Age, Growth, and Sex Ratio of American Eels in Charleston Harbor, South Carolina[1]

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Abstract: Age, growth, and sex ratio were determined from 484 yellow-phase American eels (*Anguilla rostrata*) collected from brackish waters (16.4 g/liter; mean salinity) in Charleston Harbor, South Carolina. Eels averaged 4.4 years, 437.6 mm total length, and 189.9 g live wet weight. Length-weight relationship was: $\log W = -5.7156 + 3.0067 \log L$. Length and weight increases were greatest in the third and fifth year of age, respectively. The population consisted of 85.5% mature females, 7.9% advanced females, and 6.6% males. Mature and advanced females averaged 1.6 and 3.1 years older than males (2.7 years), respectively. Males were consistently smaller than females for each age class.

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Life history information on American eels (*Anguilla rostrata*) from brackish and marine waters and from the southern United States is limited. Boetius and Boetius (1967) analyzed age, sex, and taxonomic features of 78 eels from 8 brackish water locations in Bermuda. Vladykov (1966) examined adult eels that had been collected in New Jersey, Florida, and Louisiana. Unfortunately, sample sizes were small, capture methods and salinity measurements were not included, and the eels from Florida were collected over a 59-year period. Food habits (McCord 1977) and life history information (Harrell and Loyacano 1980) have been recorded for American eels from freshwater segments of the Cooper River, South Carolina. Hansen (1979)

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added life history data for eels from low salinity (5.3 g/liter, 0–23 g/liter; mean, range) portions of the Cooper River. More recently, eels have been sampled from areas of similar salinities (5 g/liter, 0–20 g/liter) in the Altamaha River, Georgia (Helfman et al. 1984*a*).

Most eel studies report a low percentage of males in fresh and brackish water in North America (Huver 1966, Vladykov 1966, Boetius and Boetius 1967, Gray and Andrews 1970, Johnson 1974, Dolan and Power 1977, Hansen 1979, Harrell and Loyacano 1980, Facey and LaBar 1981), whereas Helfman et al. (1984*a*) observed a relatively high percentage (36%) of male eels in their samples. Vladykov (1966) suggested that males predominate in more southerly regions and prefer to stay in estuarine areas while female eels select freshwater habitats. It has also been suggested that eels exhibit phenotypic sex determination (i.e. sexual determination dependent on environmental conditions; Bertin 1956). High population densities and the associated levels of increased competition for resources (food) are environmental conditions which appear to favor the development of males. Penaz and Tesch (1970) observed a relationship between the slow growth rates of European eels (*A. anguilla*) and the predominance of male eels in the inner Elbe Estuary on the North Sea. Parsons et al. (1977) also cited phenotypic determination as an explanation for the increase in male eels in Lough Neah, Northern Ireland, during a 10-year period.

This paper presents information on the age, growth, and sex ratio of American eels from Charleston Harbor, South Carolina, and discusses these data in relation to existing theories on sex distribution in eels.

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Methods

Specimens were collected monthly from July 1978 through September 1979 at 2 sites in Charleston Harbor, South Carolina. One collection site was located at the mouth of Cooper River along an abandoned railroad trestle. Traps were fished among submerged pilings. The second site was located at Shem Creek, a tidal creek draining into the harbor. Traps were fished near pilings adjoining a commercial fishing dock on Shem Creek.

Monthly readings of temperature and salinity of surface and bottom water at high and low tides were made with a YSI salinity-temperature meter. Water temperature averaged 28.9° C (7.9° to 30.5° C) and salinity averaged 16.4 g/liter (3.8 to 27.6 g/liter).

Eels were captured in Carolina eel traps (60 × 60 × 40 cm; 5-cm throat openings) constructed of 0.6 cm-mesh galvanized hardware cloth (Berg et al. 1975). Baited traps were set in late afternoon and checked the following morning for 2 to 5 consecutive days each month. Total length (mm) and wet weight (0.1 g) were recorded for live eels.

Age determination was based on annuli in otoliths. Scale reading has been shown to be an ineffective indicator of age in eels (Tesch 1977). Both sagittae were removed and ground as described by Sinha and Jones (1967*a*). Otoliths were examined with a dissecting microscope using reflected light and a black background (Schott 1965) and annuli were identified and counted according to the method outlined by Sinha and Jones (1967*a*) and Harrell (1977).

