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Aspects of the Biology and Systematics of the American Eel, Anguilla rostrata (Lesueur)

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ASPECTS OF THE BIOLOGY AND SYSTEMATICS OF THE AMERICAN EEL, *ANGUILLA ROSTRATA* (LESUEUR)

A Thesis

Presented to

The Faculty of the School of Marine Science

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

Charles Anthony Wenner

1972

APPROVAL SHEET

This thesis is submitted in partial fulfillment of the requirements for the degree of

Master of Arts

Charles Anthony Wenner

Approved, May 1972

John A. Musick, Ph.D.

Mark Chittenden, Jr., Ph.D.

Kenneth L. Webb, Ph.D.

Frank O. Perkins, Ph.D.

DEDICATION

I would like to dedicate this humble scientific endeavor to the memories of John Steinbeck and Ed Ricketts whose escapades and scientific interests are joyfully, candidly and unashamedly presented in Steinbeck's books, "Cannery Row", Sweet Thursday", Tortilla Flats" and more seriously in "The Log from the Sea of Cortez". During the hours of frustration, indecision and sheer panic which encompassed this study, the following passage from "The Log from the Sea of Cortez" gave me the mental uplift that many people find in the 23rd Psalm:

> "We sat on a crate of oranges and thought what good men most biologists are, the tenors of the scientific world - temperamental, moody, lecherous, loud laughing, and healthy. Once in a while one comes on the other kind - what used in the university to be called a "dry-ball" - but such men are not really biologists. They are the embalmers of the field, the picklers who see only the preserved form of life without any of its principle. Out of their own crusted minds they create a world wrinkled with formaldehyde. The true biologist deals with life, with teeming boisterous life, and learns something from it, learns that the first rule of life is living. The dry-balls cannot possibly learn a thing every starfish knows in the core of its soul and in the vesicles between his rays. He must, so know the starfish and the student biologist who sits at the feet of living things, proliferate in all directions. Having certain tendencies, he must move along their lines to the limit of their potentiality. And we have known biologists who did proliferate in all directions: one or two have had a little trouble about it. Your true biolgoist will sing you a song as loud and as off-key as will a blacksmith, for he knows that morals are too often diagnostic of prostatitis and stomach ulcers. Sometimes he may proliferate a little too much in all directions, but he is very good company, and at least he does not confuse a low hormone productivity with moral ethics."

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Mrs. Pat Berry of the Microbiology Department of VIMS performed the histological preparations. Mrs. Jane Davis prepared the figures and Mr. Ken Thornberry helped with the photography. Data processing was greatly facilited by the close cooperation of the Data Processing Department at VIMS and special thanks go to Mr. John Norcross, Frank Wojcik and Robert Diaz.

Mr. Pete Larsen identified the amphipods for the food study and Mr. Jon Lucy and Thomas Duncan gave freely of their time in the confirmation and identification of polychaetes and pelecypods. Special thanks are extended to Mr. Douglas Markle who played the "Devil's Advocate" during the course of this study by presenting lucid questions and comments.

ABSTRACT

Meristic variation was examined on elvers from the York River, Virginia and was compared to the existing literature. Types and frequency of occurrence of vertebral anomalies were noted. Meristic characters showed a wide latitudinal uniformity. Elver size and time of inshore migration are related to latitude with elvers in southern estuaries arriving earlier and being smaller.

Food habits and seasonality of the American eel were studied from three Virginia rivers. Abundance in trawl surveys was related to temperature with fewer eels being caught in the colder months. Polychaetes, crustaceans and bivalves were important in the diet of _A. rostrata_ in brackish water. Considerable predation on the commercially important species, _Mya arenaria_ and _Callinectes sapidus_, was observed.

Fecundity of the American eel was estimated from 21 specimens migrating from the Chesapeake Bay during November 1970. The relationship between total length and fecundity is $\log y = -4.29514 + 3.74418 \log x$, where y is the fecundity and x is the total length, and between total weight and fecundity is $\log y = 3.22990 + 1.11157 \log x$, where y is the fecundity and x is the total weight. Gonadal condition of migratory specimens was described. Chesapeake Bay specimens are more sexually mature at the time of migration than eels of more northerly estuaries.

Eleven reproductively maturing specimens of the American eel were collected during three independent off-shore trawling operations. Three females were taken on December 5, 1967 southeast of the mouth of the Chesapeake Bay in 10 to 13 fathoms, one male and one female on November 5, 1969 southeast of Cape Cod in 35 to 45 fathoms, and six females on December 22, 1971 east of Assateague Island in 5 fathoms. Morphometrical analysis showed that the specimens were within the range of the silver phase of _Anguilla rostrata_. The ova diameters of the 1967 specimens were within the range of eels migrating from the Chesapeake Bay during November 1970, but those of the 1969 specimen were smaller and consistent with Canadian reports. The 1971 females were more sexually mature, as judged by ova diameters, than any of the other specimens.

ASPECTS OF THE BIOLOGY AND SYSTEMATICS OF THE AMERICAN EEL, *ANGUILLA ROSTRATA* (LESUEUR)

INTRODUCTION

Early studies of the European eel, _Anguilla rostrata_ (L.), were composed of fact and fancy with the latter predominating. One of the prime reasons for this state of confusion was that until 1777 the gonads of the female or male eel had not been described. This lack of knowledge led investigators to postulate that eels were generated from slime, horsehair, dew, etc. The discovery of the female gonad with the apparent lack of males led to the belief that eels were hermaphroditic or that they might even mate with water snakes. Syrski first described the testis in an eel in 1873 and thus ended the myths associated with sexuality in the European eel (for excellent brief histories of early investigations of the eel see Goode, 1881, or Bertin, 1956). At this time several facts were known about the biology of the European eel: male and female sexes did exist; in autumn large numbers of eels migrated from the river systems to spawn; in the spring, large numbers of unpigmented or slightly pigmented eels migrated into the river systems from the sea.

The task of gaining more knowledge on the biology of the eel was given to the Danish biologist and oceanographer Johannes Schmidt. His detailed investigations were reported in a series of papers from 1903 to 1935 which laid the groundwork for a taxonomic revision of the genus Anguilla which was published by Ege in 1939.

Schmidt was able to locate the spawning area of the European and American eels in the Sargasso Sea by means of larval distribution (1909, 1912, 1923).

According to Ege (1939) the genus *Anguilla* is composed of 16 species of which 14 are Indo-West Pacific in their distribution. There are two species of *Anguilla* in the North Atlantic: *A. anguilla* (L), the European eel, and *A. rostrata* (Lesueur), the American eel. This was challenged by Tucker (1959) who stated that there is but one species in the North Atlantic, *A. anguilla*. He postulated that European eels need not and do not reach the spawning area, but perish en route. According to his theory, the eel populations of Europe are replenished by the transport of larvae across the North Atlantic by the Gulf Stream with the associated larval life causing the meristic variation generally used to distinguish the two species. Tucker believed that there was but one species with the two forms being ecophenotypes. This theory was challenged by a number of investigators (D'Ancona, 1959; Deelder, 1960; D'Ancona, 1960) with the most persuasive argument defending the two species concept being published by Bruun (1963). It is now generally accepted that there are two species in the North Atlantic.

Vladykov (1955) pointed out that much of the biology of the European eel is known but that the same cannot be said of the American eel. Many aspects of the biology of *A. rostrata* are extrapolations of the results of European investigators on *A. anguilla*. This is as true today as it was in 1955. Recently, studies on age and growth, feeding habits and sex ratios have been done (Gray and

Andrews, 1970; Ogden, 1971; Gray and Andrews, 1971) but there are still numerous gaps in our knowledge of the biology of the American eel.

The purpose of this investigation is to describe certain aspects of the biology of the American eel, _A_. _rostrata_, from the lower Chesapeake Bay and to summarize and provide additional information to the present literature. Because of the wide scope of the study with the rather disjunct parts, it is divided into the appropriate sections with an overall summary.

PART I.

Meristics and vertebral anomalies of the American eel, *Anguilla rostrata* (Lesueur), with comments on elver behavior.

INTRODUCTION

The taxonomic state of the North Atlantic members of the genus *Anguilla* was in a chaotic state prior to the work of Schmidt with morphological variations being designated species (see Ege, 1939 for a list of synonymies). Schmidt (1913, 1914, 1915) employed meristics to reduce the number of North Atlantic species to two: *Anguilla rostrata* (Lesueur), the American eel, and *A. anguilla* (L.), the European eel. Ege (1939) and Ladd (1958) provided additional meristic data on the American eel. Ladd (1958) noted many osteological deformities in the vertebral columns of elvers from Nova Scotia, New Hampshire and Chesapeake Bay.

The total length of elvers and the time of inshore migration into estuaries along the east coast of North America has been reported by Schmidt (1909), Vladykov (1966) and Smith (1968). Vladykov (1966) found an increase in elver size with an increase in latitude from Florida to Quebec and divided his results into three size groups: a southern group from Florida to Chesapeake Bay (mean size less than 53 mm); an intermediate size group from Maryland to New Brunswick (mean size 55.5-56.9 mm) and a northern group (mean size greater than 58.0 mm).

The purposes of this report are: (A) to summarize and present additional meristic data on the American eel and to determine if latitudinal differences in meristics exist; (B) to describe the frequency of occurrence and major types of vertebral deformities in elvers; (C) to report observations on elver behavior during migration and (D) to determine if the mean total length of inshore migrating elvers is a linear function of latitude rather than three separate size groups as presented by Vladykov (1966).

MATERIALS AND METHODS

Stage VI-A elvers (Bertin, 1956), collected on March 15, 1970 with a fine mesh dip net in Bracken's Creek, a small tributary of the York River near Yorktown, Va., were preserved in 5% phosphate buffered formalin. Temperatures were measured in the field with a stem thermometer and salinities were determined with an induction salinometer on samples returned to the laboratory.

Preserved elvers were rinsed in tap water, cleared in 5% potassium hydroxide, stained with potassium hydroxide-alizarin red-S solution, transferred through a graded series of KOH-glycerin solutions and were then stored in 100% glycerin with thymol added to prevent fungal growth (Ladd, 1958). The following meristics of 100 randomly chosen cleared and stained elvers were counted under appropriate magnification by the method of Ege (1939): total, caudal and precaudal vertebrae; left and right pectoral fin rays; left and right branchiostegals; dorsal, anal and caudal fin rays. These and 100 additional randomly chosen specimens were examined for vertebral anomalies.

Analysis of variance was used to test for significant differences between the number of left and right pectoral fin rays and the number of left and right branchiostegals and to compare the meristic results of the present study with existing data from the literature. This was done on an IBM 360 computer using the BMD-01V program (Dixon, 1967).

Total length of the elvers was recorded to the nearest millimeter using vernier calipers. Additional elvers (USNM #18734) of stage VI-A collected 15 to 16 April 1957 at Millsboro Dam, Indian River, Del. were examined for length frequency. Total lengths of individual elvers for these specimens and data from the literature were regressed against approximate latitude of capture using an IBM-1130 computer to provide an equation relating the size of inshore migrating elvers and latitude.

RESULTS AND DISCUSSION

Notes on elver behavior:

Bracken's Creek connects Bracken's Pond and the York River and is about 2 to 5 meters wide, 0.3 to 1.5 meters deep and 100 meters long. The creek is formed by outflow of the pond over a dam about 1.5 meters in height. The rate of discharge, salinity and temperature are determined by the tidal stage of the York River and the pond level. Water temperature on the collection date (3-15-70) was 11°C at the dam and 9° in the lower stream. The salinity was freshwater at the base of the dam but 4‰ in the lower reaches of the creek at about 1/2 flood tide.

Elvers swam in the current with no apparent difficulty. Most remained concentrated out of the main current near the sides of the dam. Many individuals had burrowed into the substrate and under rocks. Several individuals were scaling the moist vertical wall of the dam and a few had reached the top. They were probably successful in their attempt to colonize the pond. Individuals out of water demonstrated the behavior associated with aerial respiration as described by Berg and Steen (1965, 1966) for large specimens of the European eel, *A. anguilla*. The elvers gulped air and kept their opercles closed, thus expanding their branchial chamber. Berg and Steen (1965) stated that yellow eels out of water obtained significant amounts of oxygen by this mechanism and by absorption through the skin. No data are available on the efficiency of this mechanism in elvers.

Meristics:

Means and their 95% confidence intervals for the present study plus data from the existing literature are found in Table 1 and their frequency distributions are found in Appendix 1. Analysis of variance showed no significant difference between the number of left and right branchiostegals (F = 0.0416, df = 1, 198) or the number of left and right pectoral fin rays (F = 0.9152, df = 1, 198). Analysis of variance showed no significant mean differences in the following meristic characters between the literature data and those of the present study: right pectoral fin rays (F = 0.5046, df = 3, 387); anal fin rays (F = 1.8326, df = 1, 342); right branchiostegals (F = 0.3886, df = 2, 950) and precaudal vertebrae (F = 1.017, df = 4, 892). Significant differences were found in the following characters: caudal vertebrae (F = 15.1905, df = 3, 787); total vertebrae (F = 39.9350, df = 9, 1744) and caudal fin rays (F = [illegible].0053, df = 1, 511). ANOVA tables for all of the above are in Appendix 2.

Table 1. Summary of meristic characters of the American eel, *Anguilla rostrata*.

Total vertebrae	St. Lawrence River (Schmidt, 1913)	Weldon, No. Carolina (Schmidt, 1913)	Tilsbury, Mass. (Schmidt, 1913)	St. Croix Virgin Islands (Schmidt, 1913)	Gloucester, Mass. (Schmidt, 1913)	
Sample size	86	80	86	101	502	
$\bar{X} \pm$ confidence interval	107.01 ± 0.27	107.29 ± 0.30	106.95 ± 0.26	107.23 ± 0.24	107.35 ± 0.12	
Range	104 - 110	104 - 110	103 - 110	104 - 110	104 - 111	
Total vertebrae	Mass. (Ege, 1939)	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (Wenner, present study)	Total
Sample size	99	298	296	99	99	1746
$\bar{X} \pm$ confidence interval	107.88 ± 0.24	107.14 ± 0.15	107.14 ± 0.14	107.13 ± 0.21	106.82 ± 0.26	107.14 ± 0.06
Range	104 - 110	104 - 110	104 - 110	104 - 109	103 - 109	103 - 111
Precaudal vertebrae	Mass. (Ege, 1939)	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (Wenner, present study)	Total
Sample size	99	298	301	100	99	897
$\bar{X} \pm$ confidence interval	42.85 ± 0.14	42.71 ± 0.09	42.74 ± 0.09	42.83 ± 0.15	42.69 ± 0.15	42.77 ± 0.04
Range	41 - 45	41 - 45	41 - 46	41 - 44	41 - 44	41 - 46

Table 1. (Cont.)

Caudal vertebrae	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (Wenner, present study)	Total
Sample size	296	297	99	99	791
$\overline{X} \pm$ confidence interval	63.43 ± 0.13	63.25 ± 0.12	63.31 ± 0.20	64.13 ± 0.26	64.31 ± 0.08
Range	60 - 68	60 - 66	61 - 66	61 - 67	61 - 68

Left branchio-stegals	West Gloucester, Mass. (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Wenner, present study)	Total
Sample size	746	100	100	946
$\overline{X} \pm$ confidence interval	11.00 ± 0.05	11.03 ± 0.14	11.05 ± 0.13	11.02 ± 0.04
Range	9 - 13	10 - 13	9 - 13	9 - 13

Right branchio-stegals	West Gloucester, Mass. (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Wenner, present study)	Total
Sample size	752	101	100	953
$\overline{X} \pm$ confidence interval	11.02 ± 0.05	11.09 ± 0.15	11.06 ± 0.14	11.03 ± 0.04
Range	9 - 13	9 - 13	10 - 13	9 - 13

Table 1. (Cont.)

Left pectoral fin rays	Virginia (Wenner, present study)	Total			
Sample size	100	100			
$\bar{X} \pm$ confidence interval	16.51 ± 0.21	16.51 ± 0.21			
Range	14 - 19	14 - 19			
Right pectoral fin rays	**West Gloucester, Mass. (Schmidt, 1914)**	**St. Croix Virgin Islands (Schmidt, 1914)**	**Mass. (Ege, 1939)**	**Virginia (Wenner, present study)**	**Total**
Sample size	140	50	101	100	391
$\bar{X} \pm$ confidence interval	16.78 ± 0.16	16.62 ± 0.25	16.71 ± 0.22	16.65 ± 0.21	16.71 ± 0.10
Range	14 - 20	15 - 19	14 - 20	14 - 19	14 - 20
Caudal fin rays	**West Gloucester, Mass. (Schmidt, 1914)**	**Virginia (Wenner, present study)**	**Total**		
Sample size	413	100	513		
$\bar{X} \pm$ confidence interval	9.91 ± 0.04	10.09 ± 0.08	9.95 ± 0.04		
Range	8 - 12	9 - 12	8 - 12		

Table 1. (Cont.)

Dorsal fin rays	Virginia (Wenner, present study)	Total
Sample size	99	99
$\bar{X} \pm$ confidence interval	231.44 ± 2.77	231.44 ± 2.77
Range	183 - 276	183 - 276

Anal fin rays	West Gloucester, Mass. (Schmidt, 1914)	Virginia (Wenner, present study)	Total
Sample size	245	100	345
$\bar{X} \pm$ confidence interval	198.65 ± 1.24	200.26 ± 2.23	199.12 ± 1.11
Range	167 - 229	168 - 227	167 - 229

The statistically significant difference between the numbers of caudal fin rays is probably not biologically significant. Schmidt (1914) studied 413 specimens which had a mean caudal fin ray count of 9.92 while the present study included 100 specimens which had a mean of 10.09. The difference of 0.17 fin rays between the two sample means is small and much significance cannot be attributed to it. The statistically significant differences in total and caudal vertebrae are attributed to the methodology of Ladd (1958). Schmidt (1913, 1914, 1915), Ege (1939) and the present study designated all vertebral elements beyond the last hour glass shaped centrum as one vertebrae whereas the last hour glass shaped centrum was the last countable vertebra for Ladd (1958). Ladd's mean counts from Nova Scotia, New Hampshire and Virginia were approximately 1 vertebra lower than the counts in other studies. To standardize methods for an overall summary of literature, one was added to each of Ladd's values for total and caudal vertebrae while the values of the precaudal vertebrae were left unchanged.

Meristic characters show a wide latitudinal uniformity (Table 1) which presents strong evidence for the existence of one spawning population of the American eel. Good taxonomic characters used to define a species should show little variation both within a sample and between samples. For this reason, it is suggested that both dorsal and anal fin rays should not be used as taxonomic characters because of their variability (dorsal fin rays: mean = 231.44, range 183-276; anal fin rays: mean = 199.12, range 167-229).

Vertebral anomalies:

Osteological deformities associated with the vertebral column were found in 78 of the 200 specimens examined. Most abnormalities (96%) were in the caudal vertebrae. Hemal spine deformities were the most abundant. Fusion or partial fusion of vertebral centra occurred in 3% of the deformed specimens. Abnormalities in more than one vertebra in the same specimen (multiple anomalies) were present in 20% of the deformed specimens. The most typical deformities are shown in Figures 1 and 2.

