AGE, GROWTH AND SEX RATIO OF THE AMERICAN EEL IN THE COOPER RIVER, SOUTH CAROLINA[1]

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Abstract: Age-growth analysis was performed on *Anguilla rostrata* from 2 study sites on the Cooper River, South Carolina. Length ranged from 98 to 834 mm and weight ranged from 1 to 1224 g. Examination of otoliths gave mean age of 5.1 years with a range of 0-15 years. Length-weight relationship was established as: log w = -6.56 + 3.34 log (L). Eels were sexed by morphological and histological examination of gonad tissue. Males comprised only 1.6 percent of the population from Pinopolis Dam and 1.3 percent from Wadboo Creek. Eels smaller than 210 mm could not be sexed.

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American eels *(Anguilla rostrata)* recently have received much attention as a commercial fishery in the waters of South Carolina. Export of eels to Europe and the Orient is increasing yearly. American stock is being used to supplement the increasing demand for eels as a food source and aquaculture stock supply, especially in Japan.

Reports of age and growth studies on American eels are available for most of the North American Atlantic Coast. Studies conducted in Canada were by Smith and Saunders (1955), Vladykov (1966), Gray and Andrews (1971), and Hurley (1972). In American studies, Gunning and Shoop (1962) found that 1 marked-recaptured eel in Louisiana almost doubled in length in 1 year. Ogden (1970) found eels from New Jersey of 14 size classes ranging from less than 20 cm, 3 to 4 yr to greater than 70 cm, 16 to 19 yr. New Jersey eels compared favorably in growth with those from Canada collected by Smith and Saunders (1955). Bieder (1971) collected eels from Rhode Island and found growth rates similar to Canadian and New Jersey populations. In Bermuda, Böetius and Böetius (1967) found eels growing at a faster rate than eels from Rhode Island.

Tesch (1928) and Bertin (1956) have proposed that geographical distribution of eels may be a function of sex. Bertin (1956) stated that male European eels. *A. anguilla*, live generally in estuaries and brackish lagoons, but that females are found only in freshwater. However, research on the American eel has not confirmed this. Bigelow and Schroeder (1953) found large eels in salt marshes and suggested they were female. Huver (1966) histologically examined gonads of 259 freshwater eels, 230 of which possessed ovaries. Three of 80 American eels examined in freshwater in Bermuda by Böetius and Böetius (1967) were males. In Newfoundland, 353 of 354 eels from 2 brackish and 3 freshwater habitats were determined histologically to be female (Gray and Andrews 1970). The 1 male was found in freshwater. Winn et al. (1975) found males predominant in catches from freshwater in Rhode Island, but these eels were sexed by macroscopic examination of gonads and in some instances by size alone. Dolan and Powers (1976) published data

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concerning histological versus morphological examination of gonads and designed a criteria which adequately allows sexing of certain sized eels by gross examination only.

Very little research has been done on the life history of the American eel between Virginia and Florida. The increasing commercial importance of American eels in South Carolina necessitated basic life history research to enable proper management of the resource. Objectives of this study were to determine the length-weight relationships, sex composition and the relationship of size and age of eels from Cooper River, South Carolina.

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METHODS

Specimens were collected from 2 areas in the Cooper River system in Berkeley County, South Carolina. One site was a sanctuary on the Tailrace Canal below Pinopolis Dam (Lat. 33° 14' 30"N, Long. 79° 59' 30"W). This area was 200 m long and characterized by a fast flow of water from turbines in the dam. Banks were covered with riprap that offered favorable habitat for eels to hide and feed. The collection area was on the east bank. Distance from the sea was 82.1 km. The other site was approximately 7.2 km downstream from the Pinopolis Dam at the mouth of Wadboo Creek (Lat. 33° 11' 30"N. Long 79° 58' 30"W), a tributary of the Cooper River. It was borded by shallow abandoned ricefields with submergent vegetation and muddy bottoms. The main channel was approximately 50 m wide with a sandy clay bottom. Distance from the sea was 74.8 km.

Eels were caught by electrofishing, trapping and angling. Monthly samples were taken with baited eel pots from June to December 1975 at Wadboo Creek, and with electrofishing from September 1975 to September 1976 at Pinopolis Dam. Collections at Pinopolis Dam included bi-weekly samples during March, April and May, 1976. A few eels from Wadboo Creek were captured on hook and line by local sport fishermen.

