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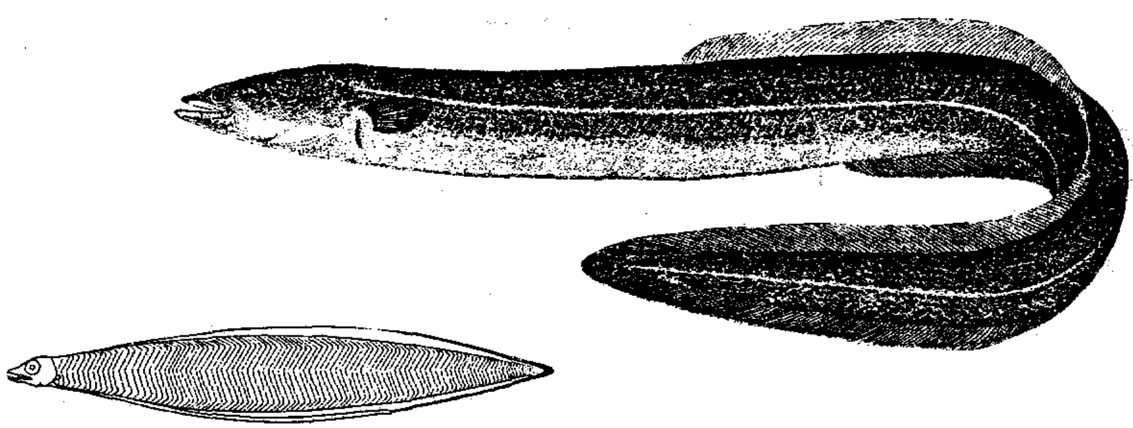

BIOLOGICAL & FISHERIES DATA ON AMERICAN EEL, *Anguilla rostrata* (Lesueur)

AUGUST 1978

Biological and Fisheries Data

on

American eel, *Anguilla rostrata* (LeSueur)

by

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Technical Series Report No. 17

August 1978

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--PREFACE

"Nothing more is known than what people repeat about the loves of Roman eels and snakes. Some say that they pair, that, full of eagerness, drunk with desire, the Roman eel comes out of the sea to go and meet her mate. Urged by devouring passion, the odious lustful snake goes crawling to the water's edge. Seeing a hole in a rock, he vomits his fatal poison; he empties his teeth entirely, clearing them of the black, pernicious fluid with which they are armed to kill; for, flying to his love, he wishes only to be gracious and amiable. Arriving on the beach, he stops, and intones his whistling love song. As soon as she hears his voice, quicker than an arrow, the black Roman eel darts towards the shore while the snake throws himself into the sea foam, and swims to meet her. Their mutual desire is satisfied. They are together. Panting with pleasure, the female draws the snake's head into her mouth. Their passion satisfied, the one returns to her element, the other with long undulations regains terra firma. There, he re-absorbs the black poison which he had previously ejected. But if sometimes a passer by, having recognized the fatal liquid, has thrown it into the water, then, in desperation, the snake bangs his head against the stones until he dies. He cannot outlive his shame."

--from "Halieutica"
by Oppian
2nd Century A. D.

"It is sobering to reflect that such a familiar animal can, despite the great amount of time, money, and effort which have been devoted to it, retain so many fundamental mysteries."

--Smith, 1968

1. IDENTITY

1.1 Nomenclature

1.1.1 Valid Name

Anguilla rostrata (LeSueur).
(=*Muraena rostrata* LeSueur, 1817, Journal of the Academy of Natural Sciences of Philadelphia, Vol. 1, No. 1, May 1817)

1.1.2 Synonymy

Muraena rostrata LeSueur 1817, p. 81.

M. bostoniensis LeSueur 1817, p. 81.

M. serpentina LeSueur 1817, p. 81.

M. argentea LeSueur 1817, p. 82.

M. macrocephala LeSueur 1817, p. 82.

Anguilla chrysypa Rafinesque-Schmaltz 1817, p. 120; Jordan and Davis 1892, p. 668: Jordan and Evermann 1896, p. 348; Meek 1904, p. 90: T. H. Bean 1906, p. 30; Schmidt 1906, p. 239.

A. blephura Rafinesque-Schmaltz 1817, p. 120.

A. laticauda Rafinesque-Schmaltz 1817, p. 445.

A. aterrima Rafinesque-Schmaltz 1820, p. 78.

A. xanthomelas Rafinesque-Schmaltz 1820, p. 78.

A. lutea Rafinesque-Schmaltz 1820, p. 78.

A. tenuirostris DeKay 1842, p. 310.

A. rostrata DeKay 1842, p. 312; B. A. Bean 1909, p. 871; Evermann and Goldsborough 1909, p. 101; Meek and Hildebrand 1910, p. 285; Schmidt 1913, pp. 13-17 and pp. 27-28 and 1915, pp. 5-17; Meek and Hildebrand 1923, p. 134; Jensen 1937, p. 6.

A. novaeorleanensis Kaup 1856, p. 43.

A. punctatissima Kaup 1856, p. 44.

A. cubana Kaup 1856, p. 44.

A. novaeterrae Kaup 1856, p. 45.

A. texana Kaup 1856, p. 45.

A. wabashensis Kaup 1856, p. 46.

A. tyrannus Girard 1859, p. 75.

M. cubana Poey 1868, p. 421.

A. bostoniensis Günther 1870, p. 31 (partim).

A. vulgaris rostrata Meek 1883, p. 430.

1.2 Taxonomy

1.2.1 Affinities

-Suprageneric

Phylum - Vertebrata
Subphylum - Craniata
Superclass - Gnathostomata
Series - Pisces
Class - Teleostomi
Subclass - Actinopterygii
Superorder - Elopomorpha
Order - Anguilliformes
Suborder - Anguilloidei
Family - Anguillidae

-Generic

Genus Anguilla Shaw, 1803, Gen. Zool. (Pisces), 4(1): 15.
Type Species by Monotypy: Anguilla vulgaris Shaw, 1803
(A subjective synonym of Muraena anguilla Linnaeus, 1758).
Gender: feminine.

"Head smooth. Nostrils tubular. Eyes covered by the common skin. Gill-membrane ten-rayed. Body roundish, smooth, mucous. Dorsal, caudal, and anal fins united. Spiracles behind the head or pectoral fins." (Shaw, 1803).

As the family Anguillidae consists of only one genus, the family characters may be considered as generic characters too. The following (family-) concept is expressed by Berg (1949):

Body elongate, snake-like. Dorsal and anal fins confluent with the rudimentary caudal fin. Pectoral fins present, ventrals absent. Body covered with minute scales. Lateral line well-developed. Vent remote from the head. Mouth terminal; jaws not particularly elongate. Teeth small, pectinate or setiform, in several series on the jaws and the vomer. Minute teeth on the pharyngeal bones, forming an ovate patch on the upper pharyngeals. Gill openings lateral vertical, quite well developed, well separated from each other. Inner gill slits wide.

Tongue present. Lips thick. Frontal bones paired, not grown together. Palatopterygoids well-developed. Premaxillaries not developed as distinct elements in adults. Pectoral girdle with 7 to 9 (up to 11 in the young) radial elements. Caudal vertebrae without transverse processes.

The generic diagnosis by Jordan and Evermann (1896) follows:

Anguilla, Shaw, General Zoology, IV, 15, 1804, (anguilla).

Muraena, Bleeker, Poey, etc., (taking as type Muraena anguilla, the first species mentioned by Artedi under Muraena).

Body elongate, compressed behind, covered with embedded scales which are linear in form and placed obliquely, some of them at right angles to others. Lateral line well developed. Head long, conical, moderately pointed, the rather small eye well forward and over the angle of the mouth. Teeth small, subequal, in bands on each jaw and a long patch on the vomer. Tongue free at tip. Lips rather full, with a free margin behind, attached by a frenum in front. Lower jaw projecting. Gill openings rather small, slit-like, about as wide as base of pectorals and partly below them. Nostrils superior, well separated, the anterior with a slight tube. Vent close in front of anal. Dorsal inserted at some distance from the head, confluent with the anal around the tail. Pectorals well developed. Species found in most warm seas, (the eastern Pacific excepted), ascending streams, but mostly spawning in the sea. The eels often move for a considerable distance on land, in damp grass. Waterfalls, dams, and other obstructions are often passed in this way. It is thought that the eel spawns only in the sea, the female dying after having once produced ova. The females are larger than the males, paler in color, with smaller eyes and higher fins. Eels are among the most voracious of fishes. "On their hunting excursions, they overturn alike huge and small stones, beneath which they find species of shrimp and crayfish, of which they are excessively fond. Their noses are poked into every imaginable hole in their search for food, to the terror of innumerable small fishes" (W. H. Ballou). The single American species differs* slightly from the European Anguilla anguilla (Linnaeus). (anguilla, the eel).

*As is shown in the following analysis:

a. Distance between the origin of dorsal and vent 5/6 to 1-1/4 in head; pectoral 3 to 3-2/3 in head; head 2-1/2 to 2-4/5 in trunk; upper jaw 3-3/4 to 4-1/4 in head. Yellow, brown, or black, underparts paler. ANGUILLA

aa. Distance between origin of dorsal and vent 1-1/6 to 2 in head; pectoral 2-5/6 to 3-2/5 in head; head 2 to 2-1/2 in trunk; body more robust and trunk slightly shorter than in anguilla, otherwise similar. CHRYSYPA, 568 (=rostrata)

-Specific

Anguilla rostrata LeSueur, 1817.
DeKay (1842) was the first to use the combination Anguilla rostrata.

Holotype: Present location of type specimen unknown.

Type locality: Cayuga Lake, New York.

Definition of species by LeSueur:

"Muraena rostrata. Snout elongated, pointed and strait (sic); eyes large and situated very near the angle of the mouth; body tumid in the centre, and narrowed to a point at both extremities; upper parts varied with gray and olive, sometimes of a slate blue, lower parts white; dorsal and anal fins reddish, which colour deepens as it approaches the tail; pectoral fins small, acute and bluish.

"Length from eighteen to twenty-four inches.

"Inhabits the lakes Cayuga and Geneva, in the state of Newyork; is esteemed for the table."

-Diagnosis of species by Jordan and Evermann (1896) (Figure 1).

574. Anguilla chrysypa,* Rafinesque.

(American eel; fresh water eel).

Distance from front of dorsal to vent 1-1/6 to 2 in head; pectoral 2-5/6 to 3-2/5 in head; head 2 to 2-1/2 in trunk. Form rather robust. Brown, nearly plain, often tinged with yellowish; paler below, the color extremely variable. Length 4 or 5 feet. Atlantic coast of the United States; very abundant from Maine to Mexico; ascending all rivers south of Canada and east of the Rocky Mountains and resident throughout the Mississippi Valley. Common in the West Indies. Not found in the Pacific. A food-fish of importance. (Χρυσός, gold; υπό, below.)

-Key to the species of Anguilla Shaw, 1803 (after Ege, 1939).

I. The average breadth of the intermaxillary-vomerine band of teeth, measured in the middle, amounts to little more than half the greatest breadth of the maxillary bands.

A. Number of prehaemal vertebrae 38 to 42, total number of vertebrae 101 to 107. Average maximum value of the preanal length without head, in percent of total length, ca. 27.0 to ca. 27.2.

* Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length ca. 9.0...... 1. A. celebesensis KAUP

** Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length ca. 13.0..... 2. A. interioris WHITLEY

B. Number of prehaemal vertebrae 40 to 44, total number of vertebrae 108 to 116. Average maximum value of the preanal length without head, in percent of total length, ca. 25.9..... 3. A. megastoma KAUP

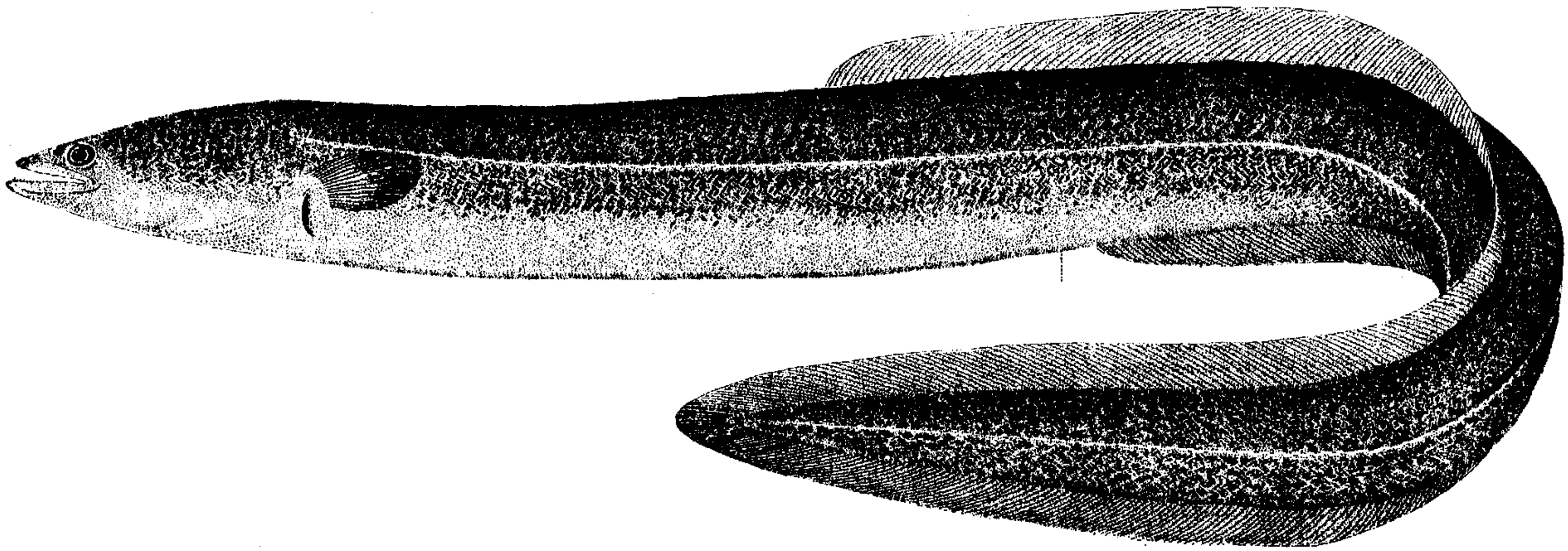

Figure 1. Adult American eel, Anguilla rostrata. (Figure 143 in Jordan and Evermann, 1896, as Anguilla chrysypa).

II. The average breadth of the intermaxillary-vomerine band of teeth, measured in the middle, greater than or equal to the greatest breadth of the maxillary bands.

A. Skin with variegated markings.

* The three rows of teeth forming the main part of the maxillary bands are regular, longitudinal groove distinct without interruptions; a projection on the inner side of the bands anteriorly. Primary pigment of the elvers forming a distinct mediolateral streak on the end of the tail. (Dentition not known in A. ancestralis, only represented by elvers).

1. Number of prehaemal vertebrae 37 to 40...... .....4. A. ancestralis EGE.

2. Number of prehaemal vertebrae 39 to 43.
   a. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 11.7 to ca.11.9....... ..... A. nebulosa McCLELLAND.

   x Total number of vertebrae 106 to 112.... .....5a. A. nebulosa nebulosa McCLELLAND.

   xx Total number of vertebrae 107 to 115.... .....5b. A. nebulosa labiata PETERS.

   b. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 16.3.................. .....6. A. marmorata QUOY and GAIMARD.

** The three rows of teeth in the maxillary bands irregular, longitudinal groove less distinct with interruptions; no projection of the inner side of the bands. The elvers without streak of primary, mediolateral pigment on end of tail... .....7. A. reinhardti STEINDACHNER.

B. Skin without variegated markings.

* Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 9.1 to ca. 14.6.

1. Average maximum value of length of gape, in percent of head length, ca. 32 to ca. 36.

a. Maxillary bands of teeth with longitudinal groove. Average maximum value of preanal length, without head, in percent of total length, ? ca. 27............. 8. A. borneensis POPTA.

b. Maxillary bands of teeth without longitudinal groove. Average maximum value of preanal length without head, in percent of total length, ca. 29.

x Total number of vertebrae 100 to 106. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 14.6........................ 9. A. mossambica PETERS.

xx Total number of vertebrae 109 to 116. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 11.1........................ 10. A. dieffenbachi GRAY.

2. Average maximum value of length of gape, in percent of head length, ca. 25 to ca. 27.

a. Maxillary bands of teeth with longitudinal groove. Average maximum value of preanal length without head, in percent of total length, ca. 26.9............ 11. A. japonica TEMMINCK and SCHLEGEL.

b. Maxillary bands of teeth without longitudinal groove. Average maximum value of preanal length without head, in percent of total length, ca. 30.1 to ca. 30.2.

x Total number of vertebrae 103 to 111. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 9.1........................12. *A. rostrata* (LeSUEUR).

xx Total number of vertebrae 110 to 119. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 11.2.......................13. *A. anguilla* (LINNAEUS).

** Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 0.2 to ca. 3.6.

1. Constriction of the intermaxillary-vomerine band of teeth begins on an average before the middle of the band. Average maximum values of preanal length without head, in percent of total length, ca. 27.0 to ca. 28.2. Number of prehaemal vertebrae 40 to 45.

a. Average maximum value of length of intermaxillary-vomerine band of teeth, in percent of distance from front margin of that band to posterior end of right maxillary band, ca. 82 to ca. 86. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 0.2 to ca. 0.8..............*A. bicolor* McCLELLAND.

x Total number of vertebrae 103 to 111..........14a. *A. bicolor pacifica* SCHMIDT.

xx Total number of vertebrae 106 to 115..........14b. *A. bicolor bicolor* McCLELLAND.

b. Average maximum value of length of intermaxillary-vomerine band of teeth, in percent of distance from front margin of that band to posterior end of right maxillary band, ca. 71.

Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 3.6..................
.....15. *A. obscura* GUNTHER.