Ladd (1958) found skeletal abnormalities in 56% of the 700 elvers of the American eel he examined. Most frequent were modifications and duplications of the neural and hemal spines. He stated that these could hardly be classified as abnormalities because they were so common. Gabriel (1944) found 26.9 to 31.1% of laboratory cultured specimens of Fundulus heteroclitus possessed abnormal vertebrae, and was unable to correlate them with temperature, developmental rates or genetic factors. The frequency of occurrence in wild populations was 2 to 3% and he attributed the high frequency in laboratory populations to "some physiological depressor present under laboratory conditions". Manion (1967) found skeletal abnormalities in ammocoetes from the Great Lakes region but not in sexually mature forms. Therefore, before accepting Ladd's proposal (1958) that the high percentage of elvers with vertebral malformations can hardly be considered abnormal, the resident populations of eels in the rivers must be examined for their presence. If the frequency of individuals with abnormal

Figure 1.

a. A cleared and stained elver of the American eel, *A. rostrata*, ready for meristic evaluation.

b. Malformed hemal spines, partially fused and fused vertebrae. Total length = 56.4 mm. Vertebrae: total = 104 (?); precaudal = 42; caudal = 62 (?). Fin rays: caudal = 10; dorsal = 227; anal = 199; left pectoral = 17; right pectoral = 18. Branchiostegals: left = 11; right = 11.

c. Partially fused caudal vertebrae with a malformed hemal spine. Total length = 51.9 mm. Vertebrae: total = 109; precaudal = 43; caudal = 66. Fin rays: caudal = 10; dorsal = 221; anal = 188; left pectoral = 17; right pectoral = 17. Branchiostegals: left = 11; right = 11.

d. Fused vertebrae, malformed hemal spines, malformed hypural plate. Total length = 49.8 mm. Vertebrae: total = 95 (countable); precaudal = 43; caudal = 52 (?). Fin rays: caudal = 10; dorsal = 211; anal = 186; left pectoral = 15; right pectoral = 15. Branchiostegals: left = 11; right = 11.

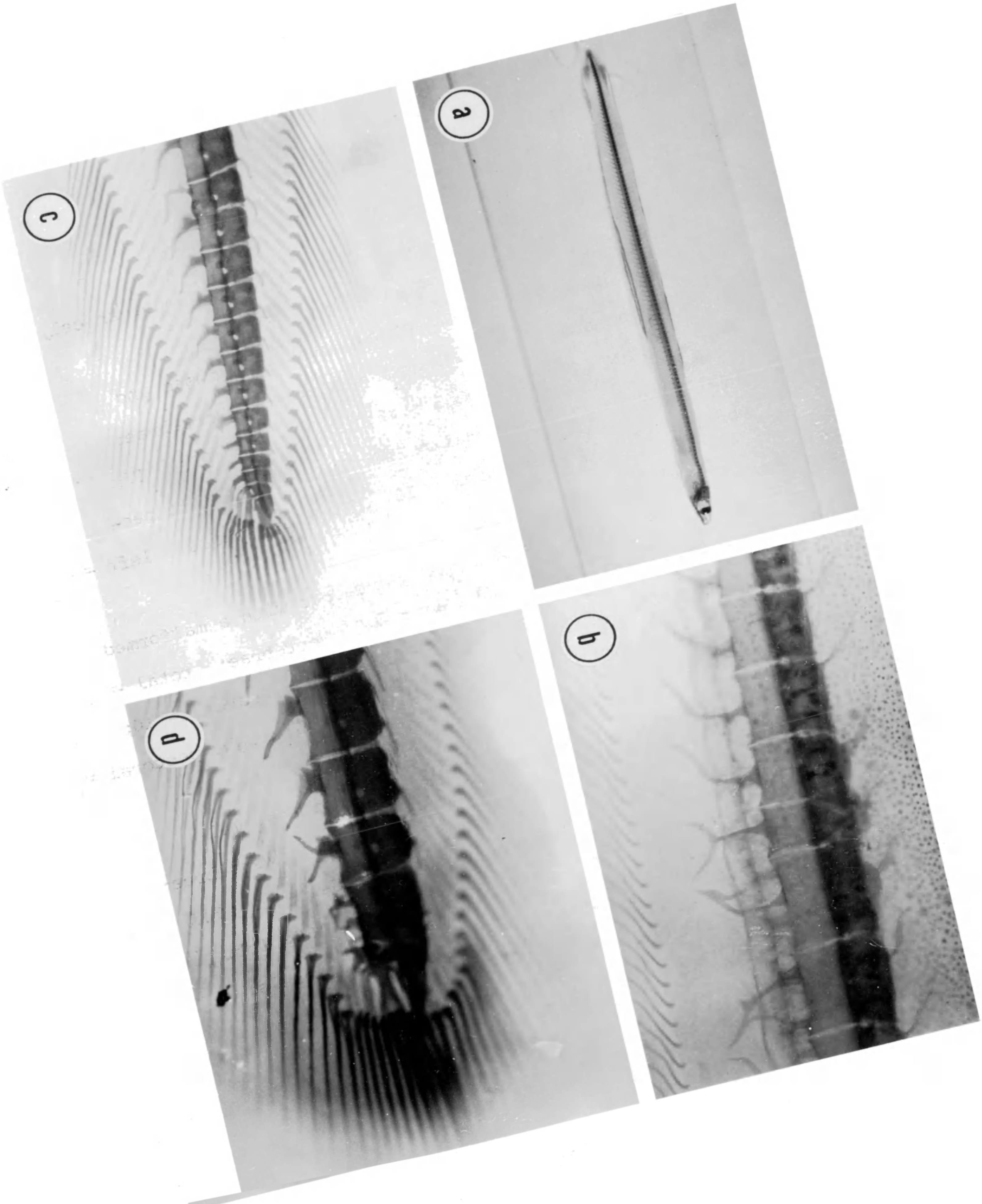

a
b
c
d

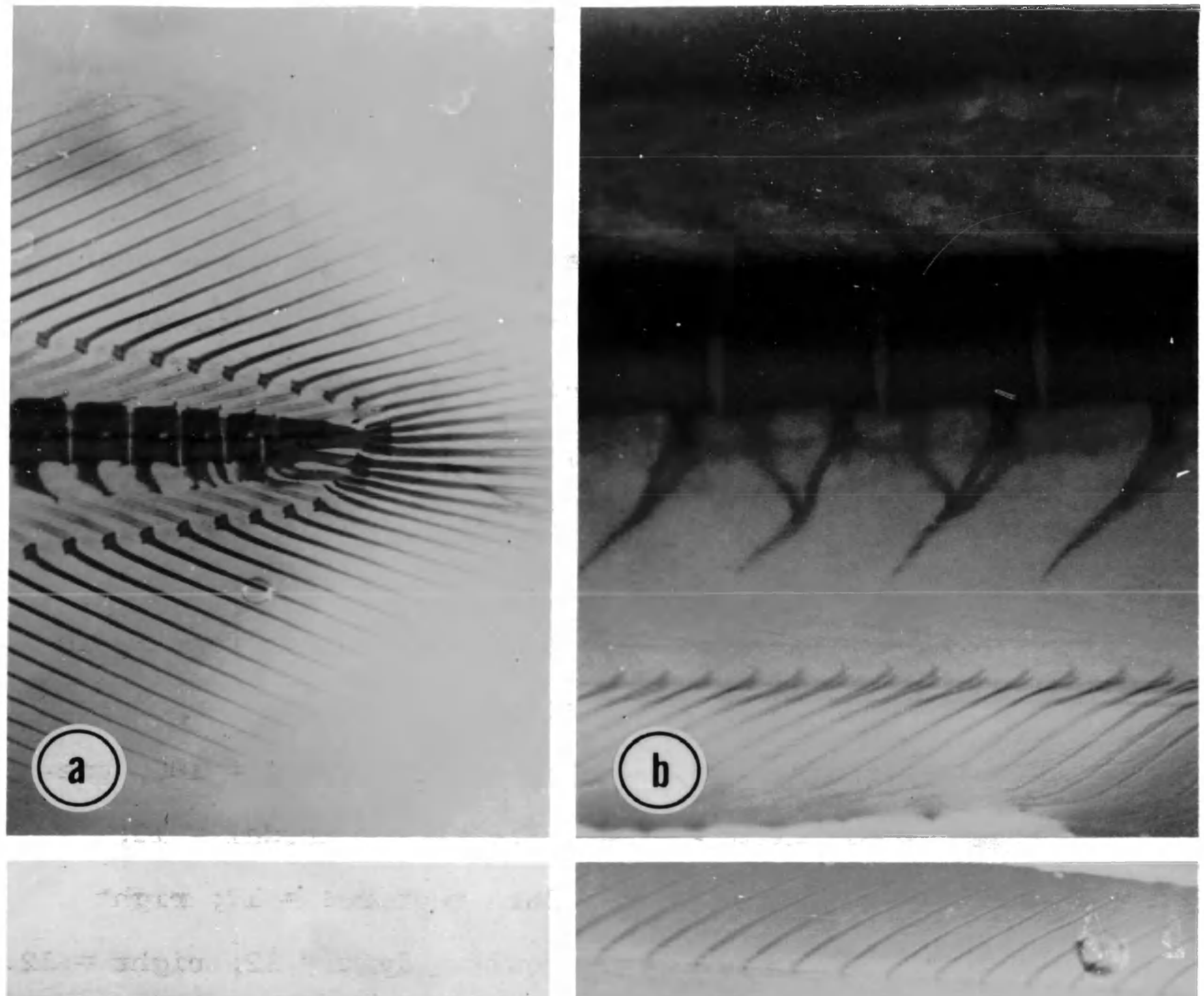
Figure 2.

a. Extra hemal spines on caudal vertebrae near hypural plate. Total length = 57.2 mm. Vertebrae: total = 106; precaudal = 41; caudal = 65. Fin rays: caudal = 10; dorsal = 235; anal = 199; left pectoral = 17; right pectoral = 17. Branchiostegals: left = 11; right = 11.

b. Extra hemal spines fused together forming an arch around the dorsal aorta in the caudal vertebrae. Total length = 53.7 mm. Vertebrae: total = 106; precaudal = 42; caudal = 64. Fin rays: caudal = 10; dorsal = 238; anal = 227; left pectoral = 17; right pectoral = 17. Branchiostegals: left = 12; right = 12.

c. Possible fused caudal vertebrae, extra and fused neural and hemal spines. Total length = 56.2 mm. Vertebrae: total = 108; precaudal = 43; caudal = 65. Fin rays: caudal = 10; dorsal = 236; anal = 207; left pectoral = 15; right pectoral = 15. Branchiostegals: left = 12; right = 11.

d. Extra and fused hemal spines on a caudal vertebrae. Meristic data same as figure 2a.


a
b
c
d

vertebrae is much lower in these populations, it would demonstrate a selection pressure against these forms.

Elver size and latitude:

Length frequency distribution of elvers collected near Yorktown, Va. is reported in Fig. 3. Their mean size was 55.6 mm. Vladykov (1966) concluded that elvers arrive earlier in the southern latitudes and that there is a gradient in size with more northern forms being larger. Table 2 summarizes data of Schmidt (1909), Vladykov (1966), Smith (1968) and the present study. Length frequency distributions are in Appendix 3. When total lengths of the elvers from the locations of these studies were plotted against approximate latitude of capture, the data showed linearity over the range of values observed. The equation for the linear relationship between mean total length of elvers and latitude is $y = 38.862 + 0.415\ x$, where y is the mean total length in mm and x is latitude in degrees (Fig. 4). The correlation coefficient ($r = 0.5598$) shows that there is a significant relationship between latitude and mean total length. The underlying assumption of the model is that the leptocephalus larvae metamorphose at smaller sizes in more southerly locales thereby producing smaller elvers. A more reliable method of predicting elver size at the time of inshore migration would be to use the distance from the spawning grounds as the independent variable, but since its position is still in doubt (Vladykov, 1964), the use of latitude may give a reasonable approximation. These data do show that the size of elvers cannot be broken into three separate categories as implied by Vladykov (1966) but are merely points on a north-south continuum.

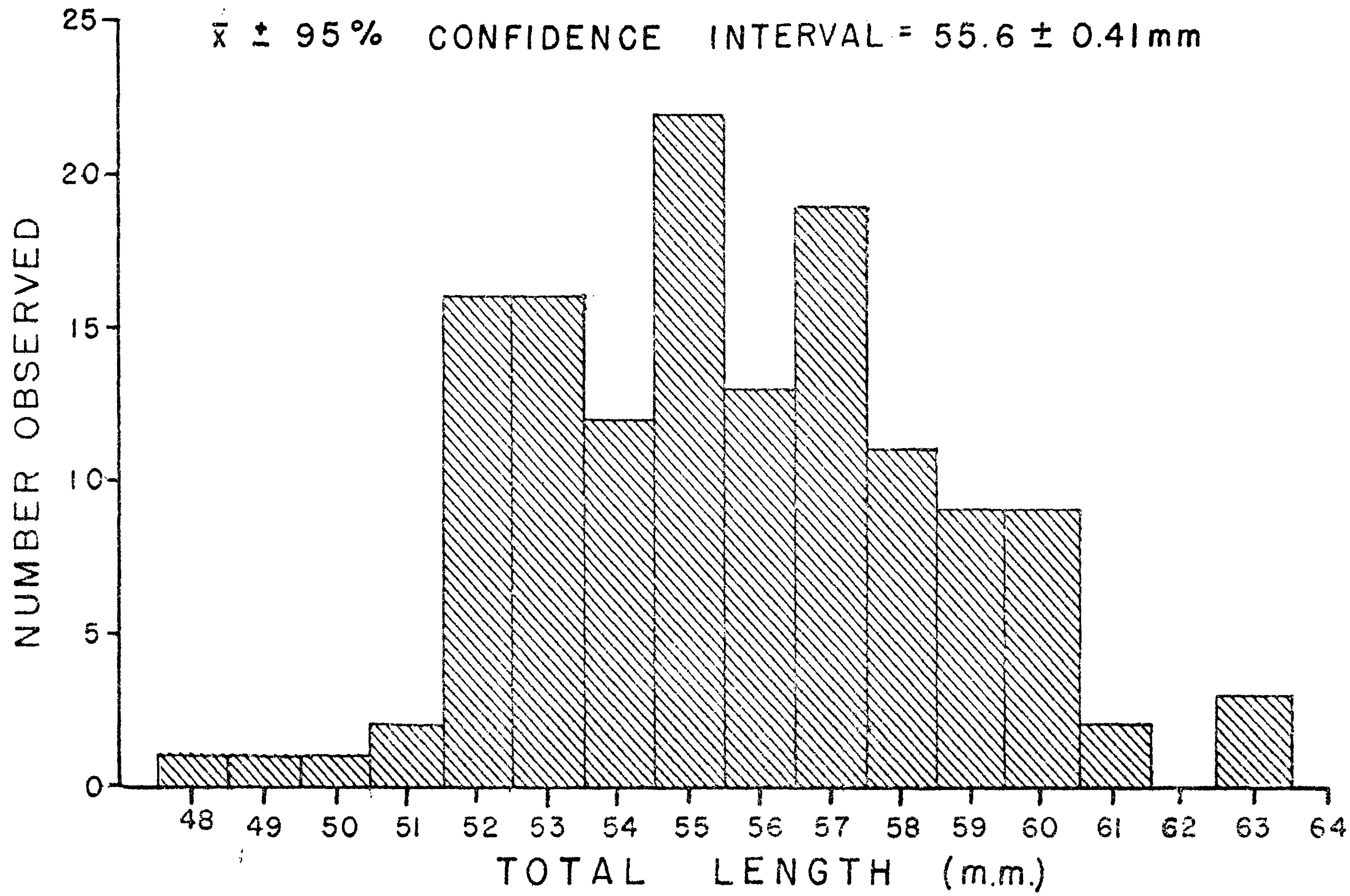
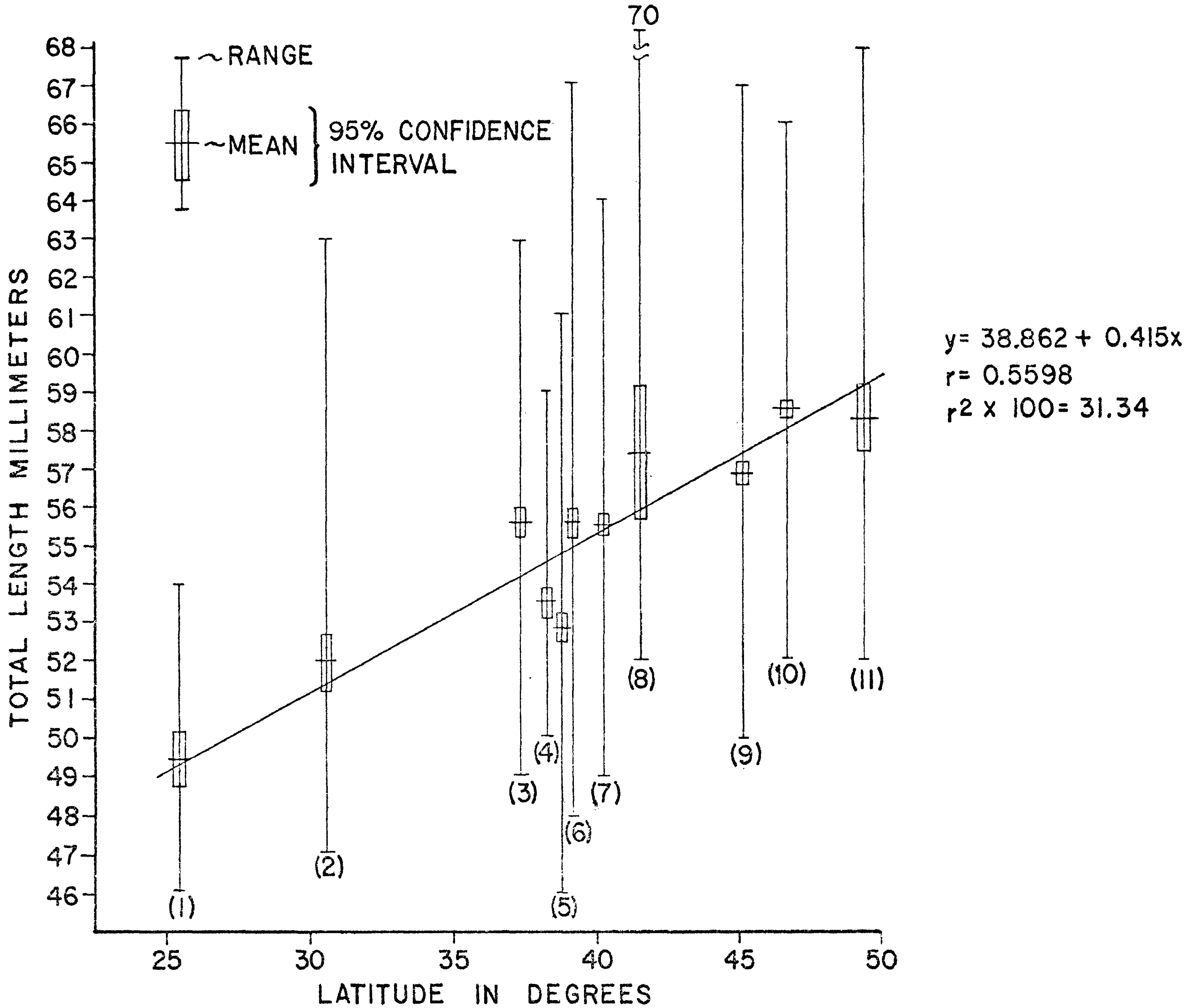

$\bar{x}$ ± 95% CONFIDENCE INTERVAL = 55.6 ± 0.41mm
NUMBER OBSERVED
0
5
10
15
20
25
48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64
TOTAL LENGTH (m.m.)

