

Sexual dimorphism and natural movements of the American eel (*Anguilla rostrata*) in Rhode Island streams and estuaries

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KURZFASSUNG: Geschlechtsdimorphismus und Wanderaktivität des Amerikanischen Aales (*Anguilla rostrata*) in Fließgewässern und Flußmündungen von Rhode Island. Der Augendurchmesser männlicher Amerikanischer Blankaale (*Anguilla rostrata*) war beträchtlich größer als derjenige von Amerikanischen Gelbaalen. Blankaalmännchen hatten eine wesentlich geringere Durchschnittslänge als Blankaalweibchen. In kleinen Fließgewässern dominierten die Männchen, in Flußmündungen war der Weibchenanteil vergleichsweise größer. Die Abwanderung ins Meer fand hauptsächlich während der Monate September bis November statt und war verstärkt bei nennenswerten Regenfällen sowie während des dritten und vierten Mondviertels. Die Untersuchungen erbrachten in vieler Hinsicht ähnliche Ergebnisse, wie sie vom Europäischen Aal bekannt sind. Es wird angenommen, daß hinsichtlich der Stimuli für Beginn und Aufrechterhaltung der Laichwanderung eine große Zahl von funktionellen Sicherungen vorhanden ist, welche die Vermehrung gewährleisten.

INTRODUCTION

It is well known that the migration of the adult European eel (*Anguilla anguilla*) occurs around the dark of the moon and that the migratory forms have enlarged eyes (BERTIN, 1956; DEELDER, 1970). Until recently, data on the European species has been applied without substantiation to the American eel (BIGELOW & WELSH, 1925; HILDEBRAND & SCHROEDER, 1928).

The life history of the American eel (*Anguilla rostrata*) is less well documented. It is well known by fishermen that at least females run near the dark of the moon (EALES, 1968). Much less is known about the male due to the fact that the mesh size of commercial traps is not small enough to contain them. Some data have been given on the effects of rain and lunar phase (SMITH & SAUNDERS, 1955). Recently, enlargement of the eye has been demonstrated (VLADYKOV, 1973; WENNER & MUSICK, 1974), and VLADYKOV (1966) has made statements about the distribution of sexes in various environments.

This paper presents data based on fyke net and fishway trap catches from 1967

to 1972 in relation to environmental variables. Eye size and distribution of sexes in freshwater streams and estuaries are shown. The catches for 1967–1968 were presented earlier (WINN & HAMMEN, 1969).

MATERIALS AND METHODS

The horizontal and vertical diameter of the eye was measured in the usual way (BOETIUS & BOETIUS, 1967). The sum of the two diameters was divided by two, and plotted against length. Ninety-nine individuals from all 1969 collecting stations and 85 collected on one day, November 9, 1972, at Station 10, were measured.

Externally, silver eels were recognized by their coloration: almost black backs and pectoral fins, bronze stripe along their sides, and silver bellies. In some cases the bellies were blotched.

The sex of silver eels was determined by gross examination of the enlarged gonads and in some cases by size alone.

Eels were captured by fyke nets with 18 mm mesh or smaller, and with wings of various lengths. In very small streams, the whole brook would be traversed, whereas 3 to 15 m wings only partially covered areas in the estuaries. Various trap locations were as follows: Station 1: entrance of cove entering Ninigret Pond, immediately west of Charlestown Naval Air Station (brackish); Station 2: off Charlestown Beach road above the bridge where Green Hill Pond enters Ninigret Pond (brackish, two traps); Station 3: exit of small pond on northernmost edge of Green Hill Pond (freshwater); Station 4: exit of small stream immediately to west of above station (freshwater); Station 6: in Saugatucket River above Peace Dale Mill and in canal by the mill (freshwater); Station 8: Pettaquamscutt River just below Middle Bridge on east side (brackish); Station 8A: Pettaquamscutt R. opposite southern end of Riverside Drive (brackish); Station 9: in stream about 100 m below the Gilbert Stuart fishway (freshwater); Station 10: fishway of Annaquatucket R. on Route 1A. Exit of Hamilton Reservoir (freshwater); Station 10A: Annaquatucket R. just below fishway on Route 1A (freshwater); Station 11: near exit of Bissel Cove (Annaquatucket R.) into Narragansett Bay (brackish).

