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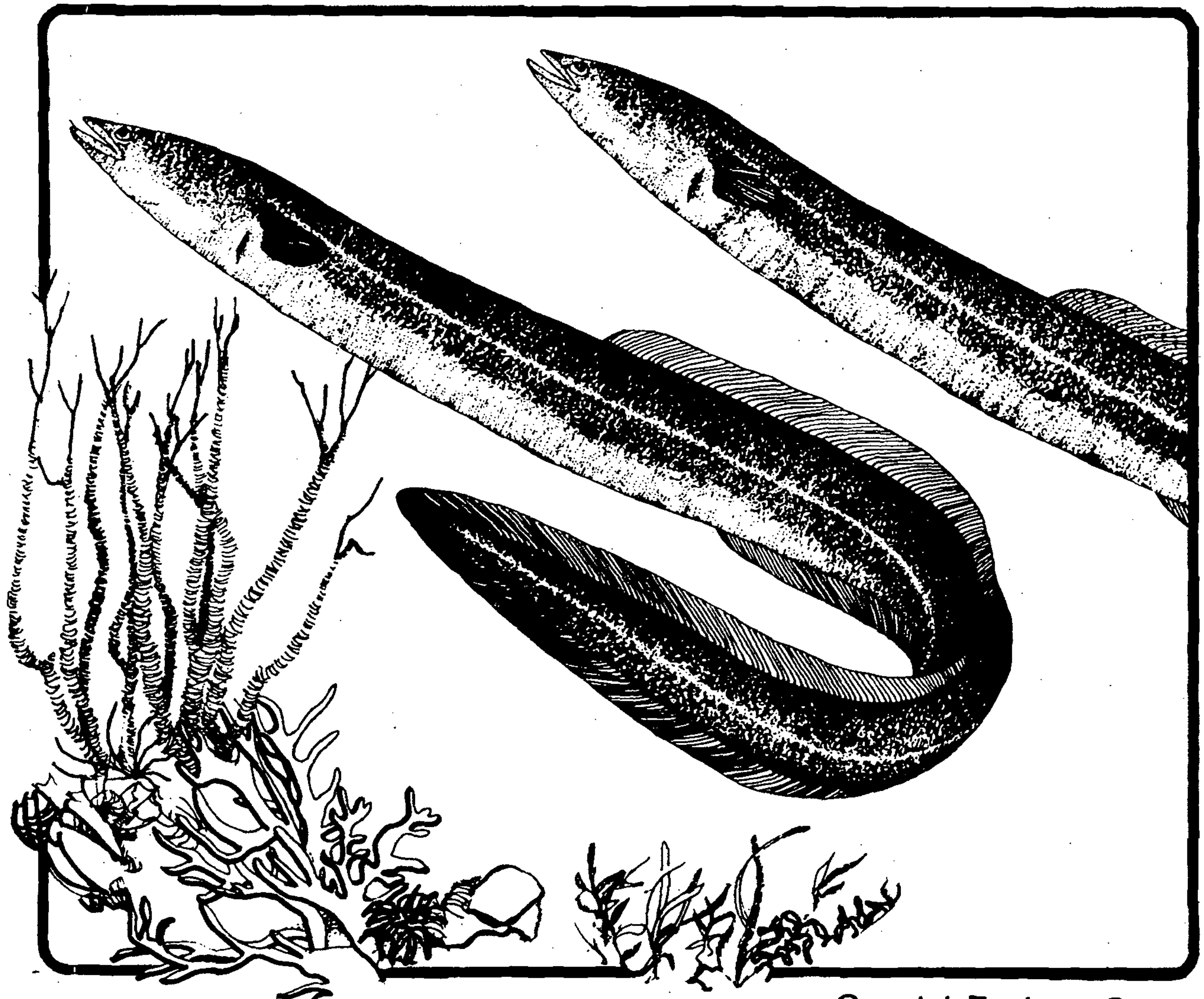
August 1987

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

AMERICAN EEL



Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

AMERICAN EEL

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

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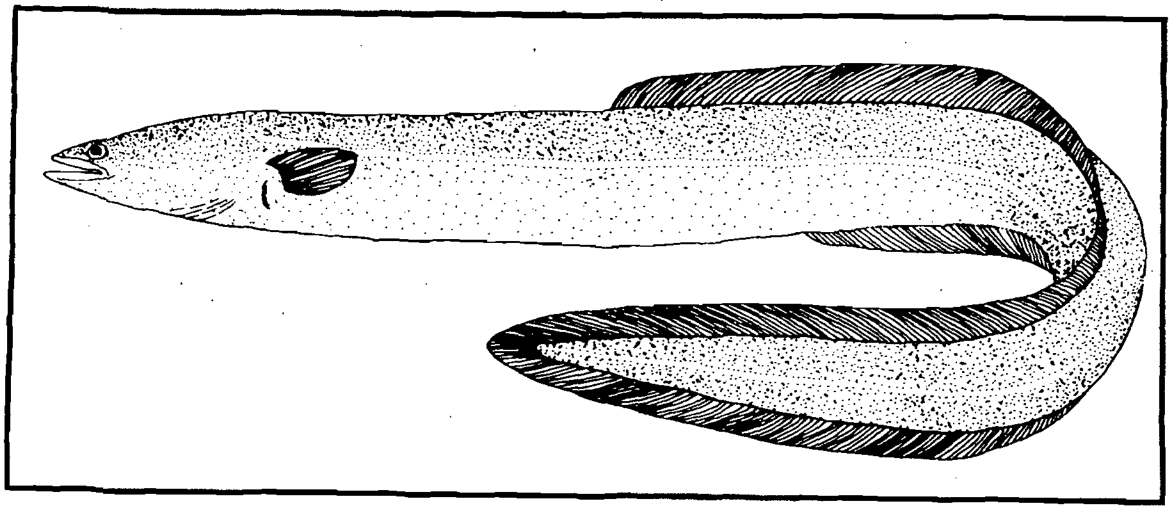

Figure 1. American eel.

AMERICAN EEL

NOMENCLATURE/TAXONOMY/RANGE

Scientific name......*Anguilla rostrata*
Preferred common name.........American eel (Figure 1)
Other common names...........Anguille, yellow eel, green eel, black eel, little eel, bronze eel, glass eel, silver eel, river eel
Class.....................Osteichthyes
Order...................Anguilliformes
Family....................Anguillidae

Geographic range: Adults or various developmental stages commonly occur in freshwater, coastal waters, and the open ocean from the southern tip of Greenland, Labrador, and Newfoundland southward along the Atlantic coast of North America, into the Gulf of Mexico as far as Tampico, Mexico, and in Panama, the Greater and Lesser Antilles, and southward to the northern portion of the east coast of South America (Tesch 1977). The species is abundant in the North Atlantic states (Figure 2), the eastern Canadian provinces, and southward to Mexico; it is resident in the Mississippi Valley, and occurs in the West Indies and Bermuda. Bertin (1956) reported the latitudinal range for the American eel as 5° to 62° N. It occurs in warm brackish and freshwater streams, estuaries, and coastal rivers, and sometimes in cold freshwater trout streams in mountainous regions. Its distribution has increased because of its