Table 2. Collection sites of elvers of *A. rostrata* from various investigators.

#	Collection Site	Latitude (°)	Date of Collection	Sample Size	Mean Length (mm)	Investigator
1	Everglades, Fla.	25.43	Jan. 19, 1966	32	49.4	Smith, 1968
2	Escambia River, Fla.	30.56	April 2-7, 1953	61	52.0	Vladykov, 1966
3	York River, Va.	37.38	March 17, 1970	137	55.6	Present study
4	Patuxent River, Md.	38.46	April 20, 1960	213	52.9	Vladykov, 1966
5	Ocean City, Md.	38.65	April 14, 1960	201	55.7	Vladykov, 1966
6	Indian River, Del.	38.66	April 15, 1957	105	53.5	Present study
7	Manasquan, New Jersey	38.09	May 28, 1960	236	55.5	Vladykov, 1966
	Woods Hole, Mass.	41.54	March 1, 1872	19	56.9	Schmidt, 1909
	New Brunswick, Canada	45.07	June 19, 1952	228	58.6	Vladykov, 1966
			May 25, 1953			
			May 13, 1960			
10	Nova Scotia, Canada	46.67	May 25, 1953	362	58.6	Vladykov, 1966
			May 10-12, 1960			
			June 1, 1955			
11	Quebec, Canada	49.29	June 29, 1945	31	58.3	Vladykov, 1966


TOTAL LENGTH MILLIMETERS
LATITUDE IN DEGREES
~RANGE
~MEAN
95% CONFIDENCE INTERVAL
70
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
y= 38.862 + 0.415x
r= 0.5598
r2 x 100= 31.34

PART II.

Food habits and seasonality of the American eel, *Anguilla rostrata* (Lesueur) from three Virginia rivers.

INTRODUCTION

Food habits of the American eel in fresh water were studied by Godfrey (1967), Compton (1968) and Ogden (1970). Little work has been reported from estuaries except for the brief descriptions of Hildebrand and Schroeder (1927), Brinkley and Brown (1935) and Bigelow and Schroeder (1953). These last three studies were qualitative rather than quantitative.

Several investigators have studied the seasonality of the American eel in freshwater. Smith and Saunders (1955) reported that eels were generally not caught in fish traps during the winter in the Maritime Provinces of Canada. Compton (1968) found eels to be less abundant during the winter months in a tributary of the Delaware River. These authors attributed this decrease in winter to hibernation of eels in mud bottoms. Eales (1968) stated that in winter inactive eels "hole up" in localized areas.

The purpose of this report is to describe the seasonality of the American eel in brackish water and to provide qualitative and quantitative data on the food habits in those regions.

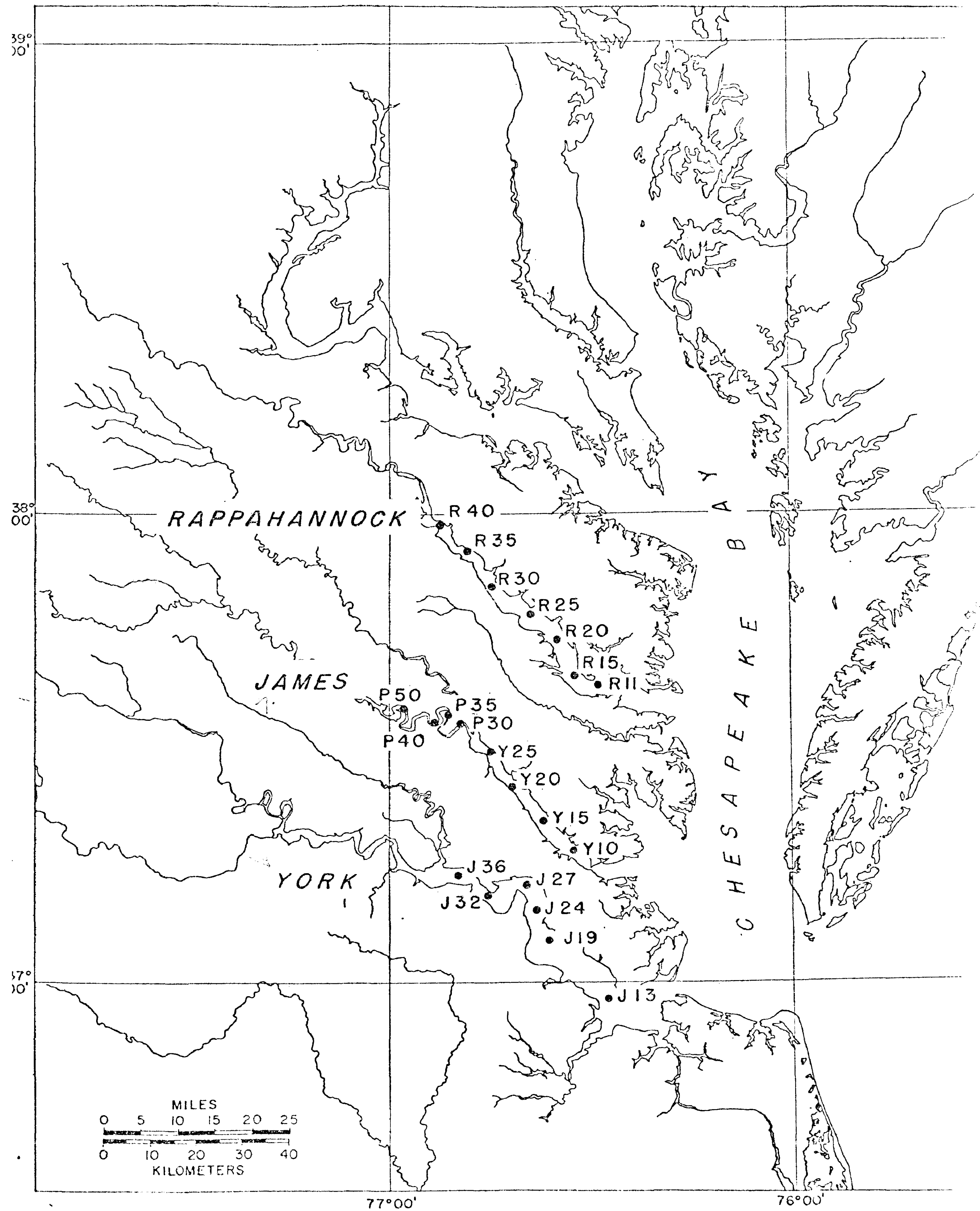
METHODS AND MATERIALS

Monthly collections were made using a 30' semi-balloon trawl with a 1/2 inch stretch mesh cod-end liner by Virginia Institute of Marine Science personnel on the R/V Pathfinder, on the York and James rivers from January 1966 to December 1970 and on the Rappahannock River from January 1967 to December 1970. Stations were occasionally not sampled due to vessel maintenance or icing conditions on the rivers during extremely cold months. Tows were 7.5 to 15 min. long at previously selected stations (Fig. 5). Temperatures were measured with a stem thermometer, salinities with an induction salinometer and dissolved oxygen by Winkler titration on bottom samples.

In order to standardize catches for different trawl times, the number of eels caught was summed for each month and divided by the total number of hours trawled. A $\log_{10}(x + 1)$ transformation for contagious distribution was then applied to the monthly values and arithmetic means of the lagarithms were calculated. The treatment of the data assumes a direct relationship between number caught and tow length, but the nature of the relationship is not known. The author was not responsible for the design of the sampling program.

Specimens for stomach analysis, collected during the April to October 1971 trawl survey, were frozen until being processed. Total length was recorded to the nearest millimeter and stomachs from 336 specimens were removed and placed in 10% phosphate buffered formalin. Contents were sorted, identified to species whenever possible, frequency of occurrence noted and volume estimated by water displacement to the nearest tenth of a milliliter. Each siphon of the bivalves *Macoma* sp. and *Mya arenaria* encountered was designated as one animal for the frequency of occurrence. Appendages of the blue crab, *Callinectes sapidus*, were also counted as one animal.

Figure 5. Station locations for the seasonality and food habits studies of the American eel.



39°
00'
38°
00'
37°
00'
77°00'
76°00'
RAPPAHANNOCK
JAMES
YORK
CHESAPEAKE BAY
R40
R35
R30
R25
R20
R15
R11
P50
P35
P30
P40
Y25
Y20
Y15
Y10
J36
J27
J32
J24
J19
J13
MILES
0 5 10 15 20 25
0 10 20 30 40
KILOMETERS

RESULTS AND DISCUSSION

Hydrography:

Means, 95% confidence limits and ranges of the hydrographic observations are found in Figures 6 through 8. Salinity varied widely at any given station during the sampling period. This is a typical estuarine situation with salinity being determined by tidal stage and amplitude, wind and fresh water run-off (Carriker, 1967). Dissolved oxygen concentrations are higher in the cooler months and decrease with increasing temperatures as expected. The Rappahannock River, a relatively unpolluted estuary, shows the lowest dissolved oxygen concentrations during the summer months with values at the lower stations (R-11, R-15, R-20) sometimes going as low as 0.7 ppm.

Food Habits:

A total of 46 of the 67 stomachs from animals collected in the James River contained food while 51 of 85 and 133 of 184 contained food in the York and Rappahannock rivers respectively. Frequency of occurrence and displacement volumes of different food items for each station are in Table 3. Frequency of occurrence and percent volume displacement of major taxa are in Figures 9 and 10.

Crustaceans, bivalves and polychaetes made up the greatest part of the stomach contents of *A. rostrata* in each river. Crustaceans were the most important numerically and volumetrically except in the Rappahannock River where the bivalves, *Mya arenaria*, *Mulenia lateralis* and *Macoma* sp. were more numerous

Figure 6. Means, 95% confidence limits and ranges of bottom hydrographic observations of the James River stations from January 1966 to December 1970.

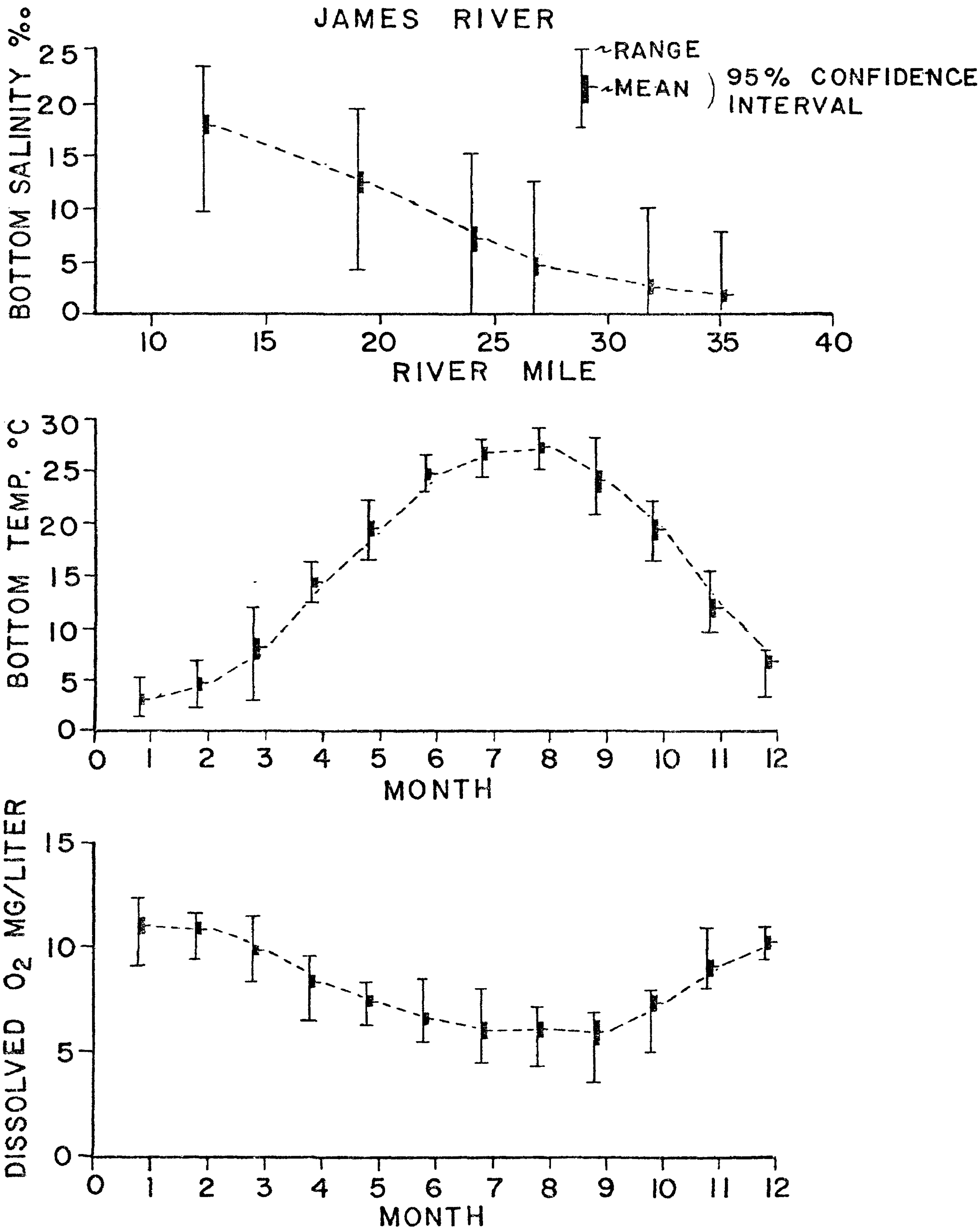

JAMES RIVER
RANGE
MEAN
95% CONFIDENCE INTERVAL
BOTTOM SALINITY ‰
0
5
10
15
20
25
10
15
20
25
30
35
40
RIVER MILE
BOTTOM TEMP. °C
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
DISSOLVED O2 MG/LITER
0
5
10
15
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH

Figure 7. Means, 95% confidence limits and ranges of bottom hydrographic observations of the York River stations from January 1966 to December 1970.

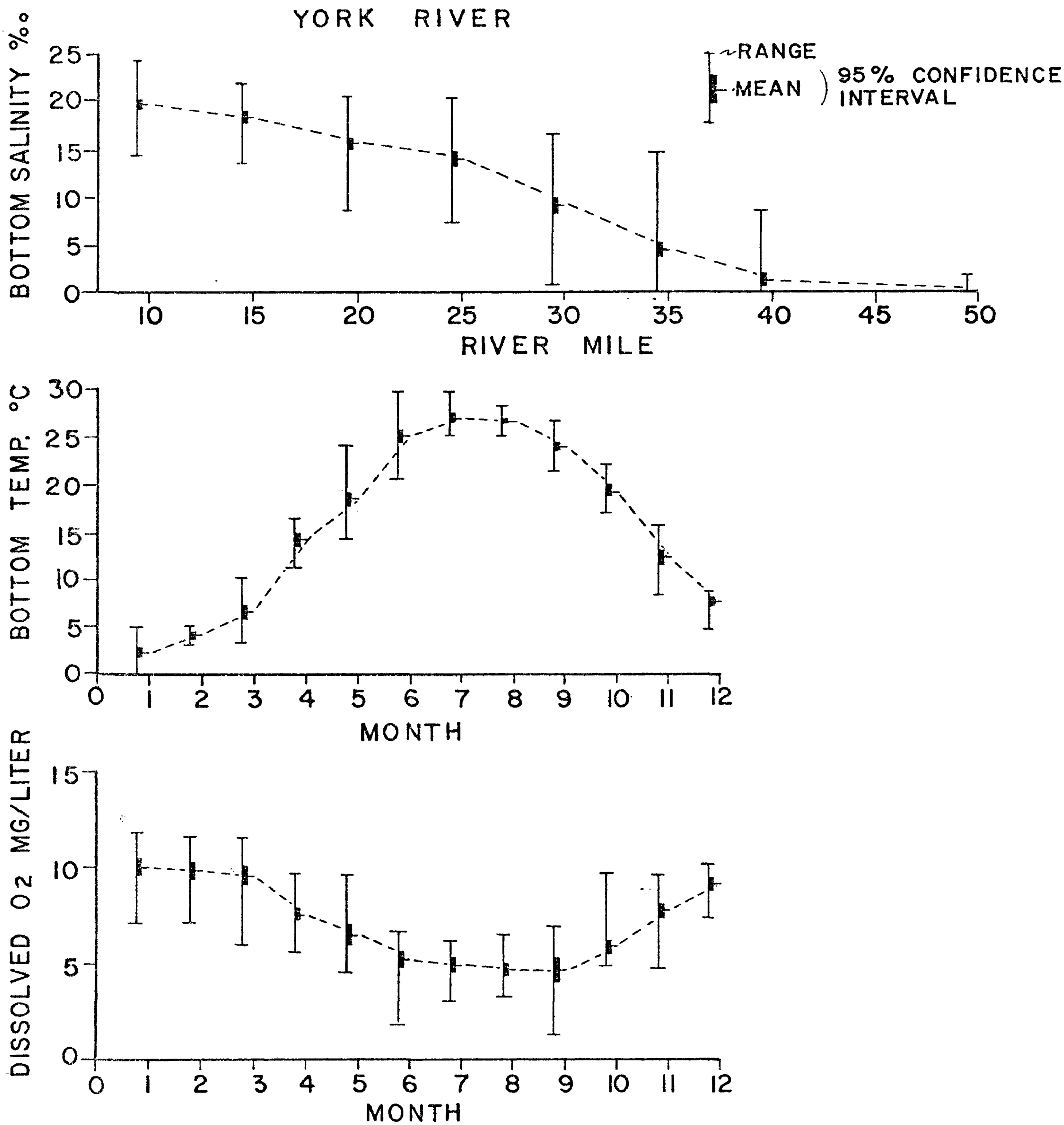

YORK RIVER
RANGE
MEAN
95% CONFIDENCE INTERVAL
BOTTOM SALINITY ‰
RIVER MILE
BOTTOM TEMP. °C
MONTH
DISSOLVED O2 MG/LITER
MONTH

Figure 8. Means, 95% confidence limits and ranges of bottom hydrographic observations of the Rappahannock River stations from January 1967 to December 1970.

