	K	L_∞ (TL, mm)	Longevity (yr)
Tomtate	*Haemulon aurolineatum*	N.C., S.C., Ga., east coast Florida	This paper		0.22017	310	9
		Campeche Banks	Calculated from Sokolova (1969)		0.235	295	5
			Sauskan and Olaechea (1974)				7
White grunt	*H. plumieri*	N.C., S.C.	Manooch (1976)	0.4 & 0.6	0.108	640	13
Red porgy	*Pagrus pagrus*	N.C., S.C.	Manooch and Huntsman (1977)	0.2	0.096	763	15
Vermilion snapper	*Rhomboplites aurorubens*	N.C., S.C.	Grimes (1976)	0.25	0.198	627	10
Gag	*Mycteroperca microlepis*	N.C., S.C., Ga., east coast Florida	Manooch and Haimovici (1978)	0.20	0.121	1,290	13
Black sea bass	*Centropristis striata*	N.C., S.C.	Mercer[1]	0.30	0.220	352	8

[1] Linda Mercer, Virginia Institute of Marine Sciences, Gloucester Point, Va.

Spawning

Growth rates of juvenile tomtates (≥130 mm TL/first year) in the South Atlantic Bight and rates estimated from larvae of similar species support the spawning season indicated by analysis of gonads. If growth of very early stages of tomtates approximates the 14 mm SL/30 d for white grunts (Saksena and Richards 1975) and French grunts (Brothers and McFarland In press), tomtates of 30-90 mm TL caught in early September may have been spawned between early April and June. Identification of peak spawning period of tomtate by associated larval abundance was impossible due to difficulties in identifying larval haemulids.

Populations of tomtates farther south appear to have a prolonged spawning season. Munro et al. (1973) reported collections of ripe females between January and August in Jamaica, while Cervigon (1966) suggested that tomtates spawn throughout the year in Brazil. Tomtates from Campeche Bank spawn primarily during July-September at depths of >50 m and again during winter at shallower depths (Sauskan and Olaechea 1974).

Management

We believe management of the tomtate fishery should be considered for three reasons. First, the species is easily captured by a variety of fishing techniques: hook and line, trap, and unlike most other reef fishes, by trawl. Second, fishing effort applied to this, and other associated, species will probably increase. And third, the tomtate is a member of a rather delicate faunal community and is a major source of food for higher trophic level, piscivorous fishes. Unwise harvest of one species could have both physical and energetic impacts on the community as a whole.

While regional catches of tomtates may at times be quite large, for instance by recreational anglers on headboats fishing inshore waters, the species ranks low in terms of poundage landed in the South Atlantic Bight by both recreational and commercial fishermen. Because tomtates are small and not competitive in value with other reef fishes in the commercial market, commercial hook and line fishermen usually discard the species or use it as bait for larger predatory fishes, such as groupers and snappers (Wenner[9]).

Given the geographical range of *H. aurolineatum*, its abundance as indicated by exploratory trawling, and relatively low harvest by fishermen, one could label it as an "underutilized species" in the South Atlantic Bight. However, assigning tomtates this status requires a thorough understanding of currently operating fisheries plus a knowledge about the role of the species in the ecosystem. We do not recommend such a designation at this time.

Although the distribution of tomtate is continuous from the southeastern coast of the United States to the Campeche Banks, the stock fished in each area should be considered separate for assessment and fishery management. Our study and the studies of Sokolova (1969) and Sauskan and Olaechea (1974) show that tomtates are a relatively short-lived, fast-growing reef fish with a high annual mortality rate when compared with other reef fishes of the region. Fish with these biological traits usually are not as readily overfished as those that grow more slowly, those that live longer, and those with a lower annual mortality rate. However, many fast-growing, high-mortality species such as mackerels (*Scomberomorus*), some tunas (*Thunnus*), and menhaden (*Brevoortia*), which are important to large fisheries, have demonstrated some signs of being overfished.

By comparing our study with those on the Campeche Bank, we can look at one stock caught at present primarily by hook and line and the other by a more intensive gear, the trawl. The major difference between the South Atlantic Bight tomtates and those from Campeche Bank is that the Atlantic stock is older and larger. There are several explanations other than biological changes in ecology or genetics for the differences between these stocks. In our study, the tomtates were caught by recreational fishermen using hook and line while those from Campeche Bank were trawled. Hook and line fishing may be more selective of larger fish and some of the smaller fish may be discarded by the fishermen resulting in larger fish of each age being sampled. A more likely explanation is that the large, old Atlantic fish have a generally low exploitation rate. The Soviet-Cuban trawlers have fished Campeche Bank since 1964 with catches of grunts averaging over 20,000 tons a year and ex-

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[9] C. A. Wenner, South Carolina Wildlife and Marine Resources Department, Marine Resources Research Institute, Charleston, SC 29412, pers. commun. January 1978.

ceeding 60,000 in 1971 and 1975 for the region according to FAO Yearbooks. If, as we suspect, most of these catches were tomtate, the Campeche stock has been much more exploited than the Atlantic for the past 10 yr.

Regional harvest of tomtates by hook and line will probably remain low. Recreational anglers will continue to catch small numbers, and commercial handliners will continue to regard *H. aurolineatum* as "trash fish" or bait. Any increase in the harvest will probably involve an expansion of a trawl fishery off South Carolina, Georgia, and northeast Florida.

Prior to development of any U.S. groundfish trawl fishery for tomtate, the possibility of habitat destruction by trawl gear should be investigated. Some bottom trawl harvest techniques may have detrimental effects on the substrate community in which tomtate are most abundant. Destruction or removal of the sponge/coral invertebrates and crab species, or damage to *Oculina* coral beds, may indirectly reduce future yields of tomtate and other fish species.

Also, during several seasons trawls may catch juveniles of a species important to both commercial and sport fisheries prior to their recruitment to harvest by hook and line. Bottom trawling for tomtate in "live bottom" areas would catch large numbers of small, commercially unimportant fish species and invertebrates which would increase costs of sorting unless the entire catch was processed as a mixed species product.

In our study the greatest relative abundance (catch/tow) of adults was during winter at which time commercial harvesting could take advantage of any concentrations of fish resulting from a shift to a more offshore distribution of the population. Reduction of fishing effort during late winter and early spring would allow the unfished stock to spawn and juveniles to be recruited to the fishery at a larger size, possibly regulated by net mesh size. Even in this case, a drastic reduction in population size could adversely affect the recreational headboat fishery.

ACKNOWLEDGMENTS

We thank the Captain and crew of the RV *Dolphin* for cooperation and patient efforts throughout the field work; Victor Burrell, Jr., Director of the South Carolina Marine Resources Research Institute for support and encouragement; Julian Mikell for preliminary summary, especially gonad/maturity data; Karen Swanson and Herb Gordy for graphic arts; Dean Ahrenholz, Gene Huntsman, and John Merriner for reviewing the manuscript; and Beverly Ashby and Beverly Harvey for typing.

Parts of this research were sponsored by the National Marine Fisheries Service (MARMAP Program Office) under contract No. 6-35147.

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