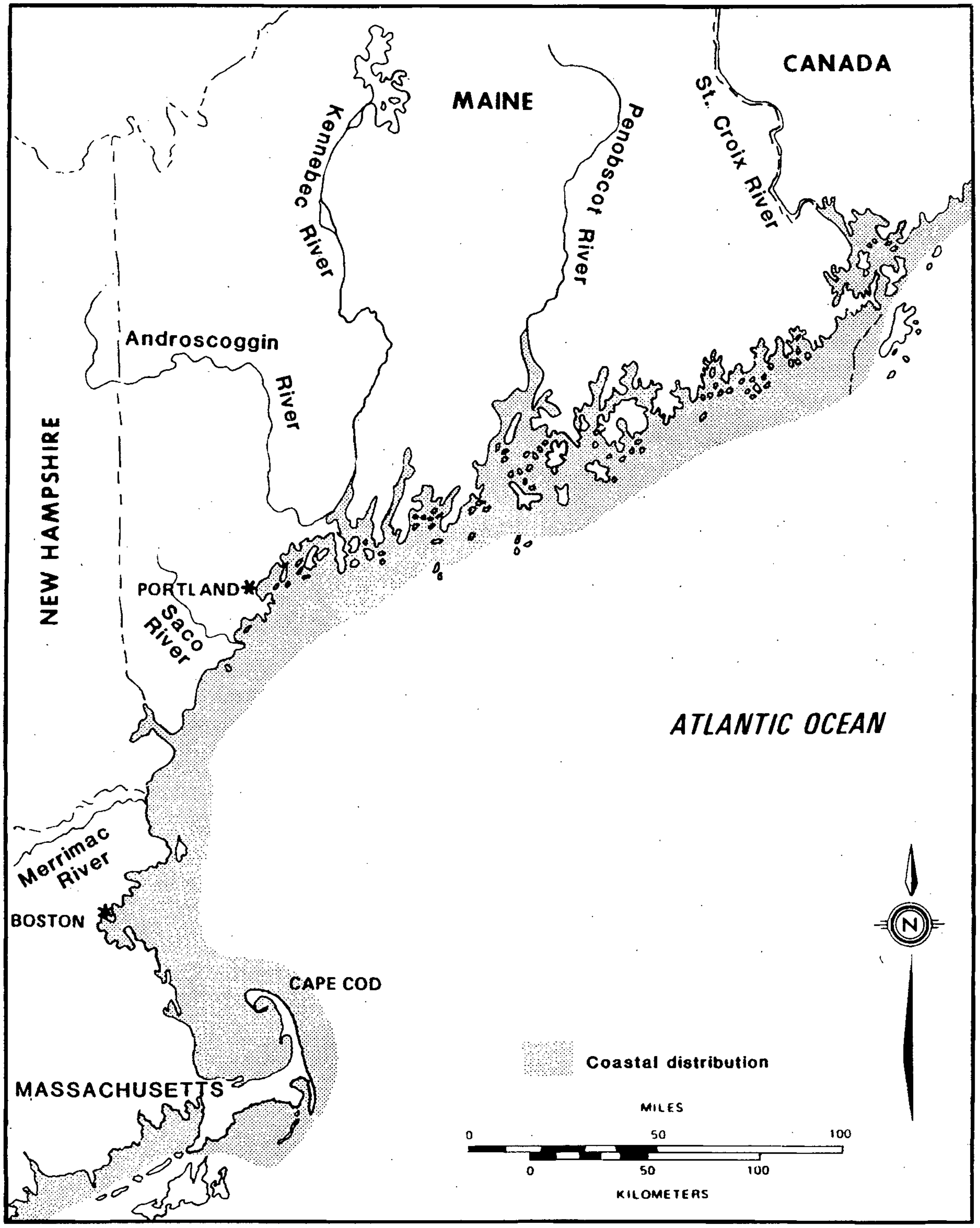

Figure 2. Major rivers that support the American eel in the North Atlantic United States. Eels also are common in other freshwater tributaries and in bays and estuaries.

hardiness (as shown by the range of habitats it occupies, including polluted areas), the ease with which it can be transplanted, and its ability to travel across damp ground and wet vertical surfaces such as dams. Adult eels are occasionally found in landlocked lakes, primarily in the northeastern United States.

MORPHOLOGY AND IDENTIFICATION AIDS

The American eel undergoes a series of morphological changes in its life cycle, which are described in the later section on LIFE HISTORY. The following information was summarized primarily from Fahay (1978) and Tesch (1977).

The body is elongate (Figure 1). The dorsal and anal fins are confluent with the rudimentary caudal fin. Pectoral fins are present, but ventral (pelvic) fins are absent. Scales form at about 3 to 5 years of age, but are minute and embedded, causing eels to appear scaleless. The lateral line is well developed. The mouth is terminal; the jaws have bands of small, pectinate, or setiform teeth, and the vomer has a long tooth patch. The number of vertebrae ranges from 103 to 111 but usually is 106 to 108 (Schmidt 1913). Ege (1939) presented comprehensive morphological data for A. rostrata.

No other anguillid eels occur in North American coastal waters, but the American eel's spawning area apparently overlaps with that of the European eel (Anguilla anguilla) (McCleave et al. 1986). Mean myomere counts for American and European eel larvae are 106.84 ± 0.032 S.E. and 114.52 ± 0.047 S.E. (Kleckner and McCleave 1985). Externally visible traits of adults are similar, but the European eel has more vertebrae (111-119; mean, 115). Some authors have argued that European and American eels should be regarded as geographical variants of the same species (Williams and Koehn 1984). Recent analysis of mitochrondrial DNA indicates that American and European eels belong to separate breeding populations (Avise et al. 1986). The lack of interbreeding even though the spawning areas overlap supports the belief that American and European eels are different species. No available data conclusively point to geographic variations in morphology, and no subpopulations have been distinguished. Koehn and Williams (1978) noted protein differences among juvenile eels collected from different locations along the Atlantic seaboard, but concluded that the differences were due to variation in selective pressures among the environments in which the eels grew. Avise et al. (1986) reported no significant geographic differentiation in the mitochondrial DNA of 108 eels collected from Maine to Louisiana. This evidence strongly supports the conclusion that American eels are a single, panmictic breeding population.

REASON FOR INCLUSION IN SERIES

The American eel supports commercial and limited recreational fisheries throughout most of its range. In the United States eels are marketed for human consumption and as bait for crabs and game fishes, including striped bass (Morone saxatilis), cobia (Rachycentron canadum), and largemouth bass (Micropterus salmoides). Adult eels often are shipped alive or frozen to Europe where they frequently are smoked before marketing. Elvers (immature eels typically < 60 mm long) have been harvested in Maine and shipped to Japan where they were cultured in ponds. Pond rearing of eels is being developed in the United States, and there is a potential for development and expansion of an eel culture industry.

The American eel is an important food of larger marine and freshwater

fishes. It preys on a variety of other animals including commercially important crabs and clams. Eels contribute to the loss of nutrients from freshwater rivers and lakes because of their high organic intake, large numbers, lengthy stay in freshwater, and subsequent migration to sea (Smith and Saunders 1955).

LIFE HISTORY

The life cycle of the American eel includes oceanic, estuarine, and riverine phases (Figure 3). Many details of its life history are only generally understood or have been inferred from knowledge of the European eel. Much of what is known has been derived from studies in the Middle and North Atlantic regions of the United States and the eastern provinces of Canada.

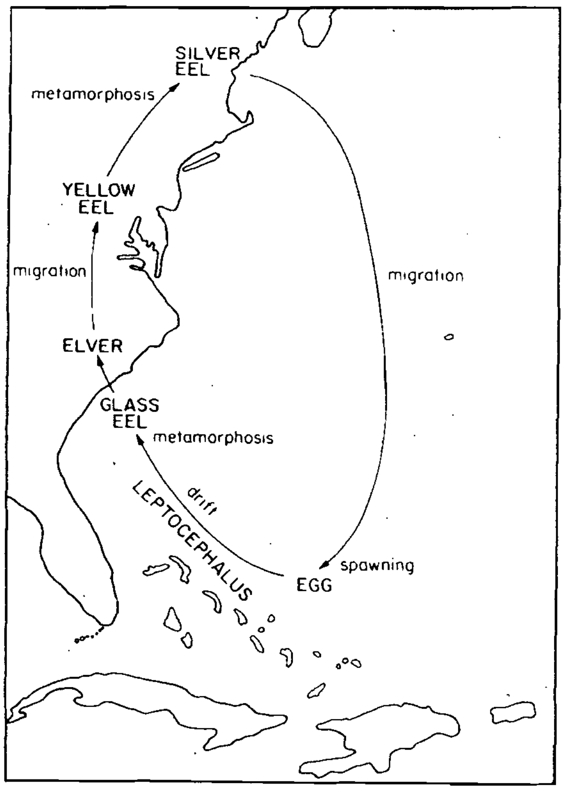

Figure 3. Diagrammatic representation of the life cycle of the American eel.