All eels were put on ice immediately after capture and stored frozen or in 10 percent formalin. Frozen specimens proved unsatisfactory for sex determination, therefore, subsequent collections were placed in 10 percent formalin.

The most reliable method for determining age of eels is by examination of otoliths. Otoliths were excised and ground as described by Sinha and Jones (1967). This method also was utilized by Gray and Andrews (1970), Beider (1971), and Hurley (1972). A black background was used to enhance readability of the otolith (Schott 1965). Frequently both sagitta were examined to insure accuracy of age determination.

Ageing of Cooper River eels was begun at the third opaque ring. This ring was formed during the eel's first growing season in freshwater (Harrell 1977). Since it had not completed a full year in freshwater an eel with otoliths exhibiting this characteristic was placed in the 0 age class.

The gonads of eels were described in 1771 by Mondini and in 1874 by Syrski (Sinha and Jones 1966). Mondini described the ovary as a wide, frilled, ribbon-like organ. The testes appeared as narrow, lobed or deeply scalloped paired organs running the length of the body cavity alongside the kidney and are known as the Organ of Syrski. The only reliable method for sex determination of eels with lobed organs has been by histological examination (Huver 1966, Sinha and Jones 1966, Vladykov 1966, Gray and Andrews 1970, Wenner and Musick 1974, Dolan and Power 1976).

Gonads fixed in 10 percent formalin were prepared for histological sectioning by dehydration through a series of alcohol concentrations. The tissue was embedded in Paraplast® (Sherwood Medical Industries, Inc.), a parafin-plastic compound, sectioned 8 micra with a rotary microtome and stained with a modified Harris hematoxylin stain, then counterstained with eosin (Gray and Andrews 1970, Wenner and Musick 1974). The stained tissue was examined at 100X under a compound microscope.

Eels from both locations were placed into 1 of 5 categories based on microscopic examination of development of stained gonadal tissue. These categories were immature female, maturing (immature) female, advanced female, male and undifferentiated (Figs. 1 and 2).

Dolan and Power (1976) determined that eels with small ribbon-like or lobed gonads should be sexed histologically and not morphologically. However, eels exhibiting large characteristically female gonads could be sexed with confidence.

Due to tissue damage in the eels preserved by freezing only 63 of 157 eels from Wadboo Creek were histologically sexed. Of the remaining 94 eels, 79 were over 400 mm in length and were sexed macroscopically. These 79 eels exhibited the frilled, ribbon-like organ described by Mondini, however, because of macroscopic examination, the state of maturity could not be determined. Eels (15) less than 40 mm in length could not be accurately sexed and were not included in sex ratio data.

RESULTS

Males comprised 1.6 percent and 1.3 percent of the population from Pinopolis Dam and Wadboo Creek, respectively (Table 1). Males were generally smaller than females. The largest male from Pinopolis Dam was 289 mm whereas the largest male from Wadboo Creek was 322 mm.

Employing the equation $\log (W) = \log a + n \text{ Log } (L)$ with data from the 2 study sites the following empirical relationships were obtained;

Pinopolis Dam $\log (W) = -6.62 + 3.36 \log (L)$
Wadboo Creek $\log (W) = -6.22 + 3.20 \log (L)$
Where W = wet weight (g) and L = total length (mm).

The 2 populations had a highly significant difference ($P < .05$) in length-weight relationship. The combined relationship was equal to $\log (W) = -6.56 + 3.34 \log (L)$.

Elvers began entering South Carolina waters in January and immigration peaked in March. Growing season for Cooper River eels was from May through October. Observations of several otoliths showed that the opaque ring first appeared at the beginning of May while the transparent ring was first evident in November. Clear distinct annuli (Fig. 3) were present on 410 of 415 otoliths used for age class determination. Mean age for eels from Pinopolis Dam was 5.2 yr with a range of 0-15 yr. Wadboo Creek eels had a mean age of 5.1 yr with a range of 2-10 yr.

Female eels varied greatly in length and age. Length of female eels overlapped in the first 4 age classes in both sites. Male eels did not exhibit this overlap.

Length in relation to age for eels from Pinopolis Dam and Wadboo Creek is shown in Figs. 4 and 5, respectively. The length increase during the first 4 years enabled distinction of several age classes to be made based upon length. The relationship between length and age roughly paralleled the age-weight relationship.