Gonads were excised and fixed in 10% buffered formalin. Tissue samples were dehydrated and cleared in a series of ethyl alcohol and xylene baths and embedded in paraffin. Gonadal tissue was sectioned at 8μm on a rotary microtome, mounted on glass slides, stained with modified Harris' hematoxylin and counterstained with eosin. Gonadal sections were examined microscopically and classified as male, maturing female, or advanced female. Males were identified by the presence of testicular tissue containing nests of secondary spermatogonia (Hyder 1969). Maturing females possessed small developing ovocytes (Gray and Andrews 1970). Advanced females contained large ovocytes that were characterized by lipid vesicles and basophilic inclusions in the cytoplasm, and a distinct nuclear membrane (Wenner and Musick 1974).

An a priori decision was made to restrict statistical treatment to age and sex classes containing 15 or more eels. Student's *t*-tests were used to detect significant difference ($P < 0.05$) in mean total length and weight between age and sex classes (Steel and Torrie 1960). Length-weight regression was calculated using the general linear model procedure of SAS (Barr et al. 1979).

Results

Age and Growth

Only 8 pairs of otoliths from a total of 484 yellow-phase eels were unreadable and not included in the age calculations. Mean age was 4.4 years with 68.9% of the eels in age classes III to V and 92.0% in age classes II to VI. Age classes I to III were dominated by males while females were most common in the older age classes (Fig. 1).

Average size of eels consistently increased from age classes I to III for males and I to VIII for females (Fig. 2). Significant differences ($P < 0.05$) occurred in the mean length (and weight) of female eels in age classes II to VI. However, considerable overlap existed in both total length and weight among ages. Greatest growth in length and weight in female eels occurred

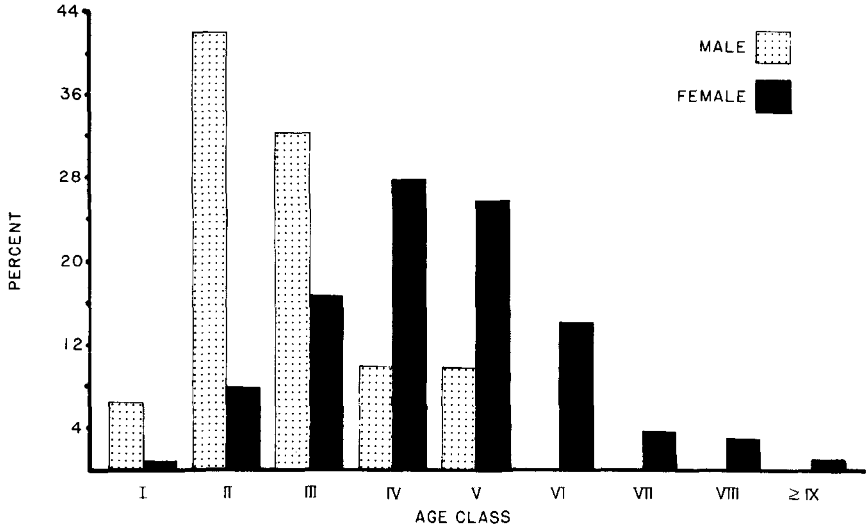

Figure 1. Age frequency distribution of male ($N = 31$) and female ($N = 444$) American eels collected from high salinity portions of Charleston Harbor, South Carolina.

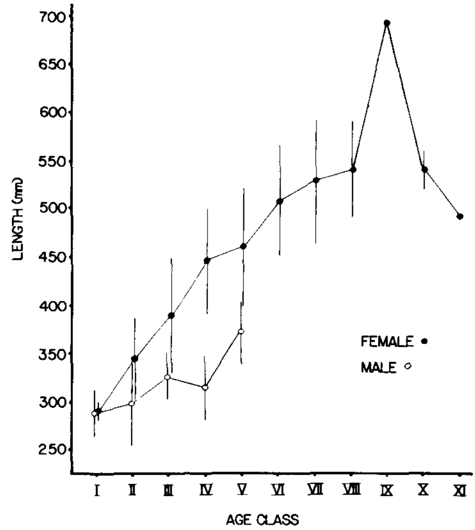

Figure 2. Mean lengths (mm) for age classes of male ($N = 31$) and female ($N = 444$) American eels collected from Charleston Harbor, South Carolina. Vertical lines represent one standard deviation about the mean.

during the third and fifth year of age, respectively. Growth comparisons were restricted to female eels and age classes II to VIII because of small sample sizes.

Mean total length was 437.6 mm (213 to 719 mm) and mean wet weight was 189.9 g (14.7 to 790.0 g). The regression of weight (g) to total length (mm) was: $\log W = -5.7156 + 3.0067 \log L$; $r^2 = 0.94$, $P < 0.05$.

Sex Ratio and Size Differences

All eels were sexed. None fit the "undifferentiated" and "immature female" stages as defined by Gray and Andrews (1970) and Harrell and Loyacano (1980). Mature female was the most abundant sex class (85.5%) followed by advanced female (7.9%) and male (6.6%). Mature females were found in each monthly sample and at percentages greater than either of the other 2 sex classes. Advanced females were only captured during 6 months of the year (July through December) while males were caught over a 9-month period (March through November).