2. Constriction of the intermaxillary-vomerine band of teeth begins on an average far behind the middle of the band. Average maximum value of preanal length without head, in percent of total length, ca. 30.3. Number of prehaemal vertebrae 44 to 48.......................
.....*A. australis* RICHARDSON.

   a. Average maximum value of distance between verticals through anus and dorsal fin, in percent of total length, ca. 1.2. Average maximum value of head length (measured in females), in percent of total length ca. 14..............................
   .....16a. *A. australis schmidti* PHILLIPS.

   b. Average maximum value of distance between verticals through anus and origin of dorsal fin, in percent of total length, ca. 2.6. Average maximum value of head length (measured in females), in percent of total length, ca. 12.......................
   .....16b. *A. australis australis* RICHARDSON.

1.2.2 Taxonomic Status

The species is well established by biological data (Schmidt, 1922; Ege, 1939).

1.2.3 Subspecies

No subspecies exist.

1.2.4 Standard Common Names, Vernacular Names.

In the United States and Canada, *A. rostrata* is known most commonly as "American eel". Other names, some dependent on life stage are:

Anguille, yellow eel (taken in summer), green eel (taken in summer), black eel (taken in autumn), little eel, whip, elver (young eels), civelles (young eels), common eel, fresh-water eel, silver eel, bronze eel (also see section 9, Glossary).

1.3 Morphology

1.3.1 External Morphology (except larvae and juveniles, for which see 3.1.7, 3.2.2 and 3.2.3) - also see 1.2.1

Generalized - the maximum weight of an American eel is considered to be 15 pounds. A female of 13 pounds and 5 ounces was taken in the autumn of 1943 at the Island of Orleans, near Quebec City. After being kept in cold storage for a year, it weighed 11 and a half pounds and measured 50 inches in length. In the Province of Quebec, the size of adult eels (females), caught during the summer and autumn, along the shores of the St. Lawrence River, varied from 30 to 50 inches, and averaged 36 inches; their weight ranged from 2 to 10 pounds. The average weight of 1500 specimens was about 3½ pounds. In general, the relation between the length and weight of the American eel is as follows: 12 inches - 1½ ounces; 24 inches - 14½ ounces; 36 inches - 3½ pounds; 48 inches - $6^3/4$ pounds (from Vladykov, 1955) (see also 3.4.3).

The typical anguilloid skull is modified as follows: 1) pterotics equipped with anterior extension; 2) parietals fused medially; 3) supraoccipital well developed; 4) hyomandibular and quadrate intimately joined, symplectic not present at their junction; 5) opercles reduced; 6) branchiostegals important for support; 7) mesocoracoid absent; 8) premaxilla fused with ethmoid, upper jaw bordered by both maxillary and ethmopremaxillary block; 9) pumping mechanism for branchial current. To be effective, mouth and gill chambers must be widely separated, thus; 10) posterior placement of gills results in posterior placement of pectoral girdle which loses attachment to skull (Figure 2).

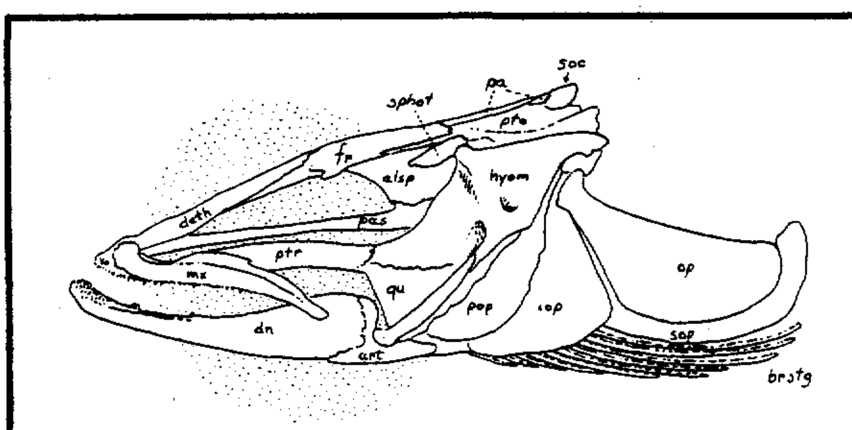

Figure 2. Typical anguilloid skull (after Gregory, 1959). See List of Figures, page vi, for explanation of abbreviations.

A summary of individual variation is contained in Table 1 (after Ege, 1939).

TABLE 1. Selected morphological data on A. rostrata (after Ege, 1939).

	300-399 mm ♀	400-499 mm ♀	500-599 mm ♀
a	43.42	43.90	42.73
b	29.79	30.10	29.83
c	8.80	9.09	9.63
d	21.00	21.01	20.23
e	13.66	13.78	12.90
f	25.88	26.52	27.23

$a = \frac{a}{t}.100$ Variation of preanal length, in % of total length.

$b = \frac{a-h}{t}.100$ Variation of preanal length without head, in % of total length.

$c = \frac{a-d}{t}.100$ Variation of distance between verticals through anus and origin of dorsal fin, in % of total length.

$d = \frac{d-h}{t}.100$ Variation of predorsal length with head, in % of total length.

$e = \frac{h}{t}.100$ Variation in length of head, in % of total length.

$f = \frac{g}{h}.100$ Variation in length of gape, in % of total length of head.

Another subject regarding individual variation concerns broad-nosed and sharp-nosed eels. In any one eelstock some individuals may be observed with a relatively broad head; others with a narrow head. This phenomenon has given rise to two hypotheses:

1) The differences between broad-nosed and sharp-nosed eels are genetically determined.

2) The differences originate from different feeding.

After a thorough investigation Thurow (1958) determined:

An eelstock mainly consists of animals with intermediate characteristics. Narrow- and broad-nosed eels are variants of a continuous population which shows great flexibility, and their occurrence is determined by environmental conditions, especially the prevailing food. -No data are available which conclusively point to geographic variation. Tucker's (1959) theory that European and American eels should be regarded as geographical variants of the same species is not generally accepted. (See also 3.1.7C). -No subpopulations can be distinguished.

Morphological changes during growth - (Descriptions of larvae and juveniles are in 3.2) - young eels (less than ∿200 mm) are in a neutral stage, since their sex is not yet differentiated. Scales first appear on the mid-body and caudal regions at a length of ca. 16 cm. Scales on the anterior region first appear at ca. 17 cm. The entire body is fully scaled at ca. 21 cm. (See also 3.4.3 and Table 5).

Coloration changes with stage of development, thus an elver, on reaching fresh water acquires a grey pigmentation over the entire body. After several years, the immature eel reaches 2 to 4 feet in length and acquires a yellow-green color, darker on the back. Some individuals with an orange-pink tint are sometimes found. At the onset of sexual maturity, the eel acquires a metallic, bronze-black sheen, and the pectoral fins change from yellow-green to black. Also at this stage, (the "migratory livery"), the eel is fattened, apparently in preparation for migration. Another adaptation apparently in preparation for travel in dark ocean depths is an enlargement of the eye (macrophthalmia) which until recently had only been observed in the European eel, *A. anguilla*. Vladykov (1973) reported on three *A. rostrata* specimens with unusually large eyes. In two of the specimens, the horizontal diameter of the eye was greater than the interorbital width.

Beatty (1975) reported on a change in visual pigments in the eye of eels. Whereas in fresh water the yellow eel's eye contains mostly Porphyropsin $P523_2$ and small amounts of Rhodopsin P501, the eye of downstream-migrating silver eels contains small amounts of Porphyropsin $P523_2$ and two Rhodopsins (P482 and P501). By the time mature silver eels enter sea water, the 2 Rhodopsins predominate. (Porphyropsin is a carotenoid pigment found in the retina of freshwater fishes; Rhodopsin is a protein pigment found in the rods of the retina and is necessary for vision in dim light).

1.3.2 Cytomorphology

The chromosome number of both A. rostrata and A. anguilla is 38 (2n) (Sick et al., 1967). But specific differences are found in the alleles: A. rostrata 20M + 18A; A. anguilla 32M + 6A (Ohno et al., 1972).

1.3.3 Protein Specificity

Sick et al. (1967) performed haemoglobin electrophoretic studies on a sample of 666 A. rostrata and 848 A. anguilla. The A. anguilla specimens all showed a characteristic two-banded pattern while most A. rostrata specimens showed the same pattern. Two other patterns were found in the A. rostrata sample, one type by 1 eel, the other type by 42 eels. The authors admit that it is theoretically possible that A. anguilla individuals carrying the unusual allele are exterminated by natural selection before being sampled, but think this is very unlikely. In the authors' words "the existence in American eels of more than 3 per cent of the haemoglobin allele which is seemingly non-existent in eels collected in Europe is strong evidence against Tucker's one-population concept." (see also 3.1.7C). Note that Koehn (1972) has suggested that most genetic inferences concerning eels have been unjustified.

2. DISTRIBUTION

2.1 Total Area

The geographic distribution is in the western North Atlantic from southern and western Greenland, Newfoundland, Prince Edward Island, Gulf of St. Lawrence, Gulf of Maine, common along the Atlantic coast of the United States, widespread in the Gulf of Mexico to Panama, common in northern Mexico, present on the north coast of South America, rarely to Brazil, and in the West Indies and Bermuda. Bertin (1956) reports the latitudinal range as between 5° and 62°N.

Adult eels are found in brackish and freshwater estuaries, coastal streams and land-locked lakes.

2.2 Differential Distribution

2.2.1 Spawn, Larvae and Juveniles

See 3.1.6 and 3.5.1.

2.2.2 Adults

Females are found principally in freshwater although some are taken in brackish and saltwater. (Inland eel fisheries in Nova Scotia, Quebec and Ontario are supported exclusively by catches of female eels). Males are found almost exclusively in salt or brackish water. Vladykov (1966) also showed that male eels predominate in southern regions of the Atlantic coast (New Jersey to Florida) while females predominate from Newfoundland to New York. Vladykov correlated these findings with a bimodality in lengths of ascending elvers examined all along the coast. The smaller class of elvers entering southern streams probably become males while the larger elvers in northern inland waters probably develop into females.

2.3 Determinants of Distribution Changes

Distribution is primarily determined by the course of the Gulf Stream and several currents which disperse the larvae and elvers along the coasts. Further distribution depends on accessibility of interior waters and on transplantations which are readily accomplished due to ease with which eels may be transported.

All areas, in the interior or along the coast, which are fit for fish contain eels. This includes all waters from warm, saline estuaries to cold, fresh trout-streams in mountainous areas.

2.4 Hybridization

Unknown.

3. BIONOMICS AND LIFE HISTORY

(To assist the reader with terminology, a diagrammatic depiction of the eel's life history, Figure 3, is included).

3.1 Reproduction

3.1.1 Sexuality

Sexual differentiation of the gonads does not occur until eels reach about 200 mm. Female eels are nearly always found in freshwater, males in brackish waters. Once sex is established in an individual, it does not change.

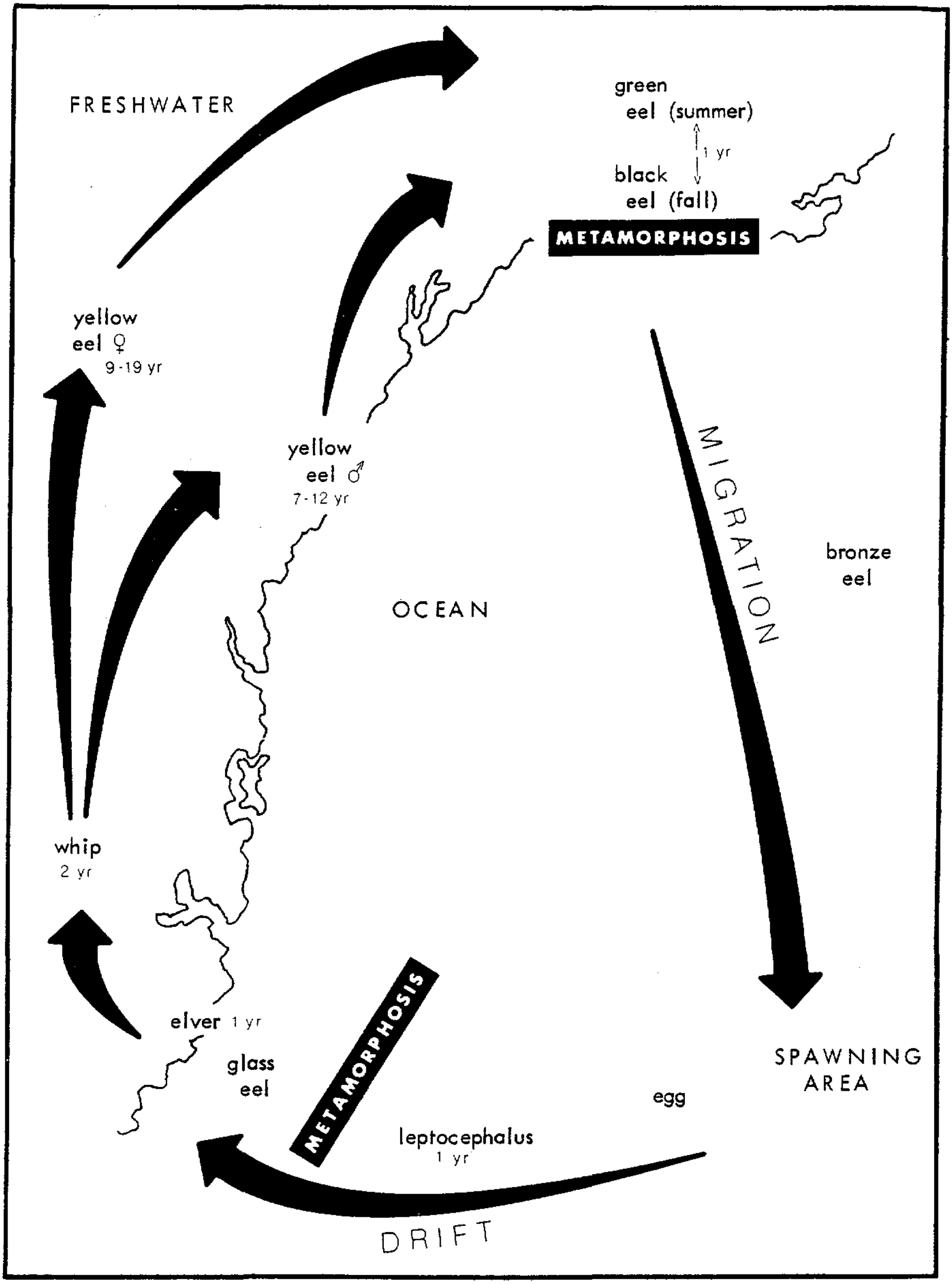

Figure 3. Diagrammatic representation of eel's life history including terminology at various stages.

Males are much smaller than females. The smallest mature males are 11 to 12 inches long (28 to 30 cm) while the smallest females are ca. 18 inches long (46 cm). Full grown females average 2 to 3½ feet long (61 to 107 cm).

3.1.2 Maturity

The age at which sexual maturity is attained is unknown. But it is probably more than seven years for females, four to seven for males. Eels as old as seven have been studied and none display the external manifestations of sexual maturity (enlarged eyes, fattened body, degeneration of the digestive system, silvery sides and black back). Presumably, ovaries mature only after the migrating female reaches salt water.

Wenner and Musick (1974) show that eels migrating from Chesapeake Bay are in a more advanced state of maturity than American eels migrating from Canadian waters. Presumably, this fact would enable eels to reach the spawning area in the same relative state of maturity.

Size at maturity presumably averages 36 inches (91 cm) and 3½ pounds for females, smaller for males (see 1.3.1). This estimate is based on sizes of sea-going adults in the fall.

3.1.3 Mating

Unknown.

3.1.4 Fertilization

Apparently external - no copulatory apparatus.

3.1.5 Gonads

The condition of the gonads of sea-going American eels has not been sufficiently studied. Shulman and Paine (1974) report that a female eel produces from 3 to 10 million eggs during spawning. Vladykov (1955) and Eales (1968) report fecundity to be 10 to 20 million and 15 to 20 million, respectively. Wenner and Musick (1974) reported on the fecundity of 21 specimens migrating from Chesapeake Bay. The relation between total length and fecundity is $\text{Log } Y = -4.29514 + 3.74418 \text{ Log } X$, where Y is fecundity and X is total length (mm). The relation between total weight and fecundity is $\text{Log } Y = 3.2290 + 1.1157 \text{ Log } X$ where Y is fecundity and X is total weight (g).

3.1.6 and 3.1.7 Spawning and Spawn

These sections are combined into one, since the various components form an inter-related subject. A discussion of A. rostrata spawning must include a discussion of A. anguilla spawning, since details of the two are so closely intertwined. Because the subject is presently unsettled and controversial, it will be dealt with in five sections: A: Historical; B: Schmidt's research; C: Tucker's "new solution"; D: Rebuttals to Tucker's theory; and E: New information.

A. Historical - Since the time of Aristotle (350 B.C.) the mystery of eel migration and spawning has occupied the attention of naturalists. It was known by the ancients that full-grown eels move downstream in the autumn to disappear into the sea. In early spring the early naturalists observed swarms of small eels returning from the sea and invading fresh waters. The origin of these offspring sparked wild and superstitious theories, of which the preface to this paper is an example. Indeed, it was variously thought that young eels were generated out of rotting vegetation, that they were formed from skin rubbed off on rocks by passing adult eels, or that they were the result of a licentious union between eels and snakes.

Grassi and Calandruccio (1897) found that the smallest European eel stage is preceded by a larval stage (found in deeper water away from the coasts) originally described as Leptocephalus brevirostris by Kaup (1856). Grassi concluded that the breeding grounds of the European eel lay in the abyssal regions of the sea, that the ova develop suspended in the sea and that the resulting leaf-shaped larvae undergo a metamorphosis, the results of which were the familiar elvers invading fresh water each spring. This discovery, albeit important, left unanswered the questions of where spawning occurred, the time it involved, and the character of the necessary migrations involved. It was at this stage in the unraveling of the mystery that Johannes Schmidt began his investigations.

