BIOLOGY OF THE SUMMER FLOUNDER, *PARALICHTHYS DENTATUS*, IN DELAWARE BAY[1]

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ABSTRACT

Data on the age, growth, food habits, and racial characters of summer flounder, *Paralichthys dentatus*, from Delaware Bay were examined. Fish were present year-round, although 95% were taken from May through September, and no mature fish were caught during the winter. Fish were aged from annuli on the largest left otolith. The growth rate for males was described by $L_{t+1} = 141.91 + 0.767(L_t)$, and for females $L_{t+1} = 136.72 + 0.843(L_t)$. The Delaware Bay commercial fishery in 1966 was primarily supported by age-groups 2 through 5. The total length-weight relationship was described by, log weight (grams) = log 0.404×10^{-5} + 3.151 log [total length (millimeters)], and the total length-standard length relationship by, total length (millimeters) = 16.695 + 1.55[standard length (millimeters)]. Age and sex made no significant difference in meristic character evaluation. The reported range of variation for some characters was extended: dorsal rays, 89-98; anal rays, 63-78; pectoral rays, 10-13; vertebrae, 40-43; standard length/head length, 3.64-4.30; and head length/upper jaw length, 1.54-2.26.

One objective of this study was to investigate the age, growth, and food habits of summer flounder, *Paralichthys dentatus* (Linnaeus), caught in Delaware Bay. Previous research on age and growth, Eldridge (1962) and Poole (1961), disagreed and additional study was needed.

A second objective was to determine the magnitude of variation in meristic characters of summer flounder from Delaware Bay for comparison with other geographic areas. Ginsburg (1952) reported that summer flounder from Chesapeake Bay and from Beaufort, N.C., might belong to two distinct racial stocks on the basis of gill raker frequency distributions. According to Poole (1966), unpublished studies found no real differences between these populations, but he added that analysis of racial data from Maryland, Virginia, and North Carolina areas suggested the need for additional research.

Summer flounder are common from Cape Cod to North Carolina and they have been reported from Maine to Texas (Bigelow and Schroeder 1953; Poole 1962). They normally inhabit coastal and estuarine waters during the warmer months of the year and move off on the continental shelf in 20 to 100 fm of water during the fall and winter (Bigelow and Schroeder 1953). Spawning occurs during the fall and winter while the fish are moving offshore or at their wintering location, and larvae and postlarvae drift and migrate inshore to coastal and estuarine nursery areas (Smith 1973).

COLLECTION OF MATERIAL

Most fish examined were caught by a 9-m (30-ft) otter trawl, 7.6-cm (3-in) stretch mesh in the body and 5.1 cm (2 in) in the cod end, during monthly fish survey trips in Delaware Bay. A total of 13 sectors were sampled during the period August 1966 through November 1971 (Figure 1), with a minimum of 3 and a maximum of 12 sampled in any 1-mo interval. Sectors sampled were selected to cover a range of salinities and depths in Delaware Bay. During the summer of 1968, three sectors were sampled during the day and again that night. Sampling at each station consisted of making a Nansen cast within 2 m of the bottom for temperature and a water sample, and trawling for 30 min. The mean tow length was 1.2 n.mi. Average water depth for each tow was determined by eye from a recording fathometer trace. Some fish were taken by beach seining, while others were caught during miscellaneous trawling operations through February 1973.

Stomachs for gut analysis were removed immediately on fish capture and placed in 95% isopropyl alcohol.

The commercial summer flounder catch from

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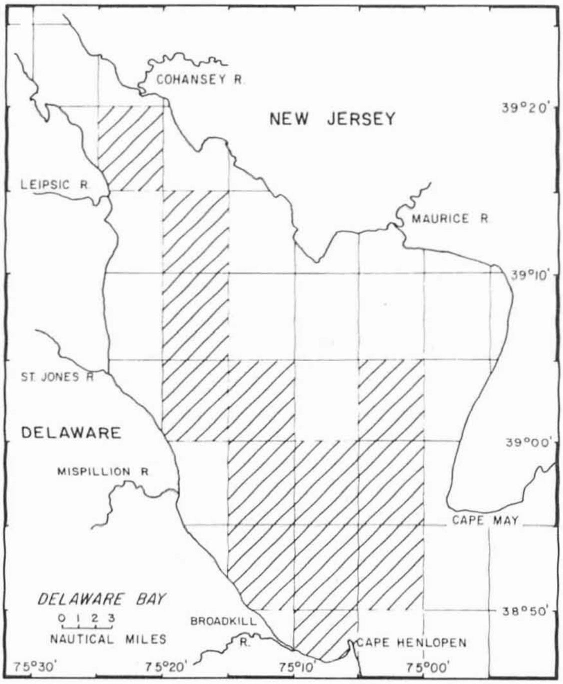