Different stages of the eel's life cycle are known by a variety of common names that are used throughout the scientific literature. The larva (leptocephalus) metamorphoses into an unpigmented glass eel which migrates into freshwater and gradually develops pigmentation. The young eel is now called an elver. Elvers may remain in coastal rivers or may continue to move upstream. The following growth phase, called the yellow eel, may last many years. Yellow eels may be sexually undifferentiated (gonads contain no definable gametes), hermaphroditic (oogonia and spermatogonia present), or sexually differentiated (females with oogonia; males with spermatogonia). Because none of these stages are capable of reproduction, all yellow eels are immature. Maturation is accompanied by changes in body color and morphology; maturing eels that migrate downriver and through the ocean to the spawning grounds are known as bronze eels or silver eels.

Spawning

The American eel is catadromous. It spends most of its life in rivers, freshwater lakes, and estuaries, but returns to the sea to spawn (Figure 3). The age at maturity has not been well defined; Fahay (1978) reported that maturation occurred after age III for males and at ages IV-VII for females from northerly populations, although females more than 15 years old have been reported in large inland lakes (Hurley 1972; Facey and LaBar 1981). Eels mature at younger ages in the southeastern United States than in New England (Helfman et al. 1984a; Hansen and Eversole 1984; Facey and Helfman, in press).

Before seaward migration in the fall, maturing eels begin metamorphosis into the silver eel stage.

(This metamorphosis and the timing of the reproductive migration are described later.)

Spawning by American eels has never been directly observed, and spawning areas have been inferred on the basis of collections of larvae. Spawning seemingly occurs in the Sargasso Sea as early as February and may continue until at least April (Kleckner et al. 1983; McCleave et al. 1986). Tesch (1977), who summarized work by Schmidt (1923), Vladykov (1964), Smith (1968), and Vladykov and March (1975), showed a spawning zone south of Bermuda and north of the Bahamas that is centered at about 25° N. and 69° W. McCleave et al. (1986) reported that American eels spawn in the area from 19.5° to 29.0° N. and 52° to 79° W., and that European eels spawn from 23° to 30° N. and 48° to 74° W. The youngest stages of American eel larvae may coexist with European eel larvae, but American eel larvae predominate west of 62° W. and south of 25° N. (Kleckner and McCleave 1985). The large overlap of spawning areas between American and European eels is evidenced by the capture of leptocephali of both species in the same trawl (McCleave et al. 1986). Thermal fronts that separate the northern and southern water masses of the Sargasso Sea are believed to form the northern limit of American eel spawning (Kleckner et al. 1983). The smallest American eel leptocephali that have been found (3.9-5.5 mm) were taken along the warm side of these fronts.

The depth at which spawning occurs is not known, but morphological and physiological evidence suggests that eels may migrate and spawn in the upper few hundred meters of the water column (Kleckner et al. 1983; McCleave and Kleckner 1985). The smallest leptocephali yet reported were taken in trawls fished at a maximum depth of about 300 m (Kleckner et al. 1983). Egg diameter of _A. rostrata_ is about 1.1 mm (Tesch 1977). Incubation periods of American eel eggs are not known, but the eggs of artificially spawned Japanese eels (_A. japonica_) are known to hatch in 38-45 hours at 23 °C (Yamamoto and Yamauchi 1974).

Relationships between eel size and fecundity for 21 eels (418-845 mm TL) were reported by Wenner and Musick (1974) as $\log F = -4.29514 + 3.74418 \log TL$, $\log F = 3.2290 + 1.1157 \log W$, where F = number of eggs per female, TL = total length (mm), and W = total weight (g). Therefore, fecundity for many American eels is between about 0.5 and 4.0 million eggs, with very large individuals (1,000 mm) producing perhaps as many as 8.5 million eggs. The European eel has fecundity estimates of 0.7 to 2.6 million eggs for individuals 630-920 mm TL (Boetius and Boetius 1980).

Adult eels presumably die after spawning. None have been observed to migrate up rivers, and spent eels have not been reported.

Larval (Leptocephalus) Stage

Hatching probably begins and peaks in February, but may continue through April (Kleckner et al. 1983; Kleckner and McCleave 1985; McCleave et al. 1986). The larval stage lasts up to about 1 year. The body is lanceolate, sharply pointed at both ends, and deepest at the middle; illustrations were published by Tesch (1977) and Fahay (1978). The length at hatching has not been described for the American eel; however, the Japanese eel is about 2.7 mm long at hatching and about 6.2 mm long 5 days after hatching (Yamamoto and Yamauchi 1974). Kleckner et al. (1983) caught larval American eels less than 5.5 mm long (perhaps less than 1 week old) from mid-February to early March. Schmidt (1925) collected larvae 7 to 8 mm long in February. The smallest larvae collected by Vladykov and March (1975) and Smith (1968) were 12 mm and

17 mm, respectively, and were caught in the summer.

American eel larvae grow as they are transported by ocean currents. Total lengths of larvae collected by Schmidt (1925) were 7 to 8 mm in February, 20 to 25 mm in April, 30 to 35 mm in June, 40 mm in July, 50 to 55 mm in September, and 60 to 65 mm by the end of the first year of life. The largest leptocephalus collected by Vladykov and March (1975) was 69 mm long. A thorough analysis of available data from 4473 larval and postmetamorphic American eels showed that the relationship between length (Y: mm TL) and collection date (X: Julian date) for 0-group leptocephali collected between 13 February and 15 October was Y=0.238 X - 6.569 (Kleckner and McCleave 1985).

Leptocephali grow rapidly until October when growth slows or stops, and many metamorphose into glass eels (Kleckner and McCleave 1985). Most leptocephali undergo metamorphosis at 55-65 mm TL and 8-12 months of age. Limited evidence suggests that some eels may remain in the leptocephalus stage for more than 1 year. Smith (1968) reported a leptocephalus 50 mm long near the spawning grounds during April; it was thus too long to have been spawned in the immediate season (Fahay 1978). Vladykov and March (1975) also suggested that larval A. rostrata may spend more than 1 year in the sea.

Larvae are transported from the spawning grounds to the eastern seaboard of North America by the Antilles Current, the Florida Current, and the Gulf Stream. Power and McCleave (1983) developed a model of surface current drift to simulate the dispersal of eel leptocephali from the Sargasso Sea. Sampling has shown that larvae are abundant in the Florida Straits and in the area between Bermuda and the Bahamas from April through August (Smith 1968). Most leptocephali probably enter the Gulf Stream directly from the Sargasso Sea, rather than by a more southerly route through the Bahama Islands (Kleckner and McCleave 1982). Eldred (1971) found larval A. rostrata in the Gulf of Mexico and Yucatan Straits, but mechanisms by which they are dispersed into the Gulf of Mexico and southward to the coast of South America have not been determined.

Glass Eel and Elver Stages

During the pelagic phase, leptocephali reach the size and physiological state at which they begin to metamorphose. The early stages of this transition involve a decrease in length and weight due to a reduction in water content, changes in the configuration of the head and jaws, and accelerated development of the digestive system (Fahay 1978). After these changes occur, the eels are similar in overall morphology to yellow eels, but lack external pigmentation and are therefore called "glass eels." Glass eels actively migrate toward land and freshwater, and develop external pigmentation as they enter coastal areas. These small, pigmented eels are called "elvers."