Males had an average age of 2.7 years, length of 317 mm, and weight of 71 g. Mature and advanced females averaged 4.3 and 5.8 years of age, 437 and 550 mm in length, and 181 and 392 g in weight, respectively. Average age and size for the male and female sex classes were significantly different ($P < 0.05$). Males were consistently smaller than females for each age class. The smallest size difference between male and female eels occurred in age class I (Fig. 2).

Discussion

The age distributions of eels from freshwater (Harrell 1977), low salinity (5.3 g/liter; Hansen 1979), and high salinity (16.4 g/liter; present study) areas of the Cooper River system were different. Eels from Charleston Harbor, the high salinity site in the Cooper River, had the lowest mean (4.4 years) and lowest modal age (4.0 years), and 63% of the eels were in age classes IV to VI. Age classes IV to VI represented 73% and 71% of eels from freshwater (Wadboo Creek) and low salinity areas of the Cooper River, respectively (Harrell 1977, Hansen 1979). Mean age of eels from Wadboo Creek (5.1 years) was only slightly higher than that of eels from low salinity areas (5.0 years), and modal ages for both collections were 5.0 years. Eels from the Tailrace Canal below Pinopolis Dam, the other freshwater site in the Cooper River system sampled by Harrell and Loyacano (1980), had the highest mean (5.2 years) and highest modal age (6.0 years). Age distribution of these eels covered the widest range (0 to XV) with 45% of the collection in age classes IV to VI (Harrell 1977).

Gear selectivity can significantly affect the age and size distribution of captured eels, and may have contributed to differences between the various studies. Capture of the youngest and smallest yellow eels and migrating silver eels is most affected by sampling method. Harrell and Loyacano (1980) utilized electrofishing to capture eels in the Tailrace Canal and reported that 10% of the eels belonged to age class 0. Baited traps, constructed of 0.6, 1.3, or 2.5-cm mesh wire, fished by Harrell and Loyacano (1980) in Wadboo Creek and Hansen (1979) in low salinity areas of the Cooper River resulted in the capture of only 7 eels from age class II and none from age classes 0 or

I. Eels from Charleston Harbor were captured using traps constructed of 0.6-cm mesh wire. These smaller mesh-sized traps captured 5 eels from age class I and 48 from age class II, many of which would ordinarily escape through larger mesh traps. Silver eels which normally are not susceptible to baited traps (Tesch 1977), represented 28% of the eels captured from the Tailrace Canal (Harrell and Loyacano 1980). These silver eels averaged 7.6 years (V to XIV) and 646 mm in length. Collection of a disproportionate number of silver eels from the Tailrace Canal partially explains why this population sample differed in age from the other 3 populations sampled in the Cooper River system.

Mean size (growth) of female eels through age class VIII was similar in brackish portions of the Cooper River (Hansen 1979) and Charleston Harbor. Female eels from these brackish areas were consistently larger than female eels from freshwater areas for age classes II to IV, but smaller for age classes V to VIII (Harrell 1977). Difference in growth between the brackish and freshwater areas for age classes II-IV could be even greater than is indicated by these data because collections by Harrell (1977) were made primarily during the warmer months (May through September) when eels feed at higher rates (Sinha and Jones 1967*b,* McCord 1977) and grow faster (Tesch 1977, Helfman et al. 1984*b*). Not all of the differences in length between freshwater and brackish water eels in age classes V to VIII can be explained by the preponderance of female silver eels (advanced) in the freshwater collections (Harrell 1977) because the recalculated mean lengths of freshwater eels, excluding the silver eels, remained larger than those for brackish water eels.

In Newfoundland, eels from freshwater streams were larger than eels from brackish water ponds at each age class (Gray and Andrews 1971). Results from fresh and brackish water areas in South Carolina do not follow this trend. Differences in growth rates of eels from different habitats is likely a function of a number of environmental parameters, not just salinity. Population density, prey abundance (trophic state), temperature, day length, and current velocity are all thought to influence the growth of eels (Sinha and Jones 1967*a*).

Mean lengths (and weights) of eels for age classes were generally larger than those reported from more northern locations (Fig. 3). Higher growth rates of eels from more southerly regions are expected because of increased water temperatures and longer growing seasons (Boetius and Boetius 1967, Sinha and Jones 1967a). The decrease in mean length observed after age class IX (Fig. 3) may in part be due to small sample size ($N = 3$). When length data from all 4 Cooper River sites were used to determine growth, a gradual decline in growth was observed. Many of the fastest growing and maturing eels may have migrated by age IX, leaving only the slower growing eels as the older residents of the population (Michener 1980).