FIGURE 1.—Delaware Bay with sampling sectors shaded.

Delaware Bay was sampled on four occasions in 1966 by measuring all (1,060) fish caught by a 14-m trawler using both a 15-m (50-ft) otter trawl, body—7.6-cm (3-in) stretch mesh, cod end—5.1 cm (2 in), and a 16-m (52-ft) otter trawl, body—10.2 cm (4 in), cod end—7.6 cm (3 in). This vessel was typical of the few commercial boats operating in the bay then, and 1966 was the last year trawling was permitted.

GENERAL OBSERVATIONS

Summer flounder seem to have a ubiquitous range in Delaware Bay. They were caught in all sectors sampled; and in water with temperatures from 1.6° to 26.8°C, salinities from 10.6 to 31.8‰, and depths from the shore to 25 m. Most (95%) fish were caught from May through September. A few juvenile fish were taken in every winter month, indicating that some juveniles move to deeper parts of the estuary during the winter rather than offshore. Poole (1966) suggested a similar phenomenon for estuaries in North Carolina.

During the 5-yr survey, the yearly mean number of summer flounder caught per nautical mile of trawling (number of fish caught per year divided by the total length of tows containing summer flounder) varied from 1.5 to 4.7, with no significant trend. No real difference was apparent in the number (34 day versus 29 night) of flounder caught between day and night tows.

AGE AND GROWTH ANALYSIS

Otoliths were used for aging fish because they were much easier to read than scales, and both Poole (1961) and Eldridge (1962) found them suitable for aging. Left and right otoliths were examined, and we found the radial length (distance from the center of the core to the anterior tip) was different between left and right ones from the same fish. This occurred because the center area or core (Figure 2) was located more posteriorly in the right otolith. We did not compare left and right otoliths to see if the relationship between radial length and the various annuli lengths were the same for both.

Left otoliths were removed from all flounder (either fresh or previously frozen) caught in

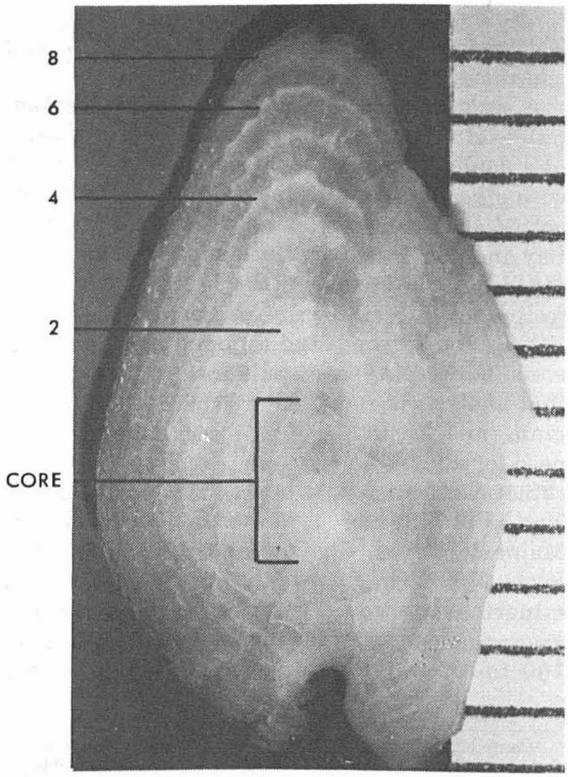

FIGURE 2.—Left otolith from an age-group 8 summer flounder, total length 69 cm, with estimated age indicated against respective annuli (rule marking in millimeters).