The young eels begin migrating upstream before pigmentation is complete. Initially they are active at night and burrow or rest in deep water during the day (Deelder 1958). They typically move up into the water column on flood tides and return to the bottom during ebb tides (McCleave and Kleckner 1982; McCleave and Wippelhauser 1986). Similar behavior was reported for elvers at the mouth of the Indian River, Delaware, by Pacheco and Grant (1973), and for elvers of the European eel by Tesch (1977). The cues that trigger the change in behavior are not known, though Creutzberg (1959, 1961) showed that European glass eels were able to detect the odor of fresh water and alter their behavior accordingly. Sorensen (1986) showed that American

eel elvers were strongly attracted to the odor of brook water and the odor of decaying leaf detritus and its associated microorganisms. Temperature gradient may also aid in the upstream orientation of glass eels (Tongiorgi et al. 1986). Glass eels and elvers may delay upstream migration at the freshwater-saltwater interface while behaviorally and physiologically adjusting to the new environment (Sorensen and Bianchini 1986).

Most glass eels and elvers move into coastal areas, estuaries, and up freshwater rivers in late winter or early spring. Vladykov (1966) suggested that elvers generally arrive in southern estuaries earlier and at smaller sizes than in the north, but records indicate considerable overlap in the timing of shoreward movements along the Atlantic coast. In the Southeastern and Middle Atlantic States, migrating glass eels and elvers have been collected from January through May (Jeffries 1960; Smith 1968; Fahay 1978; Hornberger 1978, cited by Sykes 1981; Sykes 1981; Helfman et al. 1984a).

Glass eels and elvers may reach New England estuaries as early as late winter (Jeffries 1960), but the main upstream migration is in spring. Glass eels have arrived at the coast of Maine from the end of March to about the third week of May (Dr. J. D. McCleave, University of Maine at Orono; pers. comm.). In Rhode Island the elver migration peaks during April and May (Haro 1986; Sorensen and Bianchini 1986), whereas in Maine the run is primarily from late April to June (Ricker and Squiers 1974; Sheldon 1974). Most upstream migrating eels arriving in May at the freshwater interface in a Rhode Island brook were not completely pigmented, but most were fully pigmented by July (Sorensen and Bianchini 1986). In 1974 the run along the southern and central portions of the Maine coast was composed primarily of unpigmented glass eels for the first few weeks and almost entirely of pigmented elvers by the eighth week. In northern coastal Maine the entire run was composed of glass eels. Smith and Saunders (1955) reported the arrival of elvers in Passamaquoddy Bay, New Brunswick, in late April.

Small numbers of elvers regularly arrive in estuaries in the fall, and Fahay (1978) suggested that these "early" arrivals may be the earliest spawned individuals or a segment of the main body of leptocephali that is moved northward more quickly than most by localized water currents. Alternatively, these elvers may be "late" arrivals produced from leptocephali that did not metamorphose during the previous winter and spring.

Elvers eventually begin swimming upstream and become most active during the day (Sorensen and Bianchini 1986). The onset of this active upstream migration may be triggered by changes in water chemistry caused by intrusion of estuarine water during high spring tides (Sorensen and Bianchini 1986). Tesch (1977) indicated that elvers of A. anguilla orient to river currents for upstream movement; if the current becomes too weak or too strong (velocities not specified), the fish may move into backwater areas, severely delaying upstream progress. Basic similarities in behavior of European and American eel elvers suggest that those of American eels would be similarly affected by fast or slow river currents.

Haro (1986) indicated that the main concentration of elvers in a coastal Rhode Island stream required about 1 month to move a distance of 200 m above the tidal zone, and that some American eels may continue migrating upstream as yellow eels of age II or older. The scarcity of small, young eels in lakes that are far inland supports the idea of continued upstream migration by yellow eels (Hurley 1972; Facey and LaBar

1981; Kolenosky and Hendry 1982). Eels ascending the eel ladder at the Moses-Saunders Dam on the St. Lawrence River at Cornwall, Ontario (approximately 1600 km from the ocean), were generally 3 to 8 years old (Liew 1982).

Yellow and Silver Eels

Many investigators (e.g., Bigelow and Schroeder 1953; Vladykov 1966) have stated that female yellow eels occur primarily in freshwater, and males generally in saltwater or brackish water. Dolan and Power (1977), however, after an extensive review of literature, concluded that this "female-freshwater, male-saltwater" theory was not supported. In a Georgia river, the percentage of sexually differentiated yellow eels that were males was 36 in the estuary and 6 in freshwater (Helfman et al. 1984a). In the Cooper River system in South Carolina the percentages of males were 7 in saltwater (Michener 1980), 5 in brackish water (Hansen and Eversole 1984), and 3 in freshwater (Harrell and Loyacano 1980). Winn et al. (1975) reported higher percentages of males in freshwater and females in saltwater in Rhode Island streams and estuaries, but did not explain the methods used to determine sex. Dolan and Power (1977) indicated that histological examination of the gonads is necessary to determine sex in eels.

Sexual differentiation does not occur until eels are about 200-250 mm long (Dolan and Power 1977). Before completion of the differentiation process some eels have gonads containing male and female gametes (juvenile hemaphroditism; Tesch 1977), but after gender is established, it does not change (Fahay 1978). Differentiated and undifferentiated yellow eels may overlap considerably in size and age (Gray and Andrews 1970; Dolan and Power 1977; Hansen and Eversole 1984; Helfman et al. 1984a).

In addition to the possible freshwater-saltwater variation in the sex ratio, there seems to be geographic variation in the distribution of the sexes. Vladykov (1966) wrote that males predominate from New Jersey to Florida, whereas females predominate from New York to Newfoundland. Although work in South Carolina and Georgia did not support the idea that southern stocks are predominantly male, the percentage of males was higher than that reported in northern areas. Vladykov believed that a latitudinal change in sex composition was related to the size differences in elvers along the coast, and supposed that the smaller elvers entering southern streams become males and the larger elvers entering northern systems develop into females. The presumed geographic distribution of sex in the American eel may be a result of selectivity of sampling gear and the possible exclusion of smaller males in northern studies, plus the assumption that the geographic distribution of sex in the American eel would parallel that demonstrated for the European eel (Dolan and Power 1977).

Limited evidence suggests that the gender of American eels is determined to some extent by environmental factors. Fahay (1978) wrote that the sex of the European eel can be environmentally influenced, but indicated that the factors responsible could only be speculated about. The long developmental period in freshwater or brackish water in combination with juvenile hermaphroditism provides a setting in which environmental factors could regulate the gender of eels.

Male American eels tend to be more abundant in estuaries than in upriver sites, and more males have been found in Southeastern States than in northern locations. One possible explanation is that male leptocephali and elvers do not migrate as far as females, and hence remain in southerly

or downstream areas. It is also possible that male eels prefer higher salinities than females and move downstream to coastal areas after they are differentiated, but this behavioral pattern has not been observed and it would not explain the latitudinal trend. Even where males have been found to be most abundant, in Georgia estuaries (Helfman et al. 1984a), they are still outnumbered by females.

The fact that American eels appear to be a single, panmictic population suggests that latitudinal variations in the sex ratio are not genetically determined but could be due to variations of environmental factors, such as food quality and population density (Fahay 1978). Parsons et al. (1977) believed that stocking of European eel elvers into Lough Neagh, Northern Ireland, led to a higher population density and a marked increase in the proportion of male eels that subsequently emigrated from the lake. Similarly, Egusa (1979) indicated that elvers of *A. anguilla* and *A. japonica* grown in Japanese ponds under crowded conditions produced higher percentages of males than are found in wild populations, suggesting that variations in the sex ratio of anguillid eel populations may be related to population density. Salinity apparently is not an important sex determinant; sex ratios were similar in the freshwater and brackish water culture ponds studied by Egusa.