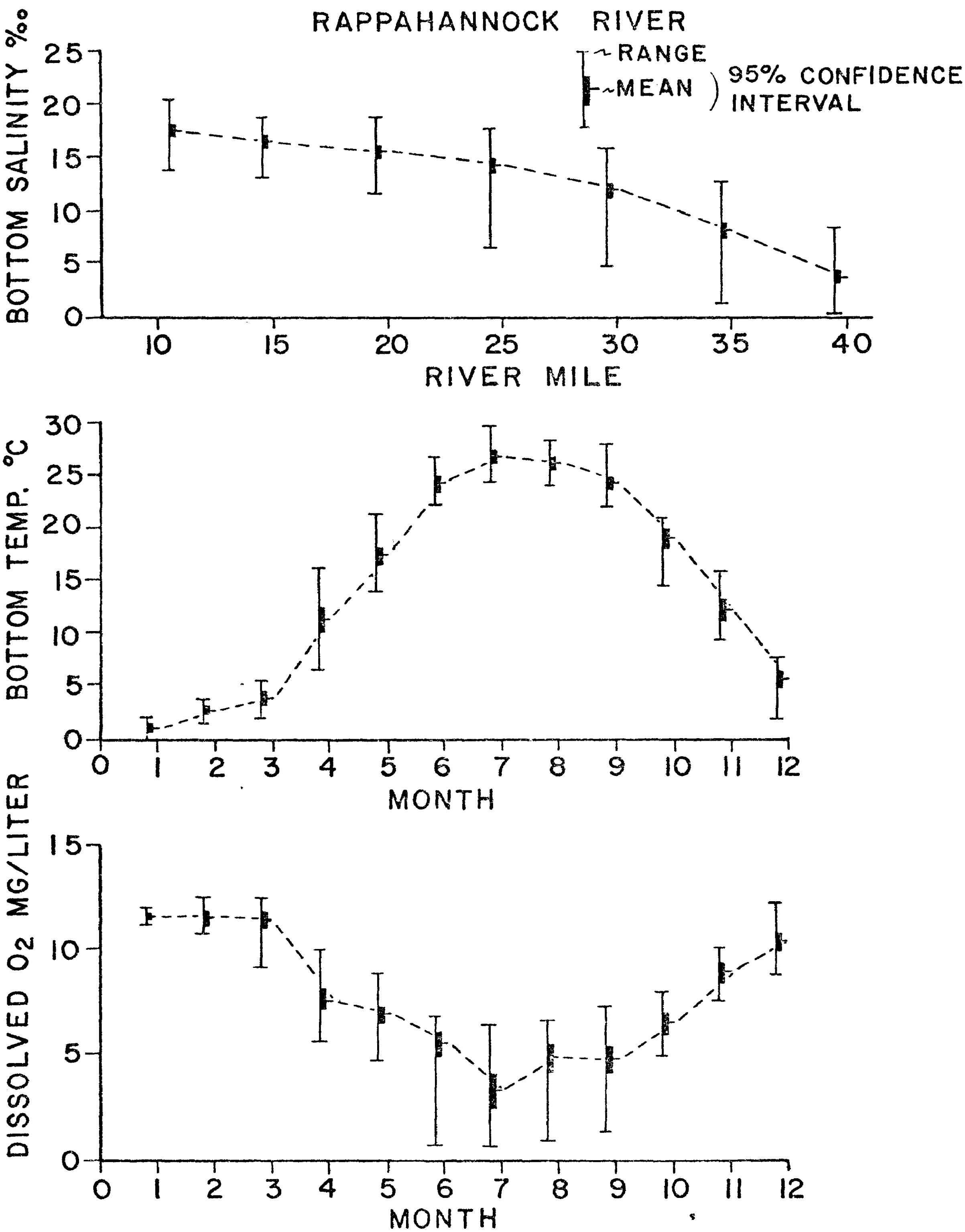

RAPPAHANNOCK RIVER
RANGE
MEAN
95% CONFIDENCE INTERVAL
BOTTOM SALINITY ‰
0
5
10
15
20
25
10
15
20
25
30
35
40
RIVER MILE
BOTTOM TEMP. °C
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH
DISSOLVED O2 MG/LITER
0
5
10
15
0
1
2
3
4
5
6
7
8
9
10
11
12
MONTH

Table 3. Frequency of occurrence, volume displacement and species composition of stomach contents of the American eel from the James, York and Rappahannock rivers by station location.

James River

Station	Class	Species	# of Individuals	Volume (ml)
J-13	Polychaeta	Pectinaria gouldii	29	6.3
		Nereis succinea	12	7.8
		unidentified	3	2.0
	Crustacea	amphipod	1	trace
		Squilla empusa	2	7.1
		Ogyrides limicola	34	1.9
		Crangon septemspinosus	2	5.6
		Neopanope texana	7	2.6
		Panopeus herbsti	7	2.6
		Xanthid crab	4	2.6
		Callinectes sapidus	3	12.8
		crustacean remains	-	0.7
	Gastropoda	unidentified	1	trace
	Pelecypoda	Mya arenaria	142	31.4
	Pisces	unidentified	1	4.9
	unidentified	materials and sediment		4.5
J-19	Polychaeta	Nereis succinea	3	2.2
	Crustacea	Callinectes sapidus	3	12.8
		unidentified	2	1.5
	Pelecypoda	unidentified	4	0.6
	unidentified	materials and sediment		1.2
J-24	Crustacea	Callinectes sapidus		34.8
J-27	Crustacea	Neomysis americana	1	trace
		Leptocheirus plumulosus	6	0.1
		Gammarus sp.	2	trace
		Ogyrides limicola	3	0.1

Table 3 (Cont.)

Station	Class	Species	# of Individuals	Volume (ml)
	Pelecypoda	*Mya arenaria*	5	0.4
	unidentified	materials and sediment		1.6
J-32	Crustacea	*Gammarus daiberi*	68	1.0
		unidentified	-	0.3
	Insecta	plecoptera	3	0.2
	Pelecypoda	unidentified	2	4.4
	Pisces	*Alosa pseudoharengus*	7	24.1
	unidentified	materials and sediment		3.6

York River

Station	Class	Species	# of Individuals	Volume (ml)
Y-10	Crustacea	*Gammarus* sp.	24	0.5
		Crangon septemspinosus	1	1.0
		Callinectes sapidus	1	3.1
		decapod	1	0.1
		crustacean remains	-	0.7
	Pelecypoda	*Ensis directus*	1	0.7
		Mya arenaria	4	2.5
	unidentified	materials and sediment		1.9
Y-15	Polychaeta	*Pectinaria gouldii*	6	4.1
	Crustacea	*Ogyrides limicola*	2	0.1
		Crangon septemspinosus	2	1.5
		Neopanope texana	1	0.4
		Callinectes sapidus	4	51.8
		decapod	1	1.4
	Pelecypoda	*Mya arenaria*	4	0.8
		unidentified	1	0.4

Table 3. (Cont.)

Station	Class	Species	# of Individuals	Volume (ml)
	Pisces	unidentified	1	0.4
	unidentified	materials and sediment		0.2
Y-20	Polychaeta	*Pectinaria gouldii*	4	1.2
	Crustacea	*Leptocheirus plumulosus*	2	trace
		Monoculodes edwardsi	3	0.1
		Gammarus sp.	6	0.1
		Edotea triloba	1	trace
		Neopanope texana	6	2.1
		Eurypanopeus depressus	3	0.5
		Callinectes sapidus	11	19.9
		crustacean remains	-	0.4
	Pelecypoda	*Ensis directus*	2	3.1
		Mya arenaria	12	4.6
		Gemma gemma	2	trace
		unidentified	1	0.2
	unidentified	materials and sediment		1.1
Y-25	Crustacea	*Gammarus daiberi*	15	1.2
P-30	Crustacea	*Neopanope texana*	1	0.1
		Callinectes sapidus	1	0.2
		amphipod	1	trace
P-35	Crustacea	*Gammarus daiberi*	45	0.5
		Leptocheirus plumulosus	21	0.2
		amphipods	2	trace
		Edotea triloba	1	trace
		Eurypanopeus depressus	3	0.3
		Callinectes sapidus	1	1.4
	Pelecypoda	unidentified	1	0.1
	unidentified	materials and sediment		0.2
P-50	Crustacea	*Gammarus* sp.	80	0.8
		Eurypanopeus depressus	1	0.2
		crustacean remains	-	0.1

Table 3 (Cont.)

Station	Class	Species	# of Individuals	Volume (ml)
	Insecta	trichoptera larvae	66	0.7
	Pelecypoda	unidentified	1	1.7

Rappahannock River

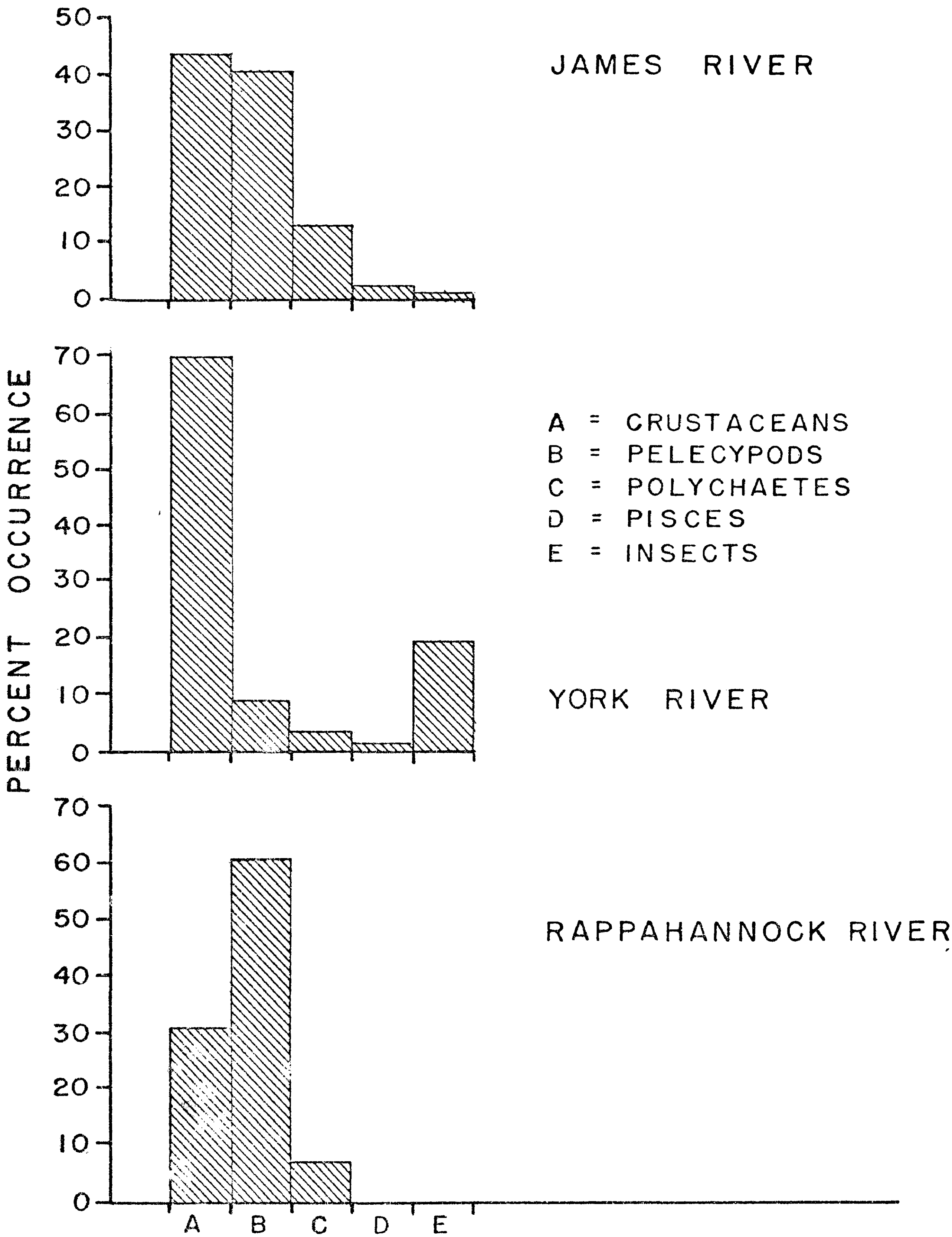
Station	Class	Species	# of Individuals	Volume (ml)
R-11	Polychaeta	*Nereis succinea*	9	3.9
		Pectinaria gouldii	22	9.9
		unidentified	8	5.3
	Crustacea	*Ampelisca verrilli*	1	trace
		Gammarus mucronatus	67	3.6
		Leptocheirus plumulosus	1	trace
		Gammarus sp.	1	trace
		Ogyrides limicola	1	trace
		Crangon septemspinosus	1	0.4
	Pelecypoda	*Mya arenaria*	8	4.0
		Macoma sp.	9	0.2
	unidentified	materials and sediment		2.0
R-15	Polychaeta	unidentified	3	2.7
	Crustacea	*Gammarus mucronatus*	59	4.4
		Crangon septemspinosus	3	0.2
		Callinectes sapidus	4	7.3
	Pelecypoda	*Mya arenaria*	4	2.7
		Macoma sp.	7	4.7
		unidentified	3	3.0
	unidentified	materials and sediment		1.4
R-20	Polychaeta	*Pectinaria gouldii*	21	6.1
	Crustacea	*Leptocheirus plumulosus*	7	0.2
		Gammarus mucronatus	3	trace

Table 3 (Cont.)

Station	Class	Species	# of Individuals	Volume (ml)
		Ogyrides limicola	9	0.8
		Callinectes sapidus	7	22.6
	Pelecypoda	_Mya arenaria_	23	12.2
		unidentified	6	6.0
	Pisces	unidentified	1	14.0
R-25	Polychaeta	_Pectinaria gouldii_	8	1.2
		unidentified	14	5.0
	Crustacea	_Gammarus_ sp.	1	trace
		Leptocheirus plumulosus	15	0.7
		Edotea triloba	1	0.1
		Ogyrides limicola	1	trace
		Callinectes sapidus	10	7.1
		decapod	1	0.1
		Balanus improvisus	2	trace
	Pelecypoda	_Mya arenaria_	156	63.3
		Macoma sp.	251	24.8
		Mulinea lateralis	184	32.0
		unidentified	10	10.4
	Pisces	unidentified	1	1.7
R-30	Crustacea	_Leptocheirus plumulosus_	4	0.1
		amphipod	1	trace
		Callinectes sapidus	2	1.2
		crustacean remains	-	trace
	Pelecypoda	_Mya arenaria_	31	25.2
		Macoma sp.	3	0.5
		unidentified	5	3.2
	unidentified	materials and sediment		1.1
R-35	Crustacea	_Leptocheirus plumulosus_	15	0.3
		Gammarus daiberi	66	0.7
		Cyathura polita	3	0.2
		Edotea triloba	9	0.2
		Callinectes sapidus	4	12.9
		crustacean remains	1	0.2

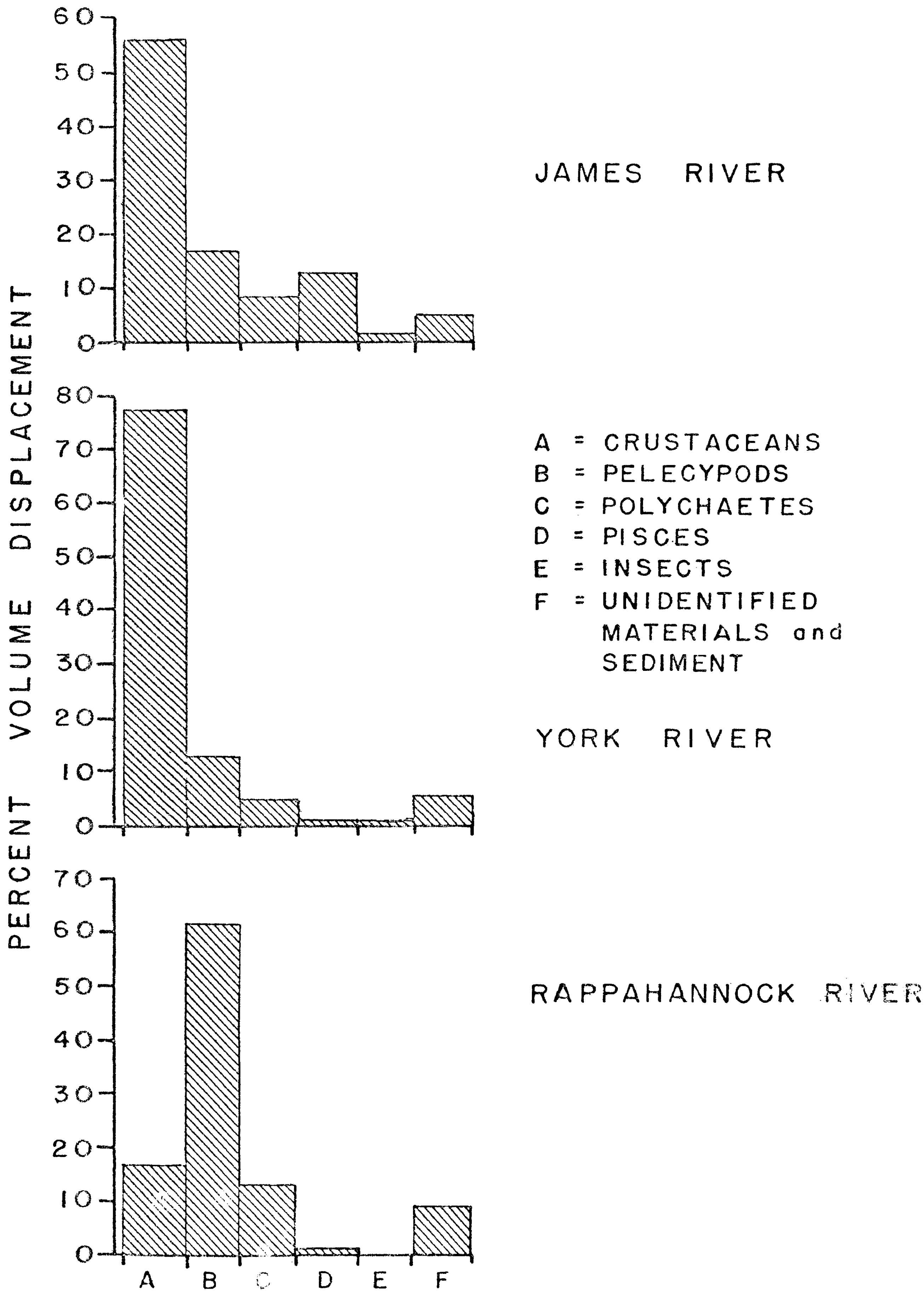
Table 3 (Cont.)