1966-68. Upon removal, they were cleaned in water and stored dry. Prior to examination, otoliths were soaked for 30 min in a 2% solution of the plant enzyme, papain, according to the technique of Pruter and Alverson (1962) for cleaning and clearing. Annuli were visible before soaking and it is doubtful this clearing process helped.

For examination, otoliths were placed in distilled water in the wells of a Coor's[3] black porcelain spot plate. They were measured with an ocular micrometer to the nearest 0.1 mm for radial length and annuli lengths with the concave surface up. All otoliths were read twice, and those very difficult to interpret a third time. Approximately 20% of the otoliths were discarded because of irregular shape or indistinct annuli, leaving 319 used in the age analysis. Mean annuli lengths are given in Table 1. No age-group 6 males were collected in this study.

There was a linear relationship between total length (TL in millimeters) and otolith radial length in millimeters, and this relationship was best described by:

$$\text{Otolith radial length} = 0.012(\text{TL})$$

Correlation coefficient = 0.998
Standard error of estimate = 0.336

This equation applied to both sexes.

Fish length at time of annulus formation or back-calculated length was calculated as described in Rounsefell and Everhart (1953), and these lengths for males and females are given in Tables 2 and 3, respectively. No correction factor was used in the calculation because: 1) the line best representing the total length-otolith radial length relationship had a zero origin and 2) correction factors obtained were not reasonable because they gave the fish a negative length at time of otolith formation. According to Rugh (1962), who used *Fundulus heteroclitus* as an example of a typical teleost, otoliths start to form in the first quarter of development. Therefore, fish length at time of otolith first formation could be considered negligible when compared with fish length at 1 yr.

The observed 17 cm length at 1 yr as reported by Eldridge (1962) is far above a 12 cm length we back-calculated using the otolith core edge as the first annulus. We assumed the first annulus was located at the core edge (radial length from 1.1 to 1.5 mm) because typically the first well-defined annulus away from the core (approximately 3.3 mm radial length, Table 1) was only present in otoliths from fish larger than 27 cm, fish we believed too large to be in age-group 1 (fish 1 or 1 + yr old). Supporting our belief is Eldridge's reported length frequency at 1 yr and our subsequent capture (1973) of Delaware Bay flounder during winter in the 15-20 cm size range. A few otoliths we examined had faint rings at radial lengths of 2.0 to 2.6 mm, but we thought these represented a false annulus. Probably these faint rings were true first annuli and they were not observed in most otoliths.

The primary reason for the difference between our back-calculated fish lengths and those given by Poole (1961) and Eldridge (1962), Tables 2 and 3, is the interpretation of age at the first annulus used. Examination of Poole's calculated length at 1 yr plus his photographs of otoliths indicated he considered the first well-defined annulus as being

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

TABLE 1.—Mean radial distance ± 1 standard deviation of annuli on otoliths from summer flounder taken in Delaware Bay during 1966-68. (No suitable first annulus was found.)

Age-group	Number of otoliths	Measured radial distance for successive annuli (mm)						
		2	3	4	5	6	7	8
Male:								
2	44	3.3±0.3						
3	51	3.2±0.3	4.2±0.3					
4	23	3.2±0.3	4.2±0.3	4.9±0.2				
5	11	3.2±0.2	4.2±0.2	4.9±0.3	5.4±0.3			
7	1	3.0	4.3	4.8	5.6	6.1	6.4	
Female:								
2	50	3.4±0.2						
3	71	3.4±0.2	4.6±0.3					
4	36	3.3±0.3	4.6±0.3	5.5±0.3				
5	22	3.3±0.3	4.6±0.4	5.4±0.4	6.0±0.4			
6	4	3.4±0.1	4.7±0.2	5.6±0.3	6.4±0.4	7.1±0.4		
7	3	3.2±0.1	4.3±0.6	5.3±0.5	6.2±0.4	7.1±0.7	7.9±0.8	
8	3	3.2±0.3	4.3±0.5	5.1±0.4	5.7±0.5	6.3±0.6	6.8±0.6	7.2±0.6

TABLE 2.—Mean back-calculated total length ± 1 standard deviation and annual percent increase in mean total length for male summer flounder captured in Delaware Bay during 1966-68. Included for comparison are mean back-calculated lengths from other studies.

