University of Rhode Island

DigitalCommons@URI

Open Access Master's Theses

1985

Size, Development of Pigment, Upstream Migration, and Relative Abundance of Young American Eels, *Anguilla rostrata* in a Coastal Rhode Island Stream

Alexander J. Haro

University of Rhode Island

Follow this and additional works at: <https://digitalcommons.uri.edu/theses>

Recommended Citation

Haro, Alexander J., "Size, Development of Pigment, Upstream Migration, and Relative Abundance of Young American Eels, *Anguilla rostrata* in a Coastal Rhode Island Stream" (1985). *Open Access Master's Theses*. Paper 971.

<https://digitalcommons.uri.edu/theses/971>

This Thesis is brought to you for free and open access by DigitalCommons@URI. It has been accepted for inclusion in Open Access Master's Theses by an authorized administrator of DigitalCommons@URI. For more information, please contact digitalcommons@etal.uri.edu.

SIZE, DEVELOPMENT OF PIGMENT, UPSTREAM MIGRATION,
AND RELATIVE ABUNDANCE OF YOUNG AMERICAN EELS,
Anguilla rostrata IN A COASTAL RHODE ISLAND STREAM

BY ALEXANDER J. HARO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
ZOOLOGY

UNIVERSITY OF RHODE ISLAND

1985

MASTER OF SCIENCE DISSERTATION

OF

ALEXANDER J. HARO

Approved:

Dissertation Committee

Major Professor

William H. Krieger
Howard E. Winn
J. Perry Jeffries
Ann H. Durbin
A. A. Michel

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

1985

ABSTRACT

Progressive epidermal pigmentation of Anguilla rostrata elvers in a coastal Rhode Island stream was essentially identical to that described for A. anguilla, and proceeded rapidly in freshwater. Earlier arriving elvers averaged larger than those arriving later in the season, paralleling studies of European elvers. Mean total lengths of elvers collected in 1984 were significantly greater than those for 1983 and are the largest recorded for the Western North Atlantic. These differences may be due to sampling technique. Migration of elvers into freshwater may be induced by decreasing flow rates and/or increasing stream temperatures. The relatively slow upstream migration of elvers in the lower section of the stream (approximately 200 m per month) is attributed to high stream gradient and the presence of obstructions. By late summer and early fall, elvers (age I+) had acquired the coloration typical of yellow eels and had grown 20 to 30 mm larger than elvers arriving in freshwater in late winter and spring. The frequency of II+ and older eels increased with increasing distance from the tidal zone. This indicates that the upstream migration of elvers is limited, and that the colonization of inland waters is accomplished mainly by yellow eels in their second and later years of continental life.

ACKNOWLEDGEMENTS

I wish to thank Dr. William H. Krueger for the initial conception of this research, as well as for his helpful suggestions and critical review of the manuscripts. Drs. Howard Winn and Perry Jeffries also provided appreciated comments and criticism of the thesis. The assistance and support of John O'Brien and William Lapin of the Rhode Island Department of Environmental Management, Freshwater Fisheries Division, is also appreciated. I am also indebted to (in alphabetical order) Tundi Agardy, Suzy Ayvazian, Tony Chatowsky, Maureen Davidson, Numi Goodyear, John Keinath, Nick Servidio and Mary Ann Tilton for assistance with the fieldwork. Special thanks to Pat Serrentino for her encouragement, interest, and tolerance of adverse field conditions. I am also grateful to Donna DeCarlo, who supplied assistance and helpful suggestions regarding graphics. Josh Hayes and Dave Hudson provided much appreciated humor and computer savvy. Thanks also to Drs. Edward Brothers, Robert Barkman, and David Bengston for suggestions regarding otoliths.

PREFACE

In the late winter and spring, elvers of the American eel, Anguilla rostrata (LeSueur), move from estuaries into freshwater streams. After entering continental waters, elvers acquire the coloration characteristic of the yellow eel, which is the primary growth phase. After spending seven to twenty years in freshwater, adult yellow eels metamorphose in the fall into the silver oceanic phase, and migrate to the Sargasso Sea, their presumed spawning place. Nothing is known concerning the exact spawning location or behavior of A. rostrata, but the transparent larvae, or leptocephali, are pelagic and drift northwestward with the Gulf Stream towards continental waters of North America. By January or February of the next year, leptocephali reach the continental shelf, and transform into unpigmented elvers, or glass eels.

Several aspects of the biology of American eels in the Annaquatucket River (Washington County, Rhode Island) have recently been investigated. Such studies have involved distribution of sexes and movements of silver eels (Winn et al., 1975), preadaptation of swimbladder physiology related to seaward migration of silver eels (Kleckner, 1980a, b; Kleckner and Krueger, 1981), and olfaction of elvers (Sorensen, 1984).

This study investigates the upstream migration and changes in morphology of elvers and juvenile yellow eels of A. rostrata within the Annaquatucket. The thesis is divided into two manuscripts. The first manuscript deals with the changes in pigmentation and total length of elvers migrating up the lower 200 m of the stream. The second manuscript investigates the age and length relationships of elvers and juvenile yellow eels at three stations located at points throughout the stream system in an effort to determine the extent of migration of elvers and subsequent age groups. These manuscripts will be submitted for publication in The Journal of Fish Biology.

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
PREFACE.....	iv
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
PIGMENTATION, SIZE, AND RELATIVE ABUNDANCE OF ELVERS (<u>Anguilla rostrata</u> (LeSueur)) IN A COASTAL RHODE ISLAND STREAM	

TITLE PAGE.....	1
ABSTRACT.....	2
INTRODUCTION.....	3
MATERIALS AND METHODS.....	8
RESULTS.....	12
I. Pigmentation of elvers.....	12
II. Lengths of elvers.....	15
III. Arrival and migration of elvers.....	16
DISCUSSION.....	28
REFERENCES.....	34

AGE AND SIZE DISTRIBUTION OF ELVERS AND YOUNG AMERICAN EELS (Anguilla rostrata (LeSueur)) IN A COASTAL RHODE ISLAND STREAM