Growth rate, which is affected by temperature, food availability, and length of the growing season, might also be a factor in determining sex. This could result in different life history strategies for males and females (Helfman et al., in press). Eels that grow rapidly, such as those in highly productive southern estuaries, may have greater reproductive fitness if they are males. This is especially true if rapid growth results in earlier maturation (see Stearns and Crandall 1984). Large size would not be beneficial to male eels because small mature males can produce an abundance of gametes. However, the fecundity of female eels is highly dependent on size. Therefore, females that grow slower but reach larger sizes, such as those in northern and upriver locations, probably contribute more eggs to the next generation than do females that grow rapidly but mature at younger ages and smaller sizes, such as those in the southeastern United States. Natural selection would perpetuate such a system where the fastest growing eels tend to be males whereas eels that grow slower but get larger are females (Helfman et al., in press).

Eels are more active at night than during the day. Direct observation of yellow eels in a north Florida cave-spring indicated that eels changed behavior at dawn and dusk, when light levels were generally 10-100 lux (Helfman 1986). Laboratory studies have shown that silver eels are also more active in darkness than in light, and that activity peaks during light-dark transition (Edel 1975, 1979). Telemetry showed that yellow eels in a tidal creek were generally inactive during the day and active at night (Helfman et al. 1983). Activity was, however, influenced by tidal cycles with eels exhibiting greater activity during high tide. In a tidal cove studied in Maine, eels were moderately abundant in seine hauls at night but were never captured during the day (McCleave and Fried 1975). Commercial harvest information also indicates that eels are more active at night (see Eales 1968; Tesch 1977).

Estimates of the home range of eels extend to 3.4 ha in small streams, tidal rivers, and tidal creeks (Gunning and Shoop 1962; Bianchini et al. 1982; Bozeman et al. 1985); from 2.4 to 65.4 ha in a large lake (LaBar and Facey 1983); and < 100

m along a tidal creek in summer in a Massachusetts salt marsh (Ford and Mercer 1986). Ford and Mercer suggested that large eels may establish territories in the wider marsh creeks, thus restricting small eels to narrower creeks at the back of the marsh. Agonistic interactions in which large eels displace smaller eels have been reported elsewhere (Helfman 1986).

Eels begin the spawning migration in late summer and fall throughout much of New England and eastern Canada. Migration from lakes that are well inland may begin earlier. Catches of eels leaving Lake Champlain by way of the Richileau River were heaviest from June to August (R. Thuot, commerical fisherman, Iberville, Quebec; pers. comm.). Eels seem to leave later in the Southeastern and Middle Atlantic United States than in New England States. This delay may function to synchronize arrival at the spawning grounds in the Sargasso Sea (Wenner 1973; Facey and Helfman, in press). Many downstream migrating eels may not yet have developed the external characteristics associated with the migratory silver eel stage. Northern eels may begin migration at an earlier developmental stage, perhaps to compensate for the longer time required to reach the spawning grounds (Wenner 1973).

The metamorphosis from yellow eel to silver eel includes several physiological changes: (1) color change (to a metallic, bronze-black sheen; pectoral fins change from yellow-green to black); (2) fattening of the body; (3) thickening of the skin; (4) enlargement of the eyes and changes in visual pigments in the eye in preparation for migrating at greater ocean depths (Vladykov 1973; Beatty 1975); (5) increased length of capillaries in the rete of the swim bladder, which also may be an indication of migration at greater depths (Kleckner and Kruger 1981); and (6) degeneration of the digestive tract. Silver (metamorphosed) eels appear to be better adapted to swimming than yellow eels (Holmberg and Saunders 1979).

Few details are known about the oceanic spawning migration of the American eel. The first collections of adults in offshore waters were reported by Wenner (1973) in the open ocean southeast of Cape Cod; east of Assateague Island, North Carolina; and southeast of Chesapeake Bay. The means by which eels locate the spawning grounds are poorly understood. Miles (1968) concluded that eels were capable of noncelestial orientation (southward), and Rommel and Stasko (1973) indicated that eels may use geoelectric fields generated by ocean currents for orientation. Robins et al. (1979) photographed two adult Anguilla eels on the floor of the Atlantic Ocean in the Bahamas at depths of about 2000 m, and although it was impossible to identify the species, the authors believed the specimens to be prespawning A. rostrata.

Stasko and Rommel (1977), who tracked five migrating eels in the lower St. Croix River estuary, New Brunswick, Canada, reported that one eel moved 25 km in 20 h and another moved 38 km in 40 h. The eels they studied showed considerable vertical movements in the water column; behavior did not change with diel or tidal cycles. Edel (1976) believed that the depth at which American eels migrate in the ocean varied with light intensity, and that swimming depth varied with turbidity of the water.

GROWTH CHARACTERISTICS

For the American eel the length at hatching is not known; however, the Japanese eel hatches at about 2.7 mm (Yamamoto and Yamauchi 1974). Growth rate of American eel leptocephali has been estimated to be 0.243 mm/day (Wippelhauser et al. 1985). Larvae

typically reach 40 to 70 mm after 1 year. The metamorphosis from planktonic larva to the upstream migrating form is accompanied by a decrease in length and weight due to reduction in water content of the body. Glass eels captured while migrating upstream in late February in Georgia were 49-56 mm long and 250-300 days old (Helfman et al. 1984a). The length of glass eels collected from January through April in South Carolina averaged 55 mm long and ranged from 45 to 65 mm (Hornberger et al. 1978). Ricker and Squiers (1974) reported that glass eels and elvers caught along the coast of Maine from late April through the end of June averaged 59.2 mm (95% confidence interval, 57.5-60.8 mm). Elvers grow slowly, reaching about 127 mm after the first year in freshwater (Bigelow and Schroeder 1953). Yellow eels typically grow slowly but reach weights up to 6.8 kg; females caught from the St. Lawrence River were 960 to 1,270 mm in length and weighed 0.9 to 4.5 kg (Fahay 1978). Females grow to a larger size than males.

Eels have been aged from otoliths and scales. Otoliths in eels consist of a translucent nucleus (formed at sea), surrounded by broad opaque summer zones and narrow translucent winter zones (Gray and Andrews 1971). Eels in Canadian waters formed their first scales at 160 to 200 mm during their third to fifth year of life, and annual rings were formed on the scales in subsequent winters (Smith and Saunders 1955). Thus, in northerly areas, age in years generally is the number of scale rings plus three. However, because scales continue to form as the eel grows, different scales from the same fish yield different ages (Smith and Saunders 1955). Although otoliths may show more than one opaque ring in a year (Deelder 1976), they are preferred for estimating the age of eels.

Growth rates within year classes are highly variable, leading to considerable variation in length at age and poor predictability of age from size. Lengths of eels at various ages in northern locales are summarized in Table 1. Eels in the Southeastern United States seem to mature at younger ages and smaller sizes and therefore may not get as large as northern eels (Helfman et al. 1984a).