B. Schmidt's research - Schmidt began his studies in 1904 dividing his work into investigations at sea and investigations in the lab. At sea, Schmidt occupied hundreds of stations across the Atlantic with plankton-collecting gear and found increasing numbers but decreasing sizes of larvae as he searched from east to west. He concluded that the origin of the European eel was situated far to the west in the Atlantic Ocean. He also discovered that he could separate the larvae of the European eel from those of the American eel (of which he caught relatively few and which he considered a "nuisance") by simply counting myomeres. Finally, by outlining the area where the smallest larvae were caught, he established the spawning area of the European eel as between 22° and 30°N and between 48° and 65°W and determined that the American eel's spawning area was situated further to the west and south. He also found that spawning commences in early spring and lasts into the summer. Spawning probably occurs between 1,000 and 1,300 foot levels over a depth of 3 miles. The larvae grow rapidly during their first months, and in their first summer average ca. 25 mm long. By their second summer the larvae have reached an average length of 50-55 mm and are located in the central Atlantic, having drifted east with favorable currents. By their third summer they arrive off the coastal banks of Europe and are fully-grown larvae (ca. 75 mm long). During the next autumn and winter, they undergo the metamorphosis which gives them their eel-like (elver) shape at which time they begin making their way up rivers and streams. Thus the average age of elvers in the spring is three years. Males apparently remain in brackish lagoons and estuaries while females move further upstream into fresh water. The length of time the adults spend in inshore and fresh waters varies from 5 to 20 years, during which time they are in the yellow or yellow-green stage. When they reach the migratory stage, the eels cease feeding, the digestive system degenerates, the color changes to a metallic sheen with a black back, the pectorals become black and pointed, the eye increases in size and the down-stream migration begins, ending with the last great journey-across the Atlantic to the spawning grounds. After spawning, the adult eels presumably die, for no spent eels have ever been seen, and large eels are never known to run upstream from the ocean.

Parenthetically, Schmidt came to some conclusions regarding American eel larvae. No American eel larvae were caught east of 50°W and Schmidt concluded the spawning area was further to the west than that of the European eel. Since American eel larvae were consistently larger than European, Schmidt concluded that the American eel spawns earlier and grows faster. In his collections, 7 to 8 mm larvae were taken in February, 20 to 25 mm larvae in April, 30 to 35 mm larvae in June, 40 mm larvae in July, 50 to 55 mm larvae in September, and by the end of the first year, full-grown larvae were 60 to 65 mm (smaller than fully-grown European eel larvae). Schmidt further showed that American eel larvae metamorphose in the winter (after one year's development) and in the spring (at an average size of 57 mm) the elvers begin moving into North American tidal marshes, bays, and streams.

These conclusions helped Schmidt to explain the "Bermuda problem": Although only the American eel was found in Bermuda as adults, larvae of the European eel predominated in surrounding waters. But the European larvae at this point were only one-third of the way through development and thus continued drifting by. American eels at this point (though fewer in numbers) had completed development and were actively seeking fresh waters, thus the establishment of American eels in Bermuda.

C. Tucker's "New Solution" - Tucker (1959) showed clearly that many of Schmidt's assumptions about the spawning areas were based on circumstantial evidence. This was particularly true in the case of the American eel. Tucker's new theory may be summarized in three parts:

1 - American and European eels are not distinct species but merely ecophenotypes of A. anguilla, their distinguishing characters being determined by differences in the temperatures of the spawning areas, specifically, during the ascent of eggs from point of spawning to the surface.

2 - European eels do not (and need not) succeed in returning to the ancestral spawning area, but perish in their own continental waters.

3 - Populations of so-called "European" eels are entirely maintained by reinforcements of larvae of "American" parentage.

As evidence, Tucker offered the following facts:

1 - On its descent to the sea, the American eel, although having undergone some morphological changes, is in relatively good condition, whereas the European eel has degenerated physically, is unable to feed, and is probably enfeebled to the point of inability to make a 3,500-mile journey.

2 - Regarding migration "guidance", there can be only one inherited pattern of migration behavior - thus behavior which enables fish to reach the Sargasso Sea from the Baltic would not help a fish leaving the Black Sea.

3 - The lack of eel sightings in the Atlantic Ocean and the complicated currents between the various European eel locations and the Sargasso Sea argue against the return of the European eel. American eels, on the other hand,

may take advantage of coastal and slope water which flow southwest and south. (Tucker ignored the fact that American eels had also not been sighted in the open ocean-MPF).

4 - Eggs ascending from the southern portion of Schmidt's proposed spawning area, meet an abrupt 4°C rise in temperature thus effectively ending segmentation in the embryo at 103 to 111 somites (typifying A. rostrata). Eggs ascending from the northern limit meet a gradual change to the surface, thus somite development continues to the genetically determined limit of 110 to 119 somites (typifying A. anguilla). Tucker used a hydrographic section from Atlantis stations 1208 to 1219 (April, 1932) to demonstrate the temperature structure in the spawning area. See Figure 4.

5 - The Atlantic Current (which runs through the spawning site) runs deeper and faster at its periphery, thus "A. rostrata" larvae begin to be transported westward earlier and while at considerable depth. See Figure 4. The result of this shearing action would be a skewed distribution of larvae (Northeast to Southwest), as Schmidt found, with "A. rostrata" located at the Southwest end.

6 - "A. rostrata" larvae, in relatively higher ambient temperatures, have a high metabolic rate which is supported by high zooplankton concentrations along their route; hence they undergo a fast growth-rate and relatively short life. For "A. anguilla" larvae the converse is true.

7 - Schmidt based his spawning area for "A. rostrata" on the distribution of 15 mm larvae, which must be a month old (a moderate estimate). As they are in a current system which travels 10 to 20 miles per day, they must be 300 to 600 miles from the point of hatching and up to twice as far from the point of spawning. Thus the 15-mm contour (of Schmidt's "A. rostrata" larvae) encloses the surface, the oblique section, of a "solid cone of larvae of diminishing age, the truncated vertex (the spawning area) of which lies deeply embedded very much farther back in the current, practically due south of the "A. anguilla" area and contiguous with it.

8 - Regarding the conclusion that "A. rostrata" spawns in January-February, while "A. anguilla" spawns in February-March; against this must be weighed: A) fortunes of

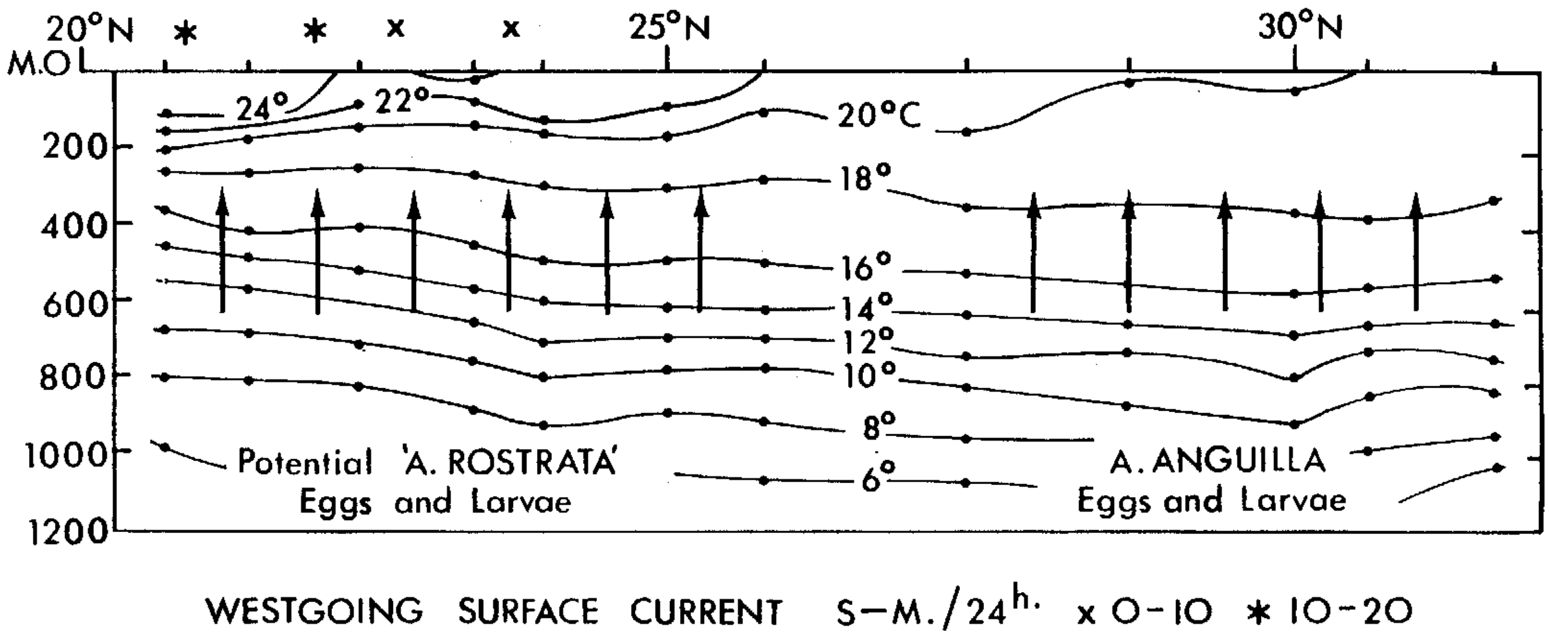

Figure 4. Hydorgraphic section across Anguilla spawning area (Tucker, 1959).

collecting, B) lengths of overall journeys from various starting points, C) disparities in sexual maturation, D) velocities of currents at various possible migration depths, E) durations of spawning, periods and annual variations in all these, F) effects of temperatures on rates of hatching and early development and rates of ascent of larvae over different portions of the spawning area.

D. Rebuttals to Tucker's theory - The publication of Tucker's "new solution" brought an immediate response from critics (D'Ancona, 1959; Deelder, 1960; Jones, 1959) mainly consisting of objections to minor details included in Tucker's paper. In 1963, Bruun published a lengthy and well-substantiated rebuttal to Tucker's theory in which he supported, step-by-step, most of Schmidt's findings and at the same time questioned the validity of many of Tucker's conclusions.

Bruun's rebuttal may best be presented by listing the essential points:

1) Tucker overlooked the population of European eels in the Azores. These eels are only 2000 miles from the Sargasso Sea (comparable to the distance from New England and Eastern Canada) thus not all European eels face a 3,500-mile journey.

2) One young American eel has been found in Europe (Northern Spain) thus casting doubt on the differential development theory. Not enough eels from the Azores have been examined but it is possible that American eels (as elvers) reach there more often than suspected. (See also E, New Information, Item 5).

3) There is not a lack of eel sightings in the open Atlantic, one having been retrieved from the stomach of a sperm whale near the Azores. Although this is only one record, and it is suspect of local provenance, it is nevertheless proof of a ripening eel occurring in the open ocean.

4) *Anguilla anguilla* and *A. rostrata* are distinct species and differ in many respects other than vertebral number. The most important character difference is in the dentition but differences also occur in pectoral ray counts, branchiostegal ray counts and several body proportions.

5) Tucker states, "There can be only one inherited pattern of migration behavior", and assumes that both American and European eels show positive reactions to high temperatures. He then disregards the fact that the American eel, in order to take advantage of the deep southerly current under the Gulf Stream, must descend to abyssal depths with very low temperatures.

6) Contrary to Tucker's statements, European eels on their descent to the sea (in the "silver eel" phase) are not physically degenerate, nor is there any sign of dehydration or demineralization in the female. Thus there is no reason to assume that only the American eel female is capable of the journey to the Sargasso Sea.

7) Bruun showed that temperature ("variations of the environment") had less of an effect on establishment of vertebral numbers within the genus Anguilla than in single species of other groups (using Zoarces viviparus and Salmo spp. as examples). This casts some doubt on Tucker's "Eco-phenotypes" theory.

E. New information

1. Wenner (1973) reported on eleven maturing American eels caught in the open ocean southeast of Cape Cod, east of Assateague Island, and southeast of Chesapeake Bay. All were in the "silver" phase of development. These specimens represent the first records of adult A. rostrata in offshore waters.

2. Miles (1968) captured American eels on their downriver spawning migration and analyzed their orientation in a circular tank with time-lapse film. All eels oriented southward with or without a view of the sky, provided they were subject to a diel rhythm of light-dark. Thus, Miles concluded the American eel is capable of noncelestial orientation. Miles noted that similar tests performed in England on European eels showed that the latter did not show any orientation.

3. Migrating adult eels may use ocean currents as orientation cues but in order to do this they must be able to determine the direction of water movement. In the absence of external, stationary reference points, the eel may use geoelectric fields, generated at right angles to direction

of water movement. Rommel and Stasko (1973) showed that eels could detect electric fields as weak as those associated with ocean currents. They also found that the eels responded to fields across the body, but not to fields along the long axis of water currents, and this ability may enable the eel to navigate in the open ocean. These same authors (Rommel and Stasko, 1973) also introduced migrating adult eels equipped with ultrasonic transmitters into Passamaquoddy Bay, New Brunswick during the autumn. The eels swam in an undulating pattern, made frequent dives from surface to bottom, and were active both day and night. The authors speculate that if such behavior is normal for eels migrating away from an estuary, it may be a mechanism for sampling the water-current-generated electric fields which are strongest near surface and near bottom.

4. Vladykov (1973) reported on the capture of three American eels displaying macrophthalmia. This unusual enlarging of the eyes is one characteristic of downstream migration and sexual maturation in the European eel but the phenomenon had not been observed in American eels before Vladykov's records.

5. Recently, Boëtius (1976) reported on the capture of several A. rostrata elvers included in a large sample of A. anguilla elvers at two Danish localities. American eel larvae are thus shown to be able to survive a transatlantic journey. The author speculates that practically none of the larvae (of either species) from the overlapping spawning zones succeed in reaching their respective continental destinies and that the few A. rostrata elvers ascending in Europe grow and migrate to sea with adult A. anguilla, thus contributing to a small process of hybridization in the "European" spawning area. In Boëtius' A. rostrata material, elvers with 110 vertebrae dominate. This phenomenon could possibly be due to the presence of hybrids with intermediate vertebrae numbers.

6. In 1964, Vladykov published a synopsis of knowledge regarding American eel spawning, including an analysis of Schmidt's research. Vladykov concluded this synopsis with six unanswered questions: a) Where in the western North Atlantic is the true spawning area of Anguilla rostrata? b) What are the conditions of the spawning area, such as the depths and temperatures? c) Do the males and females of the American eel undertake seaward

migration at different seasons? d) At what depths and at what temperatures do the American eels swim in the sea during the spawning migration? e) Do they always follow the same route? f) How do the leptocephali and elvers of A. rostrata avoid the Gulf Stream in order to reach the North American continent?

3.2 Pre-Adult Phase

3.2.1 Embryonic Phase

Unknown. The eggs identified as A. rostrata by Fish (1927) were probably those of another species of Apodes. Fish based her identification solely on coincidence of myomere number between her embryo and larval Leptocephalus grassii Eigenmann and Kennedy (=A. rostrata). Most authors have subsequently discounted her identification and Eldred (1968b) showed that Fish's eggs were actually those of the pygmy moray eel (Anarchia yoshiae).

3.2.2 Larval Phase

Eigenmann and Kennedy (1902) described larval Anguilla rostrata as Leptocephalus grassii. Their verbatim description and illustration follow (Figure 5):

"Leptocephalus grassii, sp. nov. = Anguilla chrysypa. Figures 1, 1a, 1b.

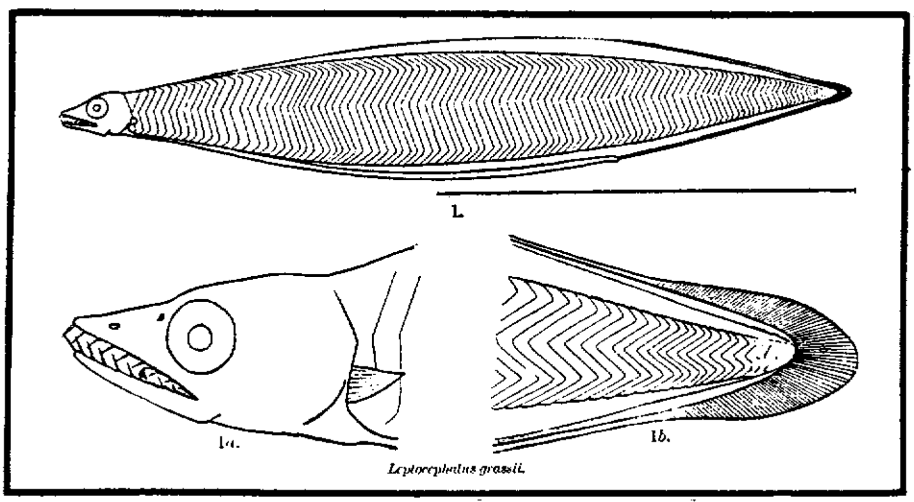

Figure 5. Earliest description of Anguilla rostrata leptocephalus (Figures 1, 1a, 1b in Eigenmann and Kennedy, 1902).

"One specimen 47 mm long, Albatross station 2103. One 49 mm long, Albatross lat. 38°25'N, 72°40'W.

"This species is distinguished by its broad well-developed vertical fins, deep and robust body, and absence of all pigment. Body lanceolate, sharp at both ends, deepest at the middle; its depth 5.66 in the length; dorsal beginning about 8 segments in front of anus, its rays becoming gradually longer to the caudal, whose rays are about 1 m. (sic) long; anal similar to the dorsal; pectoral well developed; head sharply conical, upper and lower profile equally slanting, eye large, 1.33 in snout, 4 in head; no pigment cells; segments 65 + 40 and 68 + 40.