TITLE PAGE.....	37
ABSTRACT.....	38
INTRODUCTION.....	39
MATERIALS AND METHODS.....	42

RESULTS.....	46
DISCUSSION.....	52
REFERENCES.....	57
BIBLIOGRAPHY.....	59
APPENDIX I.....	64

LIST OF TABLES

Table	Page
PIGMENTATION, SIZE, AND RELATIVE ABUNDANCE OF ELVERS (<u>Anguilla rostrata</u> (LeSueur)) IN A RHODE ISLAND STREAM	
I. Comparison of pigmentation regime established in this study with those of previous studies.....	20
II. Mean total lengths of elvers in each pigmentation stage for 1983 collections.....	23
III. Mean total lengths of elvers in each pigmentation stage for 1984 collections.....	24

LIST OF FIGURES

Figure	Page
PIGMENTATION, SIZE, AND RELATIVE ABUNDANCE OF ELVERS (<u>Anguilla rostrata</u> (LeSueur)) IN A COASTAL RHODE ISLAND STREAM	
1. Annaquatucket River watershed, Washington County, Rhode Island.....	17
2. Elver sampling areas on the lower Annaquatucket watershed.....	18
3. Established pigmentation classifications of elvers used in this study.....	19
4. Frequency distributions of pigmentation stages for 3 elver sampling stations over the 1983 sampling season.....	21
5. Frequency distributions of pigmentation stages for 3 elver sampling stations over the 1984 sampling season.....	22
6. Seasonal changes in total lengths of elvers from 1983 and 1984 collections.....	25
7. Mean total lengths and 95 per cent confidence limits of elvers collected in 1983 and 1984 compared with collections taken in the Annaquatucket in 1982 by J. DiCanzio and with Vladykov's (1966) report of collections from North America.....	26

8. Relative abundance of elvers collected at 3 sites during the 1984 sampling season, with corresponding temperature and water levels.....	27
--	----

AGE AND SIZE DISTRIBUTION OF ELVERS AND YOUNG AMERICAN EELS (Anguilla rostrata (LeSueur)) IN A COASTAL RHODE ISLAND STREAM

1. Sampling stations on the Annaquatucket River watershed, Washington County, RI.....	48
2. Otoliths taken from elvers and yellow eels.....	49
3. Distributions of age classes of elvers (age 1) and yellow eels (ages 2-6) less than 250 mm TL from collections at Mill Pond, Featherbed Lane, and Belleville Pond stations.....	50
4. Distributions of total lengths of elvers and II+ eels from Mill Pond, Featherbed Lane, and Belleville Pond stations.....	51

ABSTRACT

Pigmentation, Size, and Relative Abundance of
Elvers (Anguilla rostrata (LeSueur)) in a
Coastal Rhode Island Stream

by

Alexander J. Haro

Department of Zoology

University of Rhode Island

Kingston, Rhode Island 02881 USA

ABSTRACT

Progressive pigmentation of Anguilla rostrata elvers in a coastal Rhode Island stream was essentially identical to that described for A. anguilla, and proceeded rapidly in freshwater. Earlier arriving elvers averaged larger than those arriving late in the season, paralleling studies of European elvers. Mean total lengths of elvers collected in 1984 were significantly greater than those for 1983 and are the largest recorded for the Western North Atlantic. These differences may be due to sampling technique. Migration of elvers into freshwater may be induced by decreasing flow rates and/or increasing stream temperature. The main concentration of elvers took about one month to ascend 200 m upstream from the tidal zone. The relatively slow migration of elvers in this small stream is attributed to high stream gradient and the presence of obstructions.

Introduction

In the late winter and spring, elvers of the American eel, A. rostrata, move from estuaries towards mouths of freshwater streams. During this phase of their migration elvers gradually acquire epidermal pigmentation and ascend flowing waters, negotiating obstructions to their progress by various means. Elvers then begin to acquire the coloration characteristic of the yellow eel, which is the primary growth phase. However, little is known about upstream movements of A. rostrata beyond a few anecdotal observations (Sheldon, 1974). No previous investigation has specifically addressed upstream movements of elvers of this species and related changes in their morphology, although considerable work in this area has been performed for the European eel and some South Pacific species.

The works of Grassi (1913) and Schmidt (1906) provided the fundamental studies of development and distribution of leptocephali and glass eels of the closely related European eel, Anguilla anguilla, which formed the basis for most later studies of early Anguilla life histories. Schmidt's work, and also that of Gilson (1908) established a detailed pigmentation classification for developmental stages of early leptocephalus to early yellow eel. Strubberg (1913) used a somewhat simplified version of Schmidt's and Gilson's classifications in shipboard experiments to investigate

changes in elver pigmentation associated with various environmental factors. Strubberg found that the rate of pigmentation in elvers increased with water temperature, but was not significantly affected by salinity or incident light. Boetius (1976) used a pigmentation classification modified from Strubberg's for both A. anguilla and A. rostrata elvers present in his collections from Denmark. Boetius did not note differences in pigmentation between the species. Charlon and Blanc (1982) extended Strubberg's experimental conclusions concerning pigmentation and water temperature, noting a pigmentation rate increase in A. anguilla elvers entering warmer fresh water as opposed to delayed pigmentation in elvers from colder coastal water.

Strubberg (1913) also noted a reduction of lengths of A. anguilla elvers with the development of pigment, and cited time and/or temperature as the probable causative agents. Similar conclusions have also been drawn by others (Grassi and Calandruccio, 1897; Schmidt, 1906; Menzies, 1936; Parsons et al., 1977) However, Boetius (1976) and Charlon and Blanc (1982) attributed the observed decreases in length to later arriving elvers being shorter. Boetius theorized that these elvers metamorphosed in an area more distant from freshwater than those that had arrived earlier, and thus had a longer migration.

Vladykov (1966) described an increase in mean total length of A. rostrata elvers with latitude along the coast of eastern North America. Distribution of elver length-class frequencies from various collection sites led Vladykov to believe that male and female elvers had different mean lengths and different latitudinal distributions. Relative abundances of male and female adult eels along this same latitudinal region were cited as evidence for this hypothesis, yet there is no karyological work with elvers to support it.

Documentation of arrival of A. rostrata elvers at coastal sites has been limited. Jeffries (1960) provided data from historical collections describing incidental records of elvers entering coastal waters of northeastern North America from early January to late August. Variation in arrival dates of these elvers may have been due to the dispersal of leptocephali by wandering Gulf Stream currents. Because the timing of elver run peaks may also vary from year to year (Sheldon, 1974), environmental influences may play a major role in the distribution of leptocephali and elvers. Smith (1968) described a collection of elvers taken on 19 January in Florida, and suggested that the ascent of freshwater in Florida occurs earlier than it does farther north.