Station	Class	Species	# of Individuals	Volume (ml)
	Pelecypoda	*Mya arenaria*	6	5.3
		Macoma sp.	1	0.4
		unidentified	1	0.1
	unidentified	materials and sediment		1.1
R-40	Crustacea	*Gammarus* sp.	4	0.1
		Leptocheirus plumulosus	52	1.1
		Edotea triloba	1	trace
		Xanthid crab	1	0.4
	Oligochaeta	unidentified	7	0.1
	unidentified	materials and sediment	-	0.4



JAMES RIVER
YORK RIVER
RAPPAHANNOCK RIVER
PERCENT OCCURRENCE
A = CRUSTACEANS
B = PELECYPODS
C = POLYCHAETES
D = PISCES
E = INSECTS
A B C D E

Figure 10. Percent volume displacement of major taxa in stomachs of the American eel from the James, York and Rappahannock rivers.


PERCENT VOLUME DISPLACEMENT
JAMES RIVER
YORK RIVER
RAPPAHANNOCK RIVER
A = CRUSTACEANS
B = PELECYPODS
C = POLYCHAETES
D = PISCES
E = INSECTS
F = UNIDENTIFIED MATERIALS and SEDIMENT
A B C D E F

and of a greater volume. Fish were of little importance in the diet. One eel, 513 mm in total length from the James River taken on September 14, 1971, had eaten six juvenile alewives, Alosa pseudoharengus, with fork lengths of 51, 52, 54, 61 and 65 mm. Smaller eels generally ingested smaller food items such as amphipods, isopods, molluscan siphons and appendages from soft blue crabs. Large eels ingested whole bivalves and whole large soft blue crabs. All size groups ate polychaetes.

The results of the food analyses suggest that the American eel may be a serious predator on commercially important invertebrates. The blue crab was a major food item in all rivers making up 33.3% of the total food volume in the James River, 68.2% in the York River and 15.9% in the Rappahannock River. The soft clam, Mya arenaria, made up 17.5% of the total food volume in the James River, 7.9% in the York River and 35% in the Rappahannock River. Mya arenaria is more abundant in the Rappahannock River than in the other rivers studied (Dexter Haven, personal communication) and this is reflected by the increased importance of this species in the diet of Rappahannock River eels. Mya arenaria is frequently used by commercial fishermen as bait for eel pots in localized areas.

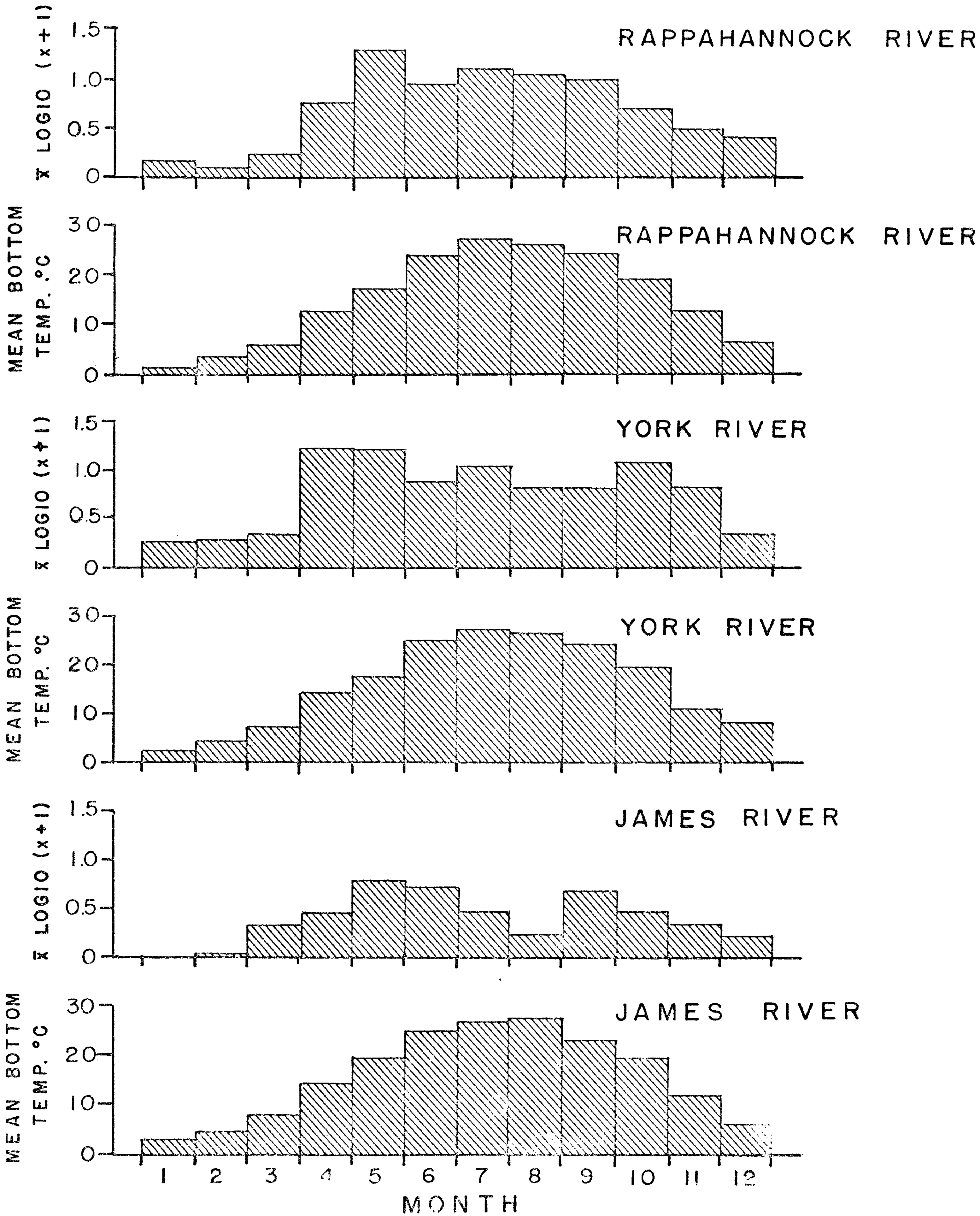
The results of food analyses compare closely to those reported in 31 Chesapeake Bay eels ranging in size from 14.5 to 29 inches by Hildebrand and Schroeder (1927). They found the following in decreasing order of importance: crustaceans, annelids, fish, echinoderms, mollusks and eelgrass. Thirteen smaller specimens contained mainly amphipods, isopods, worms and one contained the siphon of a mollusk. Bigelow and Schroeder (1953) stated that the diet is primarily small fish, shrimps, crabs, lobsters and smaller crustaceans. Brinkley and Brown (1935) observed eels feeding at dark on juvenile alewives, Alosa pseudoharengus, and menhaden, Brevoortia tyrannus.

An interesting parallel can be drawn between food habits in freshwater and estuaries. Godfrey (1967), Compton (1968) and Ogden (1970) found insects to be important items in the diet of eels in freshwater. Also important were oligochaetes, bivalves and crustaceans. In the lower reaches of estuaries where numerous varieties of crustaceans replace insects as an important part of the benthic infauna and epifauna, crustaceans become more important dietary items. Polychaetes replace oligochaetes and bivalve mollusks still remain important.

Seasonality:

Histograms of the arithmetic mean of the $\log_{10}(x + 1)$ transformed catch data are found in Figure 11. The number of eels caught during each monthly sampling varied greatly, but some trends are apparent. Catches were very low in all rivers during January and February. Numbers of eels caught increased in spring, varied in the summer and decreased with lower autumn water temperatures. The increased variation during the summer and the apparent bimodal catch results of the James River could have been a result of increased ability of eels to avoid the net or migration from the channel to shallow water areas. Compton (1968) showed a similar pattern of abundance in a small tributary of the Delaware

Figure 11. Histograms of the arithmetic means of the $\log_{10}$ $(x + 1)$ values for the number of eels caught per hour trawl time by months with the mean monthly bottom temperatures plotted below.


RAPPAHANNOCK RIVER
x̄ LOG10 (x+1)
MEAN BOTTOM TEMP. °C
RAPPAHANNOCK RIVER
YORK RIVER
YORK RIVER
JAMES RIVER
JAMES RIVER
MONTH
1 2 3 4 5 6 7 8 9 10 11 12
0 0.5 1.0 1.5
0 10 20 30

River by electrofishing. Further conclusions as to seasonal distribution from the present data are precluded because of gear selectivity and non-randomization of stations.

PART III.

Fecundity and gonad observations on American eels, *Anguilla rostrata* (Lesueur), migrating from Chesapeake Bay, Virginia.

INTRODUCTION

The fall migration of the American eel from Atlantic coast estuaries is well documented in the literature (Bigelow and Schroeder, 1953; Vladykov, 1955; Gray and Andrews, 1970). Gray and Andrews found that migratory eels leaving Newfoundland waters were more sexually mature, with ova of a greater diameter, than European silver eels (*A. anguilla*) reported by Rasmussen (1951). Wenner (see section IV) found that three silver eels captured southeast of the mouth of Chesapeake Bay on 5 December 1967 were more sexually mature than Newfoundland specimens and that the gonadal condition of one specimen collected southeast of Cape Cod on 7 November 1969 was consistent with the Canadian report. He also reported the capture of six females east of Assateague Island on 22 December 1971. These last specimens were more sexually mature than the others as judged by ova diameters. These findings appear to contradict Tucker's statement (1959) that European eels are more sexually advanced at the time of migration than American eels.

Bigelow and Schroeder (1953) reported that "eels (European) are the most prolific fish, ordinary females averaging 5 to 10 million eggs, and the largest one certainly 15 to 20 million". No data were presented. Vladykov (1955) stated that female American eels have from 10 to 20 million eggs and Eales (1968) suggested that each female produces 15 to 20 million eggs.

These reports estimate fecundity but do not relate it to fish length or weight.

This report describes fecundity of the American eel from the Chesapeake Bay region and gonadal condition of male and female silver eels migrating from the Chesapeake Bay.

MATERIALS AND METHODS

Collection of specimens:

Migrating silver eels (52 males, 46 females) were obtained from commercial pound net fishermen at Cape Charles, Va. on 23 November 1970. Specimens were transported alive to the Virginia Institute of Marine Science and were maintained in a holding tank for one to three weeks prior to being sacrificed.

Histological methods:

Animals were anesthetized in MS-222 (Sandoz Co.) (1 gm: 500 ml). Total length was recorded to the nearest millimeter, and total weight to the nearest gram. Gonadal tissue from 20 males and 23 females was placed in Bouin's fixative, acetic acid-formalin-alcohol solution (AFA fixative) and 10% phosphate buffered formalin. Tissues were dehydrated in a graded series of ethanol baths, embedded in Paraplast (Fisher Scientific Co.), sectioned at 8u on a rotary microtome, stained with Harris hematoxylin and counter stained with eosin. Ovarian sections were viewed at 150X, 675X and 1500X. Ten ova sectioned through the nucleus were measured with an ocular micrometer at 150X on each of ten specimens to determine the gonadal state of the fish. Testicular sections were viewed at 675X and 1500X to determine the state of spermatogenesis.

Treatment of ova:

Individual ovaries were excised from an additional 21 fish, and wet weight was recorded to the nearest 0.1 gm. After three months storage in Gilson's solution (Bagneal, 1967), the eggs were not completely dislodged from the ovarian connective tissue. Egg clusters were completely broken up by a 3 to 5 min treatment with a sonic cleaner (Varian Aerograph Corp., Walnut Creek, Calif.). The resultant eggs suspensions were diluted to 500 or 1000 ml and 3 one-ml aliquots were removed from the well mixed suspensions. Eggs in each aliquot were counted in a gridded Sedgewick-Rafter chamber at 150X. Since the eggs were slightly irregular in shape, the longest horizontal diameter of the first fifty eggs from each egg suspension were measured with an ocular micrometer at the same magnification. The maturity index (gonad weight in gm/total weight in gm) was calculated for each specimen.

Statistical analysis:

The number of eggs and the wet weight of the left and right ovaries were compared using paired 't' tests (Sokal and Rohlf, 1969). Egg diameters from the ovaries treated with Gilson's solution were compared between ovaries and among fish by a factorial design (Guenther, 1964). Regression analysis was performed by an IBM 1130 computer and the 95% confidence intervals about regression were calculated according to Sokal and Rohlf (1969).

RESULTS

Fecundity:

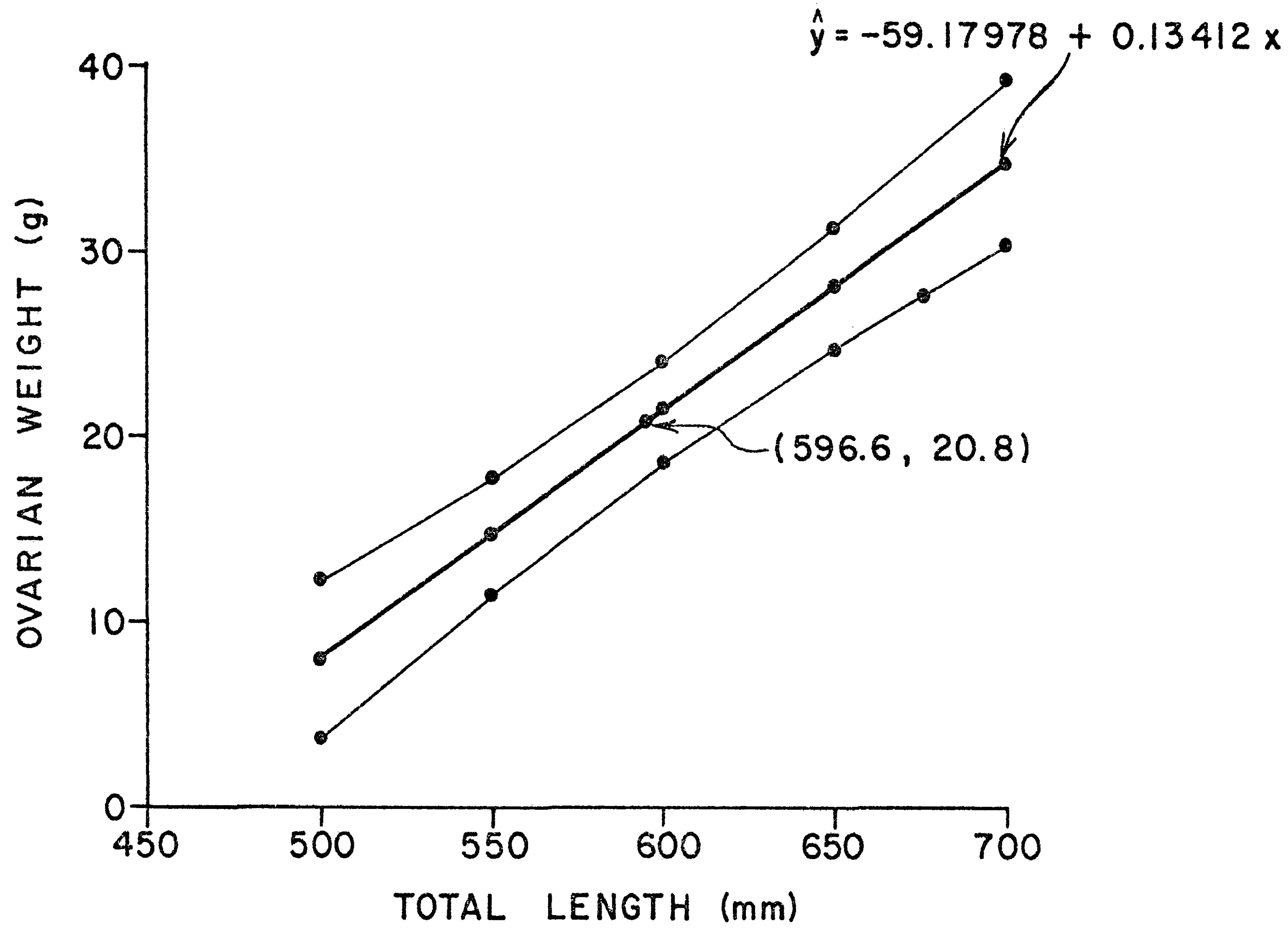
Treating the egg clusters with the sonic cleaner did not alter the total egg count. Tissue from an individual ovary in Gilson's solution was exposed to the sonic cleaner for 0, 3, 5, 8 and 15 minutes. Three 1-ml aliquots were removed from the well mixed suspension at the end of each time period and counted to determine if the sonic cleaner destroyed a significant number of eggs. Individual egg counts were plotted against exposure time and a regression equation was calculated for the values. The slope of the equation was then evaluated by a 't' test (Sokal and Rohlf, 1969) and was not significantly different from zero ($t = 0.2340$, $df = 13$).

No significant differences existed between the left and right ovarian weights ($t = 0.8471$, $df = 20$) and the number of eggs in the left and right ovaries ($t = 0.9829$, $df = 20$). The values of the maturity index ranged from 0.0265 to 0.0625 with the mean and 95% confidence interval being 0.0481 ± 0.004.

Preliminary data plots showed that the relationships between total length and gonad weight and between total weight and gonad weight were linear over the ranges of values observed. The regressions of fecundity on total length and fecundity on total weight were curvilinear and were made linear by a logarithmic transformation. Regression equations, correlation coefficients and coefficients of determination are in Table 4 and their graphic representations with 95% confidence belts about regression are in Figures 12, 13, 14 and 15.

Table 4. Regression equations, correlation coefficients and coefficients of determination of gonadal observations and fecundity of migrating female silver eels from the Chesapeake Bay, November 1970.