"This species very closely resembles *Leptocephalus breviceps*, which Grassi has shown to be the young of the European eel. The segments of the European eel are given as 116. The vertebrae of seven young eels taken at Woods Hole during the summer of 1900 range from 106 to 110, as follows: 35 + 71, 35 + 72, 36 + 71, 36 + 71, 36 + 73, 36 + 74, 42 + 65. This number agrees with the number of segments in *L. grassii*.

"The close similarity of this species to *Leptocephalus breviceps*, the absence of color, the structure of the caudal, and the difference of this species from *breviceps* in just that character, viz, number of vertebrae, in which the American eel differs from the European eel, make it quite certain that the present species is the larva of the American eel.

"We take pleasure in associating the name of Professor Grassi with the larva of the American eel."

The youngest stages of *A. rostrata* larvae are found in the area of the Sargasso Sea where they co-exist with *A. anguilla* larvae. West of 62°W and south of 24°N, *A. rostrata* larvae predominate over *A. anguilla*. As the two species drift north in currents, *A. rostrata* tends to be carried closer to the North American mainland while *A. anguilla* is carried northeast by the Gulf Stream. No *A. rostrata* larvae have been found east of 50°W. Hatching probably occurs during February and larval growth occupies about a year (3 years for *A. anguilla*). Sizes of larvae increase as follows: end of February: 7-8 mm; April: 22 mm; June: 32 mm;

July: 40 mm; September: 50-55 mm; December-January: 60-65 mm. At the end of the year metamorphosis takes place during which the leptocephalus form is replaced by the glass eel stage. Metamorphosis does not involve as much shrinkage as is the case with congrid eels (see Figure 6).

Eldred (1968a) reported on two larvae caught in the Florida Straits (the only A. rostrata larvae caught after seven years' plankton collecting around Florida). Smith (1968) found larvae abundant from April to August in the Florida Straits and area between the Bahamas and Bermuda. Tåning (1938) reported A. rostrata larvae occurring only between 300 and 1200 fathoms near Bermuda. Vladykov and March (1975) reported the capture of 790 leptocephali of A. rostrata, 12 to 69 mm and 433 leptocephali of A. anguilla 14 to 79 mm, mostly from extensive sampling in 1962, 1964, 1965 and 1968. No leptocephali of either species were taken in April or July. The greatest abundance was in June, August and September. The smallest A. rostrata leptocephali (less than 20 mm) were taken in March and June. Vladykov and March (1975) point out that Smith (1968) found two small larvae (17 and 22 mm) in August and conclude that A. rostrata spawns from February to August.

There have been two A. rostrata leptocephali reported from the Gulf of Mexico and Yucatan Straits (Eldred, 1971). The Yucatan specimen was 45.5 mm TL and was caught in July, which compares well with the size and date information supplied by Smith (1968) for the Florida East Coast. The Gulf specimen was metamorphosing (59.5 mm TL) and was caught in October, which compares well with Schmidt's (1925) findings for the western Atlantic.

No leptocephali have been caught in the Gulf of Maine. By the time larvae reach the area they have undergone metamorphosis.

Hulet et al. (1972) studied the physiology of A. rostrata leptocephali and found that water contributed 90% of the body weight and protein content was low. These facts suggest slow tissue maturation. These authors concluded that a large portion of the leptocephalus body is an extracellular fluid compartment. This conclusion is reinforced by the body structure consisting of thin epidermal layers and striated muscle layers underlain by relatively acellular mucinous matrix. The leptocephalus is thus capable of minimal ionic regulation and only gradually develops the capacity to maintain composition

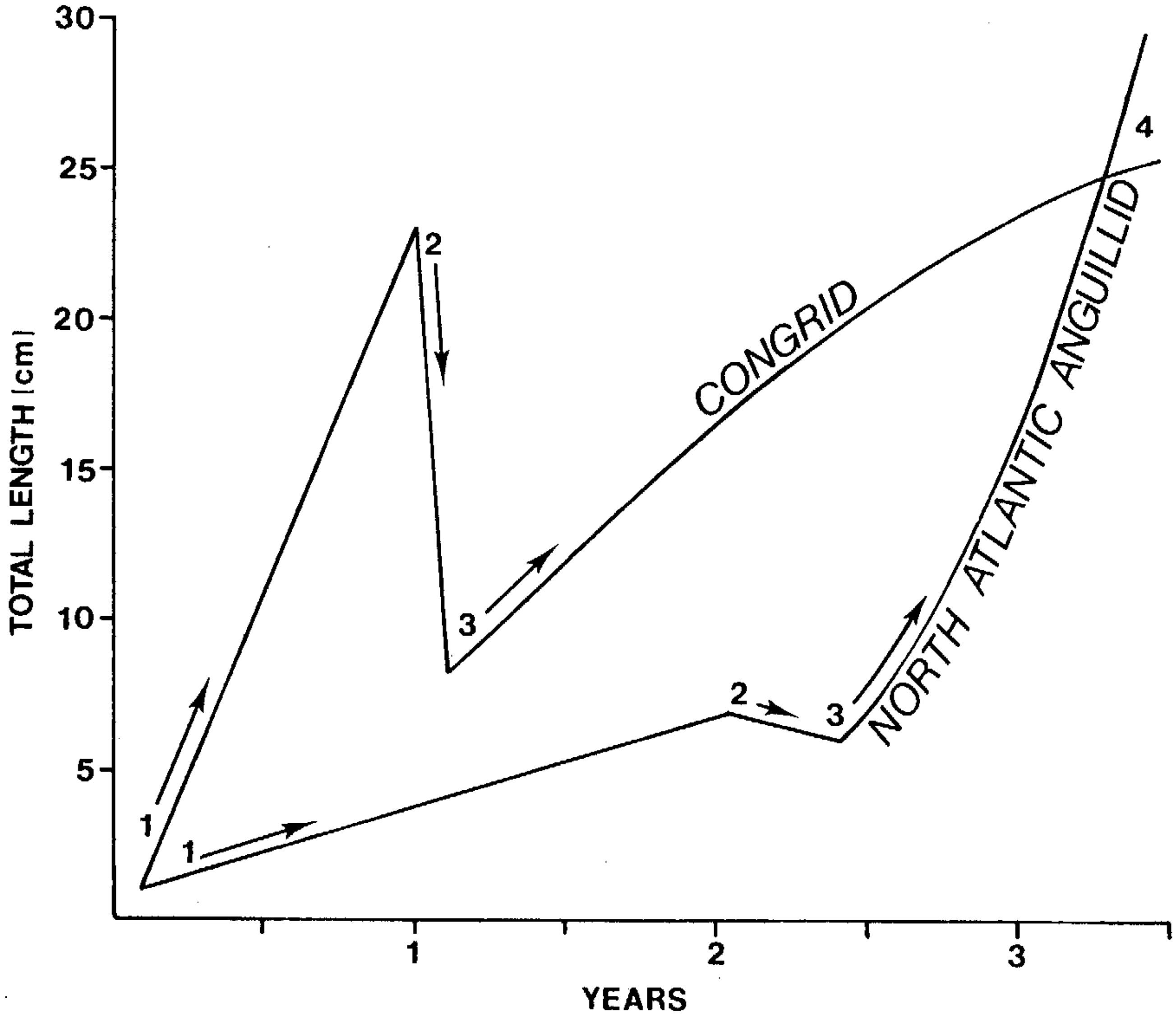

Figure 6. Relative growth rates in congrid eels and North Atlantic anguillid eels. 1: larval growth; 2: metamorphosis; 3: juvenile growth; 4: maturity (after Castle, 1968).

of electrolytes in its internal environment distinctly different from sea water. Hulet et al. (1972) state: "The leptocephalus is physiologically unique and differs from other larval teleosteans in its regulation of water and electrolyte balance - pelagic eel larvae are more in ionic equilibrium with sea water than other marine fishes (except myxini)."

As metamorphosis begins, leptocephali lose water with a resulting loss in body length and weight. Thus while a pound of large leptocephali consists of 300 individuals, a pound of glass eels consists of 3,000 individuals.

3.2.3 Elver Phase

After metamorphosis there is a reduction in length and weight of the body and an increase in thickness, the result being a cylindrical transparent body form. The larval teeth are lost and the eye darkens. Activity increases in the thyroid and pituitary glands. The configuration of the head and jaws changes and the digestive tract becomes more well-developed. Finally, as the glass eel approaches land, cutaneous pigmentation is deposited until the body is uniformly dark brown.

Metamorphosis apparently occurs in the winter and the elvers begin moving inshore in late winter, early spring. They have been collected at Indian River, Delaware as early as November, with a peak in February and March. They begin ascending the rivers around Washington, D. C. in April. Other catch records include: Raritan Bay, New Jersey in February-March; Long Island Sound in January; Rhode Island estuaries in January; Narragansett Bay, Rhode Island in mid-to-late April; Brown's Bank in April; off Nova Scotia in April; and in the Bay of Fundy during the summer. Occasional individuals may be kept at sea beyond the normal duration of larval life, such as the 50-mm specimen caught by Smith (1968) in April near the Bahamas. Vladykov (1966) showed that the total lengths of ascending elvers increase from south to north. Thus his samples from Florida average 52.0 mm while those from Nova Scotia average 58.6 mm. Smith (1968) reported elvers of about 57.0 mm ascending near Washington, D. C. Size at ascent thus increases with distance from the breeding area (see also 2.2.2).

Lengths of elvers caught in Little River, Massachusetts are shown in Table 2. Length frequencies of elvers caught in New Brunswick are shown in Figure 7. Growth

TABLE 2. Lengths of elvers caught in Little River, Massachusetts (after Schmidt, 1916).

Length (mm)	May 5, 1913 Number of Specimens	May 7, 1913 Number of Specimens
68		
67	2	
66		2
65	1	
64	2	5
63	10	8
62	16	29
61	18	52
60	31	74
59	45	85
58	65	119
57	76	156
56	73	145
55	50	108
54	28	61
53	12	65
52	11	15
51	2	3
50	1	
49		1
48		1
Total Number of Specimens	443	929
Average Length (mm)	57.3	56.9

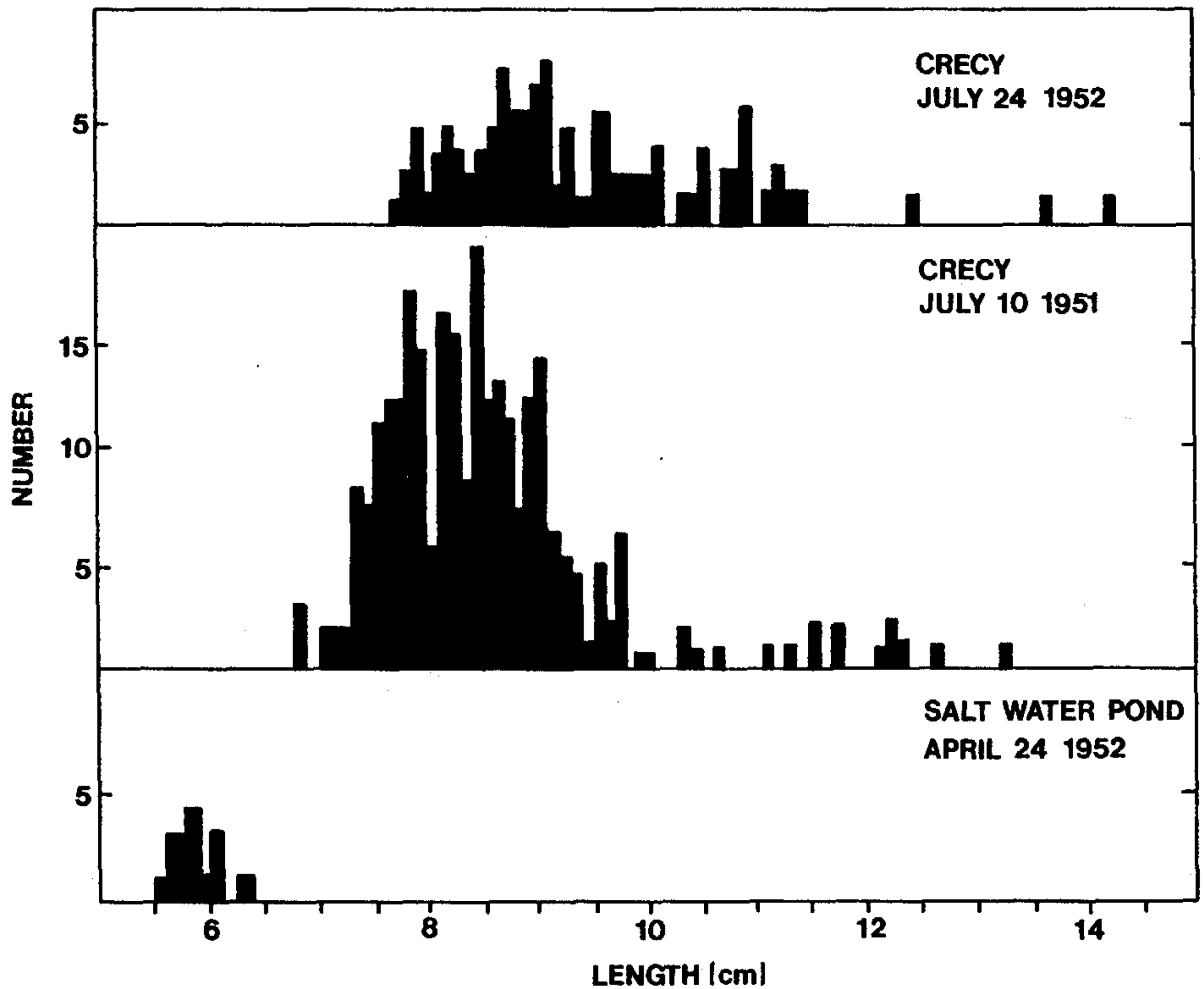

Figure 7. Length frequencies among elvers from a saltwater pond and the outlet of Crecy Lake, New Brunswick (after Smith and Saunders, 1955).

during the first year in fresh water is slow. From an average length of 2½" when the elvers first enter fresh water, the length increases only to 5" by the following spring (Bigelow and Schroeder, 1953).

Small numbers of elvers regularly arrive in estuaries several months before the main migration in spring and summer. These early arrivals may be the result of the earliest spawning or they may have been pushed northward and inland by local currents which separate them from the main body of drifting leptocephali.

Elvers moving in from the sea are at first repelled by fresh water, later attracted to it. As a result they "lag" in transition areas between fresh water and sea. Elvers orient more strongly toward fresh water effluent when the discharge is strongest. During the "lag" period, they are active at night while during the day they burrow or rest in deep water (Deelder, 1958). They are thus carried upstream during the night flood, and drift back down during ebb. But this behavior is not so much a response to tides as it is to light. Cruetzberg (1958) reported that elvers farther out to sea bury themselves during ebb and are carried toward land during flood tides.

Pacheco and Grant (1973) reported similar behavior patterns in Anguilla rostrata elvers at the mouth of the Indian River, Delaware.

Hiyama's (1953) experiments on Japanese elvers indicate they swim toward cooler water when temperatures are low (ca. 11°C) and toward warmer water when temperatures are high (ca. 14°C). This reverse thermotaxis may in part account for the winter forerunners which might be attracted to colder estuarine waters when the ocean, too, is cold. Jeffries (1960) found that American elvers may be less sensitive to low temperatures than European elvers. American elvers have been taken at -0.8°C while the lower limit for European elvers is 4.5°C.

As the upstream migration begins, males tend to stay in brackish water while females move into fresher water.

3.3 Adult Phase

3.3.1 Longevity

After entering fresh waters as elvers, eels commonly remain for 15 to 20 years before undertaking the spawning migration to sea. If eels are unable to leave a land-locked lake into which they are introduced, they will survive to an undetermined maximum age. Vladykov (1973) reported on the capture of three eels with unusually large eyes from Sherman Lake, Michigan, 35 to 40 years after their liberation as elvers.

The oldest Anguilla anguilla on record was one kept in the museum of Hälsingborg in Sweden for 88 years.

3.3.2 Hardiness

Much of what has been learned about European and Japanese eels probably also applies to the American eel. Hardiness is probably great provided eels are kept moist and supplied with oxygen. They may also be kept densely packed, a fact which is important commercially.

Boëtius and Boëtius (1967) kept a silver eel which was able to mature normally after a period of starvation of over 3 years.

Marcy (1973) reported on two American eels which survived the cooling system process at a nuclear plant. After three days, the two were found in the after canal after having been through elevated temperatures for 50 to 100 min.

3.3.3 Competitors

Competitors for spawning area are unknown. With regard to competition for shelter, eels tend to hide themselves in the bottom, in tubes, plant-masses etc. and no serious competition by other species for these habitats is known.

If all animals which share food items are to be regarded as competitors, then most species of fish which occur with eels must be included in this category. But it may be wrong to assume that because the same food is found in the stomachs of different species, competition must be taking place, for there may be an abundance of that food.

Eels are competitors and sometimes predators of trout, however, and when eel populations are reduced, the trout population generally increases.

3.3.4 Predators

For young eel stages, all fish which are able to swallow elvers may act as predators, although eels are more protected by their way of living. Grown eels are preyed upon by older eels and by birds (Sinha and Jones, 1967). Seymour (1974) reported that eels in shallow water over mudflats are captured by herring gulls and bald eagles. The gulls capture the eels with difficulty and carry them to dry land to swallow. Bald eagles catch eels stranded on flats by receding tide.

3.3.5 Parasites, Disease, Injuries and Abnormalities

A list of parasites known to affect American eels is shown in Table 3.

MacDonald and Hyatt (1973) observed gas bubbles (diagnostic of nitrogen supersaturation) on dead and dying American eels after they had gone through a turbine system at a hydroelectric dam.

3.4 Nutrition and Growth

3.4.1 Feeding

Feeding of the American eel has not been described but probably greatly resembles the habits of the European eel.