Females outnumbered males captured from both locations 342 to 6. Of the 342 classified females, 79 were larger than 400 mm and were macroscopically sexed. The remaining 67 eels were either classified sexually undifferentiated or could not be sexed because of their small size (< 210 mm) or due to the poor condition of tissue in frozen specimens.

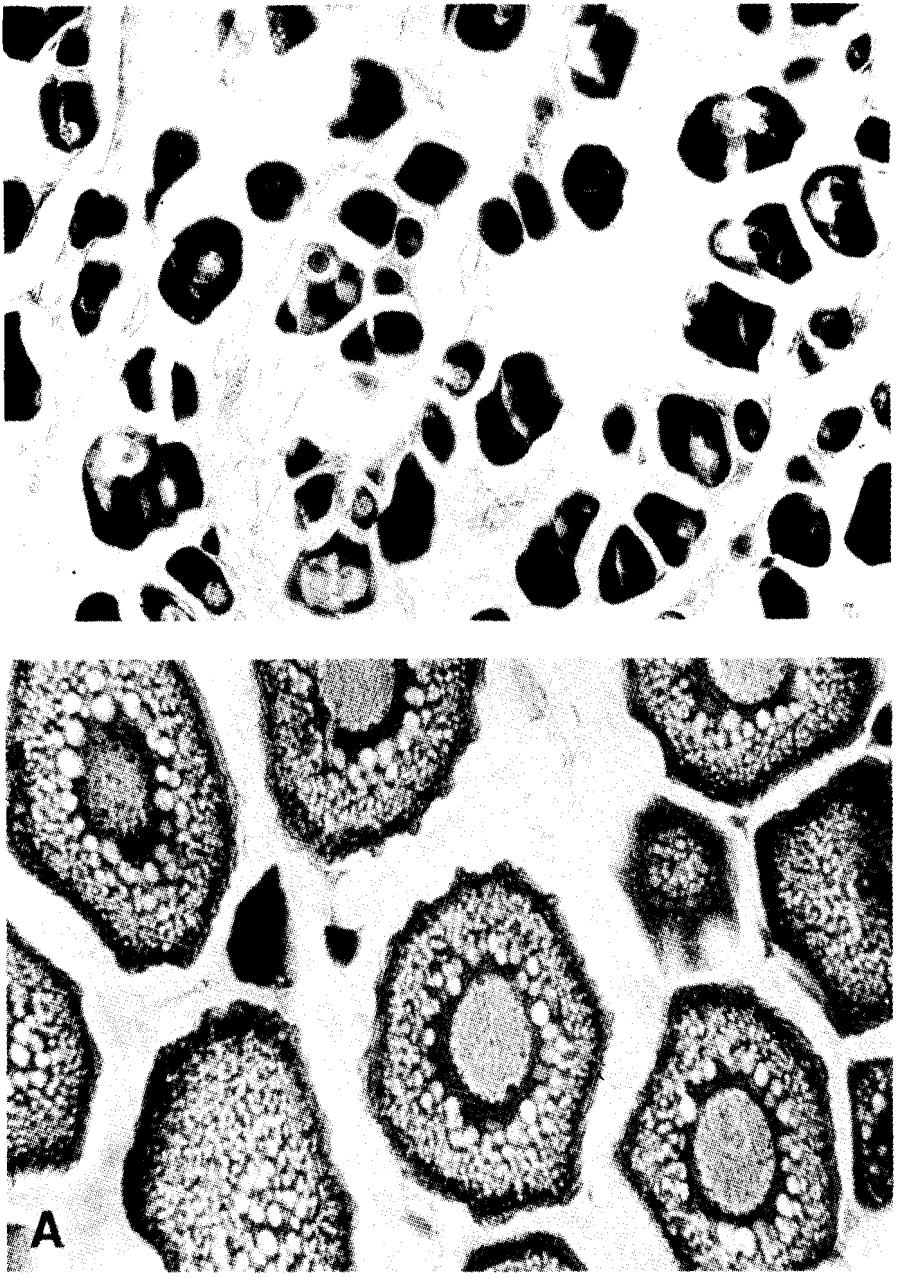

Fig. 1. Ovarian tissue of female American eels: Top—immature female (100X). Note small oocytes and little amount of cellular development. Bottom—Advanced (mature) female (100X). Note advanced cellular development of nucleus and yolk granules.