The great variability in length within an age class makes it virtually impossible to accurately estimate eel growth rates from length-age regressions. Perhaps the best way to determine growth rates is to monitor individuals during long-term tagging studies. Helfman et al. (1984b) compared growth rates estimated from length-age analysis to measured growth rates of tagged eels (initial size: 275-475 mm) in a Georgia estuary. On the basis of indirect measurements (length-age regression and mean-length-at-age analysis), estimated annual growth rates were 44 mm/year, whereas independent direct measurements (seasonal summation and long-term recaptures) yielded values of 57 and 62 mm/year. Gunning and Shoop (1962) reported that four recaptured eels (initial lengths, 255-915 mm) in Louisiana streams grew an average of 140 mm/year (range, 46-325 mm/year). In Massachusetts salt marshes, Haedrich and Polloni (1978) showed that eels averaging 52 cm long grew about 4% per year, and Polloni et al. (1980) reported that eels 500-700 mm long grew about 6% (range, 4.1-8.4%). The lengths of 10 eels tagged in 1979 and recaptured in 1986 in Vermont waters of Lake Champlain increased an average of 9.7 cm over the 7-year period (Dr. G. W. LaBar, University of Vermont, Burlington; pers. comm.).

COMMERCIAL AND SPORT FISHERIES

The European market has been the major outlet for U.S. landings of yellow and silver eels (Fahay 1978). Eels are hardy and can be densely packed and shipped alive if they are

Table 1. Total lengths (cm) of American eels at various ages in different localities.

Age group	Newfoundland[a]	New Brunswick[b]	Ontario[c]	Vermont[d]	Rhode Island[e]	New Jersey[f]	Delaware River[g]	South Carolina[h]
	Locality							
I							12-16	
II	16-19		19-20				14-25	26-33
III	21-23	20-32	20-23				18-28	29-45
IV	23-30	22-40	22-32		27-46	29-32	24-32	30-59
V	25-40	26-50	29		28-51		26-34	33-62
VI	29-46	22-56	22-67		28-51	41-67	28-42	32-63
VII	36-50	30-62	29-67		29-58	36-67	29-43	42-66
VIII	43-59	32-62	39-70	43	33-64	44-70	35-47	48-69
IX	49-66	38-66	33-74	57	38-62	37-74	35-50	46-55
X	60-78	48-66	44-86	45-71	37-65	44-86	40-52	52-66
XI	66-84		63-90	50-79	46-65	63-90	45-54	
XII	75-77		67-94	48-80		67-94	43-64	
XIII			68-98	45-72		68-98		55
XIV			78-97	43-80		78-97	56-59	
XV			78-104	53-78		78-104		
XVI			78-100	53-85		77-100		
XVII			96-99	49-83		95-99		
XVIII			91	58-90				
XIX				51-82				
XX				66-86				
XXI				52-85				
XXII				58-85				
XXIII				80				

[a]Gray and Andrews 1971.
[b]Smith and Saunders 1955. Ages estimated by adding 3 years to the number of scale rings counted by authors.
[c]Hurley 1972.
[d]Facey 1980.
[e]Bieder 1971.
[f]Ogden 1970.
[g]Johnson 1974.
[h]Hansen and Eversole 1984. Ages estimated by adding 1 year to the number of inland years reported by authors.

kept moist, cool, and supplied with oxygen. Although live eels are preferred in Europe, many are shipped frozen.

Commercial fishermen use a variety of methods to catch eels, including lift nets, drift nets, traps, weirs, otter trawls, pound nets, fyke nets, spears, handlines, eel pots, and haul seines (Fahay 1978). Yellow eels in freshwater or brackish water are taken primarily with baited traps or eel pots.

A summary of catch statistics along the Atlantic coast from 1955 to 1973 showed that landings from the Middle Atlantic (New Jersey to Virginia) consistently exceeded those from the North Atlantic (Maine to New York) and South Atlantic (North Carolina to Florida) (Fahay 1978). From 1970 to 1973, the annual North Atlantic harvest averaged 125,418 kg, with an average value of $84,000. In 1977 the eel landings for Maine, New Hampshire, and Massachusetts were about 79,700, 2,700, and 143,300 kg, valued at $263,000, $5,000, and $173,000, respectively (U.S. Department of Commerce 1984). Massachusetts landings were about 100,300 kg in 1978 and 81,800 kg in 1979 (U.S. Department of Commerce 1980a), and Maine landings were about 60,500 kg in 1978 and 50,400 kg in 1979 (U.S. Department of Commerce 1980b). By 1985 the Massachusetts catch was less than 3,800 kg (E.D. Hubbard, Massachusetts Division of Marine Fisheries; pers. comm.). Landings in Maine and Massachusetts in 1980-85 are shown in Table 2. Some of the landing statistics may be inaccurate.

Although U.S. eel harvests seemed to be increasing through the 1970's, eel fishing in New England has declined drastically in recent years. The situation may be due to reasons cited by E. D. Hubbard, in her assessment of the Massachusetts eel fishery (pers. comm., June 1986).

Table 2. Preliminary commercial fishery landings of eels in Maine and Massachusetts, 1980-1985[a]. (Information provided by R. Schultz, Resource Statistics Division, National Marine Fisheries Service).

Year	Maine weight (kg)	Maine value	Massachusetts weight (kg)	Massachusetts value
1980	47,938	$111,061	841	$219
1981	25,057	45,308	-	-
1982	20,478	36,637	205	23
1983	5,409	8,925	80	26
1984	-	-	2,148	1,679
1985	10,955	18,288	-	-

[a]Does not include 9 kg reported in New Hampshire in 1981.

"During the years from roughly 1975 to 1980 the estuarine eel fishery grew considerably in Massachusetts, principally on Cape Cod, south of Boston and in southeastern Massachusetts coastal towns. Numbers of men fishing increased as well as the total landings, although accurate statistics are lacking. This was due to the high ex-vessel prices paid to fishermen, the result of renewed interest and an ever-increasing European eel demand. Whereas nearly every European country consumes eels, apparently local supplies could not meet the total demand and so North American exports began to fill this gap.

"Somewhat abruptly in 1981 most of these U.S. export markets plummeted due to a number of factors, but principally due to the very tight economic situation in the U.S. as well as abroad. Other contributing factors were contaminated shipments of eels from Canada and grading (live eels)

problems. Exports of all finfish have slumped over the last several years due to an inflationary U.S. dollar. During this time, the Europeans imported eels from new sources across the Pacific.

"Several well established eel buyers along the American East Coast closed their doors during 1982, [primarily due] to high shipping costs and inflated exchange rates. Because buyers were not interested in eels, or at much lower prices, very few persons fished during 1982, continuing through to the present. The last major buyer/exporter in Massachusetts ceased his eel operations in 1985. With unfavorable market conditions continuing in Europe over the last 4 to 5 years, the coastal eel fishery here in Massachusetts has been practically nonexistent. In the fall months, the traditional Christmas eel demand in the larger U.S. cities means a short-term, high priced market for fishermen. But other than scattered and seasonally limited sales demand, fishermen have not set their pots, although the interest is very high. One buyer in Maine is doing business with some of the local fishermen and another company in New Hampshire has very recently expressed interest in exporting eels."

It is possible, however, that European demand for American eels may increase in the late 1980's because of the accidental release of toxic chemicals into the upper Rhine River in fall 1986; hundreds of thousands of European eels were killed. If the accident significantly affects European eel fisheries for many years, an increased demand for American eels might extend into the 1990's.

A fishery for European eel elvers began in Europe during the late 1960's to supply Japan's demand for young eels to use in pond culture. Elvers were packed live in boxes and shipped to Japan, where prices paid for local A. japonica elvers were $7/kg in 1965-68, $300/kg in 1969, and $330 to $925/kg in 1971-73 (Fahay 1978; Egusa 1979). Prices paid for European eel elvers in Japan initially were equivalent to those paid for local elvers, but European eels were inferior in the pond culture systems because of poor growth and disease problems; in 1973, the Japanese paid only $30 to $50/kg for European elvers (Egusa 1979).