Eels, being nocturnal, feed mostly at night, when they search for food by swimming to and fro. Aquarium experiments and direct observations (e.g. Berry, 1935), however, reveal that they feed in daytime too.

Feeding takes place all over the area where eels occur and where food is available. In estuarine areas daily movements may occur to and from the foodstaples in the brackish area (see 3.5.1; Koendzinsj, 1958). In springtime, spawning areas of coarse fish may attract large numbers of eels, which feed upon the spawn.

The eel exhibits different foraging behavior, depending on circumstances. Small objects are taken without difficulty. A large object, e.g. a dead fish, which is too big to swallow, is attacked in the following way: the eel bites into the flesh and then tears off a mouthful by rotating around its long axis at high speed.

TABLE 3. Parasites reported in 33 eels from the Matamek River, Quebec (Hanek and Molnar, 1974).

Parasite	Body Area Affected	# of Eels
Protozoa		
Emeria anguillae	Intestine	2
Myxidium giardi	Liver, Intestine	22
Myxosobolus sp.	Intestine, Gallbladder	1
Platyhelminthes-Trematoda		
Crepidostomum brevivitellanum	Intestine	1
Platyhelminthes-Cestoda		
Bothriocephalus claviceps	Intestine	4
Protocephalus macrocephalus	Intestine	2
Platyhelminthes-Nematoda		
Metabronema salvelini	Intestine, Stomach	1
Coelenterata		
Haplonema aditum	Intestine	5
Arthropoda-Copepoda		
Eigasilus celestis	Gills	5

Buried eels catch food in a peculiar way, of which Berry (1935) gives a vivid description: "They lie buried in mud or gravel with only the tip of the snout down to the eyes projecting. The spot selected, in e.g. a river, is out of the main current, either in front of, or behind a large stone or other barrier. Any unwary creature of suitable size which passes within a few inches of this hidden danger, is seized with surprising suddenness and bolted at a gulp or swallowed gradually head first. To see an eel catapult two thirds of its length from its tunnel to seize its prey is only less remarkable than to watch it suddenly draw backwards out of sight; the flattened tail is evidently used as a sort of spring, but it is difficult to understand how they accomplish this feat."

Big eels which are not buried in the substratum presumably swim around for a while after having seized prey. Long-line fishermen cope with this habit by using special long cross-lines or by fishing exclusively for big eels on hot days, when eels are lazy, using special sized baits such as ruff or small perch.

At all times eels seem more dependent on scent than on sight for getting food. An imitation worm or other bait dangled in front of them produces little if any interest, but any object which has been placed for some time in a tin of worms causes immediate excitement. (cf. von Fritsch, 1941; Mohr, 1969).

3.4.2 Food

A list of species serving as food for the eel has to include virtually the whole aquatic fauna (freshwater as well as marine) occurring in the eel's area. The food list might easily be augmented with animals living out of water, e.g. worms, while fresh meat is taken as well. With eels in captivity, unlike most other creatures, there is no difficulty in inducing them to feed, and they will thrive on practically any diet.

The kind of food taken is greatly influenced by size and availability (Schiemenz, 1910). Thus, big eels are more inclined to prey on fish they can swallow than small eels, and as eels are mainly bottom dwellers they prey more on the bottom fauna. Exceptions are known, and plankton may be taken when occurring in great masses (Schiemenz, 1910). Instances of fish too big to swallow being attacked and devoured gradually by eels are also known, particularly when they are caught in gill nets (Louth Neagh, Deelder, unpublished; Morrison, 1929).

Their voracity is amazing. In an aquarium, an eel of 30 cm consumed an average of 12 g, or about 25 earth worms, per day. Such an eel can consume a dozen worms each about 5 cm long in as many minutes, and after only a few hours will be ready for more (Berry, 1935).

Vladykov (1955) reports that in fresh water, eels feed on insects, worms, crayfish, crustaceans, frogs, and other fishes, while in salt water the elvers are planktivorous.

Wenner and Musick (1975) studied the food habits of estuarine eels. The stomach contents they found are listed in Table 4. Crustaceans, bivalves and polychaetes made up the greatest part of the diet, while fishes were of little importance. Two commercially important invertebrates, the blue crab and the soft clam, were significant items in the eel's diet.

Ogden (1970) examined the stomach contents of freshwater eels from streams in New Jersey. Smaller eels (less than 40 cm) fed heavily on the insect orders Ephemeroptera, Megaloptera and Trichoptera, while larger eels fed mostly on fishes and crustaceans. Most of the fish species eaten by eels were sluggish, bottom dwellers, with johnny darters found most frequently. Trout were never observed in eel stomachs.

3.4.3 Growth Rate

During their lifetime, eels pass through several phases of growth. From hatching to end of the first year, the leptocephali increase in length and weight. When they begin to metamorphose into glass eels, their bodies become shorter and narrower, resulting in a great loss of weight (due principally to a loss of water). The glass eels continue to decrease in size and weight from the time they reach the shore to the time of the onset of pigmentation (the elver stage).

From the time elvers acquire pigmentation, they begin to increase gradually in length and weight up to a maximum 15 lbs. The average female caught along the St. Lawrence River is 36" and 3½ lbs (range: 30" to 50" and 2 to 10 lbs).

All investigators agree that eels belonging to one year-class may show very different lengths and in one locale individuals of various age-groups may be the same size. "To judge an eel's age solely by its length, would be to risk an error of one to five years either way" (Bertin, 1956, p. 43).

TABLE 4. List of food items of estuarine American eels (from Wenner and Musick, 1975).

POLYCHAETA
- *Pectinaria gouldi*
- *Nereis succinea*
- Unidentified

OLIGOCHAETA
- Unidentified

PELECYPODA
- *Mya arenaria*
- *Macoma* sp.
- *Ensis directus*
- *Gemma gemma*
- *Mulinea lateralis*
- Unidentified

CRUSTACEA
- *Leptocheirus plumulosus*
- *Gammarus daiberi*
- *G. mucronatus*
- *Gammarus* sp.
- *Ampelisca verrilli*
- *Monoculodes edwardsi*
- Unidentified amphipod
- *Edotea triloba*
- *Cyathura polita*
- *Squilla empusa*
- *Balanus improvisus*
- *Ogyrides limicola*
- *Crangon septemspinosus*
- *Neopanope texana*
- *Eurypanopeus depressus*
- *Panopeus herbsti*
- Unidentified xanthid
- *Callinectes sapidus*
- Unidentified crustacea

INSECTA
- Plecoptera
- Trichoptera

PISCES
- *Alosa pseudoharengus*
- Unidentified fish

Figure 8 shows the length-frequency of eels of various age-groups (data from Smith and Saunders, 1955), while Figure 9 shows the same for eels migrating out of a New Brunswick lake.

Gray and Andrews (1971) studied length and weight in relation to age in migrating silver eels in Newfoundland. A summary of their findings is illustrated in Figure 10.

Ogden (1970) studied the relation between age and length in New Jersey freshwater eels. The largest eels (greater than 70 cm) ranged from 16 to 19 years, while the smallest eels (less than 20 cm) were 3 or 4 years (Figure 11).

Hurley (1972) studied eels in Lake Ontario and the Ottawa River. Hurley's findings regarding growth in length in relation to age are shown in Figure 12.

Aging of eels depends on a study of the scales or otoliths. Size rather than age probably determines when scales first appear. The onset of scalation is shown in Table 5. The study by Smith and Saunders (1955) is important enough to include herein two points from their summary verbatim:

"1. Scales were not found on young eels until they had attained lengths of from 16 to 20 centimeters. Elvers may reach lengths of at least 8 to 10 centimeters during their first year in fresh water. On this basis it has been judged that scales appeared during the third year in those fresh waters with which we were concerned. The eel continues to lay down scales as it grows and re-readings showed that scales with the maximum number of annual rings are not infrequently missed, giving rise to one of the more important sources of error in age determinations by the scale method.

2. Scale readings were made for representative samples of eels from two lakes treated with fish poisons and for eels comprising the runs from a third lake during one fall season. At least nine age-groups were represented, with scales in each of the three samples. Dominant age-groups among the poisoned eels were those with 2 and 3 annual rings on the scales and among the migrating fish those with 3 and 4; these represent eels in their fifth and sixth, and sixth and seventh years in fresh water, respectively. Being immature and undisturbed by spawning and senescence, the poisoned eels exhibited a uniform growth pattern, and length plotted against age approximated closely a straight

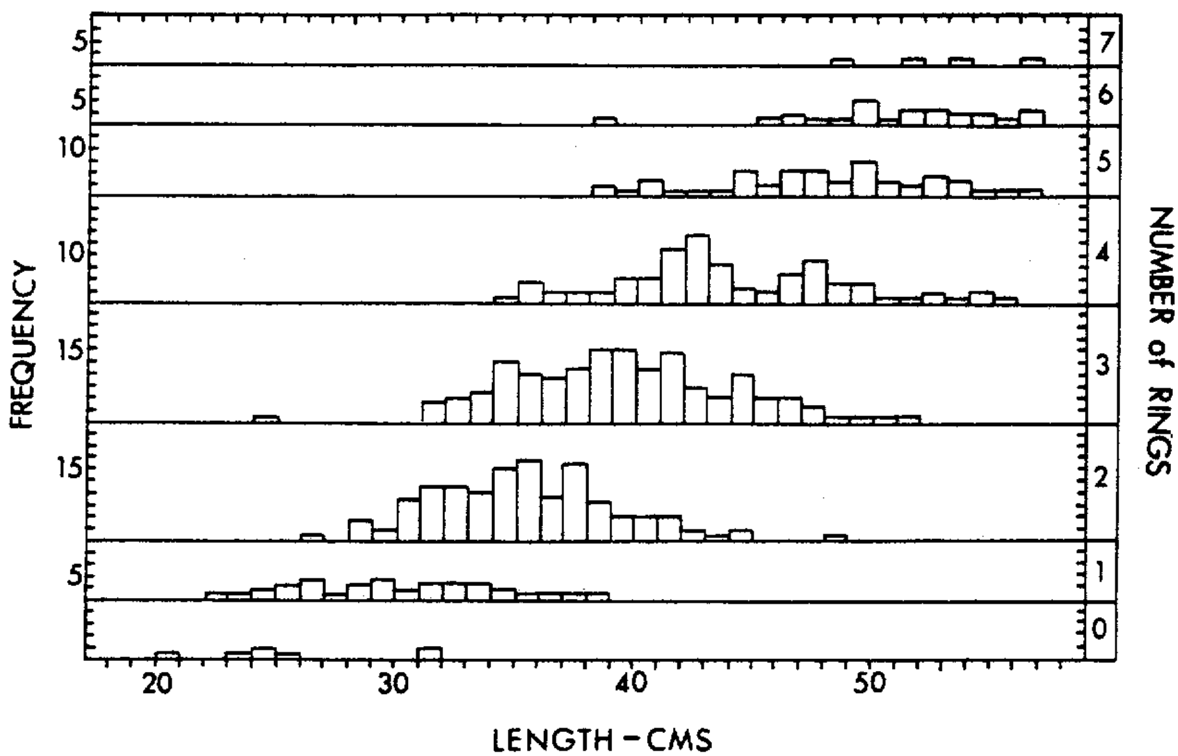

Figure 8. Length frequencies in various age-groups of eels from Bill's Lake, New Brunswick (after Smith and Saunders, 1955).

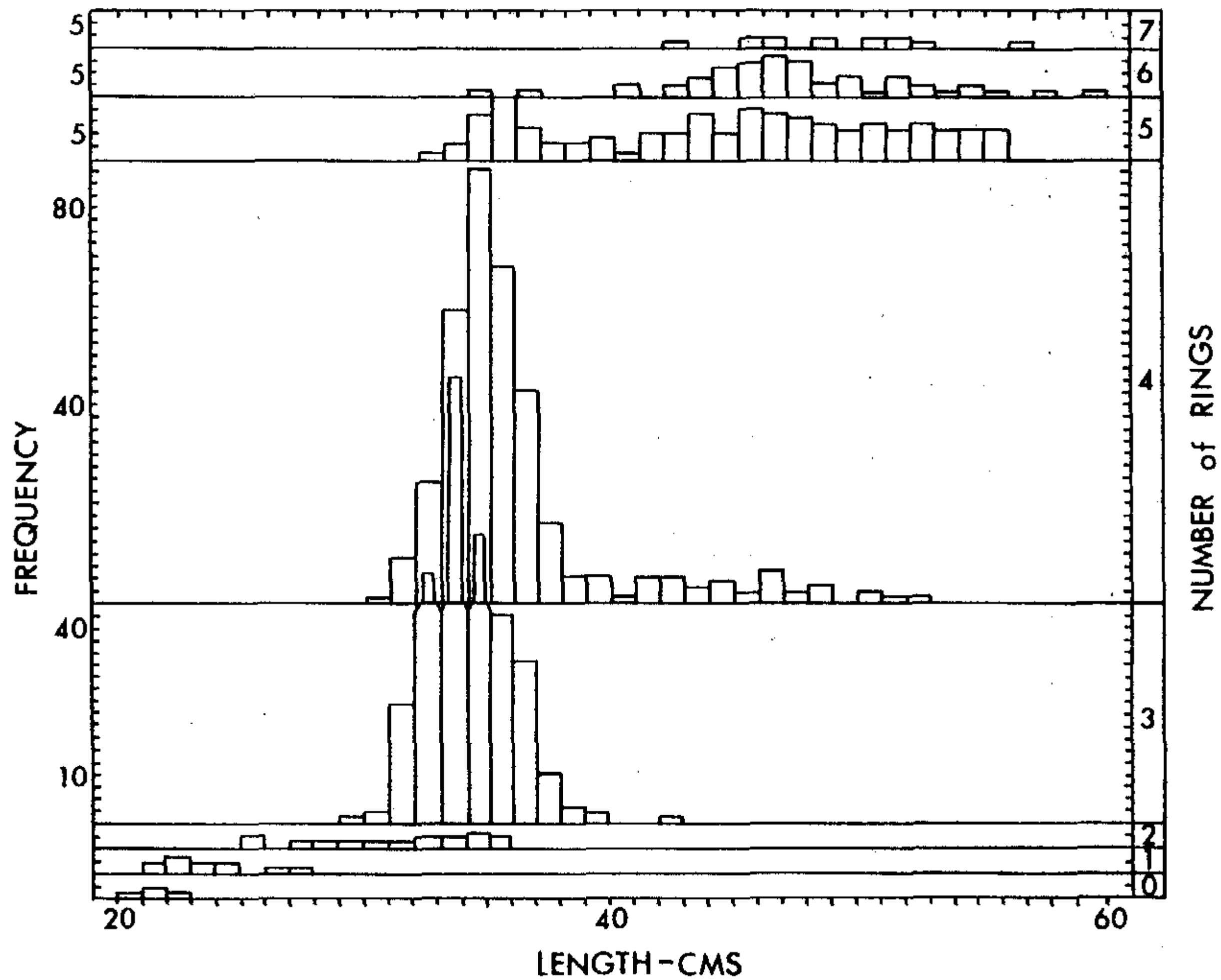

Figure 9. Length frequencies in various age-groups of eels running from Crecy Lake, New Brunswick (after Smith and Saunders, 1955).

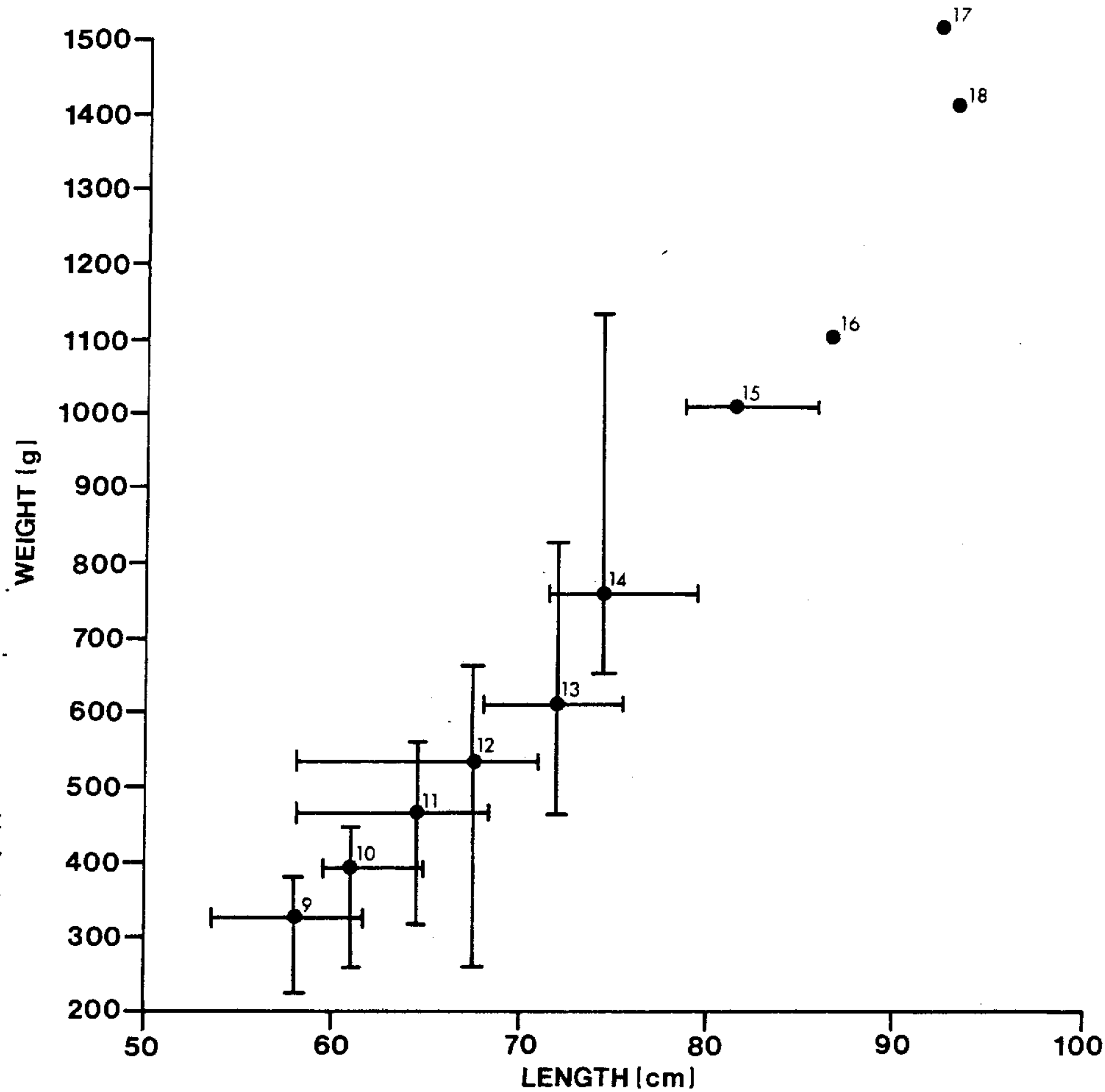

Figure 10. Analysis of length and weight in relation to age in migrating silver eels in Newfoundland. Whole numbers indicate ages 9 through 18 years. Lines indicate ranges in length and weight and intersect on the means. Ages 16 through 18 each represented by one fish (after Gray and Andrews, 1971).