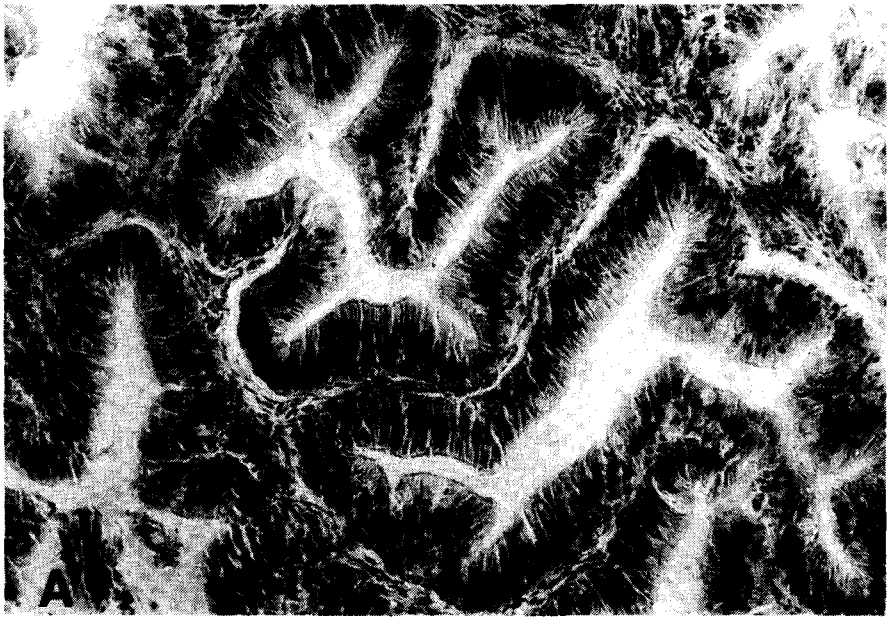

Fig. 2. Testes of male American eel (100X).

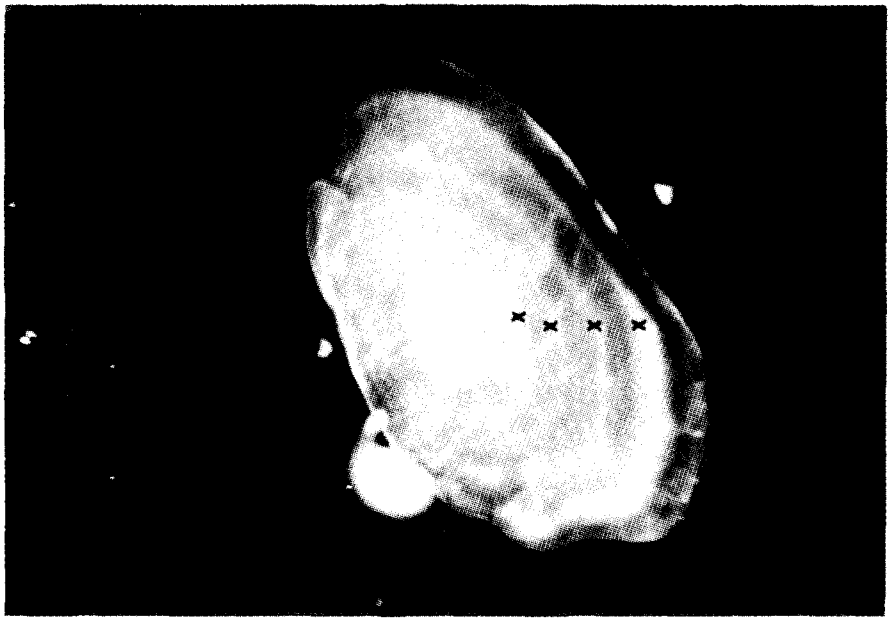

Fig. 3. Otolith of American eel of the Cooper River, South Carolina. (X) marks annuli.

Table 1. Numbers, percentage of each sexual classification, mean age (year), and mean and range of length (mm) of American eels from Cooper River, South Carolina.