Invasion of freshwater by A. rostrata is thought to be similar to that of A. anguilla, for which many studies of upstream migration exist. Upstream movement of elvers by tidal transport in estuarine areas has been shown for European (Deelder, 1952; Creutzberg, 1958; McCleave, 1980) and also American (McCleave and Kleckner, 1982) eel elvers. Deelder (1958) provided descriptions of changes in migratory behavior and response to salinity in A. anguilla elvers once they had arrived at a boundary area between the outlet of a stream and a tidal area. Factors affecting the movements of elvers into streams can be complex. Sorensen (1951) stated that upstream migration of A. anguilla elvers was initiated when a stream reached a certain threshold temperature of approximately 15 C. Other cues which appear to initiate upstream migration in elvers of various species of Anguilla have included lunar cycles (Gollub, 1959; Jellyman, 1979), rainfall and/or stream size (Jellyman and Ryan, 1983), intensity of daylight and current velocity (Sorensen, 1951; Sloane, 1984a, 1984b), and high spring tides (Matsui, 1952; Sorensen, 1984).

Progress of elvers upstream can be rapid. A. anguilla elvers have been observed to move upstream at the rate of 1 to 3 kilometers per month (Parsons et al., 1977). However, their upstream migration can also be inhibited by environmental conditions. McCleave (1980) determined that A. anguilla elvers could not progress against currents

greater than 50 cm per second, and inferred that movement upstream was facilitated by elvers alternating between burst swimming and utilization of bottom topography (i. e. resting behind rocks, boulders, etc.) or burrowing into bottom sediments. Dams and other man-made structures, as well as natural ones, also impede the upstream progress of elvers and young eels (Ogden, 1970; Hurley, 1973; Sheldon, 1974; Parsons et al., 1977).

This study investigates several aspects of the biology of A. rostrata elvers within a coastal stream in Rhode Island, specifically: 1) Development of pigment in elvers, both throughout the season of migration and from year to year, 2) comparison of total lengths of elvers arriving at and ascending the stream over these same time and distance parameters and 3) relative abundance of elvers within sections of the stream throughout the season of migration.

Materials and Methods

Elvers were collected from the Annaquatucket River watershed, Washington County, Rhode Island ($41^{\circ} 33' N$; $76^{\circ} 26' W$; Fig. 1). The watershed drains approximately 52 square Km, and the main portion of the river is approximately 9 Km long, containing several impoundments created by damming in the 1800's (Guthrie and Stolgitis, 1977).

Elvers were collected at three stations between Mill Pond and Bissel Cove (Fig. 2) during the day at low tide. The Tidal station represents the junction of the fresh water of the Annaquatucket with the estuarine water of Bissel Cove. During high tide, water levels at the Tidal station average 0.5 m higher than at low tide, and the river itself is relatively slow-moving. At low tide, the water moves rapidly and is completely fresh. The Epitidal station was approximately 30 m upstream from the Tidal station and exhibited no tidal influence. The Fishway station was located 180 m upstream from the Tidal and 20 m below the fishway at Mill Pond dam. Elvers reaching this station would be considered entirely acclimated to fresh water. Stream depth at all three stations was approximately 0.25 to 0.5 m (at low tide). Stream width ranged from approximately 5 to 10 m depending on location, tide, and stream flow. Bottom type at these locations consisted of a mixture of

sand, gravel, and cobble. Once elvers had been collected at the Fishway station, additional surveys for the presence of elvers were made below Featherbed Lane, but no elvers were collected at this upstream site during the spring sampling period.

Sampling was conducted 30 March to 28 May, 1983 and 27 January to 19 June, 1984. In 1983 elvers were captured by dipnetting through the upper 5 to 10 cm of stream bottom sediment. The dipnet consisted of a circular frame 28 cm in diameter with a shallow 1 mm mesh bag. Approximately 50 percent of the catch from each station was placed into 95 percent ethanol solution. The remainder of the catch was placed in 10 percent formalin buffered with 10 g of sodium bicarbonate to 100 ml of formalin solution. Formalin specimens were fixed for not less than 72 hours and transferred to 70 percent ethanol solution. Because ethanol induces shrinkage of specimens, total lengths of elvers in the two different preservative concentrations were compared. Although elvers preserved in 70 percent ethanol averaged larger (mean TL = 56.818, n = 764) than those preserved in 95 percent ethanol (mean TL = 56.384, n = 610), this difference was not significant (t-test, $p < 0.05$).

The majority of elvers caught during the 1984 season were obtained using a Smith Root Type VII electrofisher. Control settings on the electrofisher were held at 400 volts, 60 Hz frequency and 6 ms pulse width for each sample. Sections of stream approximately 8 m in length were electrofished in a downstream direction over a 1 m wide swath. At the downstream end of each electrofishing area, a one-sixteenth inch nominal mesh seine (6 ft width, 2 ft by 2 ft bag) was stretched between two steel pipes driven into the stream sediment approximately 1 m apart. Each area was electrofished for an approximately equal amount of time. Once the electrofisher was moved downstream and had arrived at the net, the net was removed from the water onto the bank and elvers were extracted by hand. Fish were anesthetized with MS-222 to enhance straightening, fixed in 10 percent buffered formalin and then transferred to 70 percent ethanol.

During the 1984 season, stream level was recorded to the nearest centimeter at a water level gauge above the Mill Pond dam that had been installed by the Rhode Island Department of Fish and Wildlife. Temperature of the stream was also recorded to the nearest 0.5°C during 1984 using a hand-held thermometer in mid-stream below the Mill Pond dam.

All elvers in the 1983 samples were used in the analyses, but in 1984 large collections were subsampled by removing 100 specimens at random. To evaluate the validity of this methodology, a subsample of 100 fish was selected from a sample of 227. No significant difference was found between the mean total length of the subsample and that of the entire sample of 227 (t-test, $p > 0.05$). Total lengths were measured with dial calipers to the nearest 0.1 mm.

Pigmentation stages of elvers were identified by direct viewing under a binocular dissecting microscope at 15X magnification. The range of pigmentation stages of elvers was assessed for both yearly samples, and a pigmentation stage regime was derived based on previous classifications by Strubberg (1913), Boetius (1976), and Charlon and Blanc (1982). Complete descriptions of each derived pigmentation stage and a rationale for their selection are given in the Results section. Analyses of length and pigmentation data were performed using the Statistical Analysis System (SAS Institute, 1982).