Age-group	Number of fish	Back-calculated length at successive annuli (mm) 1	2	3	4	5	6	7	8
2	44		277±20						
3	51		261±23	344±16					
4	23		258±21	342±17	400±14				
5	11		261±12	348±10	403± 9	445±11			
7	1		242	347	388	452	493	517	
Mean length			260	345	397	448	493	517	
Annual % increase				24.6	13.1	11.4	9.1	4.6	
Poole (1961)		251	326	387	427				
Eldridge (1962)[1]		170	240	319	357	381	399	414	426

[1]Lengths given for Eldridge at the end of year 1 and 2 are estimates of the average observed length frequency.

TABLE 3.—Mean back-calculated total length ± 1 standard deviation and annual percent increase in mean total length for female summer flounder captured in Delaware Bay during 1966-68. Included for comparison are mean back-calculated lengths from other studies.

Age-group	Number of fish	Back-calculated length at successive annuli (mm) 1	2	3	4	5	6	7	8	9
2	50		301±21							
3	71		280±19	383±21						
4	36		279±25	389±24	465±25					
5	22		289±20	399±24	470±22	526±22				
6	4		273±23	379±33	450±21	512±22	568±25			
7	3		252±12	332±48	412±34	484± 5	553±16	612±19		
8	3		289±12	395±20	469± 6	521±12	575±18	624±14	661± 9	
Mean length			280	380	453	511	565	618	661	
Annual % increase				26.3	16.1	11.4	9.6	8.6	6.5	
Poole (1961)		271	377	465	531	644				
Eldridge (1962)[1]		170	240	377	424	471	518	566	613	657

[1]Lengths given for Eldridge at the end of year 1 and 2 are estimates of the average observed length frequency.

formed at the end of the first year. Eldridge decided that Poole's calculated length at 1 yr seemed too high when compared with observed length frequencies, so he considered this first well-defined annulus to be formed at first spawning, or at the end of the flounder's third year. We considered the first well-defined annulus to be formed at age 2. Therefore, Poole's age 1 fish = our age 2 fish = Eldridge's age 3 fish. Work by Richards (1970) supported our age interpretation. He found summer flounder growth curves generated by analog simulation only fit Poole's length data when Poole's age-groups were shifted 1 yr forward, i.e., his age 1 fish were made age 2. Richards did not examine Eldridge's age data.

Comparing Poole's (1961) lengths to ours after adjustment for age interpretation, we find them similar except for age 5 females. With age interpretation adjustment, Eldridge's (1962) lengths for males are smaller than ours except at ages 2 and 3 when they are larger, and his lengths for females are noticeable larger until age 5 when they begin to agree quite well.

The length-frequency distribution of the 1966 commercial catch and the 1966-71 research catch revealed that both were primarily composed of age-groups 2 through 5. Figure 3, using the 1966 and 1968 research catch because lengths were by sex, is representative of this distribution. This age composition is similar to the age composition reported by Poole (1961) for the sport fishery catch of Great South Bay, N.Y., after adjustment is made for age interpretation differences.

Equations representing growth rates from Walford's growth transformation (Rounsefell and Everhart 1953) are:

for males $$L_{t+1} = 141.91 + 0.767\,(L_t)$$

Correlation coefficient = 0.996
Standard error of estimate = 7.39

for females $$L_{t+1} = 136.72 + 0.843(L_t)$$

Correlation coefficient = 0.998
Standard error of estimate = 6.20

where L_{t+1} = fish length (millimeters) at time t plus 1 yr
L_t = fish length (millimeters) at time t.