	Pinopolis Dam					Wadboo Creek				
				Length					Length	
Sex Class	No.	Percent	Age	Mean	Range	No.	Percent	Age	Mean	Range
Advanced Female	72	27.9	7.6	646	541-834	30	19.1	6.0	543	369-703
Maturing Female	75	29.1	6.1	501	336-794	6	3.8	6.3	513	401-609
Immature Female	57	22.1	4.3	397	280-577	23	14.6	4.4	425	312-514
Male	4	1.5	3.0	257	214-289	2	1.3	3.0	318	314-322
Non-differentiated	50	19.4	1.3	213	98-403	2	1.3	2.5	299	284-315
Not Sexed						94[1]	59.9	4.9	485	290-703
Total	258					157				

[1]79 of these eels were larger than 400 mm and were macroscopically examined and determined to be female. These were not included in sex class data.

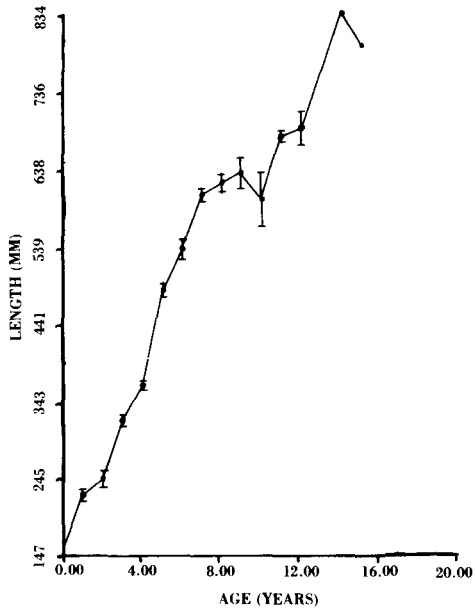

Fig. 4. Length-age relationship of eels caught at Pinopolis Dam. Graph shows mean length/age and standard error of the mean.

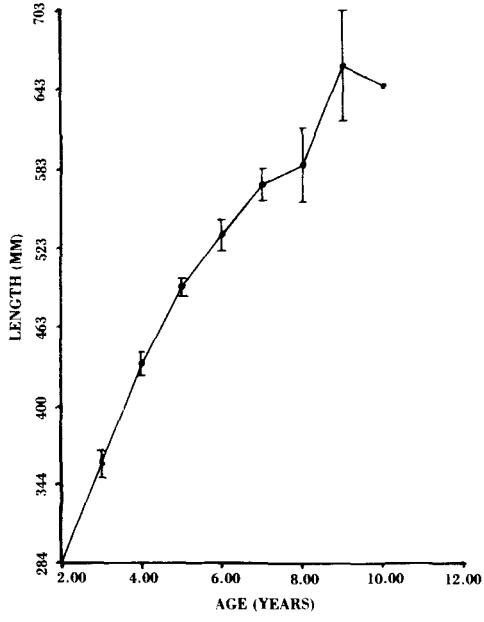

Fig. 5. Length-age relationship of eels caught at Wadboo Creek. Graph shows mean length/age and standard error of the mean.

Advanced females (102) were the most prevalent of the 415 eels captured. The mean age of advanced females was 7.6 yr and 6.0 yr from Pinopolis Dam and Wadboo Creek, respectively (Table 1). This category of fish combined together, in the majority of the cases, to be the most abundant, the oldest and the largest fish collected. Five of the 6 males captured from the 2 sites were taken during August 1976. Advanced females also appeared in large numbers during this time. These males were smaller and younger than females. Average age class for males from the Cooper River was 3.0 yr from both locations. Undifferentiated eels were those small, young individuals in which gonadal tissue was difficult to locate or showed no signs of development.

Advanced females were found all year with most captured in late summer and fall. Immature females were found throughout the collection year. Male eels were found mainly in August 1976 and all males were silver eels.

DISCUSSION

A student's t-test was used to determine significant differences between the 2 regression length-weight lines. The results were positive at $P < .05$. However, due to the closeness in proximity of the 2 sampling sites and considering the sample size, the data obtained were considered to be from the same population. The difference in the 2 lines was probably due to sampling methods. Eels from Wadboo Creek were trapped in eel pots in which the smallest mesh size used was 1.3 cm. Several small eels were observed escaping through these openings. This gear selectivity could also account for lack of small eels in Wadboo Creek samples, as well as bias in catch data. Additionally, the majority of eels from Wadboo Creek were trapped during the summer when they should have been feeding actively, whereas, at Pinopolis Dam, all sizes were caught by electrofishing and sampling was over the entire year. Eels at Pinopolis Dam included those caught in winter when feeding was curtailed. Electrofishing was a less selective method of capture and enabled collection of more eels sizes. Thus, samples from Pinopolis Dam included a greater range of sizes more evenly distributed than those from Wadboo Creek.