Relationship	Equation	'r'	Coefficient of Determination
total length - gonad weight	$y = -59.17978 + 0.13412\ x$	0.8847	78.27
total weight - gonad weight	$y = -4.40673 + 0.06139\ x$	0.9764	95.34
total length - fecundity	$\log y = -4.29514 + 3.74418 \log x$	0.8844	78.22
total weight - fecundity	$\log y = 3.22990 + 1.11157 \log x$	0.9595	92.06


ŷ = -59.17978 + 0.13412 xi
(596.6, 20.8)
OVARIAN WEIGHT (g)
0
10
20
30
40
450
500
550
600
650
700
TOTAL LENGTH (mm)

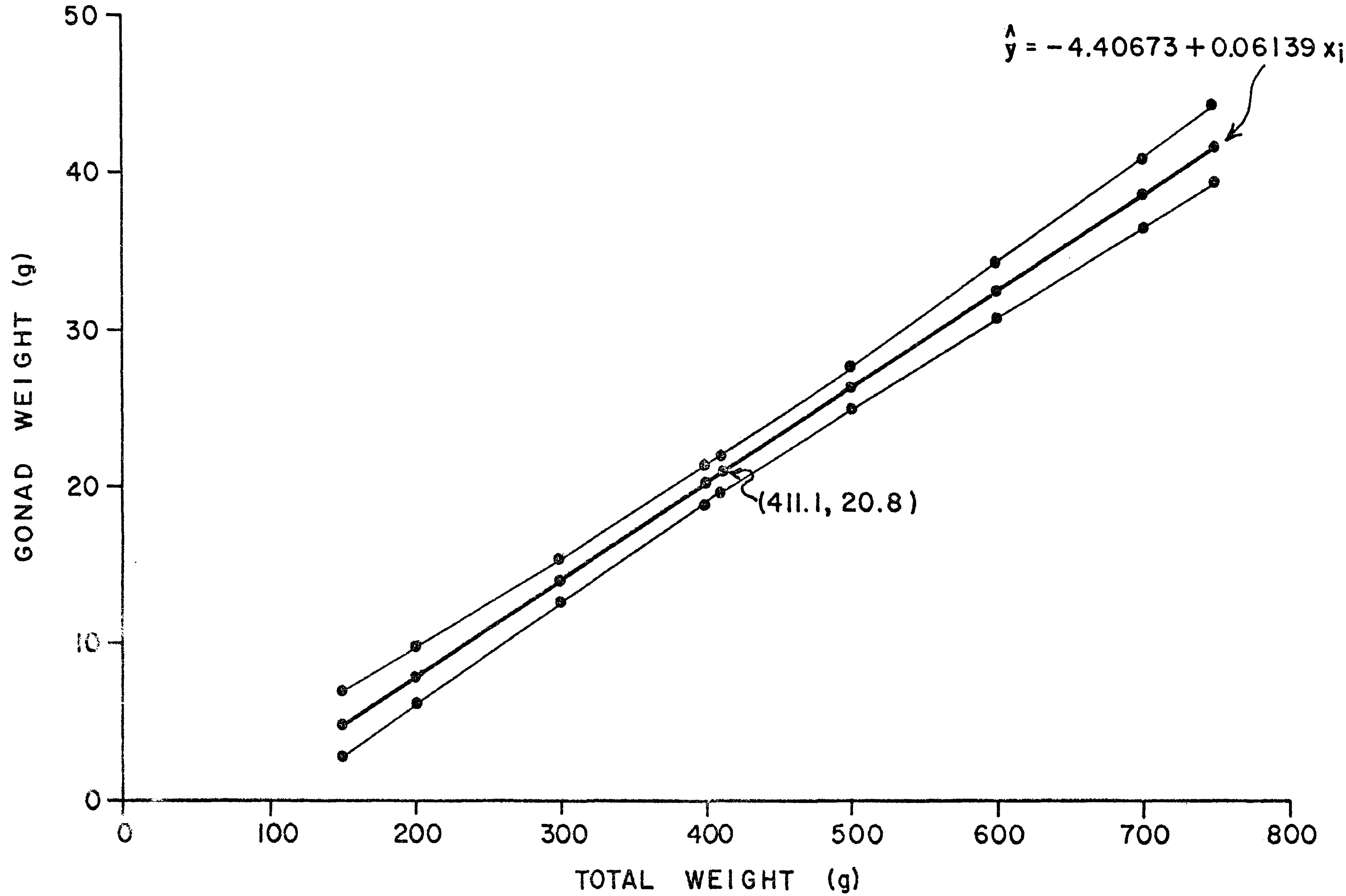
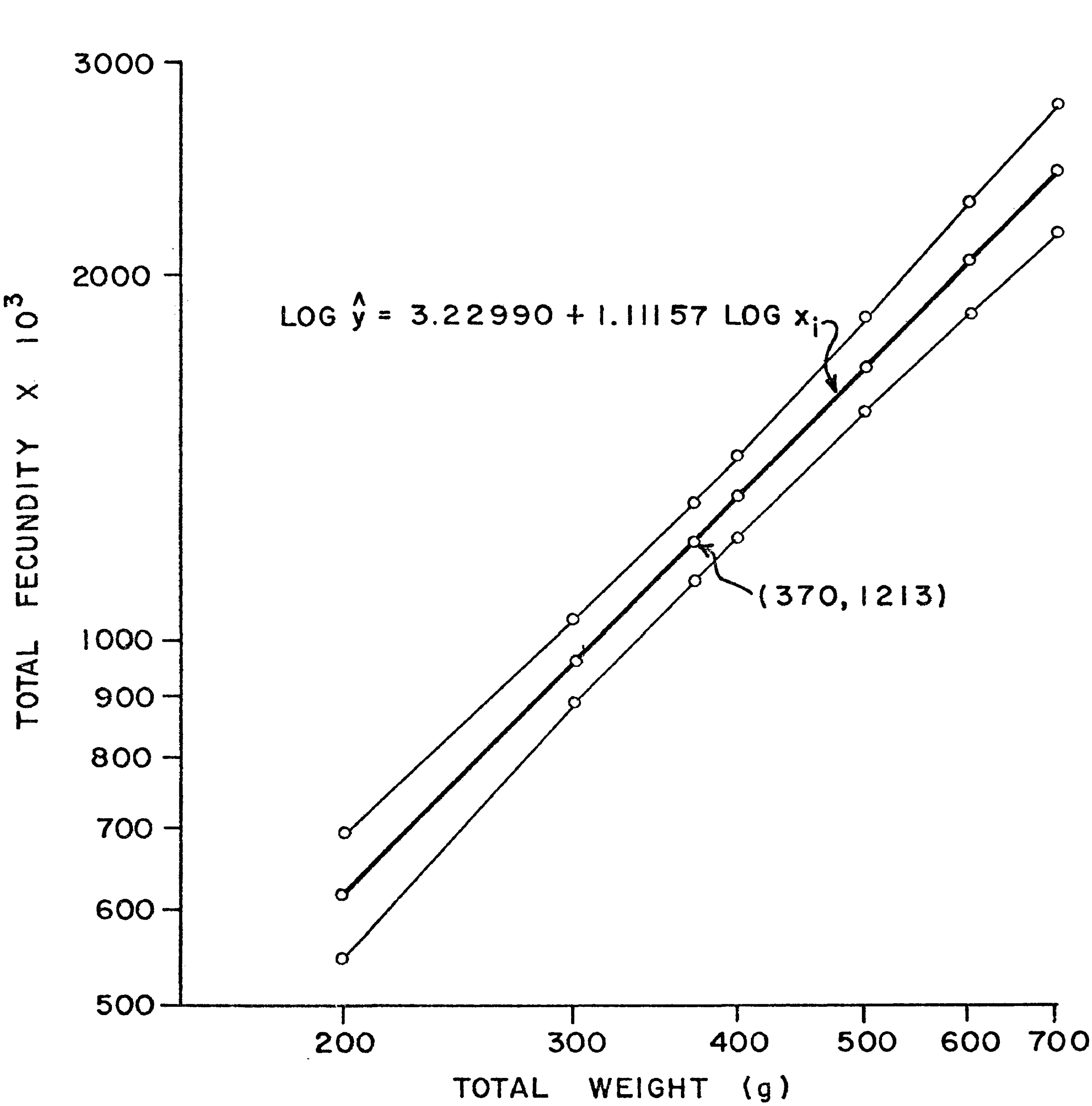
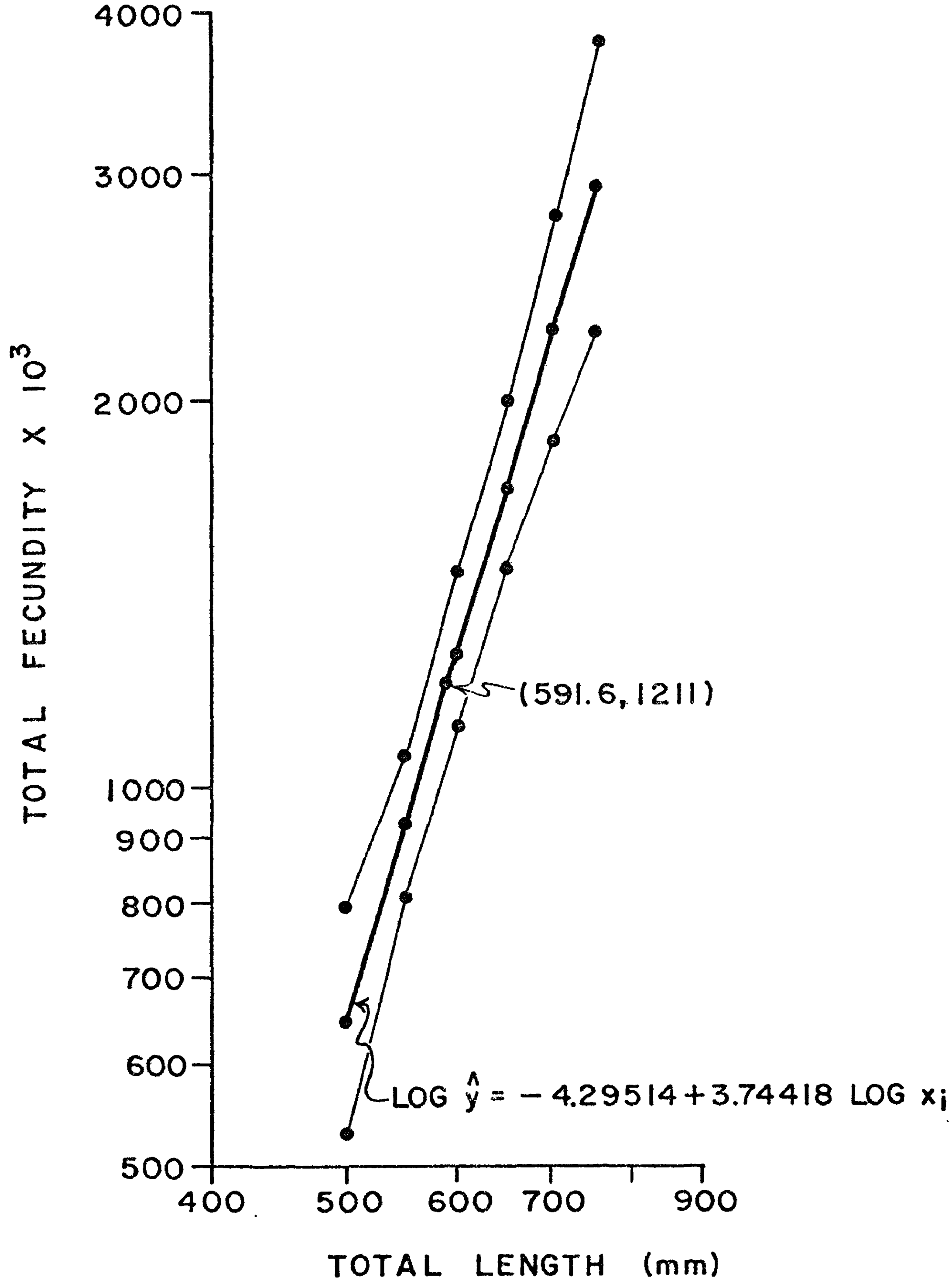

$\hat{y} = -4.40673 + 0.06139\,x_i$
(411.1, 20.8)
GONAD WEIGHT (g)
TOTAL WEIGHT (g)
0
10
20
30
40
50
100
200
300
400
500
600
700
800

Figure 14. Regression relationship between total weight and fecundity with 95% confidence belt about the regression for female silver eels migrating from Chesapeake Bay, November 1970.



LOG $\hat{y}$ = 3.22990 + 1.11157 LOG x_i
(370, 1213)
TOTAL FECUNDITY X 10^3
3000
2000
1000
900
800
700
600
500
200
300
400
500
600
700
TOTAL WEIGHT (g)

Figure 15. Regression relationship between total length and fecundity with 95% confidence belt about the regression for female silver eels migrating from Chesapeake Bay, November 1970.



4000
3000
2000
1000
900
800
700
600
500
TOTAL FECUNDITY X 10³
(591.6, 1211)
LOG ŷ = − 4.29514 + 3.74418 LOG xᵢ
400
500
600
700
900
TOTAL LENGTH (mm)

An analysis of variance demonstrated a significant difference in mean ova diameter among fish ($F = 118.00$, df = 20, 2058), but not between left and right ovaries ($F = 0.333$, df = 1, 2058). Mean ova diameter and its 95% confidence intervals were 0.244 ± 0.004 mm. The frequency distribution of the egg diameters from all fish is depicted in Figure 16 and all fecundity data is found in Appendix 3.

Histological results:

The preferred fixative for gonadal sections was Bouin's. AFA gave good nuclear detail with less loss of cytoplasmic inclusions than Bouin's, but the cells were distorted and reduced in volume. Ten percent phosphate buffered formalin was completely unsatisfactory because tissue tended to harden in it and crack when sectioned. The following descriptions are based upon gonadal tissue placed in Bouin's fixative.

Most eggs were spherical with a centrally located nucleus. A large number of vesicles were present in the cytoplasm, presumably representing regions of lipid concentration which were leached out during histological preparation. Extremely basophilic inclusions were observed throughout the cytoplasm in many of the larger oocytes, but they appeared more concentrated toward the periphery of the cell. These inclusions resembled yolk granules in *Brevoortia patronus* oocytes described by Combs (1969). The nuclear membrane was evident and the nucleoplasm was slightly basophilic. Deep staining basophilic inclusions were seen around the inner side of the nuclear membrane (Figure 17a, b, c). Developmental stages of the oocytes varied. A small fraction of the

Figure 16. Frequency distribution of ova diameters of Gilson's solution treated specimens of the American eel.

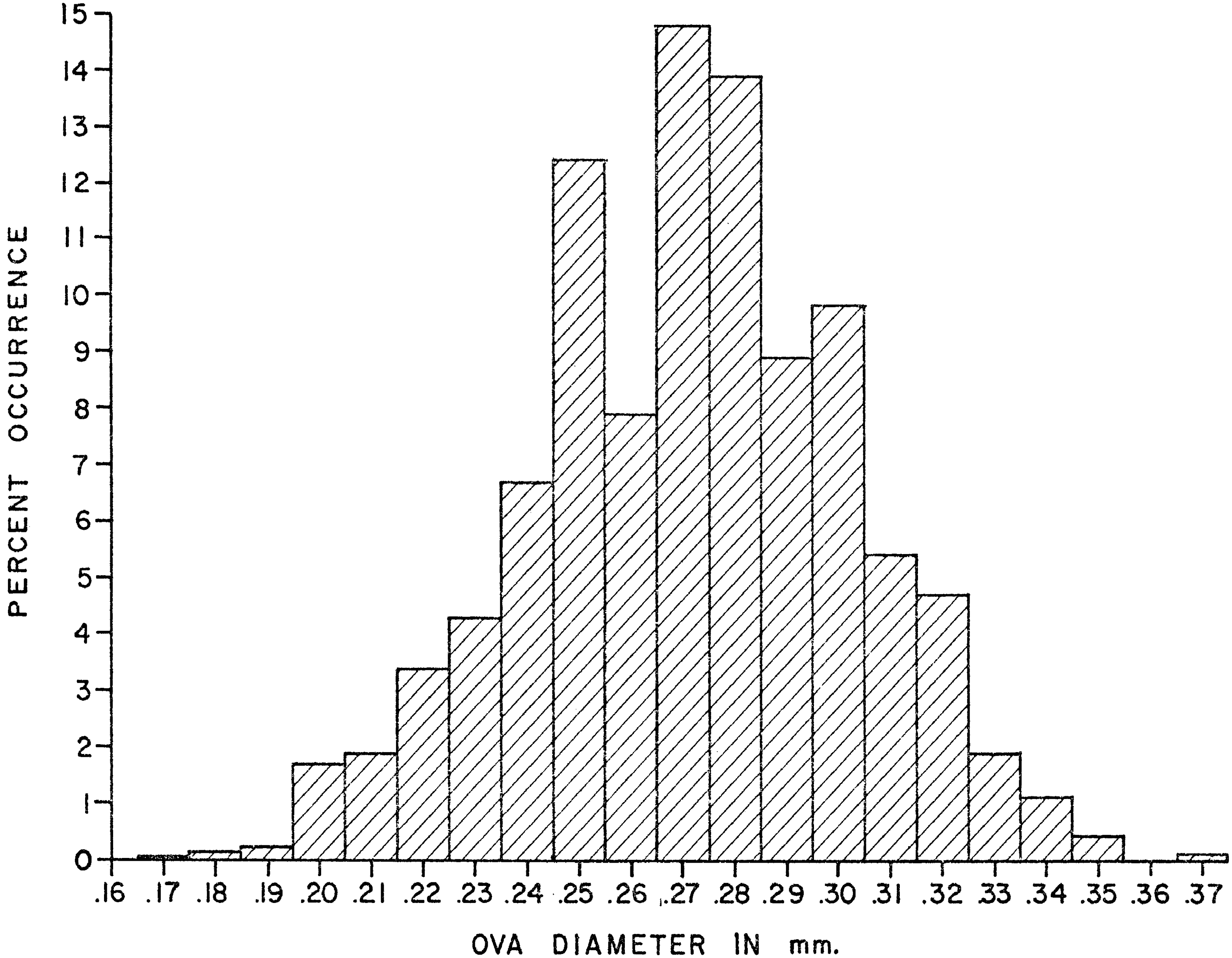

PERCENT OCCURRENCE
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.16 .17 .18 .19 .20 .21 .22 .23 .24 .25 .26 .27 .28 .29 .30 .31 .32 .33 .34 .35 .36 .37
OVA DIAMETER IN mm.