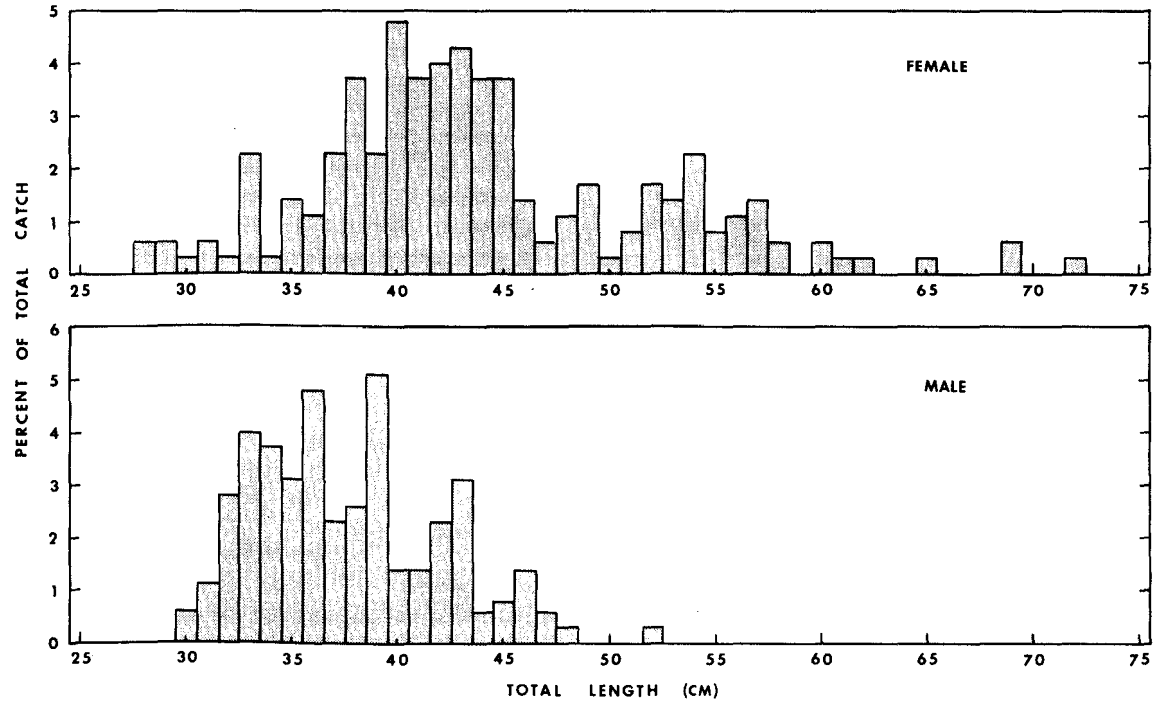

FIGURE 3.—Total length-frequency distribution for 149 male and 202 female summer flounder caught in Delaware Bay in 1966 and 1968.

We found no significant difference in growth rates between the sexes, although both Poole (1961) and Eldridge (1962) did report a significant difference. The growth rates probably are significantly different, an indication of this being the large difference in predicted maximum lengths from Walford's growth transformation (62 cm for males and 88 cm for females), but our limited sample size in older age-groups, particularly males, prevented this difference from being significant. The percent increase in annual length (Tables 2, 3) is similar for both sexes until age 6, and then it begins to decline more rapidly in males.

Our calculated growth rates underestimate those actually observed. Bigelow and Schroeder (1953) stated that the largest summer flounder for which they could find a definite record weighed 11,793 g (26 lb), and the largest fish recorded in sport fishing was 94 cm (37 in) long and weighed 9,072 g (20 lb). Using our predicted maximum lengths and length-weight relationship (see next section), we calculated that a male 62 cm (24.4 in) would weigh 2,339 g (5.21 lb) and a female 88 cm (34.7 in) would weigh 8,199 g (18.1 lb). Also our predicted length of 14 cm at age 1 (Y-axis intercept from Walford's growth transformation) is 3 cm smaller than the observed length given by Eldridge (1962). The lack of samples from age-group 1 and above age-group 8 and the limited samples in age-groups 6 through 8 might account for most of this error. A small change in the female growth rate would give a predicted maximum length of 98 cm, and then we have a fish weighing 11,793 g (26 lb). The growth rate of fish in age-groups 2 through 5 may approximate the growth of the same age-groups in the actual population.