Results

I. Pigmentation of elvers

The epidermal pigmentation of Annaquatucket elvers was very similar to that described for A. anguilla. The earliest-arriving elvers all possessed the head pigmentation or "tache cerebrale" of European elvers entering freshwater. Caudal pigment was always present, and no elver was wholly unpigmented. A pigmentation regime of seven stages was established so that the entire spectrum of the pigmentation range of the collected sample would be represented, and each stage could be recognized with a minimum of discrepancy between stages (Fig. 3). Comparisons of this regime with other historical classifications are given in Table I.

The following descriptions of each pigmentation stage are based on the degree of epidermal pigmentation on the body and fins in the region between the origins of the dorsal and anal fins:

Stage 1

No pigment present on any part of the body between the dorsal and anal fin origins.

Stage 2

Pigment uniformly distributed along the dorsal surface of the body between the dorsal and anal fin origins, but not extending laterally beyond the angles formed by the apices of the dorsal posterior cone myosepta.

Stage 3

Progression of pigment ventrally along each myoseptum, but not extending to the lateral line. Intermyoseptal pigment may or may not be present.

Stage 4

Pigmentation present on dorsolateral surfaces, including but not extending below the lateral line, and following this structure between the myosepta, forming a distinct line of pigment. Intermyoseptal pigment on the dorsolateral surfaces usually present.

Stage 5

Pigment extending below the lateral line to midway between the lateral line and the angles formed by the apices of the ventral posterior cone myosepta. Intermyoseptal pigment always present on dorsolateral surfaces, but pigment always more intense along the myosepta in this area.

Intermyoseptal pigment on ventrolateral surfaces may or may not be present.

Stage 6

Pigment present from halfway between the lateral line and the angles formed by the apices of the ventral posterior cone myosepta to the posterior cone myosepta themselves. Some pigment extending below this area along the myosepta, forming an irregular ventral margin of pigment. Dorsolateral surfaces uniformly pigmented. Intermyoseptal pigment usually present below the lateral line, but the myosepta themselves usually distinctly pigmented. Pigment on the base of the dorsal fin may or may not be present.

Stage 7

Similar to Stage 6, except that previously pigmented surfaces of the body are uniformly pigmented, without distinctly pigmented myosepta. Ventral margin of pigment forming a distinct line. Base of dorsal fin usually pigmented, while the base of the anal fin may or may not be pigmented.

Elvers became progressively more pigmented with the advancing season at all three stations in both years (Figs. 4,5). Comparisons of mean total lengths for each pigmentation stage are provided in Tables II and III.

II. Lengths of elvers

Total lengths of elvers showed a decreasing trend over time (Fig. 6). Total length distributions between sampling stations were usually not significantly different (t-tests, $p < 0.05$) for any given sample date for either year. The 95 percent confidence intervals for each sampling site indicate that mean total lengths of elvers collected in 1984 were usually greater than those caught in 1983 for comparable dates. Overlapping confidence intervals are probably due to high variances induced by small sample sizes ($n = 16$ for 23 April, 1983; $n = 19$ for 7 June, 1983). Figure 7 compares total length distributions of all elvers collected in 1983 and 1984 with collections from the same area of the Annaquatucket during the spring of 1982 by a previous investigator (J. DiCanzio, unpublished data), and with data from Vladykov's (1966) collections from North America. Although elvers collected in 1983 are not significantly larger than those from 1982 (t-test, $p > 0.05$), mean total lengths of 1984 elvers are significantly greater (t-test, $p < 0.05$) and are the largest reported for North America.

III. Arrival and migration of elvers

Elvers were first collected at the tidal and epitidal sites on 30 March, 1983, which was the first sampling date for this season. Elvers first appeared at the fishway site on 16 April, 1983. In 1984, elvers were first collected at the Tidal station on 30 January, three days after sampling had begun. Elvers first appeared at the epitidal site on 14 March, and at the fishway site on 23 April. Figure 8 shows relative abundances of elvers collected at each site during the 1984 season from 14 March to 19 June, along with corresponding temperatures and water levels. Peak abundances of elvers at the Tidal and Epitidal stations occurred on 23 April, while numbers of elvers at the Fishway station did not reach a peak until 20 May. Thus, the period of movement of the main elver mass from the Tidal and Epitidal stations to the Fishway station is presumed to have occurred between these two dates. This same time period coincides with the greatest increase in stream temperature (from 10.5 to 21.5°C) and the lowest water levels (5 or more cm below the datum) for the sampling period. Relative abundances of elvers at the Tidal and Epitidal stations decreased to less than 2.5 percent after 4 June, while the relative abundance of elvers at the Fishway station declined to 13 percent after this date.

Figure 1. Annaquatucket River watershed, Washington County, Rhode Island. Shaded areas indicate marine or estuarine zones.

Figure 2. Elver sampling areas on the lower Annaquatucket watershed. Shaded regions depict areas of tidal influence.

Figure 3. Established pigmentation classifications of elvers used in this study.

Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

Stage 6

Stage 7

Table I. Comparison of pigmentation regime established in this study with those of previous studies.

This Study	Strubberg, 1913	Boetius, 1975	Charlon and Blanc, 1982
1	VB	A	1
2	VI AI, 1	B	2
3	VI AII, 1- VI AII, 4	C	3
4	VI AIII, 1- VI AIII, 3	C	3, 4
5	VI AVI, 1- VI AVI, 3	D	4
6	VI AVI, 4	D	5, 6
7	VI B, 1	E	7

Figure 4. Frequency distributions of pigmentation stages for 3 elver sampling stations over the 1983 sampling season. Column A: Tidal station, Column B: Epitidal station, Column C: Fishway station. Only samples where $n > 10$ are included.

Figure 5. Frequency distribution of pigmentation stages for 3 elver sampling stations over the 1984 sampling season. Column A: Tidal station, Column B: Eptidal station, Column C: Fishway station. Only samples where $n > 10$ are included.

Table II. Mean total lengths of elvers in each pigmentation stage for 1983 collections. Numbers in parentheses indicate sample sizes for individual collections from given dates.