In 1971, at Station 10, hourly counts were made of downstream passages with a Smith-Root Model 602 Electronic Fish Counter. The system was described by RICHKUS (1975). In 1969, eels were caught with a fyke net attached to the counter. In 1970, 1971, and 1972, eels were captured by a modified Wolf-type trap (RICHKUS, 1974). The traps were primarily designed to catch juvenile alewives (*Alosa pseudoharengus*).

RESULTS

The relationship of eye size (vertical plus horizontal diameters divided by 2) is plotted against length in Figures 1 and 2. The eels measured in Figure 1 were caught at various stations throughout the fall of 1969, and those for Figure 2 were caught the same day (see "Materials and Methods"). Silver males had an average diameter of

6.4 mm in Figure 1 and 5.5 mm in Figure 2. Yellow male-sized individuals in Figure 1 averaged 4.1 mm. Female-sized yellows in Figure 1 averaged 5.21 mm, silver females in Figure 1, 6.89 mm, and silver females in Figure 2, 6.8 mm. The eyes of the silver males were larger than those of comparably sized yellow eels and almost as large as

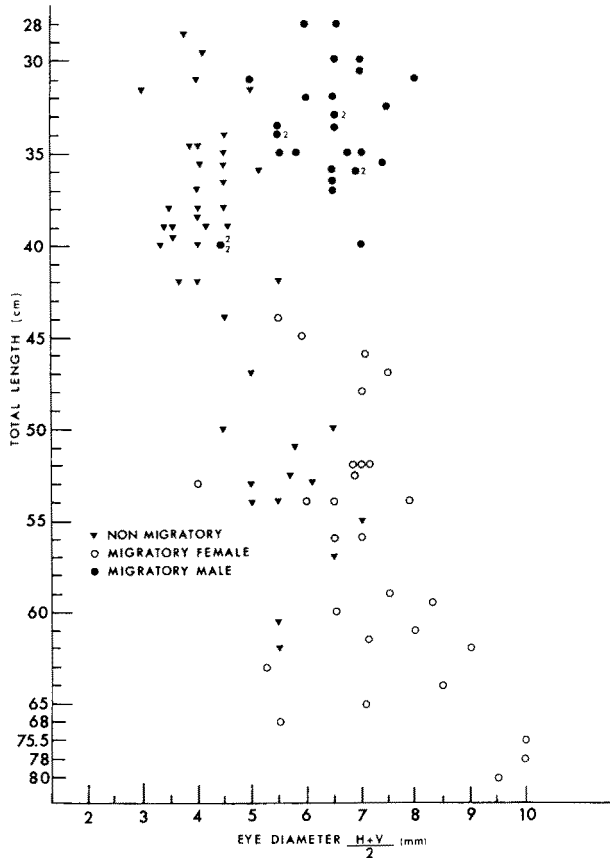


Fig. 1: Eye diameter of *Anguilla rostrata* (horizontal plus vertical divided by 2) plotted against total length of a series of eels caught at various stations in the fall of 1969

the eye of silver females. The data were inadequate to determine whether or not the silver females had slightly larger eyes than comparably sized yellow eels. On an absolute basis, large yellow non-migratory eels had larger eyes than small yellow non-migratory male-sized eels. There was less variation in the one day catch of Figure 2.

Migratory males varied in length from 28 to 40 cm; however, those caught on the same day (Fig. 2) were on the average smaller than those of Figure 1. Females varied from 41 to 80 cm.