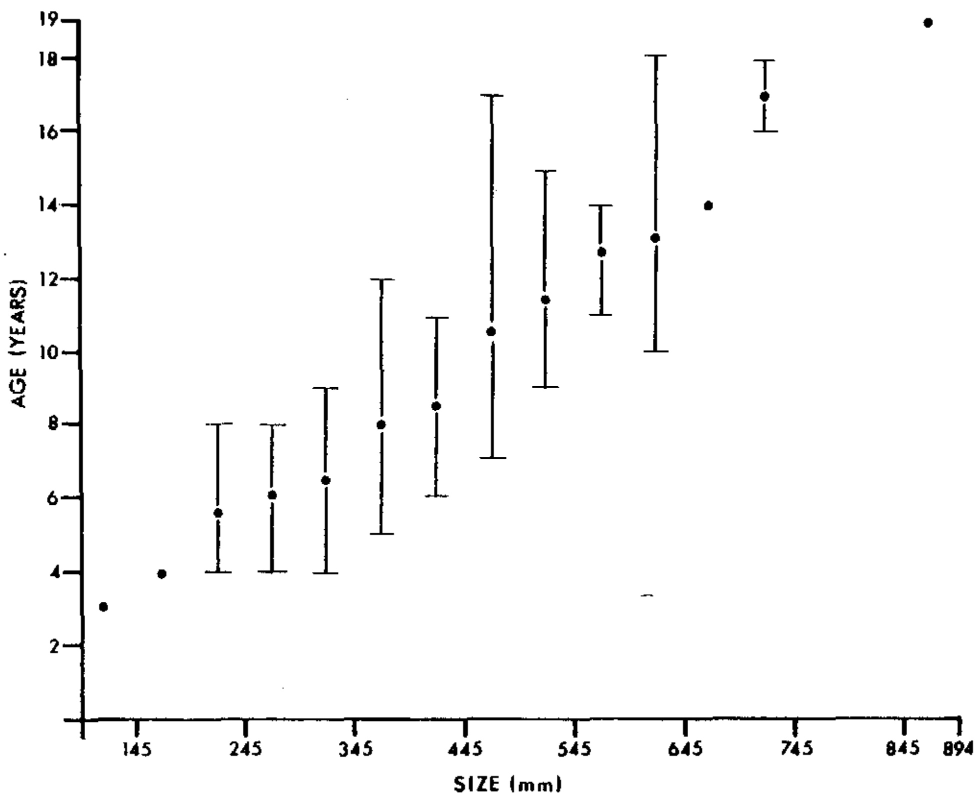

Figure 11. Ages, as determined from otolith analysis, of New Jersey freshwater eels in 14 size classes. Dots represent the mean ages while vertical lines represent the ranges (after Ogden, 1970).

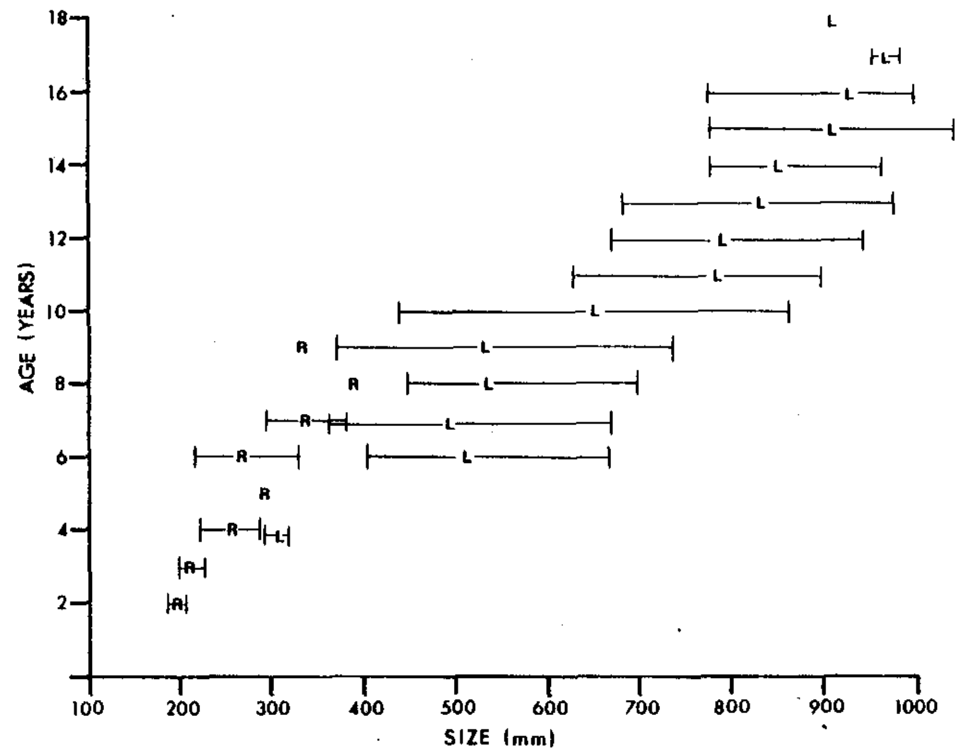

Figure 12. Growth in length in relation to age in eels from Ottawa River and Lake Ontario. Each R represents the mean size for age groups 2 through 9 Ottawa River eels. Each L represents the mean size for age groups 4 through 18 Lake Ontario eels. Horizontal lines represent the range in lengths (after Hurley, 1972).

TABLE 5. Relation between length of eels and appearance of scales based on eels from Tedford Lake. (A--absent; P--area partially covered; F--area fully covered) (from Smith and Saunders, 1955).

Length of Specimen (cm)	Anterior Area	Middle Area	Caudal Area
10.9	A	A	A
11.5	A	A	A
13.8	A	A	A
14.0	A	A	A
15.7	A	A	A
15.7	A	A	A
16.0	A	A	A
16.0	A	A	A
16.2	A	P	P
16.3	A	A	A
16.8	A	A	A
16.8	A	A	P
17.3	A	P	P
17.3	A	P	P
17.6	P	P	P
17.7	A	A	A
17.8	P	P	P
18.0	P	P	P
18.6	P	P	P
19.6	A	A	P
20.4	F	F	F
20.5	P	F	F
20.8	A	P	P
21.1	F	F	F
22.0	F	F	F
22.2	F	F	F

line. This situation did not hold in the sample of migrating eels, possibly because it was subjected to a selection inherent in the causes underlying the eel movements."

Liew (1974) demonstrated the validity of age determination from otoliths in American eels. Around a translucent nucleus formed in the sea, the otolith forms broad, opaque summer zones and narrow, translucent winter zones. In determining age, the winter zone was counted as an annual zone. Checks (or translucent supplementary zones) were also formed in elvers (after transplanting into a freshwater pond and before freshwater growth started) and were found also to be correlated with periods of starvation induced by low temperatures, sudden temperature changes, handling or starvation under laboratory conditions.

3.4.4 Blood Physiology

Detailed work has been done on erythrocytes and hemoglobin of the American eel. Eisler (1965) captured 12 eels off Sandy Hook, New Jersey with a mean length of 352 mm and computed a mean count of 202 erythrocytes per cu. mm/10^4 with a range of 175-243. The mean hemoglobin concentration was 10.86 gm/100 ml with a range of 7.74-14.79 gm/100 ml. Hall and Gray (1929) analyzed hemoglobin concentration in marine fish and found that more active fish had a higher concentration of hemoglobin. They found in eels the concentration to be lower than the "active" fish even though eels are a migratory species. Poluhowich (1972) separated the components of eel hemoglobin, and found the hemoglobin to be polymorphic consisting of two major and one or more minor components. The third component was an oxidized form of one of the single major components and constituted 24% of the total hemoglobin concentration. He further found that the individual components exhibited opposing oxygenation behavior in response to changes in the ionic environment. He suggested that the multiple hemoglobins served as an adaptive role by not allowing changes in the ambient temperatures to have a large effect upon the oxygen transport properties of the blood thereby maintaining a relatively constant oxygen affinity of the blood.

Geoghegan and Poluhowich (1974) determined through ion-exchange chromatography that guanosine triphosphate (GTP) and adenosine triphosphate (ATP) were the two major acid-soluble phosphates associated with erythrocytes of eels acclimated to fresh and salt water. In marine eels there was a high GTP:Hb ratio and low ATP:Hb ratio. The reverse was true for fresh water eels having a low GTP:Hb ratio and high ATP:Hb ratio. They discussed two hypotheses for the increased GTP to a major phosphate in eels. The first hypothesis stated that as the eel went thru salt and fresh water transitions, certain substances within the hemoglobin molecule may have become displaced, disfiguring the molecule to the point that the first phosphate no longer fit the shape of the hemoglobin molecule, thus increasing the affinity for oxygen. At this point, a second phosphate may have been activated that better fit the new hemoglobin molecule to maintain a balance of oxygen affinity. The second hypothesis stated that there were several hemoglobin molecules in the blood of eels that were functional during certain ionic conditions and nonfunctional during others. The change in the organic phosphate accompanying the change in environmental conditions may have been necessary to facilitate or initiate the functioning of certain hemoglobin molecules which were better suited for that particular environment.

Munroe and Poluhowich (1974) studied the ionic composition of the plasma and whole blood of marine and fresh water eels. They found that marine eels had a greater concentration of sodium, potassium and chloride in both the plasma and whole blood than fresh water eels. They felt this qualitative shift was dependent upon ambient salinity. The shift was particularly seen in regard to the chloride ion which they determined was in a passive equilibrium between the plasma and erythrocytes.

Hall and Gray (1929) studied the blood sugar of marine fish and found a higher concentration of blood sugar in "active" fish such as the eels.

Sindermann and Krantz (1968) described the complexities of the eel's isoagglutinin-isoantigen systems. Eels appear to have a number of antigens in various combinations, almost to the point where each individual fish has an antigenic identity.

<u>Corpuscles of stannius and calcium ion exchange</u> - Bailey and Fenwick (1975) studied ionic plasma calcium levels and blood pressure of eels. In one experiment, they found that angiotensen II caused an increase in plasma Ca^{2+} and blood pressure but had no effect on the total Ca or Mg.

Removing the corpuscles of stannius resulted in a decrease in plasma Ca 2^+ but had no effect on other parameters. In another experiment the corpuscles of stannius were removed from tap-water adapted eels which resulted in a hypercalcemic and hypotensive response. These responses did not occur when stanniectomized eels were placed in an acalcemic environment, but rather the eels displayed hypercalcemia (Fenwick, 1974b) relative to the same groups held in water containing dissolved Ca. They suggested that there was a mobile internal store or pool of Ca and a stanniectomy did not affect the mobilization or activity. They felt the corpuscles may attenuate the overall flux between the animal and the environment.

Excretory system - Schmidt-Nielsen and Renfro (1975) studied the urine formation of acclimated fresh water and salt water American eels and found that salt water eels maintained higher plasma and urine osmotic and ionic concentrations than fresh water eels. The glomerular filtration rate of salt water and fresh water eels showed no difference, but the urine flow rate in salt water eels was one-third that of fresh water eels. The primary urinary solubes in both types of eels were Mg and Cl. A tubular fluid secretion occurred in both but to a lesser degree in salt water eels. Schmidt-Nielsen and Renfro assumed that the water reabsorption was secondary to Mg reabsorption, and clearance data was used to evaluate all possible explanations for what appears to be fluid secretion. They found that furosenide caused diuresis in both groups apparently by inhibiting Mg reabsorption of the distal tubes but there was no apparent affect on the tubular fluid secretion. They hypothesized that the secretion may have a possible ion driving force involving either K, Ca, or Mg, any of which may be found in the proximal section and reabsorbed in the distal part of the nephron.

Fenwick (1974a) also studied the release in vitro of calcium from fried and defatted eel and rat bone fragments. He found that the rate of withdrawal of Ca in inorganic solvents from eel bone fragments, was greater than the rate for rat bone fragments. In eel plasma, eel bone fragments supported a higher plasma Ca concentration than in normal plasma in vivo. His results were consistent with the view that in normal eels, plasma is undersaturated with Ca in respect to the simple solubility of bone Ca. He further hypothesized that the simple solubility of Ca plays a greater role in maintaining a Ca homeostasis in fishes than in mammals.

Metabolism - Butler and Langford (1967) analyzed the electrolyte composition of eels. Two types of adrenalectomies were performed on immature yellow female eels. The first was a partial adrenalectomy where cortical tissue was removed or ligated in the right and left posterior cardinal veins and right anterior cardinal vein. A second operation (a mock adrenalectomy) was performed where the above areas were ligated but not removed. After three weeks, it was found that there was no significant difference in tissue electrolyte composition between the two groups. They hypothesized, then, that adrenocortical cells remaining *in situ* produced hormonal steroids which tended to keep osmoregulatory mechanisms functional.

4. POPULATION

4.1 Structure

4.1.1 Sex Composition

Sex composition may vary exceedingly, from nearly 100% males in estuaries to 100% females in rivers and tributaries.

4.1.2 Age Composition

No correlation is known between age composition and such items as depth, time of day, seasons, etc. Density of age groups is mainly determined by the size of the annual elver immigration or by stocking rates.

4.1.3 Size Composition

In enclosed areas, size composition is dependent on immigration and stocking. In unenclosed areas, in view of the eel's habit of migrating regularly, no consistent composition occurs. See also 3.4.3.

4.2 Abundance and Density

Estimates of the density of eel stocks are almost impossible due to the elusiveness of the fish. But estimates of the standing crop of eels in eight poisoned maritime lakes have been made (Smith and Saunders, 1955). The results of these studies are condensed in Table 6. (Trapping of migrating eels in five other lakes resulted in the estimates shown in Table 7). Table 8 shows the relative abundance of eels and other species in the eight lakes.

TABLE 6. Standing crops of eels in eight Maritime lakes (Smith and Saunders, 1955).

Lake	Area ha.	Area acres	Number of shore sections for count	Length of each section (metres)	Perimeter of lake (metres)	Mean number per section	Number estimated or counted in lake	No. per hectare	Number per acre	Estimated Weight kg./ha.	Estimated Weight lb./acre
Bill's, N.B.	4	10.5	total collection				2,246	529	214	79.3	70.8
Boar's Back, N.S.	23	56	6	85	2,815	8.8 ± 4.0	293	12	5	0.2	0.2
Cook, N.B.	20	50	5	40	4,250	4.2 ± 1.5	446	22	9	not determined	
Jesse, N.S.	18	45	4[1]	--	3,265	--	1,095	59	24	0.8	0.7
McCormick, N.S.	4	8	total collection				0	0	0	0	0
Potter's, N.B.	45	111	total collection				2,368	52	21	9.0	8.0
Tedford, N.S.	21	52	5	85	2,205	108.8 ± 15.9	2,822	133	54	2.6	2.3
Trefry's, N.S.	21	53	13	40	2,389	54.6 ± 29.2	3,262	153	62	2.9	2.6

[1]Eels from four unequal sections were counted: 87 on 120 m; 6 on 70 m; 5 on 90 m; 6 on 30 m.

TABLE 7. Number and weight of eels taken in traps (Smith and Saunders, 1955).

Lake	Year	Number	Total Weight lb.	Total Weight kg.	Per Unit Area lb./acre	Per Unit Area kg./ha.
Chamcook	Fall, 1935	210	99.2	50.0	0.1	0.1
Crecy	Fall, 1949	897	234.6	106.4	4.6	5.1
	Spring, 1950	90	17.0	7.7	0.3	0.4
	Fall, 1950	237	78.8	35.8	1.8	2.0
	Spring, 1951	55	11.6	5.3	0.2	0.3
	Fall, 1951	457	103.9	49.1	2.1	2.4
Gibson	Fall, 1945	203	219.1	99.4	2.1	2.4
	Fall, 1946	44	37.6	17.0	0.6	0.7
	Fall, 1947	15	8.8	4.0	0.1	0.2
	Spring, 1948	65	7.6	3.5	0.1	0.15
	Fall, 1948	5	8.1	3.6	0.1	0.1
	Fall, 1949	164	200.7	91.0	1.9	2.2
	Spring, 1950	74	17.0	7.7	0.2	0.2
	Fall, 1950	0	0	0	0	0
	Fall, 1951	191	264.2	119.9	2.5	2.85
Welch	Fall, 1946	21	8.4	3.8	0.1	0.2
	Fall, 1947	24	2.9	1.3	<0.1	<0.1
	Fall, 1948	45	74.7	33.9	1.7	1.9
Wheaton	Apr.-Dec., 1936	7	+	+	+	+
	Apr.-Dec., 1937	0	0	0	0	0
	Apr.-Dec., 1938	117	42.2	19.1	approx. 0.1	0.1

TABLE 8. Estimated standing crops of eels and other fish in Maritime lakes (Smith and Saunders, 1955).