Date	n	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
3/30	11	-	57.23 (9)	59.50 (2)	-	-	-	-
3/31	10	60.00 (1)	57.93 (6)	56.10 (3)	-	-	-	-
4/2	15	-	55.55 (2)	57.46 (11)	61.10 (1)	57.40 (1)	-	-
4/8	98	58.00 (1)	57.29 (29)	58.19 (55)	57.24 (13)	-	-	-
4/16	189	58.45 (6)	58.38 (11)	57.53 (84)	57.26 (70)	55.98 (16)	53.85 (2)	-
4/23	128	58.67 (3)	59.17 (13)	57.29 (61)	55.63 (38)	55.48 (13)	-	-
4/30	257	56.20 (1)	56.94 (10)	56.72 (47)	56.82 (76)	57.00 (109)	56.14 (14)	-
5/7	287	-	-	54.60 (6)	56.24 (49)	56.28 (167)	56.69 (60)	54.72 (5)
5/14	229	53.65 (2)	55.73 (3)	54.83 (10)	56.23 (27)	55.97 (137)	56.67 (42)	54.78 (8)
5/28	121	-	-	55.25 (2)	55.0 (6)	55.98 (54)	56.16 (39)	55.00 (20)
6/7	30	-	-	-	-	55.42 (11)	56.03 (15)	56.05 (4)

Table III. Mean total lengths of elvers in each pigmentation stage for 1984 collections. Numbers in parentheses indicate sample sizes for individual collections from given dates.

Date	n	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
2/27	24	60.43 (23)	64.00 (1)	-	-	-	-	-
3/7	6	61.92 (5)	60.60 (1)	-	-	-	-	-
3/14	101	61.52 (62)	59.88 (27)	60.90 (9)	58.23 (3)	-	-	-
3/26	103	60.22 (72)	59.16 (23)	57.76 (7)	48.90 (1)	-	-	-
4/9	200	62.20 (19)	60.77 (60)	60.83 (111)	60.28 (8)	58.60 (1)	64.30 (1)	-
4/23	207	59.35 (17)	58.77 (22)	59.56 (76)	58.70 (58)	58.01 (34)	-	-
5/7	254	-	-	61.25 (11)	60.18 (52)	58.71 (172)	59.73 (19)	-
5/20	300	-	-	59.49 (8)	60.20 (10)	58.90 (184)	59.25 (90)	57.51 (8)
6/4	105	-	55.66 (5)	60.37 (3)	54.40 (1)	58.42 (25)	57.32 (54)	58.40 (17)
6/19	121	-	-	-	-	57.18 (14)	58.11 (68)	58.00 (39)

Figure 7. Mean total lengths (vertical bars) and 95 percent confidence limits (rectangles) of elvers collected in 1983 and 1984 compared with collections taken in the Annaquatucket in 1982 by J. DiCanzio and with Vladykov's (1966) report of collections from North America. Numbers in parentheses indicate sample size of each collection.

50 52 54 56 58 60

TOTAL LENGTH (mm)

Figure 8. Relative abundance of elvers collected at 3 sites during the 1984 sampling season, with corresponding temperature and water levels. Water levels are measured from an arbitrary datum.

Discussion

Progressive pigmentation in A. rostrata elvers was nearly identical to that of European eel elvers. The only difference noted was that A. rostrata obtained pigment on the base of the dorsal fin somewhat later than A. anguilla. However, fin pigmentation was highly variable in the timing of its appearance among individuals. Anal fin pigment was noted only on those elvers arriving later in the season and generally among fish in poor condition. Since most yellow eels lack pigment on the area of the anal fin origin, pigment formation in this area may occur more frequently in elvers which arrive in poor condition or are parasitized. Trematode parasites were commonly observed infecting the pericardial regions of later-arriving elvers possessing this extension of pigmentation development. No elvers were completely unpigmented, which indicates that A. rostrata elvers first develop cerebral and caudal pigment offshore, as has been noted for A. anguilla (Bertin, 1956).

All elvers were more pigmented as the season progressed, regardless of location within the stream (Figs. 4, 5). On any one sampling date, the modes of the pigmentation stage distributions from the Tidal, Epitidal, and Fishway stations were usually the same. This suggests that elvers in all parts of this lower section of the stream are affected equally by the environmental influences on

their pigmentation. Stream temperature may be a primary factor, and was comparable at all three stations on each sampling date. Also, the largest increase in modal pigmentation stage of elvers captured at the Tidal station in 1984 occurred between 23 April and 7 May (Fig. 5), when stream temperature increased at its highest rate for the season (Fig. 8). Clearly, there is a strong association between stream temperature and the rate at which elvers recruit pigment. In addition, later arriving elvers tend to be more pigmented, which suggests that initiation of pigmentation takes place further offshore as the season progresses and the temperature of coastal waters increases.

Regardless of time or temperature, most elvers were highly pigmented (Stage 4 and beyond) by the time they reached the Fishway station. This rapid pigmentation of elvers soon after they enter freshwater may be an adaptation of elvers to a benthic habitat where cryptic pigmentation plays an important role. Elvers collected above Mill Pond in summer and fall (Haro, second manuscript) had developed the coloration typical of small yellow eels.

Reduction in elver mean total length over time also reiterates previous studies with A. anguilla. Since development of pigment is not highly correlated with length, it is likely that this trend of decreasing length is due to smaller sizes of later-arriving elvers rather than a

metamorphosis or "shrinking" of individual fish. Differences in mean total length of elvers between collecting stations are not evident (Fig. 6), since there is great variability in sizes of elvers within any single collection, and the reduction in size is fairly gradual as the season progresses. Also, it is not likely that individual elvers remained in a particular sampling area for any great period of time; thus the collections represent successive groups of elvers migrating upstream.

Mean total lengths of elvers from pooled collections for each year are unexpectedly dissimilar to published data. Although the 1983 collections consist of elvers of the size that one would expect from Vladykov's (1966) report of sizes of elvers taken from the Northwestern Atlantic (Fig. 7), elvers from the 1984 collection averaged longer than Vladykov's specimens from Nova Scotia, which were the largest from his series. Some of Vladykov's collections were stored for up to eight years before they were measured; therefore his estimates of mean total length may have been affected by shrinkage. The much greater mean total length of elvers caught in 1984 versus 1983 may be due to sampling selectivity, since elvers were captured by dipnetting in 1983 and by electrofishing in 1984. Samples taken in 1982 by J. DiCanzio were also collected with a dipnet, and are comparable in size to 1983 elvers (Fig. 7). The two collections of this study (1983 and 1984) may

represent a true natural difference in size of elvers from the two different year classes, but there is strong evidence for sampling bias between the two methodologies.