LENGTH AND WEIGHT RELATIONSHIPS

A linear relationship existed between total length-standard length (Table 4), standard length-head length, and head length-upper jaw length. There were no significant differences in these relationships when the sexes are considered separately. The slope (3.151) of the line representing the total length-weight relationship (Table 4) was not significantly different from that (3.146) reported by Lux and Porter (1966) for summer flounder caught in June off Massachusetts. They found no difference between the slopes of the lines when sex was considered, but

TABLE 4.—Calculated values for regression equations describing the total length (TL in millimeters)-weight (W in grams) relationship and the total length (TL in millimeters)-standard length (SL in millimeters) relationship for summer flounder from Delaware Bay.

Number of fish	Sex	Intercept	Slope	Correlation coefficient	Standard error of estimate
		log W = log intercept + slope (log TL)			
[1]333	both	0.404×10^{-5}	3.151	0.995	0.095
102	male	0.102×10^{-4}	2.994	0.953	0.086
167	female	0.227×10^{-5}	3.246	0.987	0.086
		TL = intercept + slope (SL)			
314	both	16.695	1.155	0.986	4.035
102	male	11.044	1.173	0.994	3.531
168	female	18.861	1.150	0.998	4.351

[1]This includes 20 juveniles from North Carolina.

they stated that males were slightly heavier than females on an equal length basis. We found no real difference between the weights of equal sized males and females in Delaware Bay, nor did Eldridge (1962) for fish off Virginia. Twenty fish from North Carolina were included in our total length-weight relationship so we could have some data points from fish in age-groups 0 and 1.

GONAD DEVELOPMENT

Summer flounder gonads were examined from 1966 to 1968 for size and the ovaries for the presence of eggs. Gonads were small and flaccid from April through mid-August. From mid-August through November, the gonads began to enlarge or mature, and the ovaries contained eggs up to 0.4 mm in diameter. Murawski[4] stated that the size of mature eggs is 1.0 to 1.1 mm. There was never more than one-third of any catch during the fall with ripening gonads, and no mature fish were caught from December through March. We concluded that fish leave the bay as they ripen, supporting reports that summer flounder spawn after moving offshore during the winter. The smallest male taken with ripening testes was 30.5 cm, and the smallest female with ripening ovaries was 36 cm. These observations agree with those reported by Eldridge (1962) who stated summer flounder become sexually mature at age 3.

FOOD PREFERENCE

Stomachs from 131 flounder, ranging in size from 31 to 72.5 cm, were examined under a dissecting microscope, and 57% of them contained food. Food items found, listed in order of percent frequency of occurrence were: sand shrimp (*Crangon septemspinosa*, 41%), weakfish (*Cynoscion regalis*, 33%), mysid (*Neomysis americana*, 20%), anchovy (*Anchoa* sp., 7%), squid (*Loligo* sp., 4%), silverside (*Menidia menidia*, 1%), herring (*Alosa* sp., 1%), hermit crab (*Pagurus longicarpus*, 1%), and isopod (*Olencira praegustator*, 1%). On a volume basis weakfish were first, sand shrimp second, and the rest remained in the same order. Fish under 45 cm fed predominantly on invertebrates, while larger ones ate more fish. Poole (1964) found sand shrimp the primary organism eaten by summer flounder in Great South Bay, and that out of 10 fish species eaten, the winter flounder, *Pseudopleuronectes americanus*, was first by weight and the weakfish next to last. These observations indicate that the diet of summer flounder reflects local abundances of prey species.

Flounder caught during the day had a greater volume of food in their stomachs ($\bar{x}$ = 5.1 ml) than those caught at night ($\bar{x}$ = 3.3 ml), but the difference was not significant according to *t*-tests.

RACIAL ANALYSIS

The following morphometric and meristic characters were measured or counted on fish caught in 1966: total, standard, head, and upper jaw lengths; dorsal, anal, and pectoral fin rays; gill rakers on the first arch; and vertebrae (Table 5). All measurements and counts were made on the left side for uniformity. The number of caudal fin rays (17) and pyloric caeca (4) was constant so counting of these characters stopped after 20 fish. Woolcott et al. (1968) reported 18 caudal fin rays, with the posteriormost dorsal ray being very small and easily overlooked in unstained specimens. We missed this 18th ray in our count.

Ranges of some meristic and morphometric characters examined exceed those reported in the literature (Table 5). Analysis of variance showed no significant difference in the counts of the six variable meristic characters due to age or sex.