In Table 1 the distribution of sexes in various catches is given. All freshwater

stations had a high percentage of males. Except for Station 8, there were fewer males caught in the brackish water stations.

Figure 3 shows that over a 15 month period, most eels were caught in September, October and November. This data includes both silver and yellow eels. There were 169 silver eels caught only in the months of September through December (only 5 in December), and of the 100 yellow eels caught, 72 were obtained from September through December (only 3 in December).

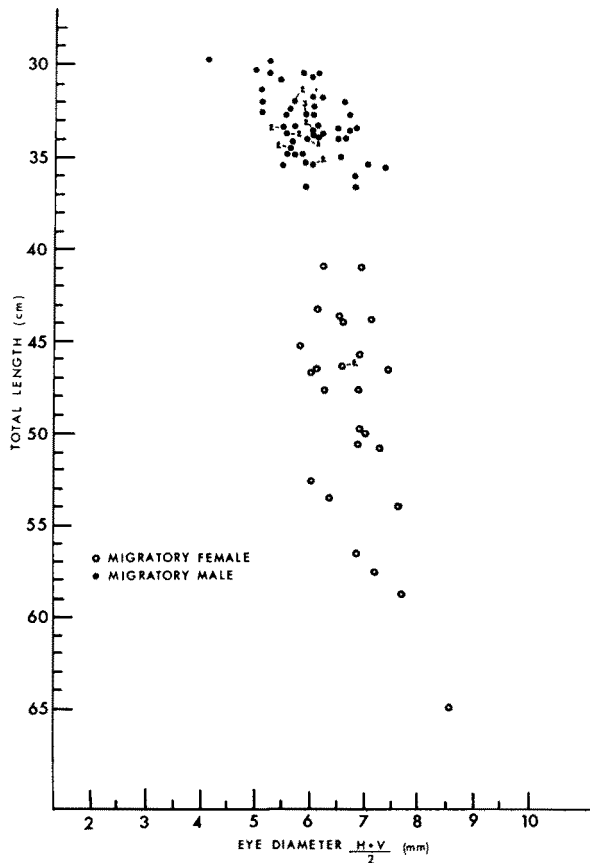


Fig. 2: Similar to Figure 1 but based on a one day collection at Station 10 on November 9, 1972

In Figures 4, 5 and 6, catches were related to rainfall and lunar period. It is obvious that runs occur after heavy rains. It is less obvious that there are larger runs between the full and new moon. Only a few times were there significant runs without rain. One was in a 7 day period around September 22 in Figure 4; another in the 3 day period of October 19 to 22, 1970 in Figure 5; October 25 to 28, 1972 in Figure 5; and November 11, 1970, shown clearly in Figure 7. All occurred between the full and new moon. One small run occurred in August, 1971 (Fig. 5).

Table 1

Anguilla rostrata. Sex ratios at various stations (see "Materials and Methods"). Stations where less than 9 were caught were not included and not all catches at Station 10 were included

Station	Year or date	Fresh or brackish water	Males	Females	Percent of males
2	1967	brackish	6	10	38
8	1967	brackish	11	4	74
9	1967	fresh	12	3	80
11	1967	brackish	4	5	44
6, 6A	1967	fresh	18	4	67
2	1968	brackish	18	19	49
3	1968	fresh	19	0	100
8	1968	brackish	13	2	87
8	1969	brackish	6	8	43
9	1969	fresh	30	0	100
10	1972	fresh			
	October 8		418	22	95
	October 10		90	1	99
	October 17		17	6	74
	October 26		20	6	77
	October 27		11	8	58
	October 29		438	74	86
	October 30		173	43	80
	Total Station 10		1167	160	88

Runs occurred between the beginning of the 1800 h and the end of the 2300 h (Figs 6 and 7). Counts were 295 between the beginning of 1800 and end of 2300 h, and all other hours, 14, on November 7; 43 vs. 6 on November 11; 83 vs. 12 on November 13; and 81 vs. 8 on November 15. Two of the days are not shown in the figures. The actual catches were usually less than the counts but were always correlated.