Arrival of elvers and their subsequent movement upstream also appear to be regulated by environmental factors. Such factors are, however, not entirely limiting. This is evidenced by the collection of a 57.8 mm elver in pigmentation stage 5 below Mill Pond on 6 November, 1983. Such an appearance of elvers "out of season" indicates that they may arrive on the coasts of North America throughout the year, yet only in substantial numbers during the spring months. Sloane (1984a) observed similar year-round arrivals of A. australis elvers in Tasmanian streams.

Although the rate of upstream migration could not be precisely defined, the main concentration of elvers seems to take about one month to move from the Tidal and Epitidal stations to the Fishway station. In comparison, Sorensen (1984) postulated that it took elvers several weeks to pass a 400 m stretch of Gilbert Stuart Brook, which has a gradient similar to that of the Annaquatucket. Upstream movements of elvers may be mediated by temperature and/or water level. Temperatures greater than 10°C have been noted to initiate upstream migration of elvers (Sorensen, 1951; Smith, 1955; Mann, 1963). This generalized "threshold" temperature correlates closely with the

temperature increase associated with the greatest amount of movement of elvers from the Tidal to Epitidal stations (from 10.5 to 21.0°C). Decreased water levels (and thus decreased current velocities) may encourage upstream movement of elvers which had previously been hindered in their progress at the Tidal station by heavy spring runoff. However, some elvers were found in areas that had been flooded above the stream banks by high water levels. Under these circumstances, elvers may facilitate their upstream progress by moving through these flooded areas away from the main current. Thus water level may affect elver movement upstream positively or negatively depending on habitat type (low banks which become flooded versus high banks which do not). Elvers migrating from the tidal zone may also time their ascent based on spring tides or lunar cycles (Jellyman, 1979; Sorensen, 1984), but these effects are difficult to correlate precisely with the results from this study since samples were taken only once every two weeks.

The morphological changes in A. rostrata elvers associated with upstream migration, as well as the effects of stream temperature, gradient, and water level are comparable to those described for other species of Anguilla. The similarity between species at this particular life history stage is not surprising, since the environmental conditions that elvers encounter in migrating upstream are about the same for most streams and rivers that these

species enter as juveniles. However, the rate at which A. rostrata elvers ascend the lower section of the Annaquatucket is much less than that reported in most cases for A. anguilla. This phenomenon may be due to the high gradient and current velocity of the Annaquatucket in this lower region. These conditions are in direct contrast to those found in larger rivers with lower gradient and current velocities (especially near banks) where extensive movements of elvers have been observed. Tidal transport of elvers in larger rivers may also account for a large portion of the distance that elvers migrate upstream in these systems. Thus, the physical nature of a stream or river and the specific environmental conditions that elvers encounter while migrating upstream may dictate the speed and distance of their ascent.

References

- Bertin, L. 1956. Eels, a biological study. Cleaver-Hume Press, London, 192 pp.
- Boetius, J. 1976. Elvers, Anguilla anguilla and Anguilla rostrata from two Danish localities. Size, body weight, developmental stage and number of vertebrae related to time of ascent. Meddr. Danm. Fisk. Havunders., 7: 199-220.
- Charlon, N. and J.M. Blanc. 1982. Etude des civelles d'Anguilla anguilla L. dans la region du bassin de l'Adour. 1. Caracteristiques biometriques de longueur et de poids en fonction de la pigmentation. Arch. Hydrobiol., 93(2): 238-255.
- Creutzberg, F. 1958. Use of tidal streams by migrating elvers (Anguilla vulgaris Turt.). Nature, 181: 857-858.
- Deelder, C.L. 1952. On the migration of the elver (Anguilla vulgaris Turt.) at sea. J. Cons. perm. int. Explor. Mer, 18: 187-218.
- . 1958. On the behaviour of elvers (Anguilla vulgaris Turt.) migrating from the sea into fresh water. J. Cons. perm. int. Explor. Mer, 24: 135-146.
- Gilson, G. 1908. L'anguille, sa reproduction ses emigrations et son interet economique en Belgique. Annls. Soc. r. zool. malacol. Belg., 42: 7-58.
- Gollub, H. 1959. Uber die im Bezerk Schwerin durchgefuehrten Aalforderungsmabnahmen. Dt. FischZtg. Radebeul, 6: 86-89.
- Grassi, B. 1913. Metamorphosi dei Murenoidi. Jena. Verlag von Gustav Fischer.
- , and S. Calandruccio. 1897. Riproduzione e metamorphosi delle anguille. Giorn. ital. Pesca e Aquic., 7: 139-208.
- Guthrie, R. and J. Stolgitis. 1977. Fisheries investigations and management in Rhode Island lakes and ponds. R. I. Dept. of Nat. Res., Fisheries Rept. No. 3. 256 pp.
- Hurley, D.A. 1973. The commercial fishery for the American eel, Anguilla rostrata (LeSueur), in Lake Ontario. Trans. Am. Fish. Soc., 1973(2): 369-377.

- Jeffries, H.P. 1960. Winter occurrences of Anguilla rostrata elvers in New England and middle Atlantic estuaries. *Limnol. Oceanog.*, 5(3): 338-340.
- Jellyman, D.J. 1979. Upstream migration of glass-eels (Anguilla spp.) in the Waikato River. *N. Z. J. Mar. Freshw. Res.*, 13(1): 13-22.
- _____, and C.M. Ryan. 1983. Seasonal migration of elvers (Anguilla spp.) into Lake Pounui, New Zealand, 1974-1978. *N. Z. J. Mar. Freshw. Res.*, 17: 1-15.
- Mann, H. 1963. Beobachtungen uber den Aalaufsteig in der Aalleiter an der Staustufe Geesthacht im Jahre 1961. *Fischwirt.*, 13: 182-186.
- Matsui, I. 1952. Studies on the morphology, ecology and pondculture of the Japanese Eel (Anguilla japonica Temminck u. Schlegel). *J. Shimonoseki Coll. Fish.*, 2(2): 1-245.
- McCleave, J.D. 1980. Swimming performance of European eel (Anguilla anguilla (L.)) elvers. *J. Fish Biol.*, 16: 445-452.
- _____, and R.C. Kleckner. 1982. Selective tidal stream transport in the estuarine migration of glass eels of the American eel (Anguilla rostrata). *J. Cons. perm. int. Explor. Mer.*, 40: 262-271.
- Menzies, W.J.M. 1936. The run of elvers in the River Bann, Northern Ireland. *J. Cons. perm. int. Explor. Mer.*, 11: 249-259.
- Ogden, J.C. 1970. Relative abundance food habits, and age of the American eel, Anguilla rostrata (LeSueur), in certain New Jersey streams. *Trans. Am. Fish. Soc.*, 99: 54-59.
- Parsons, J., K.U. Vickers, and Y. Warden. 1977. Relationship between elver recruitment and changes in the sex ratio of silver eels Anguilla anguilla L. migrating from Lough Neagh, Northern Ireland. *J. Fish Biol.*, 10: 211-229.
- SAS Institute Inc. 1982. SAS user's guide: Basics, 1982 edition. Cary, N.C. 923 pp.
- Schmidt, J. 1906. Contributions to the life-history of the eel (Anguilla vulgaris Flem.). *Rapp. P.-V. Reun. Cons. perm. int. Explor. Mer.*, 5: 137-264.