Reports of $100 to $2,000 per kg attracted some Maine fishermen into the elver market, but they found that these reports were inflated over the actual value of a successful shipment (Ricker and Squiers 1974). Elvers vary widely in size, and the number per kilogram may range from about 2,200 to more than 12,000 (Ricker and Squiers 1974). Sheldon (1974) reported locations and techniques for catching, holding, and transporting elvers in Maine. In Maine, elver landings were 10 metric tons in 1977 and 7.6 in 1978, valued at $110,000 and $63,251 (Dow 1982). Massachusetts prohibits harvesting of elvers except for aquaculture purposes, for which a permit is required. From 1978 to 1986 only one such permit was requested and issued (E.D. Hubbard; pers. comm.). The Japanese Elver Culture Association began assessing the performance of Maine elvers in the mid 1970's. There have been reports that the elvers of the American eel did not thrive and that the Japanese eel culture industry began buying A. japonica elvers from China (L. Flagg, Maine Department of Marine Resources; pers. comm.).

The feasibility of commercial "grow-out" operations in North Carolina was assessed by Easley and Freund (1977). Interest in culturing was stimulated by rising prices during the late 1960's and early 1970's, but considerable refinement of techniques was needed. Development of eel aquaculture has focused on methods for collecting elvers and on physical features of grow-out systems. Hormone injections can be used to induce

maturation of female American eels (Edel 1976), but proper spawning conditions are unknown, and eel culture remains dependent on capturing wild elvers. Hinton and Eversole (1978, 1979, 1980) evaluated the toxic effects of chemicals commonly used in aquaculture on glass eels (mean length, 55 mm), elvers (mean length, 97 mm), and yellow eels collected from South Carolina rivers. Lower temperatures and the shorter growing season might make commercial culturing of eels less practical at northern latitudes.

Restrictions on eel harvest vary among the North Atlantic states. In Maine the size of catch is not regulated, but certain permits and regulations pertain to some towns and rivers (Ricker 1976). Commercial fishing licenses are issued by the Department of Marine Resources, or by the Department of Inland Fisheries and Wildlife (for inland waters). The Department of Marine Resources also issues licenses for anyone buying or selling eels in the wholesale trade. In Massachusetts, coastal towns regulate commercial eel fishing in saltwater and estuaries (Amaral 1982; E.D. Hubbard; pers. comm.). Only eels 102 mm (4 inches) long or longer may be harvested, and only by nets, pots, spears and angling. Commercial fishing for eels is permitted in inland waters, but a permit and fishing license are required. Only eel pots with a mesh no less than 13 mm (0.5 inch) and a funnel opening not greater than 51 mm (2 inches) may be used. Fishermen are required to keep daily logs, and no eels less than 102 mm long may be taken. The Division of Marine Fisheries issues the licenses required to sell eels. New Hampshire also prohibits the taking of eels less than 102 mm long (T. Spurr, New Hampshire Fish and Game Department, Concord; pers. comm.).

Population size and biomass estimates of American eels are scarce and vary widely. Bianchini et al. (1982, cited by Bozeman et al. 1985) estimated eel biomass at 75 kg/ha in the tidal section of a Rhode Island river. Bozeman et al. (1985) reported about 13 kg/ha in a Georgia tidal creek. A 600-m section of a marsh creek in Massachusetts was estimated to contain about 350 yellow eels, a stock density equivalent to 875 eels/ha (Ford and Mercer 1986). Standing crops up to about 80 kg/ha were reported in lakes in New Brunswick, Nova Scotia, and Prince Edward Island (Smith and Saunders 1955). The eel biomass in Coleback Lake, Maine, was about 50 kg/ha (Rupp and DeRoche 1965), whereas estimates in shallow (<2 m) portions of Lake Champlain, Vermont, were 161 to 421 kg/ha (LaBar and Facey 1983). The biomass estimates in Lake Champlain may have been high because there had been no commercial eel fishery on the lake before the study.

Estimates of mortality or other vital statistics of eel stocks generally have not been reported, and factors regulating survival or stock size have not been evaluated. Helfman (unpubl. MS.[1]) suggested that the eel's long life in freshwater may make the stocks prone to local overharvest. Keefe (1982) suggested that declines in catch of eels per unit of fishing effort in North Carolina indicated overharvest. Because all American eels spawn in the Sargasso Sea, and there are apparently no genetically distinct stocks or subpopulations (Koehn and Williams 1978; Avise et al. 1986), overharvest in one region could affect recruitment in other regions. Kolenosky and Hendry (1982) suggested taking a conservative approach to the harvesting of eels in Canadian waters

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[1] Development and expansion of the fishery for American eels in Georgia. G.S. Helfman, Department of Zoology, University of Georgia, Athens, GA 30602. Project summary, University of Georgia Sea Grant Program, 1983.

of Lake Ontario, partly because of the declining catch per unit of effort. Nevertheless, some management policies allow or encourage locally heavy exploitation of migrating silver eels or elvers under the assumption that the numbers of elvers returning in later years will be maintained by escapement of spawning stock from other areas.

American eels are caught by sport fishermen along the entire east coast of the United States. The estimated catch in 1979 by marine and estuarine recreational fishermen was 113,000 eels in the North Atlantic States, 172,000 in the Mid Atlantic, 47,000 in the South Atlantic, and 43,000 in the Gulf coast region (U.S. Department of Commerce 1981).

ECOLOGICAL ROLE

Yellow eels are nocturnal, and a significant amount of their feeding is at night (Helfman 1986). They probably depend more on scent than on sight to locate food (Fahay 1978). The diet is diverse and generally includes nearly all types of aquatic fauna that occupy the same habitats. Eels swallow some types of prey whole, but also can tear pieces from large dead fish, crabs, or other items. Helfman and Clark (1986) documented the ability of eels to grasp large food items and spin rapidly to tear away pieces. Eels in freshwater feed on insects, worms, crayfish and other crustaceans, frogs, and fishes. Elvers collected from the Cooper River, South Carolina, ate aquatic insects (mainly larval and adult chironomids), cladocerans, amphipods, and fish parts (McCord 1977). The diet of yellow eels from the Cooper River varied with eel size and season. More types of food were eaten by intermediate-sized eels than by elvers or maturing eels; fish occurred in the diet primarily in winter and spring, whereas insects and mollusks were eaten from spring through fall. Crustaceans, bivalves, and polychaetes were the major prey of eels in lower Chesapeake Bay; blue crabs (Callinectes sapidus) and soft-shell clams (Mya arenaria) were significant prey (Wenner and Musick 1975). Eels shorter than 40 cm in New Jersey streams ate mainly aquatic insects whereas larger eels fed mostly on fishes and crustaceans (Ogden 1970). Most fishes eaten were bottom dwellers, reflecting the tendency of eels to feed near the bottom. In Vermont waters of Lake Champlain, eels ate primarily insects, crayfish, and fishes; larger eels ($\geq$ 58 cm) ate more crayfish and fishes than did smaller eels (Facey and LaBar 1981). Eels have been considered significant predators on young salmonids, but this is not well supported by the literature. In New Brunswick streams, only 6 of 300 eels with food in their stomachs had eaten salmonids (Godfrey 1957). Of 4,340 European eels examined from six Welsh rivers, Sinha and Jones (1967) found only 10 that had eaten salmonids.

Little has been published about predation on eels. Hornberger et al. (1978) reported that elvers and small yellow eels were eaten by largemouth bass and striped bass in the Cooper River, South Carolina, but that eels were never a major component of these predators' diets. Leptocephali, glass eels, elvers, and small yellow eels probably are eaten by a variety of predatory fishes. Sorensen and Bianchini (1986) stated that older eels eat incoming glass eels and elvers. Grown eels are eaten by species of eels other than anguillids and by gulls, bald eagles (Haliaeetus leucocephalus), and other fish-eating birds (Sinha and Jones 1967; Seymour 1974).