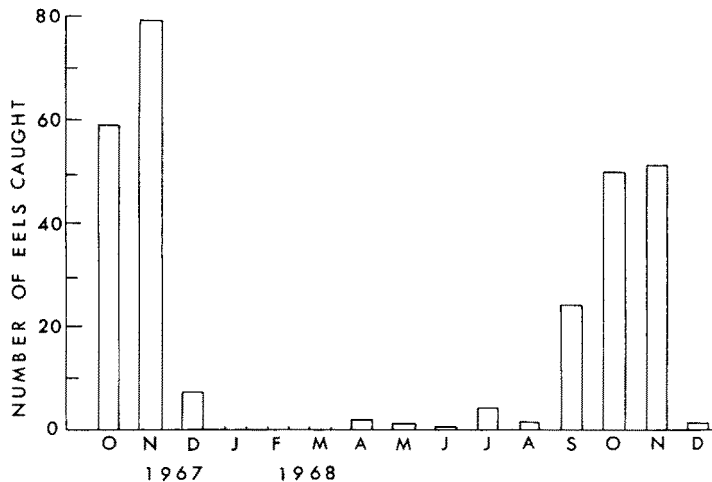


Fig. 3: Catches of eels per month in various passive fyke net traps set over a 15 month period. These were caught at Stations 1, 2, 3, 6, 8, 8A, 9, 10A, and 11

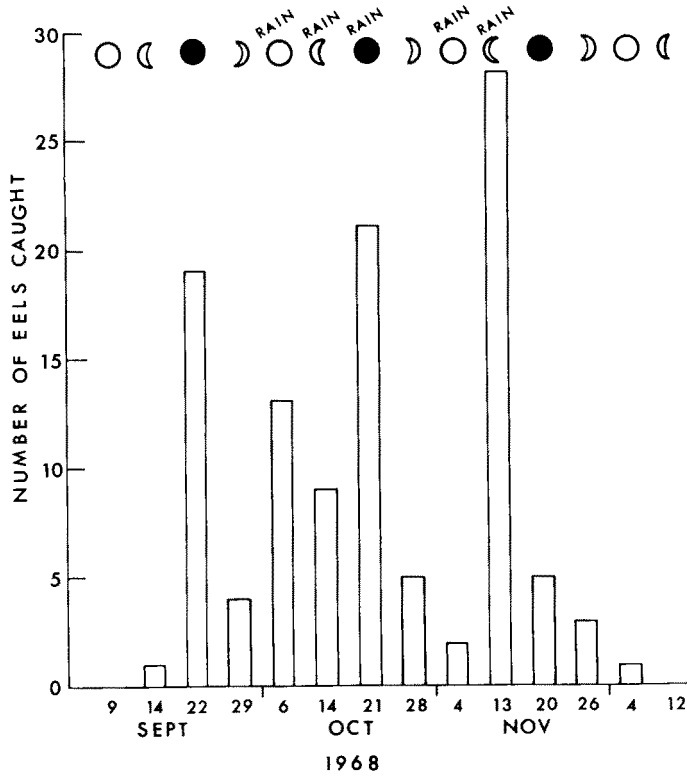


Fig. 4: Number of eels caught in relation to the lunar period and rainfall for 1968. Each bar represents seven days of catch; the date is the center of the 7 day period. These were caught at Stations 2, 3, 4, 6, 8, and 9