Species of Fish	Bill's	Boar's Back	Cook	Jesse	McCormick	Potter's	Tedford	Trefry's
	NUMBER							
Alewife (*Alosa pseudoharengus*)	-	-	-	-	-	-	-	4,346
Smelt (*Osmerus mordax*)	-	-	-	-	-	-	-	4,424
Brook trout (*Salvelinus fontinalis*)	3	23	-	29	611	-	-	-
White sucker (*Catostomus commersoni*)	-	364	6,524	22	-	207	-	-
Lake chub (*Couesius plumbeus*)	661	-	-	-	-	-	-	-
Fallfish (*Semotilus corporalis*)	-	-	595	22	-	-	-	-
Creek chub (*Semotilus atromaculatus*)	-	-	-	-	-	-	-	-
Redbelly dace (*Chrosomus eos*)	-	-	6,991	-	-	-	-	-
Golden shiner (*Notemigonus crysoleucas*)	-	1,071	104,741	2,611	-	-	7,922	841
Common shiner (*Notropis cornutus*)	-	-	106	-	-	-	-	-
Blacknose shiner (*Notropis heterolepis*)	-	-	11,858	-	-	-	-	-
Brown bullhead (*Ameiurus nebulosus*)	-	2,114	-	1,179	-	8,642	1,691	776
Chain pickerel (*Esox niger*)	-	-	-	-	-	2,690	-	-
Banded killifish (*Fundulus diaphanus*)	-	1,275	4,803	10,098	-	-	42,621	8,738
White perch (*Morone americana*)	-	-	-	5,781	-	27	23,726	11,761
Yellow perch (*Perca flavescens*)	-	22,630	53,954	14,177	-	8,655	7,383	1,360
Pumkinseed (*Lepomis gibbosus*)	-	-	30,759	-	-	888	-	-
Smallmouth black bass (*Micropterus dolomieui*)	-	-	-	-	-	2,252	-	-
Ninespine stickleback (*Pungitius pungitius*)	b	-	1,998	11	-	-	52	9
American eel (*Anguilla rostrata*)	2,246	293	446	1,095	-	2,368	2,822	3,262
Total Number and Weight	2,910+	27,770	222,765	35,025	611	25,729	86,217	35,517
Percentage of Eels	77.2	1.1	0.2	3.1	0	9.2	3.3	9.2

a - No weights obtained.
b - *Pungitius* present but not enumerated.

TABLE 6. (continued)

Species of Fish	Bill's	Boar's Back	Jesse	McCormick	Potter's	Tedford	Trefry's
	WEIGHT IN POUNDS						
Alewife (*Alosa pseudoharengus*)	-	-	-	-	-	-	51.2
Smelt (*Osmerus mordax*)	-	-	-	-	-	-	21.7
Brook trout (*Salvelinus fontinalis*)	a	7.2	17.4	50.4	-	-	-
White sucker (*Catostomus commersoni*)	-	450.4	a	-	266.3	-	-
Lake chub (*Couesius plumbeus*)	8.4	-	-	-	-	-	-
Fallfish (*Semotilus corporalis*)	-	-	a	-	-	-	-
Creek chub (*Semotilus atromaculatus*)	-	-	-	-	-	-	-
Redbelly dace (*Chrosomus eos*)	-	-	-	-	-	-	-
Golden shiner (*Notemigonus crysoleucas*)	-	22.4	90.9	-	-	141.7	5.6
Common shiner (*Notropis cornutus*)	-	-	-	-	-	-	-
Blacknose shiner (*Notropis heterolepis*)	-	-	-	-	-	-	-
Brown bullhead (*Ameiurus nebulosus*)	-	238.0	230.0	-	229.1	285.6	77.0
Chain pickerel (*Esox niger*)	-	-	-	-	331.2	-	-
Banded killifish (*Fundulus diaphanus*)	-	9.7	70.3	-	-	303.4	69.5
White perch (*Morone americana*)	-	-	249.9	-	13.6	921.6	456.6
Yellow perch (*Perca flavescens*)	-	220.1	205.0	-	118.4	101.5	71.6
Pumpkinseed (*Lepomis gibbosus*)	-	-	-	-	79.0	-	-
Smallmouth black bass (*Micropterus dolomieui*)	-	-	-	-	347.2	-	-
Ninespine stickleback (*Pungitius pungitius*)	b	-	-	-	-	0.3	-
American eel (*Anguilla rostrata*)	745.4	12.6	29.5	-	887.8	117.9	140.3
Total Number and Weight	753.8	960.4	893.0	50.4	2,272.6	1,872.0	939.5
Percentage of Eels	98.9	1.3	3.3	0	39.9	6.3	14.9

a - No weights obtained.
b - *Pungitius* present but not enumerated.

4.3 Natality and Recruitment

Vladykov (1955) stated that female American eels produce from 10 to 20 million eggs and Eales (1968) suggested 15 to 20 million eggs. See also 3.1.5.

4.4 Mortality and Morbidity

No reliable data available.

4.5 Dynamics of Population

No information available.

4.6 The Population in the Community and the Ecosystem

The fish species composition of the eel's fresh water habitat was shown in Table 8.

5. EXPLOITATION

5.1 Fishing Equipment

American eels are captured with a variety of gear including the following: lift nets, drift nets, traps, weirs, otter trawl, hook and line, pound nets, fyke nets, spear, hand-line, eel pot, haul seine, gill-net stake, and hoe.

Of these gears, the trap accounts for the largest landings. The trap in common use consists of a mesh wire cylinder with an entrance made of cloth at one end and an interior funnel, of nearly the same configuration, inserted approximately half way through the cylinder. The interior funnel separates the trap into two compartments, and a cloth tail bag closed with draw strings is attached to the other end. It is untied to remove the trapped eels and replenish the bait supply in the rear compartment. Three styles of traps are shown in Figure 13. The traps must be worked every 6 to 8 hours because the eels are vigorous and will eventually find a way out or tear a hole in the trap in order to escape. Traps cost about $3.50 each. Captured eels are held and transported in burlap sacks and barrels packed in ice.

Recently, a fishery for elvers has begun. Captured elvers are shipped alive to Japan where they are raised to adulthood in that country's extensive pond fish culture. Topp and Raulerson (1973) described exploratory methods of capturing elvers in the

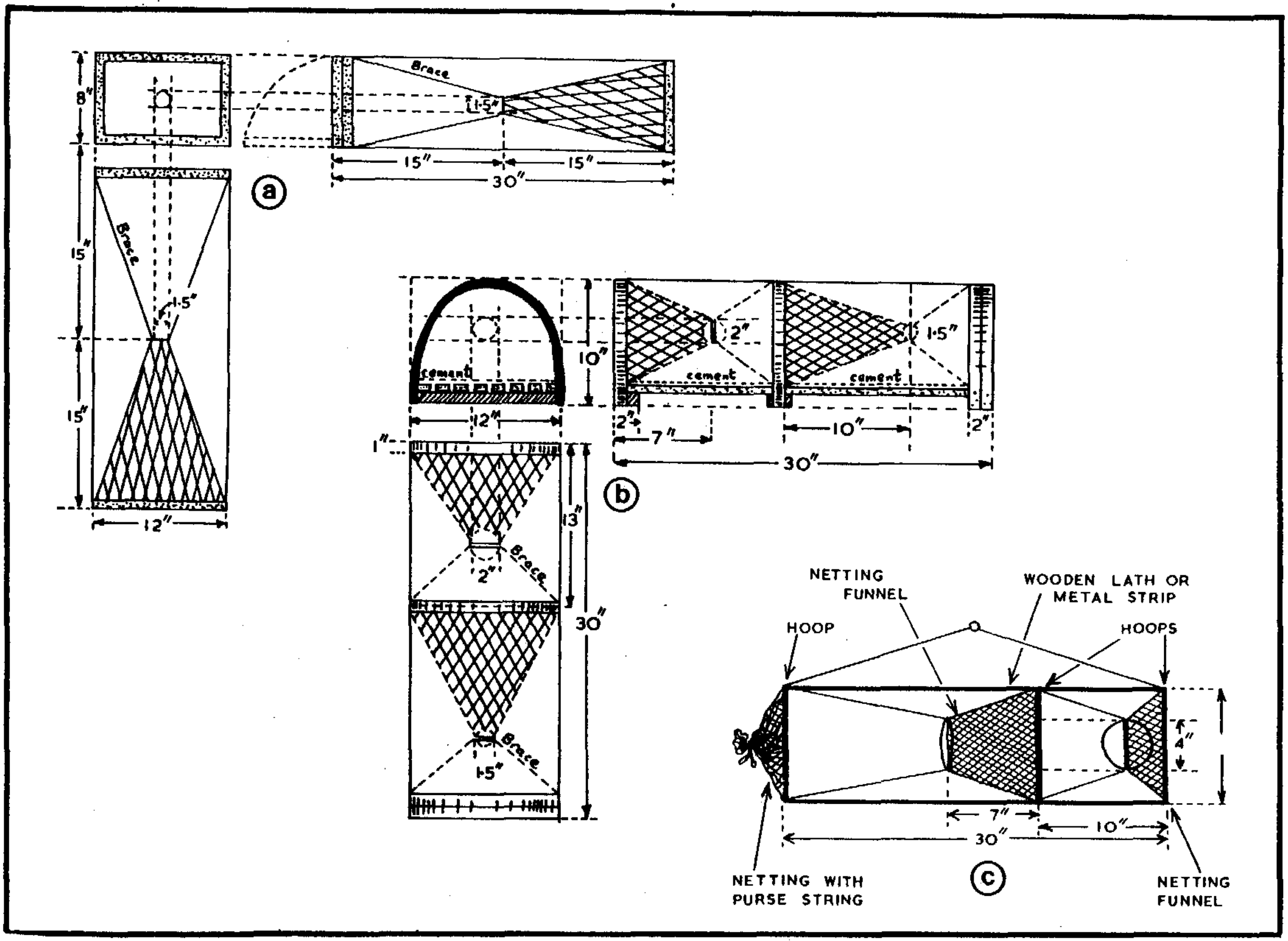

Figure 13. Three designs for lobster traps (after Eales, 1968). a: rectangular wire trap; b: semicylindrical wire trap; c: cylindrical wire trap.

St. John's River (Florida). These authors utilized 1) a trotline, 2) dip nets, and 3) a modified fyke net in their study. The trotline consisted of a long-line with finely branched weighted brushes at 10' intervals. Elvers become tangled in the brushes and are removed by hand. Dip-netting was done at the base of a dam, and resulted in 7 lbs of pigmented elvers per hour. The size of these elvers was 50/lb. The fyke net (Figure 14) with Coleman lantern suspended over the cod-end was used at night in depths of less than 2 m. The mouth was pointed downstream, thus only elvers moving actively upstream were subject to capture. This method resulted in the capture of 300-500 glass eels in the size range of 3,700/lb - although not a commercial quantity this method shows the most promise. Sheldon (1974) reported on similar trials in Maine during the elver run in May and June. He reported that up to 10 lb of elvers can be transported in a wooden box 2' x 2' x 10" and that the elvers should be wet but not covered with water, as elvers have the ability to absorp 3/5 of all required oxygen through their skin.

5.2 Fishing Areas

Eels are taken commercially from the gulf states and all along the Atlantic Coast of the United States into Canada where the catch is much higher. Canada's fishery is centered in Quebec where 93% of that country's eels are taken. Fishing in Quebec is restricted to fresh and brackish water, is seasonal, and most of the eels caught are exported to Europe. The principal fishing area in Canada is the St. Lawrence River where the weir is used mostly.

In the United States, the middle Atlantic region (New Jersey to Virginia) accounts for most of the eel landings (see section 5.4.3).

5.3 Fishing Seasons

The primary weir fishery takes place in late summer and fall when mature eels are actively migrating downstream toward the ocean. In lakes and upper reaches of rivers and streams in Canada there is a minor fishery for yellow eels in April and May. Most of the eels caught in these upstream areas are males, and all are smaller than the bronze eels caught in the fall run.

During the fall, migrating eels move in periods of darkness and the best catches are made at night. Reportedly, the best years are those when prevailing northeast winds cause a drop in water temperatures which forces eels closer to shore (Vladykov, 1955).

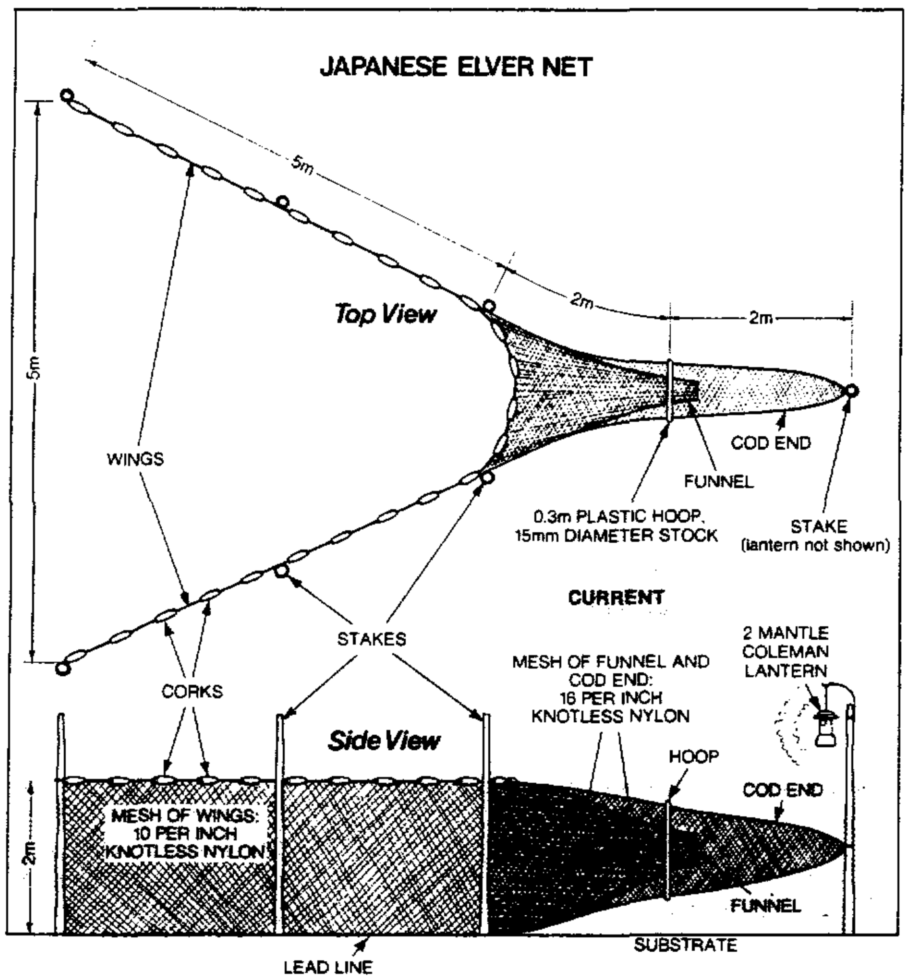

Figure 14. Details of fyke net used to capture elvers in the St. John's River, Florida (from Topp and Raulerson, 1973).

During winter, eels lie dormant in the mud and are captured with spears through the ice.

5.4 Fishing Operations and Results

Catch statistics are shown in Tables 9 through 12.

Table 9 summarizes the Canadian landings for 1961 through 1972.

Table 10 shows the United States landings by region for the years 1955 through 1973.

Table 11 shows the landings, separated by gear, for two regions combined (north and middle Atlantic states) for the representative years: 1950, 1955, 1960, 1965 and 1970.

Table 12 shows the catch reported by sportfishermen in brackish and salt water.

5.5 Miscellaneous Notes on Fishery

Eels are consumed in the United States as "blind robins" (strips of smoked eel flesh). See also section 10.

The European market has created an outlet for export of United States caught eels. The British market alone accounts for 800 tons per year in United States exports. Most exports to Britain are from December to March when live eels from Ireland are not available. When live eels are shipped, mortality is low (less than 2% in one shipment of 70 tons). If eels are not shipped live, they are first held in tanks for 5 days until digestive systems are purged. They are then graded by weight, packed in 25-lb boxes and quick frozen at -40°F. The frozen eels are then shipped in 15,000 lb lots. In 1973, 250,000 lbs were shipped to Europe from North Carolina alone.

The eel which is commercially important in North Carolina is the silver eel (mature, roe-bearing females which have turned from brown-black to silver-grey and are moving downstream in late summer, early fall to begin journey to the sea). The gear most widely used in North Carolina is the fyke net. Fifty fishermen are active in Albemarle Sound. The price in 1973 was 21-25¢/lb and in 1974 50¢/lb.

TABLE 9. Canadian landings of adult eels 1961-1972.