Comparison by *t*-test of meristic character counts on summer flounder sampled in Delaware Bay, Chesapeake Bay, and North Carolina (Table 6) gave inconclusive results. There was no significant difference between these areas for numbers of dorsal fin rays and vertebrae. Differences based on gill raker counts by Woolcott et al. (1968) might not be valid, because Deubler (1958) stated

[4]Murawski, W. S. 1966. Fluke investigations. N.J. Fed. Aid Proj. F-15-R-7 (Completion Rep. Job No. 3). N.J. Dep. Conserv. Econ. Dev., 24 p.

TABLE 5.—Meristic and morphometric data for summer flounder taken from Delaware Bay in 1966, and ranges reported in the literature that were exceeded.

Characters	Number of fish	Range	Mean	Standard error	Literature reported range
Meristic:					
Dorsal fin rays	194	80-98	88.92	0.20	[1]80-96
Anal fin rays	194	63-78	68.54	0.16	[2]60-73
Pectoral fin rays	196	10-13	11.83	0.05	[1]11-13
Gill rakers:					
Lower arch	196	14-19	16.31	0.08	
Upper arch	196	4- 7	5.59	0.05	
Vertebrae	195	40-43	41.34	0.04	[3]40-42
Morphometric:					
Standard length/head length	235	3.64- 4.30	3.96	0.01	[2,4] 3- 4
Head length/upper jaw length	235	1.54- 2.26	2.05	0.005	[2]2- 2.26

[1]Ginsburg (1952).
[2]Hildebrand and Schroeder (1928).
[3]Deubler (1958).
[4]Jordan and Evermann (1898).

TABLE 6.—A comparison of some summer flounder meristic characters between Delaware Bay (present study), Chesapeake Bay (Ginsburg 1952), and North Carolina [1 (Deubler 1958), 2 (Ginsburg 1952), and 3 (Woolcott et al. 1968)].

							Gill rakers			
	Dorsal fin rays		Anal fin rays		Vertebrae		Upper arch		Lower arch	
Location	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Delaware Bay	88.9	2.8	68.5	2.3	41.3	0.6	5.6	0.7	16.3	1.1
Chesapeake Bay	88.6	2.6	68.6	2.3			5.6	0.6	16.5	0.9
N.C. (1)	89.0	2.7	68.4	2.6	41.3	0.5				
N.C. (2)	88.1	2.7	67.7	2.2			5.0	0.7	15.6	1.3
N.C. (3)	88.4	1.4	68.3	1.2	41.2	0.6	5.2	1.0	14.6	1.5

						Gill rakers							
	Anal fin rays					Upper arch				Lower arch			
Location	Del. Bay	Ches. Bay	N.C. (1)	N.C. (2)	N.C. (3)	Del. Bay	Ches. Bay	N.C. (2)	N.C. (3)	Del. Bay	Ches. Bay	N.C. (2)	N.C. (3)
Delaware Bay				*				**				**	**
Chesapeake Bay				*				**				**	**
N.C. (1)													
N.C. (2)	*	*				**	**			**	**		*
N.C. (3)										**	**	*	

* = significant difference at 0.05 level.
** = significant difference at 0.01 level.

the definitive number of gill rakers is not usually present until summer flounder are 18 mm standard length. Woolcott et al. used fish below this length, and this could account for the significant difference between their counts of lower arch gill rakers and the counts by Ginsburg (1952), also for fish from North Carolina.

Anal fin and gill raker data (Table 6) do suggest, however, that summer flounder from North Carolina belong to a population that is racially different from the population containing Chesapeake Bay and Delaware Bay flounder. This supports Smith's (1973) observation that there is mounting evidence for the existence of separate populations of summer flounder based on: 1) distribution of eggs and larvae, 2) meristic differences, 3) tag returns, and 4) commercial flounder landings. It is possible that separate populations or stocks exist because summer flounder undergo fairly rapid development, 74 to 94 h hatching time (Smith 1973), and conditions affecting egg and larval transport may minimize mixing between geographic areas. This possibility is suggested by Chang and Pacheco (1976) even though they assumed a unit stock for their population evaluation. There should be more research into the possibility of multiple populations before final management recommendations are made.

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