DISCUSSION

Only recently has it been shown that the eye of the American eel enlarges. VLADYKOV (1973) measured the enlarged eyes of three museum specimens, at least two of which were males. WENNER & MUSICK (1974) demonstrated that silver males had larger eyes relative to gape length than females and that silver female eyes were slightly larger than yellow eel eyes. The yellow eel sample was not comparable to the silver female sample in average total length, which might make a difference if there was some allometric increase in eye size with length, as shown in Figures 1 and 2. The eyes of silver males were much larger than comparably-sized yellows and essentially the same size as larger yellow and silver females in our sample (Figs. 1 and 2). The largest of silver females appeared to have larger eyes than smaller females and males. Our sample is inadequate to determine differences in eye size between female-sized yellow and silver eels. The greater increase in eye size of the American male eel, as it adds its migratory livery, and leaves the rivers and estuaries, is comparable to the

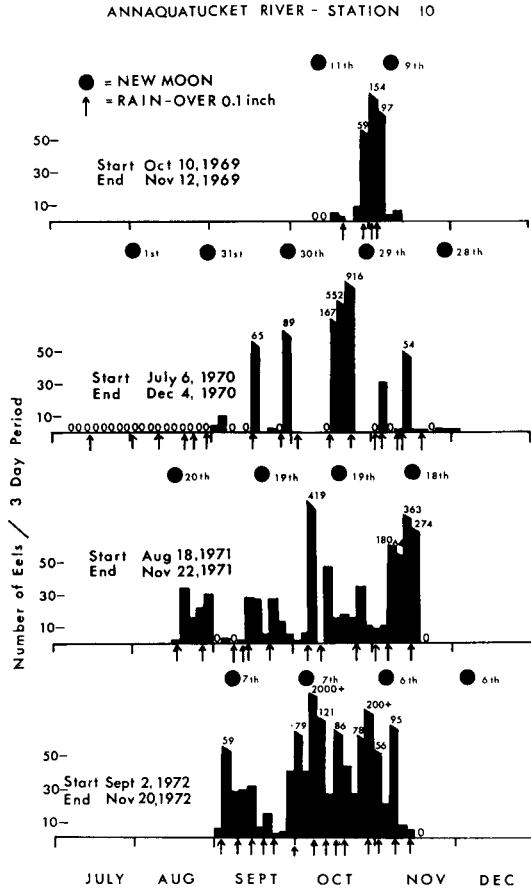


Fig. 5: Catches for three day periods in the Hamilton fishway of Annaquatucket River (Station 10) for four years. If there was a fourth day at the end of a month it was included in the last 3 day period of the month. Starting and ending dates are given along with periods of over 0.1 inches (2.5 mm) of rain. Zeros indicate no catch; dates without a zero or a catch are times the trap was not operating

European eel condition (DEELDER, 1970; TESCH, 1973). In several studies, it was shown that in changing into the silver phase, the male eye increases greatly, and the female eye may increase slightly (BOËTIUS et al., 1962; BOËTIUS & BOËTIUS, 1967). CARLISLE & DENTON (1959) said that the enlarged eye can gather more light. We interpret the increased eye size of the male as an adaptation to gathering dim light in a comparable manner to females on their oceanic migration. It has also been suggested that the increase in eye size is degenerative rather than functional (BERTIN, 1956). Whether female eyes typically enlarge significantly in the seaward phase of the migration is an open question. Several females, caught at sea, had unusually enlarged eyes (SVÄRDSON, 1949; RASMUSSEN, 1951).