Year	Thousands of Metric Tons	Thousands of Dollars (U.S.)
1961	0.3	128
1962		
1963	0.4	175
1964	0.8	401
1965	0.8	529
1966	0.7	471
1967	0.8	419
1968	0.9	479
1969	1.1	569
1970	1.1	530
1971	1.2	724
1972	1.1	768

TABLE 10. U. S. landings of adult eels (in thousand of pounds) by region, 1955-1973

	North Atlantic Maine-New York	Middle Atlantic New Jersey-Virginia	South Atlantic North Carolina-Florida	Gulf W. Florida-Texas	Total
1955	341	977	43	5	1,366
1956	325	975	119	5	1,424
1957	278	883	80	0.4	1,230.4
1958	359	909	94	1	1,269
1959	315	894	100	-	1,309
1960	197	250	67	-	514
1961	328	420	58	-	806
1962	238	358	43	-	639
1963	319	610	40	-	969
1964	269	591	181	-	1,041
1965	374	1,062	115	12	1,563
1966	284	867	126	-	1,277
1967	289	1,174	130	4	1,597
1968	372	1,127	196	1	1,696
1969	307	1,366	112	6	1,791
1970	302	1,806	73	-	2,181
1971	384	1,788	118	5	2,295
1972	228	645	191	-	1,064
1973	192	349	297	-	838

U. S. value (in thousands of dollars) by region, 1955-1973

	North Atlantic Maine-New York	Middle Atlantic New Jersey-Virginia	South Atlantic North Carolina-Florida	Gulf W. Florida-Texas	Total
1955	67	126	3	0.4	196.4
1956	64	133	5	0.2	202.2
1957	54	113	3	-	170
1958	67	121	3	<1.0	192
1959	52	103	4	-	159
1960	27	34	3	-	64
1961	53	50	2	-	105
1962	38	46	2	-	86
1963	53	74	2	-	129
1964	49	51	9	-	109
1965	65	198	7	0.9	270.9
1966	60	143	8	-	211
1967	63	181	12	<1.0	257
1968	74	190	21	<1.0	286
1969	76	235	12	0.4	323.4
1970	62	364	8	-	434
1971	103	446	39	0.8	588.8
1972	92	150	27	-	269
1973	79	88	83	-	250

TABLE 11. North and Middle Atlantic (Maine-Virginia) landings of adult eels by gear, 1950, 55, 60, 65, and 70 in thousands of pounds.

Year	Lift Nets	Drift Nets	Traps	Wiers	Otter Trawl	Eel Pot	Haul Seine	Hook and Line	Pound Nets	Fyke Nets	Spear	Hand Line	Gill Net Stake	Hoe
1950	-	-	-	50.0	-	1,250.8	46.4	0.9	140.3	42.1	27.0	0.1	14.8	14.6
1955	9.1	0.2	23.6	20.3	0.3	858.8	37.1	0.5	176.7	98.1	90.7	0.1	2.3	-
1960	1.9	-	-	17.4	0.6	242.3	20.7	0.4	73.0	24.8	63.9	-	1.5	-
1965	-	52.1	-	12.6	0.2	966.1	32.9	-	216.7	67.7	87.3	0.3	-	-
1970	-	0.2	-	33.8	45.0	1,297.2	97.0	-	464.8	114.9	51.6	3.3	44.9	-
Total	11.0	52.5	23.6	134.1	46.1	4,615.2	234.1	1.8	1,071.5	347.6	320.5	3.8	63.5	14.6

TABLE 12. Sportfishermen's catch of adult eels from brackish waters for three years.

		All Regions	Maine to New York
1970	Number of eels	3,111,000	2,489,000
	Number of fishermen	363,000	227,000
	Weight of eels	4,123,000	3,166,000
1965	Number of eels	4,118,000	3,502,000
	Number of fishermen	326,000	278,000
	Weight of eels	4,073,000	3,293,000
1960	Number of eels	2,079,000	1,485,000
	Number of fishermen	99,000	159,000
	Weight of eels	2,170,000	1,490,000

When bait fishing is possible, the best bait is the fish which is running at the time (i.e. shad, herring). Other usable baits are fresh crab scraps, shrimp heads, etc. Although eels are both scavengers and predators, they apparently prefer fresh-killed food.

The Japanese eel culture has created a possible demand for American elvers. Elvers destined for shipment to Japan are held first in Los Angeles in an aerated tank where they are tested for disease problems, adaptability to pond culture and growth potential. Two recent prices paid in Japan for live elvers are 1971: $147.27/lb and 1973: $417.00/lb - (in the size range 3,000 to 3,700 glass eels/lb).

6. PROTECTION AND MANAGENENT

No instances are known of limitations or restrictions on fishing effort.

7. POND FISH CULTURE

In contrast to the active pond fish culture in Japan, there have been no commercially successful attempts to rear American eels to marketable sizes, however, some experimental rearing projects are underway.

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9. GLOSSARY

Black eels - freshwater stage, caught in the fall - Canadian fishermen's term.

Bronze eels - adult eels, fat and nearly mature, ready to migrate to sea for spawning - corresponds to "Black eels".

Catadromous migration - refers to run made by a freshwater fish into the sea to spawn.

Civelles - French slang for elvers.

Eco-phenotype - refers to closely-related species which are differentiated as embryos by differing environmental parameters.

Elver - small eel (2" to 3") after acquisition of pigment.

Freshwater eels - eels of the family Anguillidae, which spend most of their lives in freshwater - as opposed to marine eels belonging to any of 22 other families.

Glass eels - first oceanic stage after metamorphosis from leptocephalus - resemble adults but lack pigment.

Green eels - freshwater stage, caught in the summer - Canadian fishermen's term.

Leptocephalus - larval eels with transparent, willow leaf-shaped body, tiny head and prominent teeth.

Little eels - see "Whips".

Macropthalmia - enlargement of the eye in preparation for deep, oceanic migration.

Metamorphosis - process of bodily change undergone twice in the eel's life history: 1) the change from leptocephalus to elver which involves shrinkage, thickening and pigmentation of the body; 2) the preparation for the spawning migration which includes color change, skin-thickening, eye enlarging, fattening of the body, and degradation of the digestive system.

Migratory livery - refers to metallic sheen the eel acquires at the onset of maturity.

Myomeres - highly visible muscle segments along the body - the number of which (in the larva) corresponds to the number of vertebrae (in the adult).

Sargasso Sea - supposed center of eel spawning in the western North Atlantic - located east of the Bahamas and north of the West Indies.

Silver eels - European eel counterpart of the American bronze eel.

Whips - young eels captured in fresh water - Canadian term.

Yellow eels - the freshwater stage in the eel's life history - also called the "feeding stage" for it is only during this stage that they feed.

10. UTILIZATION AS FOOD

The following five recipes are included to show the diverse uses of eels as food.

1- Fried Eel

- 1 or 2 skinned and cleaned eels, about one and one-quarter pounds total weight.
- Milk to cover
- Salt and freshly ground pepper to taste
- 1/4 tsp. tabasco sauce
- 1/2 cup flour
- Oil for deep frying
- 1 large bunch parsley, optional
- Lemon wedges
- Tartar sauce (see recipe)

1. Cut the eels into three-inch lengths. Place in a mixing bowl and add milk to cover, salt, pepper and tabasco sauce.

2. Drain well. Dredge the eel pieces in flour seasoned with salt and pepper.

3. Heat the oil in a deep fryer or a skillet and when it is hot and almost smoking, add the eel pieces. Cook, stirring occasionally and turning the pieces, until golden brown and cooked through. Drain on paper toweling.

4. If used, trim off and discard the parsley stems. If the parsley is totally clean, do not wash it. If it is rinsed, it must be patted thoroughly dry. Add the parsley if it is used, and deep fry until crisp. It will darken as it cooks. Drain well and serve with the eel pieces. Serve with lemon wedges and tartar sauce.

   Yield: 6 or more servings.

Tartar Sauce

- 1 egg yolk
- 1 teaspoon wine vinegar
- 2 tablespoons prepared mustard, preferably Dijon or Dusseldorf
- A few drops of tabasco
- Salt and freshly ground pepper to taste
- 1 cup olive oil, preferably a light olive oil or a combination of olive oil and peanut, vegetable or corn oil
- Lemon juice to taste, optional
- 1/4 cup finely chopped parsley
- 3 tablespoons finely chopped green onion
- 1/4 cup finely chopped cornichons or sour pickles
- 3 tablespoons chopped drained capers

1. Place the yolk in a mixing bowl and add the vinegar, mustard, tabasco, salt and pepper to taste. Beat vigorously for a second or two with a wire whisk or electric beater.

2. Start adding the oil gradually beating continuously with the whisk or electric beater. Continue beating and adding oil until all of it is used. Add more salt to taste if necessary, and the lemon juice if desired.

3. Add the remaining ingredients and blend well.

Yield: about 1 1/2 cups.

2- Anguilles au vert
(Eels in green sauce)

-1 bunch watercress
-1 pound fresh spinach in bulk or one 10-ounce package fresh spinach in plastic bag
-1 cup loosely packed fresh parsley
-1/2 cup coarsely chopped green part of green onions
-2 fresh sage leaves or 1/2 tsp. dried sage
-2 sprigs fresh tarragon or 1/2 tsp. dried
-2 sprigs fresh savory or 1/2 tsp. dried
-1/2 cup loosely packed fresh dill, optional
-1 1/2 to 2 lbs. cleaned, skinned fresh eels, one or two eels, depending on size
-4 tablespoons butter
-Salt and freshly ground pepper to taste
-1 cup dry white wine
-6 egg yolks
-2 tablespoons lemon juice

1. Cut off and discard the tough bottoms of the watercress. Place the watercress leaves in container of an electric blender or food processor. It may be necessary to blend the watercress and other greens in one or two stages. In any event, start blending to a puree and continue until all the watercress is blended. Spoon and scrape into a saucepan.

2. Rinse and dry the spinach. Blend the spinach with the parsley, onions, sage, tarragon, savory and dill. Do this in one or two stages until all the greens are a fine puree. There should be about two cups. Add to the watercress in the saucepan.

3. Cut the eels into three-inch lengths. Melt the butter in a large skillet and add the eel pieces. Add salt and pepper to taste. Cook, turning often, when the eels change color, add the wine. Cover closely and simmer about 8 to 10 minutes. Spoon the eel pieces into a serving dish or mixing bowl. Let cool.

4. Add the yolks to the pureed greens and bring just to the boil, stirring constantly and vigorously with a wire whisk. Add lemon juice, salt and pepper to taste. Do not boil or the eggs will curdle. Immediately pour the sauce over the eel pieces. Let cool. Serve cold or at room temperature as an appetizer.

Yield: 6 to 10 servings.

3- Matelote of eel

- -2 cleaned, skinned eels, about $2^1/2$ lbs. total weight
- -1/4 cup plus $1^1/2$ tablespoons flour
- -Salt and freshly ground pepper to taste
- -3 tablespoons peanut, vegetable or corn oil
- -1 cup finely chopped onion
- -2 cloves garlic, chopped
- -3/4 cup finely diced carrots
- $-2^1/2$ cups dry red wine
- -1/2 teaspoon dried thyme or 2 sprigs fresh thyme
- -1 bay leaf
- -1/2 lb. mushrooms, preferably button mushrooms (if the mushrooms are large, slice them)
- $-3^1/2$ tablespoons butter
- -1/4 cup water
- -Juice of 1/2 lemon
- -1 tablespoon anchovy paste
- -6 to 8 slices French bread
- -1 clove garlic, peeled and cut in half
- -Boiled potatoes

1. Cut each of the eels into three-inch lengths. Dredge pieces in 1/4 cup flour, seasoned with salt and pepper.

2. Heat the oil in a heavy skillet and brown the eel pieces on all sides, turning often, about five minutes. Pour off the fat.

3. Scatter the onion, garlic and carrots between the eel pieces and cook about three minutes.

4. Add the wine, thyme, bay leaf and simmer about 10 minutes.

5. Meanwhile, combine the mushrooms in a saucepan with one tablespoon of the butter, water, lemon juice, salt and pepper to taste. Bring to a boil and simmer, stirring, about five minutes. Add the mushroom liquid to the eel. Set the mushrooms aside. Simmer the eels in the sauce five minutes longer.

6. Remove the eel pieces and keep warm.

7. Blend the remaining butter with the remaining flour. Add it bit by bit to the sauce, stirring. Strain the sauce through a sieve into another skillet and bring to a boil. Simmer about five minutes. Add the anchovy paste. Add the eel pieces and mushrooms.

8. Toast the French bread slices and rub on all sides with garlic. Serve the eel and mushrooms hot with the sauce poured over and the toast on top. Serve with boiled potatoes.

Yield: 6 to 8 servings.

4- Broiled Eel with Mustard Butter

The eel:

- 1 $1^{1}/4$ to $1^{1}/2$ pound skinned eel (cleaned weight)
- 3 tablespoons butter
- Salt and freshly ground pepper to taste

The mustard butter:

- 4 tablespoons butter at room temperature
- Juice of half a lemon
- 2 teaspoons imported mustard, preferably Dijon or Dusseldorf
- 3 tablespoons finely chopped parsley
- 1/4 teaspoon Worcestershire sauce
- Tabasco sauce to taste
- Salt and freshly ground pepper to taste

1. Preheat broiler to its highest heat.

2. Using a sharp knife, score the eel flesh top and bottom. To do this, make shallow one-eighth-inch parallel incisions at half-inch intervals. Cut the eels into six-inch lengths.

3. In a baking dish, gently melt the three tablespoons butter and add the eel pieces. Sprinkle with salt and pepper and turn the eel pieces in the butter until coated all over.

4. Place the dish of eel about four to six inches from the source of heat and broil about one and one-half to two minutes. Turn the pieces and cook about two or three minutes longer. Pour off all the fat that has accumulated in the pan. Serve immediately with the mustard butter.

5. To make the mustard butter, combine all the ingredients for the butter and beat rapidly with a whisk or wooden spoon until well blended. Spoon equal amounts of the unmelted butter over the fish sections and serve immediately.

Yield: 6 servings.

5- Fish Soup with Eel

- -5 tablespoons olive oil
- -2 tablespoons finely chopped onion
- -1 tablespoon coarsely chopped garlic
- -1 teaspoon leaf saffron, crumbled
- -1/4 cup flour
- -1 cup dry white wine
- -4 cups fish broth or use half-bottled clam broth and half water
- -3 1/2 cups canned Italian peeled tomatoes
- -1/2 teaspoon thyme or 2 sprigs fresh thyme
- -1 bay leaf
- -1/2 teaspoon anise or fennel seed
- -Salt and freshly ground pepper to taste
- -1 three-quarters-to-one pound eel, cleaned and skinned
- -1 1/2 to 2 pounds fresh fish such as cod, striped bass, sea bass and so on, preferably with bones
- -1 pint shucked oysters
- -1 1/2 pounds fresh scallops
- -1 cup heavy cream
- -1 to 2 tablespoons Pernod, Ricard or other anise-flavored liqueur
- -2 tablespoons chopped parsley

1. Heat three tablespoons of oil in a heavy skillet and add the onion and garlic. Cook briefly until onion is wilted. Add the saffron and sprinkle with flour. Add the wine and broth, stirring rapidly with a whisk.

2. When the mixture boils, add the tomatoes, thyme, bay leaf, anise seed, salt and pepper to taste. Bring to a boil and simmer 30 minutes.

3. Meanwhile, cut the eel into 12 sections of equal length. Set aside.

4. Cut the other fish into two-inch cubes.

5. Heat the remaining two tablespoons oil in a skillet and add the eel. Sprinkle with salt and pepper and cook, turning the pieces, about three minutes. Pour off the fat from the skillet.

6. Strain the sauce over the eel, pushing with the back of a wooden spoon to extract as much liquid as possible from the solids. Discard solids. Bring to a boil and simmer five minutes. Add the cubed fish and cook five minutes longer.

7. Add the oysters and scallops and bring to a boil. Add the cream. Return to a boil. Add the Pernod or Ricard to taste and serve piping hot. Serve sprinkled with chopped parsley.

Yield: 6 or more servings.

NORTHEAST FISHERIES CENTER
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TECHNICAL SERIES REPORTS

NUMBER	TITLE AND AUTHOR	DATE
1	Proceedings of a workshop on egg, larval and juvenile stages of fish in Atlantic coast estuaries, by Anthony L. Pacheco (editor).	August 1973
2	Diagnosis and control of mariculture diseases in the United States, by Carl J. Sindermann (editor).	December 1974 (out of print)
3	Oxygen depletion and associated environmental disturbances in the Middle Atlantic Bight in 1976 (composite authorship).	February 1977 (out of print)
4	Biological and fisheries data on striped bass, *Morone saxatilis* (Walbaum), by W. G. Smith and A. Wells.	May 1977 (out of print)
5	Biological and fisheries data on tilefish, *Lopholatilus chamaeleonticeps* Goode and Bean, by Bruce L. Freeman and Stephen C. Turner.	May 1977
6	Biological and fisheries data on butterfish, *Peprilus triacanthus* (Peck), by Steven A. Murawski, Donald G. Frank, and Sukwoo Chang.	March 1978
7	Biological and fisheries data on black sea bass, *Centropristis striata* (Linnaeus), by Arthur W. Kendall.	May 1977
8	Biological and fisheries data on king mackerel, *Scomberomorus cavalla* (Cuvier), by Peter Berrien and Doris Finan.	November 1977 (out of print)
9	Biological and fisheries data on Spanish mackerel, *Scomberomorus maculatus* (Mitchill), by Peter Berrien and Doris Finan.	November 1977 (out of print)
10	Biological and fisheries data on Atlantic sturgeon, *Acipenser oxyrhynchus* (Mitchill), by Steven A. Murawski and Anthony L. Pacheco.	August 1977
11	Biological and fisheries data on bluefish, *Pomatomus saltatrix* (Linnaeus), by Stuart J. Wilk.	August 1977 (out of print)

NUMBER	TITLE AND AUTHOR	DATE
12	Biological and fisheries data on scup, *Stenotomus chrysops* (Linnaeus), by Wallace W. Morse.	January 1978
13	Biological and fisheries data on northern searobin, *Prionotus carolinus* (Linnaeus), by Susan C. Roberts.	June 1978
14	A guide for the recognition of some disease conditions and abnormalities in marine fish, by Carl J. Sindermann, John J. Ziskowski, and Valentine T. Anderson.	March 1978
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16	The seasonal maxima of *Ceratium tripos* with particular reference to a major New York Bight bloom, by John B. Mahoney.	June 1978
17	Biological and fisheries data on American eel, *Anguilla rostrata* (Lesueur), by Michael P. Fahay.	August 1978
18	New York Bight ichthyoplankton survey - procedures and temperature and salinity observations, by Myron J. Silverman and Arthur W. Kendall, Jr.	August 1978