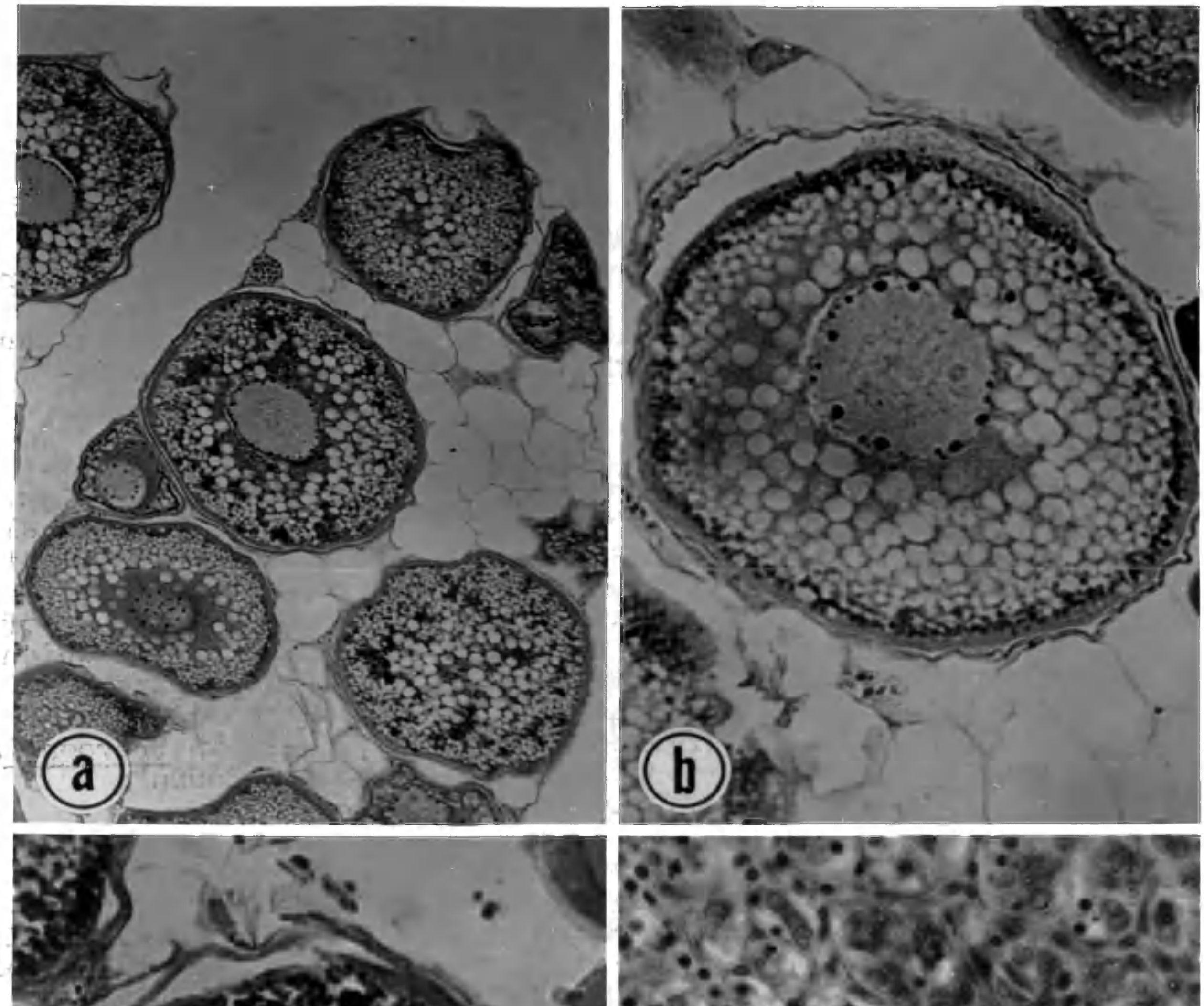
Figure 17.

a. Longitudinal section of ovarian tissue from a migratory silver eel. Total length of specimen = 645 mm; total weight = 545 gm. Horizontal diameter of oocyte in center of field = 0.24 mm with a mean horizontal diameter of 10 oocytes = 0.21 mm. Note large amount of adipose tissue between developing oocytes. Bouin's fixation, Harris-hematoxylin-eosin stain.

b. Cross section of an oocyte from a migratory silver eel. Total length of sepcimen = 613 mm; total weight = 424 gm. Horizontal diameter of oocyte = 0.22 mm. Mean horizontal diameter of 10 oocytes = 0.22 mm. Note the thin layer of connective tissue surrounding the oocyte, developing vitelline membrane, yolk granules around the periphery of the oocyte, cytoplasmic vesicles devoid of contents which were presumably lipids lost in histological preparation and basophilic inclusions around the inner margin of the nuclear membrane referred to by Combs (1969) in *Brevoortia patronus* oocytes as proto-vitellonucleoli. Bouin's fixation, Harris-hematoxylin-eosin stain.

c. Cross section of an oocyte from a migratory silver eel; total length of specimen = 624 mm; total weight = 550 gm. Horizontal diameter of oocyte = 0.26 mm. Mean horizontal diameter of 10 oocytes = 0.27 mm. Note large lipid vesicles and more densely packed yolk granules. Bouin's fixation, Harris-hematoxylin-eosin stain.

d. Cross section of the testis from a migratory silver eel; total length = 378 mm; total weight = 91 gm. Distance across field = 0.25 mm. Note nests of secondary spermatagonia as defined by Hyder (1969). Bouin's fixations, Harris-hematoxylin-eosin stain.


a
b
c
d

oocytes was characterized by a cuboidal shape, smaller size and an extremely basophilic cytoplasm. Whether or not these cells would have continued to develop into mature oocytes is conjecture. Testicular sections (Figure 17d) showed nests of secondary spermatogonia as defined by Hyder (1969).

DISCUSSION

Fecundity estimates of American eels from Chesapeake Bay are lower than those stated by Bigelow and Schroeder (1953), Vladykov (1955) or Eales (1968). This lower estimate was not caused by the destruction of eggs by the sonic cleaner because exposure time did not affect counts. The largest female studied was 724 mm in length and weighed 755 gm. This specimen has an observed fecundity of 2,561,000. The possibility that larger specimens have fecundity estimates closer to the stated values of previous authors cannot be positively excluded because the predictive value of a regression line is strictly valid only over the range of observed values.

The gonads of female silver eels migrating from the Chesapeake Bay comprise a mean of 4.81% of the total weight of the animal. This value probably increases as the migratory females approach the Sargasso Sea. The maturity index was significantly correlated with the mean ova diameter in the 21 specimens used for fecundity studies ($r = 0.80925$, coefficient of determination = 65.49). This relationship is obvious because as more material is incorporated into the individual eggs, thereby increasing their diameter, the gonadal weight increases thus elevating the maturity index. Maturity indices of specimens of different estuarine origins along a latitudinal gradient should be examined to make a more valid comparison of gonadal condition of migratory forms.

The horizontal diameters of eggs treated with Gilson's solution agreed closely with those determined by sectioning tissue fixed in Bouin's (means and 95% confidence intervals: Bouin's: 0.246 $\pm$ 0.0014 mm; Gilson's: 0.244 $\pm$ 0.004 mm). These diameters are larger than those reported by Gray and Andrews (1970) for the American eel migrating from Newfoundland waters where the mean value was 0.165 (range: 0.109 - 0.214 mm). Rasmussen (1951) stated that the average egg diameter of migratory European eel, *A. anguilla*, is from 0.1 to 0.2 mm while Brunn et al (1949) reported three untreated *A. anguilla* in an endocrinological study as having ova diameters of 0.18, 0.13 and 0.12 mm. From these data, it is concluded that migratory silver American eels leaving Chesapeake Bay are closer to sexual maturity than specimens leaving more northerly estuaries, and also more advanced than *A. anguilla* migrating from continental Europe (Table 5). This is in direct contradiction with the hypothesis (Tucker, 1959) that the European eel is much more sexually advanced than the American eel at the onset of migration.

The eggs are presumed to be pelagic and about 1 mm in diameter when spawned (Bertin, 1956). The presence of large cytoplasmic vesicles devoid of contents in histological preparations indicates the large amount of lipid materials in the egg. Combs (1969) described the peripheral displacement of the nucleus and

Table 5. Comparative data of gonadal conditions of female silver Atlantic eels.

Species	Location	$\bar{x}$ ova Diameter (mm)	Range (mm)	$\bar{x}$ Maturity Index
A. rostrata	Newfoundland (Gray & Andrews, 1970)	0.165	0.109-0.214	------
A. rostrata	Southeast of Cape Cod (Wenner, 1972)	0.172	0.12 -0.27	------
A. rostrata	East of Assateague Island (Wenner, 1972)	0.356	0.25 -0.45	0.0587
A. rostrata	Southeast of Chesapeake Bay (Wenner, 1972)	0.275	0.17 -0.37	------
A. rostrata	Chesapeake Bay (present study)	0.244	0.17 -0.37	0.0481
A. anguilla	Danish waters (?) (Rasmussen, 1951)	-----	0.10 -0.20	------
A. anguilla	Danish waters (?) (Bruun, 1949)	-----	0.12 -0.18	------

the formation of a centrally located oil globule in the pelagic eggs of Brevoortia patronus. This aggregation of oil droplets in the eggs of A. rostrata was not demonstrated in the specimens observed but cannot be ruled out. A similar flotation mechanism may be employed as the spawning grounds are approached.

Histological sections showed that all male specimens had small, rather undeveloped testis markedly immature by comparison to a male A. anguilla (Bertin, 1956) and those of A. anguilla brought to a spawning condition by Boetius and Boetius (1967). The organs of Syrski were small and vascularized and it was evident that much development must take place before spawning. Excellent gross morphological descriptions of the ovaries and testis of the European eel may be found in the original descriptions of Goode (1881).

PART IV.

Occurrence of the silver phase of the American eel, *Anguilla rostrata* (Lesueur), in waters overlying the eastern North American Continental Shelf.

INTRODUCTION

The American eel is a catadromous fish residing in estuaries and river systems from West Greenland (Jensen, 1926), Labrador (Backus, 1957), eastern Newfoundland, and the northern side of the Gulf of St. Lawrence south to the Gulf of Mexico, Panama, the West Indies to the northern coast of South America (Bigelow and Schroeder, 1953). The complex life cycle has been summarized by Bigelow and Schroeder (1953), Vladykov (1955), Bertin (1956) and Eales (1968).

Although the annual fall migration of reproductively maturing specimens has been well documented, their capture in off-shore waters has not been reported. This communication reports the capture of 3 eels in 1967, 2 eels in 1969 and 6 eels in 1971 in waters overlying the continental shelf of the northeastern United States.

METHODS AND MATERIALS

The 1967 migratory eels were captured in an Atlantic Western trawl during a 1 hour tow by the *Sea Breeze*, a commercial trawler chartered by the Virginia Institute of Marine Science. The 1969 specimens were collected with a #36 Yankee trawl equipped with a 1/2 inch stretch mesh cod end liner aboard the R/V *Albatross IV* during groundfish investigations of the U.S. Bureau of Commercial

Fisheries. The 1971 specimens were collected during a 45 min tow with a 50 ft trawl equipped with a 1 inch stretch mesh cod end liner aboard the Cynthia, a commercial trawler chartered by the National Marine Fisheries Service Laboratory at Oxford, Maryland. The 1967 and 1969 bottom temperatures were taken from bathythermograph tracings while the 1971 bottom temperatures were taken by a stem thermometer; 1967 and 1971 bottom salinities were determined by an induction salinometer.

Vertebrae were counted from X-ray photographs, and morphometrics of the preserved specimens were taken using the method of Ege (1939). The 1971 specimens were frozen after capture. After thawing, the individual ovaries were removed and weighed to the nearest 0.1 gram prior to formalin fixation. The maturity index (Gonad weight/total weight) was calculated for these specimens. The longest horizontal diameter of 100 eggs from each ovary was measured at 150X magnification. Previous statistical analysis of ova diameters from specimens migrating from the Chesapeake Bay showed no significant differences between ovaries (see section III). Therefore, the ova diameters from both ovaries of individual fish were pooled and tested for significant differences between fish by analysis of variance (Guenther, 1964).

RESULTS AND DISCUSSION

Hydrographic data and sites of capture are found in Table 6; morphometrics and vertebral counts are in Table 7. Frequency distributions of ova from the three collection dates are found in Figure 18.

Table 6. Location and hydrographic data of off-shore specimens of *Anguilla rostrata*.

Specimen Code	Date	Location		Depth (fms)	Temperature (°C)		Salinity (‰)	
		Longitude	Latitude		Surface	Bottom	Surface	Bottom
A	7 Nov 69	41°40.5'N	69°39'W	45	10.8	8.5		
B	7 Nov 69	41°38' N	69°42'W	30	10.8	9.0	-	
C	5 Dec 67	35°51' N	75°30'W	10	10.7	10.7	31.66	30.94
D	5 Dec 67	35°41' N	75°18'W	12	11.3	11.4	31.58	31.81
E	5 Dec 67	35°25' N	75°18'W	13	12.0	12.0	31.14	32.21
F-K	22 Dec 71	37°51' N	75°19'W	5	8.0	8.0	28.43	30.97

Table 7. Morphometrics and vertebral counts of off-shore specimens of *Anguilla rostrata* along with morphometric ranges of silver eels migrating from the Chesapeake Bay, November 1970.

Specimen	A	B	C	D	E	F	G	H	I	J	K	Chesapeake Bay	
Sex	♀	♂	♀	♀	♀	♀	♀	♀	♀	♀	♀	♀	♂
Total Vertebrae	108	109	108	108	107								
Total Length (mm)	642	373	512	579	561	658	648	657	617	609	627		
Total Weight (gm)						525	568	543	540	529	529		
Preanal Length (mm)	266	158	217	237	232	284	280	282	252	273	257		
Preanal Length / Total Length x 100%	41.4	42.3	42.4	40.9	41.3	43.2	43.2	42.9	40.8	44.8	41.0	36.6-45.2	39.5-43.8
Preanal-Head Length (mm)	188	106	147	159	161	197	194	195	168	196	183		
Preanal-Head / Total Length x 100%	29.3	28.4	28.7	27.5	28.7	29.9	29.9	29.7	27.2	32.2	29.2	25.6-32.2	25.4-30.9

Table 7. (Cont.)

Specimen	A	B	C	D	E	F	G	H	I	J	K	Chesapeake Bay ♀	Chesapeake Bay ♂
Predorsal Length (mm)	221	126	168	195	187	220	223	218	203	217	212		
Predorsal Length / Total Length x 100%	34.3	33.8	32.8	33.7	33.3	33.4	34.4	33.2	32.9	35.6	33.8	30.8-36.7	29.1-35.6
Predorsal-Head Length (mm)	143	74	119	117	116	133	137	131	119	140	138		
Predorsal-Head / Total Length x 100%	22.3	19.8	23.2	20.2	20.7	20.2	21.1	19.9	19.3	23.0	22.0	17.5-24.6	16.0-24.1
Preanal-Predorsal Length (mm)	45	32	49	42	45	64	57	64	49	56	45		
Preanal-Predorsal / Total Length x 100%	7.0	8.6	9.6	7.2	8.0	9.7	8.8	9.7	7.9	9.1	7.2	4.5-11.5	5.4-11.8

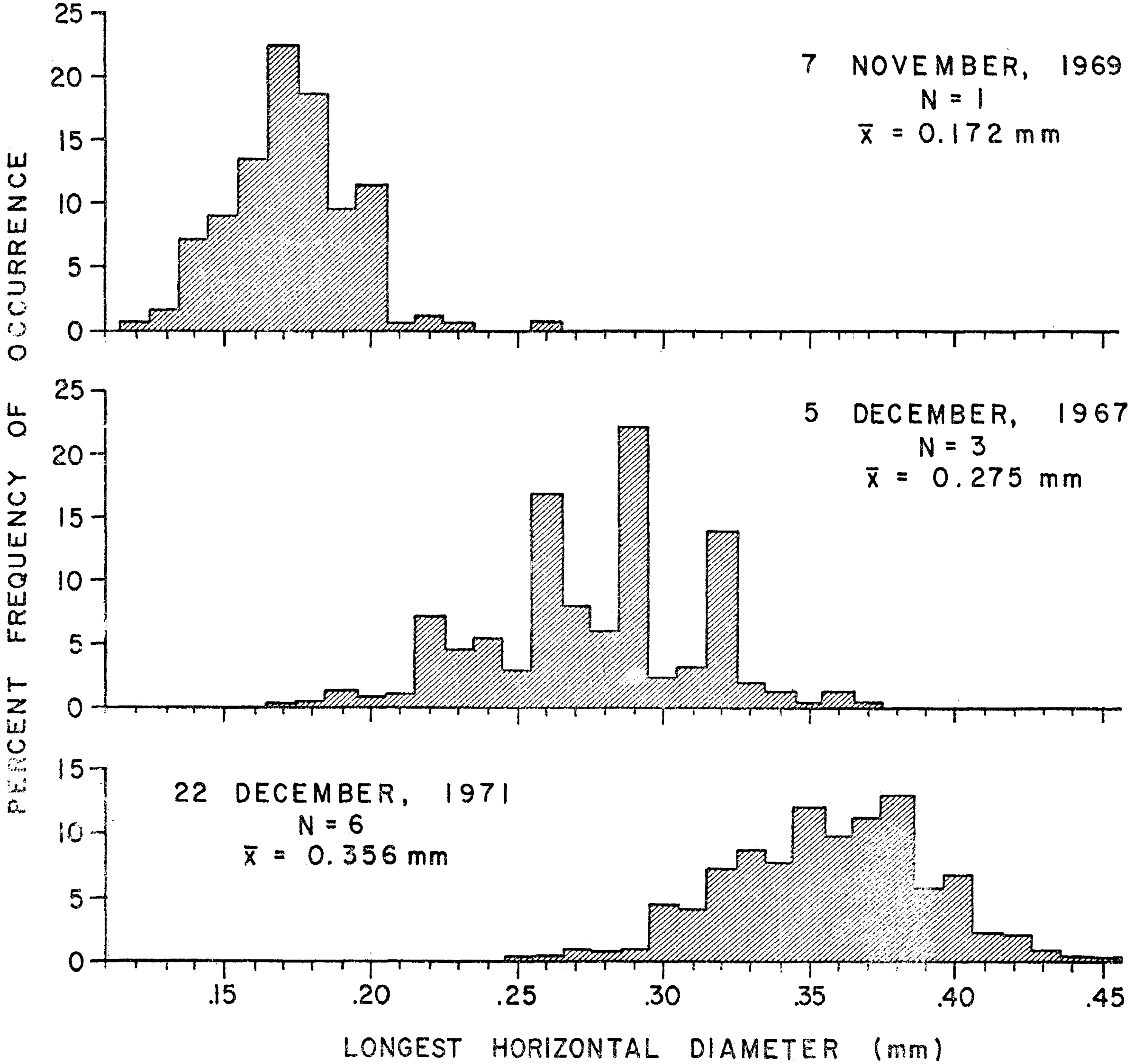
Table 7. (Cont.)

Specimen	A	B	C	D	E	F	G	H	I	J	K	Chesapeake Bay ♀	Chesapeake Bay ♂
Head Length (mm)	78	52	70	78	71	87	86	87	84	77	74		
Head Length / Total Length x 100%	12.1	13.9	13.7	13.5	12.6	13.2	13.3	13.2	13.6	12.6	11.8	10.5-13.8	11.2-14.1
Gape Length (mm)	17.2	11.3	17.9	21.8	17.4	21.5	24.5	18.5	18.8	18.1	19.4		
Gape Length / Head Length x 100%	22.0	21.7	25.6	27.9	24.5	24.7	28.5	21.2	22.4	23.5	26.2	19.7-32.1	16.7-26.9
Horizontal Diameter of the eye (mm)	8.5	6.5	8.0	9.6	7.9	10.2	10.0	9.7	11.1	8.8	9.0		
Diameter / Gape Length x 100%	49.4	57.5	44.7	44.0	45.4	47.4	40.8	52.4	59.0	48.6	46.4	34.2-68.8	42.0-100.0

Table 7. (Cont.)

Specimen	A	B	C	D	E	F	G	H	I	J	K	Chesapeake Bay ♀	Chesapeake Bay ♂
Left Ovarian Weight (gm)						18.5	14.9	16.9	18.9	13.8	10.9		
Right Ovarian Weight (gm)						18.4	14.9	16.8	17.1	16.4	12.7		
Total Ovarian Weight (gm)						36.9	29.8	33.7	36.0	30.2	23.6		
Maturity Index						.0702	.0524	.0620	.0660	.0570	.0446		

Figure 18. Frequency distribution of ova diameters from offshore specimens of the American eel, *A. rostrata*.


7 NOVEMBER, 1969
N = 1
x̄ = 0.172 mm
5 DECEMBER, 1967
N = 3
x̄ = 0.275 mm
22 DECEMBER, 1971
N = 6
x̄ = 0.356 mm
PERCENT FREQUENCY OF OCCURRENCE
LONGEST HORIZONTAL DIAMETER (mm)
25
20
15
10
5
0
.15
.20
.25
.30
.35
.40
.45

The conclusion that all of the off-shore specimens were silver eels was based on external morphology and coloration and gonadal condition. The horizontal diameter of the eye expressed as percent of the gape length of all fish ($\bar{x}$ = 48.7%; range, 44.0-59.0) was statistically greater (F = 13.973; df = 1.165) than values obtained for 156 female yellow eels ($\bar{x}$ = 41.8%; range, 30.7-59.1) collected from Chesapeake Bay sub-estuaries (Wenner, unpublished observations). The dorsal aspect of the pectoral fins and the caudal fin were darkly pigmented and the lateral line was prominent in all off-shore specimens. The general body coloration was that of a "silver" eel, or as Vladykov (1955) described migratory American eels, a "bronze" eel. The gross appearance of the gonads of all specimens showed a stage of maturity that resembled the gonadal state of eels migrating from the Chesapeake Bay.