Average length and weight for each age class of males was smaller than the corresponding lengths and weights for females. Sexual dimorphism (size) has been reported for eels from most locations in North America (Boetius and Boetius 1967, Gray and Andrews 1970, Bieder 1971, Johnson 1974, Wenner and Musick 1974, Dolan and Power 1977, Hansen 1979, Harrell and Loyacano 1980).

During the present study, fewer male eels were caught than females. It has been hypothesized that male eels mature more rapidly than females and spend a shorter time in inland waters before initiating their spawning migration (Bertin 1956). In support of this hypothesis, Harrell (1977) found that female silver eels ranged from age class IV to XV, while male silver eels ranged from II to VI. The paucity of male eels in Cooper River and Charleston Harbor, however, cannot be fully explained by differential developmental and migration patterns. Bigelow and Schroeder (1953) and Vladykov (1966) stated that male eels occur primarily in brackish water while females occur predominately in freshwater. Data from the Cooper River system indicate a gradual increase in the percentage of males from 1.5% in freshwater (Harrell

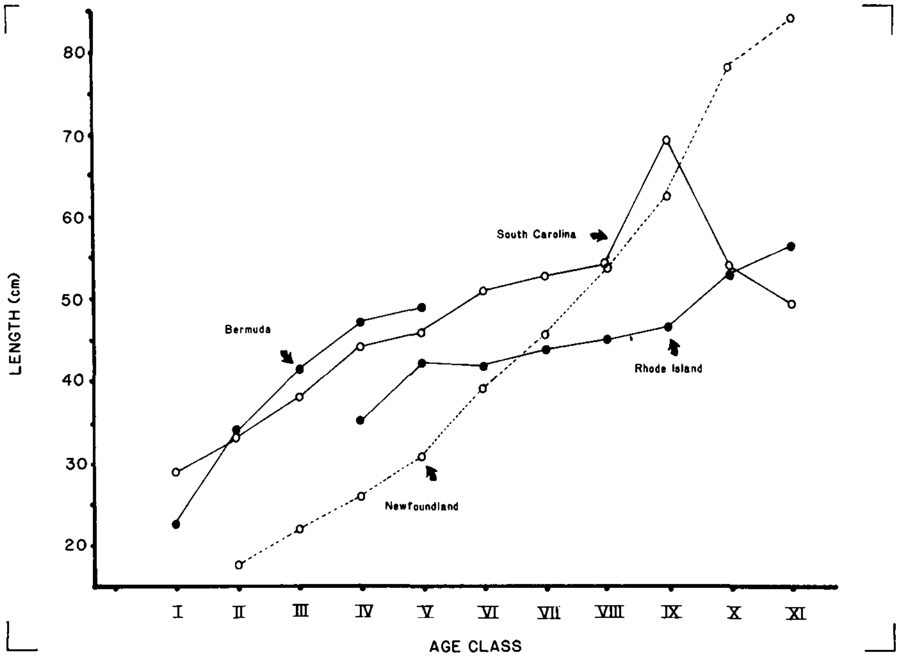

Figure 3. Mean lengths (cm) for age classes I–XI of American eels from Bermuda (Boetius and Boetius 1967), Newfoundland (Gray and Andrews 1971), Rhode Island (Bieder 1971), and South Carolina (present study).

and Loyacano 1980) to 4.1% in low salinity (Hansen 1979) and 6.1% in higher salinity brackish water. Helfman et al. (1984*a*) found among the sexually differentiated yellow eels collected in the Altamaha River, Georgia that 6% were males in freshwater and 36% were males in brackish water areas. These findings also lend support to the proposal by Vladykov (1966) that males predominate in the more southerly regions of their distribution. However, there is no firm evidence to explain what mechanisms would lead to or maintain such distribution patterns.

Male predominance may be related to high population density and increased competition for food (Penaz and Tesch 1970). Parsons et al. (1977) provided evidence that an increase in the percentage of male European eels in Lough Neah, Northern Ireland, was due to an overstocking (crowding) of elvers and not to salinity. Egusa (1979) found that freshwater and brackish culture ponds stocked at high densities with elvers of European eels produced male dominated sex ratios, and sex ratios were similar in both the brackish and freshwater ponds. If faster growth rates are indicative of decreased competition for food, and sex is determined phenotypically, we would expect to find relatively fewer males in those populations with faster growth rates. The higher proportion of males and the faster growth rates of females in age classes II to IV in Charleston Harbor compared to freshwater areas in the Cooper River, however, does not provide support for this hypothesis.

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