Crane and Eversole (1980) found no parasites on glass eels migrating into the Cooper River, South Carolina, but examinations of elvers yielded four genera of protozoans (Trichodina,

Ichthyophthirius, *Myxidium*, and *Myxobolus*) and one species of monogenetic trematode (*Gyrodactylus anguillae*). Crane and Eversole (1981) reported that 214 of 218 yellow eels collected from brackish waters of the Cooper River, South Carolina, were parasitized by 1 or more of 22 helminth species. About 48% of yellow eels collected from brackish portions of the Cooper River were infested with one or more ectoparasitic species from the classes Monogenea and Crustacea (Crane and Eversole, in press). Levels of parasitism by *Ergasilus cerastes* and *E. celestis* varied seasonally and with size and age of the host. Parasites of American eels in Quebec included protozoans, trematodes, nematodes, cestodes, and copepods (Hanek and Molnar 1974). The myxosporidian protozoan *Myxidium zelandicum* has been found in the kidneys and on the gills of the American eel (Komourdjian et al. 1977).

ENVIRONMENTAL REQUIREMENTS

Temperature

The eel's broad geographic range and diverse habitats suggest flexible temperature requirements. Elvers and yellow eels live in waters ranging from cold, high-elevation or high-latitude freshwater streams and lakes to warm, brackish coastal bays and estuaries in the Gulf of Mexico. Jeffries (1960) found elvers at temperatures as low as -0.8 °C.

Barila and Stauffer (1980) acclimated yellow eels to a range of temperatures between 6 and 30 °C and then measured preferred temperatures. Although preferred temperatures tended to increase with increased acclimation temperature, group differences were not significant, and the authors reported a final mean temperature preference of 16.7 °C. Karlsson et al. (1984) disagreed with the techniques and interpretation of Barila and Stauffer (1980), and claimed that acclimation temperature does influence preferred temperature. They found a final temperature preferendum of 17.4 ± 2.0 °C (95% confidence interval). Marcy (1973) reported that American eels survived passage through the cooling system of a nuclear power plant, during which they were exposed to elevated temperatures for 1-1.5 hr. Poluhowich (1972) suggested that the American eel's multiple types of hemoglobins serve to maintain a nearly constant blood oxygen affinity when the eel is exposed to temperature changes. American eels acclimated at 10 to 20 °C fed regularly and exhibited compensatory adjustments in oxygen consumption characteristic of many ectotherms (Walsh et al. 1983). However, acclimation to temperatures ≤ 5 °C for over 5 weeks resulted in cessation of feeding and a dramatic decrease in oxygen consumption.

Salinity

The mechanisms by which glass eels or elvers orient during their shoreward migration have not been described. Eels are known for their extremely sensitive sense of smell, and olfaction may play a role in the ability of elvers to locate freshwater (Sheldon 1974; Sorensen and Bianchini 1986; Sorensen, 1986). European glass eels and elvers become positively rheotactic when they first encounter freshwater that is mixed with seawater (Tesch 1977). Alterations of patterns or magnitudes of freshwater inflows to bays or estuaries could alter flow regimes and thereby affect the size, timing, and spatial patterns of upstream migrations by elvers.

Like temperature requirements, salinity requirements of postlarval eels can be inferred as being broad from the fact that the postlarval eels occur throughout a gradient of strictly fresh to brackish waters. Elvers do appear to delay upstream migration at the freshwater interface, however, perhaps to permit physiological

adaptation to the new environment (Sorensen and Bianchini 1986). Leptocephali are in near-ionic equilibrium with sea water (Hulet et al. 1972), but the osmolality of glass eels and elvers has not been reported.

Dissolved Oxygen

Dissolved oxygen requirements have not been thoroughly documented, but eels generally select water with high oxygen tension (Hill 1969). Elvers are sensitive to low oxygen, and should be held and transported in water with an oxygen concentration of at least 11 ppm (Sheldon 1974). Because elvers can absorb oxygen through the skin, they can better be transported damp and in air than in poorly oxygenated water. Evidently this is also true of adult eels. Tesch (1977) wrote that, "The capacity of the adult eel to survive in both air and water is associated with its ability to use both branchial and cutaneous modes of respiratory gas exchange. The eel survives better in air than in poorly oxygenated or polluted water...."

Habitat Structure

Postlarval eels tend to be bottom dwellers and hide in burrows, tubes, snags, plant masses, other types of shelter, or the substrate itself (Fahay 1978). This behavior is reflected in their food habits, protects them from predators, and influences commercial fishing techniques. Few other freshwater fishes display similar habitat use; interspecific competition for living space may therefore be limited. The presence of soft, undisturbed bottom sediments is important to migrating elvers as shelter. Edel (1979) indicated that eels in his experimental systems were less active when shelter was present than when it was lacking. Vladykov (1955, cited by Fahay 1978) reported that adult eels in northern habitats lie dormant in the bottom mud during winter.

River and Tidal Currents

The glass eel's and elver's nocturnal activity and reliance on tides for upstream movement have already been mentioned. Flow alteration in estuaries might affect upstream migration of small eels. Dams and other obstructions probably inhibit migrating elvers (Tesch 1977), and limit recruitment to upstream sites; however, eels can travel over wet vertical surfaces such as dams.

Tides and the time of day affected movements of yellow eels in a tidal creek in Georgia (Helfman et al. 1983). Movements of eight telemetered eels were restricted to the main creek channel during the day, but at night the fish were near the mouths of feeder creeks at low tide or in flooded marsh areas during high tide. Helfman et al. (1983) termed this movement "a nocturnal activity pattern modified by tidal flow," and suggested that such movements were foraging trips.

Contaminants

Little work has been done on toxic effects of pollutants or the tolerance limits in American eels. Tolerance would be expected to vary with developmental phase, and the eel's long residence in freshwater rivers could lead to repeated doses of toxicants and accumulation of toxic levels (Holmberg and Saunders 1979). Work done by Hinton and Eversole (1978, 1979, 1980) on toxicity of aquacultural chemicals to various life stages of eels suggested that tolerance to chemicals increases with size or age.

In September 1976 the New York State Department of Environmental Conservation and the Department of

Health banned the possession and sale of eels taken from the Hudson River and Lake Ontario because levels of polychlorobiphenyls (PCBs) exceeded the U.S. legal maximum level of 2 ppm: they were 50-75 ppm in Hudson River eels and 2.5-4.5 ppm in Lake Ontario eels (Blake 1982). This ended the Hudson River fishery for eels. In 1978 the restrictions were modified to allow sales of Lake Ontario eels to foreign markets, which apparently permit higher PCB concentrations than are allowed in the United States.

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of taxonomy, life history, and environmental requirements of coastal fishes and aquatic invertebrates. They are prepared to assist with impact assessments. The American eel is an ecologically and economically important catadromous species that occupies freshwater streams, rivers, brackish estuaries, and the open ocean during various phases of its life cycle. Adult eels apparently spawn in the Sargasso Sea, and ocean currents transport the developing larvae northward until the young metamorphose into juveniles capable of swimming shoreward and moving upstream into coastal areas, estuaries, and rivers. Developing eels commonly remain in freshwater or brackish areas for 10-12 years before migrating to spawn. American eels tend to be bottom-dwellers and feed on a variety of fauna that occupy the same habitats. Eels occupy areas having wide ranges of temperature, salinity, and other environmental factors, suggesting broad tolerance limits, but few studies of requirements have been reported. Salinity patterns and water currents created by river discharges into coastal areas apparently provide the gradient that cues shoreward migration of juvenile eels. Alteration of patterns of freshwater inflows to estuaries and bays could affect upstream migrations.

17. Document Analysis a. Descriptors

Estuaries, Fisheries, Salinity, Temperatures, Life cycles, Growth, Oxygen, Contaminants, Animal migrations, Aquaculture

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