- _____. 1922. The breeding places of the eel.
Phil. Trans. Ser. B., 211: 179-208.
- Sheldon, W.W. 1974. Elvers in Maine - Techniques of locating, catching, and holding. Sea Grant Pub. 4266.3030, 25 pp.
- Sloane, R.D. 1984a. Invasion and upstream migration of glass eels of Anguilla australis australis Richardson and A. reinhardtii Steindachner in Tasmanian freshwater streams. Aust. J. Mar. Freshw. Res., 35: 47-59.
- _____. 1984b. Upstream migration by young pigmented freshwater eels (Anguilla australis australis Richardson) in Tasmania. Aust. J. Mar. Freshw. Res., 35: 61-73.
- Smith, D.G. 1968. The occurrence of larvae of the American eel, Anguilla rostrata, in the Straits of Florida and nearby areas. Bull. Mar. Sci., 18: 280-293.
- Smith, M.W. 1955. Control of eels in a lake by preventing the entrance of the young. Can. Fish Cult., 17: 13-17.
- Sorensen, I. 1951. An investigation of some factors affecting the upstream migration of the eel. Rep. Inst. Freshw. Res. Drottingholm, No. 32, 126-172.
- Sorensen, P. 1984. The use of olfaction by migrating elvers of the American eel, Anguilla rostrata (LeSueur). Ph.D. Thesis, Univ. of Rhode Island. 236 pp.
- Strubberg, A. 1913. The metamorphosis of elvers as influenced by outward conditions. Medd. Komm. Havunders. Ser. Fisk., 4(39): 1-11.
- Tesch, F.W. 1977. The eel. John Wiley and Sons, New York. 434 pp.
- Vladykov, V.D. 1966. Remarks on the American eel (Anguilla rostrata LeSueur). Sizes of elvers entering streams; the relative abundance of adult males and females; and the present economic importance of eels in North America. Verh. Internat. Verein. Limnol., 16: 1007-1017.

ABSTRACT

Age and Size Distributions of Elvers and Young
American Eels (Anguilla rostrata (LeSueur)) in a
Coastal Rhode Island Stream

by

Alexander J. Haro

Department of Zoology

University of Rhode Island

Kingston, Rhode Island 02881 USA

ABSTRACT

Small American eels (<250 mm TL) were sampled in late summer and fall in a coastal Rhode Island stream and aged by examination of otoliths. Elvers (age I+) had acquired the coloration typical of yellow eels, were much larger than glass eels or partially pigmented elvers collected in late winter and spring, and had a greatly expanded outer otolith growth zone. The frequency of II+ and older eels increased with increasing distance from the tidal zone. This indicates that the upstream migration of elvers is limited, and that colonization of inland waters is accomplished mainly by yellow eels in their second and later years of continental life.

Introduction

While the upstream migration of European eel (Anguilla anguilla L.) elvers and small yellow eels has been well documented, the movements of these juvenile forms of the American eel (A. rostrata (LeSueur)) are virtually unknown. A. rostrata elvers have been shown to utilize selective tidal transport to reach mouths of freshwater streams (McCleave and Kleckner, 1982), but their movements within freshwater have received only anecdotal treatment (Sheldon, 1974). Sorensen (1984) recorded elver movements within the lower 400 m of a Rhode Island stream, but did not investigate migrations upstream of this zone. Helfman et al. (1984) noted an increase in proportion of older eels in an upstream section of a Georgia river, although this increase could not be distinguished from a possible strong year class. Younger eels (smaller than 200 mm TL) were not represented in their collections due to sampling selectivity of baited traps. Telemetric studies of larger eels (Gunning and Shoop, 1962; LaBar and Facey, 1983) and arrival of eels of age III+ or older at locations far upstream (e.g. Lake Champlain and Lake Ontario (Hurley, 1973; Facey and LaBar, 1981)) provide the only information regarding monitored movements of yellow stage A. rostrata in freshwater.

Knowledge of upstream migration in juvenile European eels is also far from complete. While European elvers have been known to migrate from 30 to 150 kilometers during their first year in freshwater (Tesch, 1965; Deelder, 1970; Parsons et al., 1977), movements of juvenile eels past the elver stage have never been intensively studied. Tesch (1967) collected primarily juvenile A. anguilla in weirs more than 150 Km upstream on two German rivers. Elvers at these weirs were relatively rare. Tesch assumed that because these juvenile eels averaged 150 mm in total length, they had taken at least two years since entering freshwater to reach these upstream sites.

Other studies (Deelder, 1970; Moriarty, 1978) have shown similar limited movement of A. anguilla yellow eels during their first few years in freshwater, with eels collected farther inland showing an increase in size and age. Such effects on the distribution and age composition are thought to be amplified by obstructions to eel progress, such as weirs and dams (Tesch, 1977). Sloane (1984) postulated that A. australis past the elver stage migrate upstream for several years in succession, since age groups II+, III+, and IV+ were more abundant than elvers at sites further upstream. No elvers of this species were collected more than 6 Km inland.

This study investigates the distribution of A. rostrata elvers and yellow eels smaller than 250 mm TL at three sites in a coastal Rhode Island stream. Relative proportions of age classes at each site are used to determine the extent of upstream migration of elvers and young yellow eels.