An analysis of variance showed a highly significant difference (F = 969.60, df = 9, 1990) in ova diameters between fish. All morphometric values fell within the ranges of values for silver Anguilla rostrata leaving Chesapeake Bay during November 1970 (see Table 7). The ova diameters of the 1967 fish were also within the ranges of ova diameters of fish migrating from the bay ($\bar{x}$ = 0.27 with a range from 0.17-0.37 mm; see section III). The date of capture closely coincides with the peak of the eel fishery in lower Chesapeake Bay, but the possibility of a different estuarine origin cannot be excluded.

Gray and Andrews (1970) reported ova diameters ranging from 0.109 to 0.214 mm with a mean of 0.165 mm in silver eels leaving Newfoundland waters. These values are close to those of the 1969 female silver eel collected southeast of Cape Cod ($\overline{x}$ = 0.17, range, 0.12-0.27 mm). The 1971 eels had larger ova and greater maturity indices than any other specimens encountered in this study. The gonads comprised a mean of 5.78% of the total weight and the ova had a mean diameter of 0.356 with a range from 0.25 to 0.45 mm.

Although the 1971 specimens are more sexually mature as judged by ova diameters, their estuarine origin and the gonadal condition at the time of entrance into the sea is uncertain. Vladykov (1955) states "the exact routes of the eels in the sea and their behavior are not yet known". The possibility that migratory eels follow the coastline down to some region and then cross the Gulf Stream to reach the spawning grounds cannot be ruled out. It appears that eels from the Chesapeake Bay have larger eggs when they enter the sea and migrate later in the season than eels of more northerly estuaries. Consequently, fish from different estuaries may reach the spawning at approximately the same time and the same reproductive state.

SUMMARY

Meristic variation of the American eel, *Anguilla rostrata* (Lesueur) was studied. A compilation of the results of this study and the literature yielded the following mean values: total vertebrae = 107.14; precaudal vertebrae = 42.79; caudal vertebrae = 64.31; left branchiostegals = 11.02; right branchiostegals = 11.03; left pectoral fin rays = 16.51; right pectoral fin rays = 16.71; caudal fin rays = 9.95; dorsal fin rays = 231.44; anal fin rays = 199.12. Because of the wide variation in the numbers of dorsal and anal fin rays, it was suggested that they are of little taxonomic value.

Osteological deformities associated with the vertebral column were noted in 39% of the specimens examined. Ninety-six percent of the deformities were in the caudal vertebrae. Most abnormalities were in the structure of the neural and hemal spines with only 3% of the abnormal specimens having fused or partially fused vertebral centra.

The mean size of stage VI-A elvers sampled on March 17, 1970 in a small creek flowing into the York River, Va. was 55.6 mm. Mean lengths of elvers from the present study and those from the literature were regressed on latitude of capture and the equation is $y = 38.862 + 0.415\,x$, where x is the latitude of capture and y is the mean total length. 31.34% of the variation in size was associated with latitude. Elvers of southern latitudes entered

estuaries earlier and were smaller.

Seasonality of the American eel was studied in the brackish regions of the James, York and Rappahannock rivers. Monthly catches of eels showed a great deal of variability over the sampling period, but a temperature related trend was observed. Eels are fewer in number or absent in trawl catches during the winter months and are greater in number during the warmer months.

Food habits of the American eel were studied from the brackish regions of the James, York and Rappahannock rivers during the period from April to October, 1971. Crustaceans, pelecypods and polychaetes were the most important food items from all three rivers. Predation on the commercially important species, Mya arenaria and Callinectes sapidus, was apparent from all rivers with the blue crab making up 33.3% of the diet by volume in the James River, 68.2% in the York River and 15.9% in the Rappahannock River. Mya arenaria was a more important item by volume in the Rappahannock River eels (35%) than in the James River eels (17.5%) or in the York River eels (7.1%). This is consistent with the known abundance of the soft clam in the study area.

Fecundity of the American eel was estimated from 21 specimens migrating from the Chesapeake Bay in November 1970. The total weight and fecundity relationship is $\log y = 3.22990 + 1.11157 \log x$, where y is the total fecundity and x is the total weight in grams, and the total length and fecundity relationship is $\log y = -4.29514 + 3.74418 \log x$, where y fecundity and x is the total length in millimeters. The mean maturity index (gonad weight/total weight) for female eels was 0.0481 with a range from 0.0265 to 0.0625 and showed a significant correlation with mean ova diameter. Ova diameters of the Chesapeake Bay specimens were greater than those of silver eels leaving Newfoundland waters and from available data it is proposed that a latitudinal gradient in sexual maturity exists at the time of migration, with the more northerly forms being less sexually advanced at the onset of migration. Results of this investigation do not support Tucker's hypothesis that European silver eels, *Anguilla anguilla*, are more sexually advanced than American silver eels at the time of the onset of the spawning migration.

Eleven reproductively maturing specimens of the American eel were collected during three independent off-shore trawling operations. Three females were taken on December 6, 1967 southeast of the mouth of Chesapeake Bay in 10 to 13 fathoms, one male and one female on November 5, 1969 southeast of Cape Cod in 35 to 45 fathoms and six females on December 22, 1971 east of Assateague Island in 5 fathoms of water. Morphometrical analysis showed that the specimens were within the range of the "silver" phase of *Anguilla rostrata*. The ova diameters of the 1967 specimens were within the range of eels migrating from the Chesapeake Bay during November 1970 while those of the 1969 female were smaller and consistent with reports of eels migrating from Newfoundland waters.

APPENDICES

Appendix 1. Frequency distributions of meristic characters of the American eel, *A. rostrata*.

Vertebral Number	St. Lawrence River (Schmidt, 1913)	Weldon, No. Carolina (Schmidt, 1913)	Tilbury, Mass. (Schmidt, 1913)	St. Croix, Virgin Islands (Schmidt, 1913)	Gloucester, Mass. (Schmidt, 1914)
111	-				3
110	1	7	1	3	19
109	11	6	3	11	61
108	18	20	7	29	131
107	24	24	23	30	162
106	23	18	34	20	107
105	8	3	16	7	16
104	1	2	1	1	3
103	-	-	1	-	-

Appendix 1 (Cont.)

Vertebral Number	Mass. (Ege, 1939)	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (present study)	Total
111					3	
110	2	9	12			54
109	9	35	24	11	11	182
108	24	72	71	22	20	414
107	35	96	104	42	27	507
106	19	55	64	19	27	386
105	9	22	15	3	10	109
104	1	9	6	2	3	29
103	-	-	-		1	2

Appendix 1 (Cont.)

Precaudal Vertebrae	Mass. (Ege, 1939)	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (Present Study)	Total
46	-	-	1	-		1
45	1	4	2	-	-	7
44	12	37	39	16	13	117
43	60	143	156	55	46	460
42	23	96	83	25	36	263
41	3	18	20	4	4	49

Appendix 1 (Cont.)

Caudal Vertebrae	Nova Scotia (Ladd, 1958)	New Hampshire (Ladd, 1958)	Virginia (Ladd, 1958)	Virginia (Present Study)	Total
68	1				1
67	9	3	2	5	19
66	35	36	9	8	88
65	107	78	30	26	241
64	78	115	38	24	255
63	52	48	17	29	146
62	13	15	3	6	37
61	1	2		1	4

Appendix 1 (Cont.)

Left Branchiostegals	West Gloucester, Mass. (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Present Study)	Total
13	9	1	4	14
12	159	22	16	197
11	416	56	64	536
10	152	21	15	188
9	10	-	1	11

Appendix 1 (Cont.)

Right Branchiostegals	West Gloucester, Mass. (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Present Study)	Total
13	12	1	1	14
12	170	30	22	222
11	406	48	58	512
10	153	21	19	193
9	11	1	-	12

Appendix 1 (Cont.)

Left Pectoral Fin Rays	Virginia (Present Study)	Total
19	3	3
18	12	12
17	36	36
16	34	34
15	12	12
14	3	3

Appendix 1 (Cont.)

Right Pectoral Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	St. Croix, Virgin Islands (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Present Study)	Total
20	1		1		2
19	5	1	3	3	12
18	22	5	22	17	66
17	58	23	28	34	143
16	44	16	37	36	133
15	9	5	7	8	29
14	1	-	3	2	6

Appendix 1 (Cont.)

Right Pectoral Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	St. Croix, Virgin Islands (Schmidt, 1914)	Mass. (Ege, 1939)	Virginia (Present Study)	Total
20	1		1		2
19	5	1	3	3	12
18	22	5	22	17	66
17	58	23	28	34	143
16	44	16	37	36	133
15	9	5	7	8	29
14	1	-	3	2	6

Appendix 1 (Cont.)

Caudal Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	Virginia (Present Study)	Total
12	2	1	3
11	8	10	18
10	360	86	446
9	39	3	42
8	4	-	4

Appendix 1 (Cont.)

Dorsal Fin Rays	Virginia (Present Study)	Total
276	1	1
260		
259		-
258	1	1
257	2	2
256	2	2
255		
254		
253		
252		
251		
250		
249		
248	1	1
247	1	1
246	4	4
245		
244		
243	2	2
242	4	4
241	4	4
240	1	1
239	2	2
238	4	4

Appendix 1 (Cont.)

Dorsal Fin Rays	Virginia (Present Study)	Total
237	2	2
236	7	7
235	3	3
234	6	6
233	3	3
232	2	2
231	5	5
230	2	2
229	2	2
228	6	6
227	4	4
226	2	2
225	2	2
224	2	2
223		
222		
221	3	3
220	2	2
219		
218	5	5
217	1	1
216	3	3
215		
214		

Appendix 1 (Cont.)

Dorsal Fin Rays	Virginia (Present Study)	Total
213		-
212	2	2
211	2	2
210	1	1
209		
208		
207		
206		
205		
204		
203		
202		
201	1	1
191	1	1
183	1	1

Appendix 1 (Cont.)

Anal Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	Virginia (Present Study)	Total
229	1		1
228			-
227		1	1
226			
225			
224			
223			
222	1	-	1
221	1	2	3
220	2	3	5
219	-	1	1
218	2		2
217	2	2	4
216	4	1	5
215	-		
214	3	2	5
213	4	1	5
212	4	3	7
211	6	3	9
210	6	2	8
209	3	4	7
208	5	2	7
207	7	4	11

Appendix 1 (Cont.)

Anal Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	Virginia (Present Study)	Total
206	8	-	8
205	8	-	8
204	8	3	11
203	9	3	12
202	12	3	15
201	10	8	18
200	11	4	15
199	8	7	15
198	11	6	17
197	10	2	12
196	7	1	8
195	10	4	14
194	9	2	11
193	4	2	6
192	6	5	11
191	10	3	13
190	10		10
189	3	-	3
188	6	3	9
187	5	3	8
186	4	2	6
185	6	1	7
184	5		5

Appendix 1 (Cont.)

Anal Fin Rays	West Gloucester, Mass. (Schmidt, 1914)	Virginia (Present Study)	Total
183	4	1	5
182	2	2	4
181	2	1	3
180			
179	1		1
178	1		1
177	2		2
176	1		1
175		-	-
174		1	1
173		1	1
172			
171			
170			
169		-	-
168	-	1	1
167	1	-	1

Appendix 2. Analysis of variance table testing for significant differences between left and right branchiostegals. Treatment groups: left branchiostegals; right branchiostegals. Data from York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' Ratio
Between Groups	0.0200	1	0.0200	0.04164 ns.
Within Groups	95.2598	198	0.4811	
Total	95.2798	199		

Appendix 2. (Cont.) Analysis of variance table testing for a significant difference between left and right pectoral fin rays. Treatment groups: left pectoral fin rays; right pectoral fin rays. Data from York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	0.9787	1	0.9787	0.9152 ns.
Within Groups	211.7380	198	1.0694	
Total	212.7187	199		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of total vertebrae counts. Treatment groups: St. Croix, Virgin Islands (Schmidt, 1913); Weldon, North Carolina (Schmidt, 1913); Virginia (Ladd, 1958); York River, Virginia (present study); West Tilsbury, Massachusetts (Schmidt, 1913); West Gloucester, Massachusetts (Schmidt, 1914); Massachusetts (Ege, 1939); New Hampshire (Ladd, 1958); Nova Scotia (Ladd, 1958); St. Lawrence River (Schmidt, 1913).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	499.6753	9	55.5195	35.935***
Within Groups	2694.4341	1744	1.5450	
Total	3194.1094	1753		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of right branchiostegal counts. Treatment groups: West Gloucester, Massachusetts (Schmidt, 1915); Massachusetts (Ege, 1939); York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	0.4290	2	0.2145	0.3886 ns.
Within Groups	524.3330	950	0.5519	
Total	524.7620	952		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of anal fin ray counts. Treatment groups: West Gloucester, Massachusetts (Schmidt, 1915); York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	195.2676	1	195.2676	1.8326 ns.
Within Groups	36440.7031	342	106.5518	
Total	36635.9688	343		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of caudal fin ray counts. Treatment groups: West Gloucester, Massachusetts (Schmidt, 1915); York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	2.4583	1	2.4583	14.9153***
Within Groups	84.2233	511	0.1648	
Total	86.6816	512		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of precaudal vertebrae. Treatment groups: Massachusetts (Ege, 1939); York River, Virginia (present study).

ANOVA TABLE

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	1.2930	1	1.2930	2.4364 ns.
Within Groups	104.0191	196	0.5307	
Total	105.3121	197		

Appendix 2. (Cont.) Analysis of variance table testing for significant differences between various reports of right pectoral fin ray counts. Treatment groups: West Gloucester, Massachusetts (Schmidt, 1915); St. Croix, Virgin Islands (Schmidt, 1915); Massachusetts (Ege, 1939); York River, Virginia (present study).

ANOVA TABLE

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	'F' ratio
Between Groups	1.5676	3	0.5225	0.5046 ns.
Within Groups	400.7717	387	1.0356	
Total	402.3391	390		

Appendix 3. Length frequency distributions of elvers of the American eel (*Anguilla rostrata*).

Length (mm)	Latitude and Source					
	25.43° Smith, 1968	30.56° Vladykov, 1966	37.38° Present Study	38.46° Vladykov, 1966	38.65° Vladykov, 1966	38.66° Present Study
46	2	-	-	1	-	
47	7	2	-	1		
48	7	5	1	11		-
49	1	5	1	12	-	5
50	3	13	1	26	2	9
51	6	5	2	13	8	12
52	2	7	16	33	19	9
53	2	13	16	25	15	19
54	2	3	12	35	27	10
55		2	22	25	30	13
56		3	13	10	30	21
57		2	19	10	20	5
58	-	1	11	3	21	1

Appendix 3. (Cont.)

Length (mm)	Latitude and Source					
	25.43° Smith, 1968	30.56° Vladykov, 1966	37.38° Present Study	38.46° Vladykov, 1966	38.65° Vladykov, 1966	38.66° Present Study
59		-	9	5	12	1
60			9	2	10	
61		1	2	1	3	
62		-	-		1	
63		1	3		1	
64						
65						
66						
67						
68						
69						
70	-	-	-	-	-	-

Appendix 3. (Cont.)

Length (mm)	Latitude and Source				
	38.09° Vladykov, 1966	41.54° Schmidt, 1909	45.07° Vladykov, 1966	46.67° Vladykov, 1966	49.29° Vladykov, 1966
46	-	-	-	-	-
47					
48	-				
49	2		-		
50	4		1		
51	6	-	3	-	-
52	11	3	11	3	1
53	29	1	12	6	-
54	34	1	25	14	1
55	37	3	29	15	2
56	32	3	32	48	3
57	31	2	28	44	4
58	23	1	23	58	9

Appendix 3. (Cont.)

Length (mm)	Latitude and Source				
	38.09° Vladykov, 1966	41.54° Schmidt, 1909	45.07° Vladykov, 1966	46.67° Vladykov, 1966	49.29° Vladykov, 1966
59	12	2	20	43	3
60	8	2	16	52	3
61	2		9	27	1
62	2	-	10	22	2
63	1	2	5	13	1
64	2	-	2	8	
65			-	5	
66			1	4	
67			1		-
68					1
69		-			
70	-	1	-	-	-

Appendix 4. Fecundity and gonadal observations on silver eels migrating from the Chesapeake Bay, November 1970.

Total Length (mm)	Total Weight (gm)	Ovarian Weight (gm)		Number of Eggs ($x10^2$)		Maturity Index	Mean Ova Diameter (mm)		
		Left	Right	Left	Right		Left	Right	Total
653	567	16.4	16.4	10940	10630	0.0573	0.285	0.288	0.287
590	370	10.2	10.4	07600	08980	0.0557	0.297	0.292	0.295
676	510	15.4	12.2	09720	08650	0.0541	0.282	0.285	0.283
715	740	19.4	19.9	11530	13720	0.0531	0.268	0.272	0.270
694	701	23.4	20.4	10810	10470	0.0625	0.319	0.311	0.315
617	411	09.0	09.6	06410	06090	0.0452	0.269	0.269	0.269
618	416	11.5	11.9	08370	07450	0.0562	0.288	0.293	0.291
514	236	04.6	04.9	04850	05985	0.0402	0.246	0.242	0.244
533	264	06.8	07.4	04060	04060	0.538	0.277	0.280	0.278
506	176	02.8	02.9	02750	02210	0.0324	0.256	0.248	0.252
554	327	07.8	06.8	05320	05560	0.0446	0.261	0.255	0.258
622	506	12.9	10.3	07430	07320	0.0456	0.264	0.260	0.262
493	247	04.0	04.0	03730	03640	0.0324	0.247	0.243	0.245

Appendix 4. (Cont.)

Total Length (mm)	Total Weight (gm)	Ovarian Weight (gm)		Number of Eggs ($x10^2$)		Maturity Index	Mean Ova Diameter (mm)		
		Left	Right	Left	Right		Left	Right	Total
581	409	12.4	11.5	07790	06150	0.0584	0.285	0.291	0.288
677	327	07.0	05.6	05210	04810	0.0385	0.248	0.262	0.255
687	695	17.7	16.0	13570	11720	0.0485	0.265	0.268	0.267
724	755	21.2	21.3	12930	12680	0.0563	0.272	0.261	0.267
536	345	08.3	08.5	04280	04060	0.0487	0.285	0.280	0.283
553	308	06.9	07.0	05860	05910	0.0451	0.278	0.271	0.275
487	157	04.5	04.3	01970	0.2160	0.0560	0.266	0.264	0.265
498	166	02.3	02.1	02080	02295	0.0265	0.246	0.262	0.254

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