The sexual dimorphism of size in our samples is quite similar to that of the

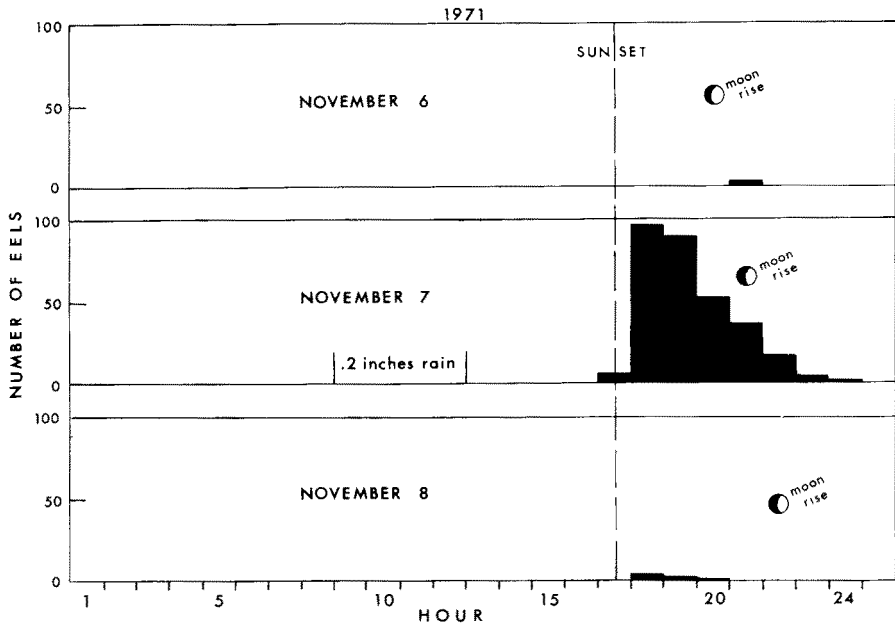


Fig. 6: Hourly counts on the electronic counter for 3 days in the fishway of Annaquatucket River (Station 10) in 1971. Lunar phase is shown

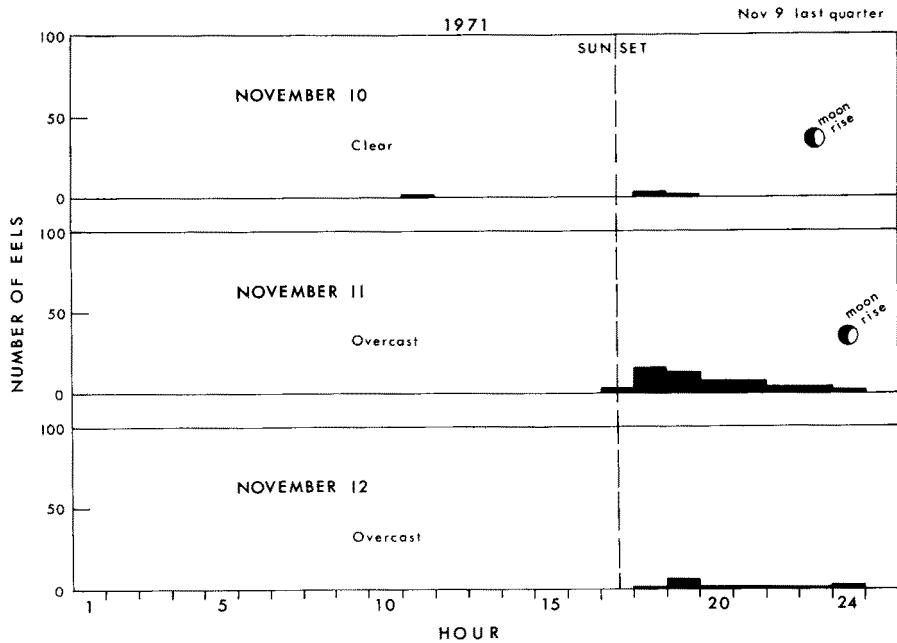


Fig. 7: Hourly counts on the electronic counter for 3 days in the fishway of Annaquatucket River (Station 10) in 1971. Lunar phase is shown

European eel (see summaries in DEELDER, 1970; TESCH, 1973) and to reports on the American eel (WENNER & MUSICK, 1974; VLADYKOV, 1973). The males were somewhat smaller on the average in our samples than for some other studies (DEELDER, 1970).