Variation in growth of female eels exhibited by large overlaps of 4 age classes correspond to data on eels from Newfoundland (Gray and Andrews 1971), Lake Ontario (Hurley 1972), and Rhode Island (Bieder 1971). Male eels did not show this variation, but this may have been due to the small number of males captured.

In general, Cooper River eels grew at a faster rate than those of Rhode Island (Bieder 1971), Newfoundland (Gray and Andrews 1971), or Lake Ontario (Hurley 1972) (Table 2). The difference may be attributed to the warmer climate and longer growing season present within South Carolina.

The small number of males suggested that male eels are scarce in fresh water or cannot be sexed as male until the silver stage is reached. The presence of few males was consistent with previous published information concerning sex ratio of eels in North American freshwaters (Vladykov 1966, Gray and Andrews 1970, Dolan and Power 1976). Information gathered during this study neither corroborates nor refutes previous publications concerning sexual preference to environmental conditions (Tesch 1928, Bertin 1956). However, since no samples were made in brackish or estuarine waters, the possibility still exists.

Mean age of advanced female eels corresponded with age at which length and weight increases began to diminish. There were a large number of immature females caught during the spring of the year in which the oocytes were of a larger diameter. However, they were still not large or differentiated enough to be classed as advanced females. These eels would probably become advanced females during the next spawning season, especially since their mean age was near advanced females.

Table 2. Comparisons of mean length (cm) of American eels of age classes 0 -XIV from Canada, Rhode Island, Bermuda, and South Carolina.

Location a/	0	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIV
Newfoundland			17.4	22.0	26.0	30.9	39.2	45.6	53.9	62.5	78.3	84.0		
Lake Ontario					30.9		50.9	49.5	43.2	53.2				
Rhode Island					35.2	42.2	41.7	43.9	44.9	46.5	53.2	56.4		
S. Carolina	15.3	22.4	24.9	33.7	40.3	49.0	53.6	59.6	61.2	63.8	50.9	68.0	69.0	83.4
Bermuda		22.6	33.4	41.8	47.2	48.9								

a/Sources:
Newfoundland; Burnt Berry Brook, Gray and Andrews (1971)
Lake Ontario; Hurley (1972)
Rhode Island; Point Judity Pond, Bieder (1971)
Bermuda; Boetius and Boetius (1967)
South Carolina; Present study.

A large number of undifferentiated eels was captured throughout the year and males were caught only at the time of migration of silver eels, an indication that some undifferentiated eels may have been undeveloped males. Since we were unable to accurately sex these eels, this is only a suggestion and not an inference. Even if all undifferentiated eels in the sample were male, the ratio of female to male would be only 5 to 1. This is still too small a ratio to definitively state that males were common in freshwater.

Electrofishing was conducted from September 1975 to September 1976. No male eels were found at Pinopolis Dam until August 1976. If eels did migrate earlier, for example, July and August, the 1975 collection would have been missed completely. No collection was made in July 1976 because of mechanical failures. The 2 collections in August 1976 contained 5 male eels, whereas the following collections in September had none. During the span of 3 months, from the last of June to the last of September, 1 collection was missed, 1 contained males and 1 had no males. The males could have matured and migrated. This could explain why male eels were not caught other than in August.

If environment has no effect on determining sex ratio of eels in Cooper River, then males may still have been present in a state of undevelopment. Captured males were all in the silver phase and were probably migrating. This may account for the August 1976 collection of males.

Small eels were observed escaping through the mesh of eel traps. Since the smallest eel captured by eel pots was 284 mm and range of male eels captured from Cooper River was 214-322 mm, eels of this size range would be expected to escape from pots with the smallest mesh used (1.3 cm). Eels trapped were larger and classified mainly female using macroscopic examination of gonads. This may explain why Wadoo Creek collections did not have more male eels later in the migration season.

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