In Europe, males occur in estuaries and females in large rivers, although there is some variation (for summaries see BERTIN, 1956; DEELDER, 1970; TESCH, 1973). In our area, males predominate in small freshwater streams. Catches of females increased in estuaries and it appears as if males caught in estuaries came from fresh water, because we know males are running out of fresh water at the same time. We suspect, but cannot adequately document, that females would increase in proportion to males in large river systems as is the case in Europe. Large, female yellow eels predominated in our estuarine collections. VLADYKOV's (1966) statements that females are found principally in fresh water and that the proportion of males increases to the south in North America must be discounted. A random sample cannot be demonstrated; nor were samples comparable, due to the complex distribution of sexes in estuaries and fresh water. The mesh size of commercial traps, which provided some of his data, is usually too large to contain males. Apparently, SMITH & SAUNDERS (1955) had many males in their Canadian catches, based on the size of animals in the autumn downstream runs.

In our hourly eel counts, it was clear that most of the eels ran down the fish ladder just after sunset to 2300 hr. Similarly, European eels usually run at the same time (DEELDER, 1970; LOWE, 1952; BRÄUTIGAM, 1961). This coincided with the moon rising later each day in the early hours of the third and fourth quarters, as HAIN (1975) has discussed.

The catches of Figure 3 were very small, which indicates that our traps were inefficient, even when we attempted to block the entire stream. Usually swollen streams destroyed the set, which was when we expected to catch the most eels. Our choice of trap positions, in the shallow estuaries, was completely controlled by boat traffic and we were unable to set them in places we considered desirable. In most cases, the depth of water at high tide was less than five feet.

More yellow eels were captured when silver eel captures increased, but in smaller numbers. This supports HAIN's (1975) contention that even yellow eels exhibit the initial tendencies to migrate under the appropriate environmental conditions. He obtained negative rheotactic responses by both yellow and silver eels under certain conditions.

It has been well documented in Europe that eels run after rains and more often in the third and fourth lunar quarters (DEELDER, 1954; FROST, 1950; LOWE, 1952; see also summaries in TESCH, 1973 and DEELDER, 1970). This is known for the American eel by fishermen (EALES, 1968) and reported by SMITH & SAUNDERS (1955) for eels in the Maritime provinces of Canada. Our catches support these observations. Runs occurred after rains and during the third and fourth lunar quarters when rain is not a factor.

Some European studies (KNÖPP, 1952; summary in DEELDER, 1970) emphasize that multiple factors initiate migratory runs. The environmental effects of rain are multifaceted. Temperature changes, flow increases, turbidity increases, chemical composition of the water changes, and light is reduced. The relation of early evening movement to the absence of moonlight in the third and fourth quarter has suggested light as a causal

factor in releasing the downstream movement. HAIN (1975) triggered movement by darkening tanks. Several authors (BOËTIUS, 1967; JENS, 1953) reported that light is not causal because a lunar related escapement was obtained in tanks darkened for several months. Thus, it would seem clear from HAIN's experiments that light is an exogenous control with an underlying endogenous component. If one were to have three months of complete cloud cover, theoretically, the eels would leave at the proper time due to an endogenous rhythm. Microseisms also have been implicated as a correlated factor (DEELDER, 1954). It cannot be ruled out that other stimuli resulting from rain might be releasing stimuli also (e.g. pressure, chemical changes). Thus the strategy would be a system in which a great deal of redundancy is built in so that no disastrous mistakes are made in the reproductive and final critical phase of their life cycle.

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SUMMARY

1. The eyes of silver males were much enlarged, but not those of female *Anguilla rostrata* specimens.
2. Silver males were smaller than silver females.
3. Males predominated in freshwater and the proportion of females increased in estuaries.
4. In trap catches from 1969 to 1972, most silver eel runs occurred from September through November and came after rains or in the third and fourth lunar quarters. More yellow eels are also caught at this time.
5. Based on records from an electronic fish counter, silver eels moved primarily from just after sundown to 2300 hr.
6. It is suggested that with regard to stimuli initiating migration, a great deal of redundancy is built into the system so that reproduction is assured.

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