Materials and Methods

All specimens used in this study were taken from the Annaquatucket River watershed, Washington County, Rhode Island ($41^{\circ} 33' N$; $76^{\circ} 26' W$; Fig. 1). The watershed drains approximately 52 square Km, and the main portion of the river is approximately 9 Km long, containing several impoundments created by damming in the 1800's (Guthrie and Stolgitis, 1977). The lowermost impoundment, Mill Pond, is 4 ha in area and about 200 m upstream from the mouth of the river, where it empties into Bissel Cove, an estuary adjacent to Narragansett Bay. A second impoundment exists above the dam at Featherbed Lane, 850 m upstream of Bissel Cove. Belleville Pond (64 ha) is the largest impoundment on the Annaquatucket, 2.5 Km upstream of Bissel Cove. Because of damming and its coastal location, the Annaquatucket is slow-moving for most of its length, with little gradient, averaging 4 m of drop per Km of stream run. However, the stream has a relatively high gradient from below Mill Pond dam to Bissel Cove, dropping 4 m in this 200 m stretch. All three dams were made passable to diadromous fishes by the installation of fishways by the Rhode Island Department of Fish and Wildlife from 1969 to 1971.

Elvers and small yellow eels were collected from below each of the three dams by electrofishing. A 4 by 20 foot blocking seine of one-sixteenth inch nominal mesh was stretched across the stream below the area to be electrofished. The electrofisher was moved downstream, towards the net, and swept the entire width of the stream. After the electrofisher had reached the net, the net was removed from the stream and fish were extracted by hand. Total lengths were determined to the nearest millimeter using a measuring board, and eels greater than 250 mm total length were returned to the stream. All three sites were sampled on 20 August, 23 September, and 6 November, 1983. The Featherbed and Belleville sites were sampled again on 7 August, 1984. After transport to the laboratory, eels were anesthetized with MS-222, measured to the nearest mm, labeled, and frozen for later analysis.

Otoliths (sagittae) were extracted from thawed eels by splitting the entire head sagittally with a scalpel and removing the otoliths with a pair of fine forceps. Otoliths were then cleaned in distilled water, dried, and mounted by imbedding the whole otolith in a small bead of molten thermoplastic (Crystalbond, Aremco Products, Inc.) placed on a 2.5 cm by 7.5 cm microscope slide. Most otoliths were ground by hand by placing the slide otolith side down on a piece of 30 micron grit lapping film (Imperial Lapping Film, 3M Corp.) bonded to a plate glass backing and wetted with

distilled water. Otoliths were ground using a circular motion until the nucleus was well defined when viewed under a dissecting microscope. Ground surfaces of otoliths were polished on 0.3 micron aluminum oxide lapping film. To avoid crushing small otoliths, a grinding apparatus similar to that described by Neilson and Geen (1981) was used on otoliths from eels smaller than approximately 100 mm. Ground and polished otoliths were covered with a drop of mineral oil to prevent drying while they were stored until they could be read.

Otolith annuli were identified and counted using a dissecting microscope at 100X. Transmitted light was usually sufficient to reveal annuli, but reflected light was also used on each otolith to reveal transparent and opaque rings described by Gray and Andrews (1971) that are associated with annuli. The sea-water or metamorphic ring was regarded as one year of larval growth (I+) and all subsequent rings as later annuli (II+ and older). As a check for inaccuracies in aging, a linear discriminant analysis (LDA) was performed on the aged fish using total length as a means to classify into age groups. If the observed age was not equal to the age determined by the LDA, the otolith was read again to check for an aging error. The reaged data was then subjected to a second LDA to improve the aging classification.

Total lengths of eels collected in 1984 were measured, but these fish were not aged. Instead, ages were assigned to individual fish based on their total lengths in comparison to groupings determined by the second LDA for the 1983 collection. Age class distributions were assembled from the 1983 plus the 1984 (aged and non-aged) data. All data analyses were performed using the Statistical Analysis System (SAS Institute, 1984).

Results

Pigmentation of elvers in the late summer and fall was more dense and appeared more yellowish and greenish dorsally and laterally than the most highly pigmented elvers collected in late spring of 1983 and 1984 at the Mill Pond station study (Stage 7; Haro, first manuscript). Summer and fall elvers from the Mill Pond station were also significantly larger (mean TL = 76.06 mm) than stage 7 elvers collected at the same station during late spring (mean TL = 56.98 mm; t-test, $p < 0.0001$). Otoliths of elvers collected in late summer and fall (Fig. 2B) showed a greatly expanded outer growth zone compared with those taken in the spring (Fig. 2A). Summer and fall elver otoliths were also characterized by a jagged margin and prominent rostrum, while spring elver otoliths had a more uniform periphery. Age II+ eels were distinguished from elvers by the presence of an annulus surrounding the metamorphic or seawater otolith ring. Annuli of all eels were normally accompanied by opaque rings (Fig. 2B,C) and appear to form during the winter months.

Correct classifications of ages using linear discriminant analysis on the raw age data were: age I+: 86.1 pct, age II+: 70.0 pct, age III+: 62.5 pct, age IV+: 42.9 pct, age V+: 23.1 pct, age VI: 50.0 pct. All otoliths with conflicting age determinations (first reading vs. LDA

classification) were rechecked. Although a total of 61 otoliths were reanalyzed, only 19 were reaged. The second LDA produced improved correct classification of ages: age I+: 93.8 pct, age II+: 81.8 pct, age III+: 66.7 pct, age IV+: 42.9 pct, age V+: 23.1 pct, age VI+: 50.0 pct. LDA classifications cannot be taken verbatim due to the nature of the analysis to classify absolutely into age groups based on the single classification variable, total length. This allows for no overlap of age groups in terms of total length. Since other studies have shown great overlap in lengths for most age groups of this species, some misclassification of ages by the LDA must be allowed.

Distributions of all age classes from collections at the Mill Pond, Featherbed Lane, and Belleville Pond stations are given in Figure 3. More elvers than II+ eels were present at Mill Pond, while II+ eels predominated over elvers at the other two sites. Age V+ and VI+ eels were absent from Mill Pond. Total length distributions of elvers and II+ eels from the three sites are given in Figure 4.

Figure 1. Sampling stations on the Annaquatucket River watershed, Washington County, RI

Figure 2. Otoliths taken from elvers and yellow eels.
 A: Otolith from elver captured 30 April, 1983,
 B: Otolith from elver captured 23 October, 1983,
 C: Otolith from II+ yellow eel captured 23
 October, 1983. Bar equals 0.1 mm.

A

B

C

Figure 3. Distributions of age classes of elvers (age 1) and yellow eels (ages 2-6) less than 250 mm TL from collections at Mill Pond, Featherbed Lane, and Belleville Pond stations.

Figure 4. Distributions of total lengths of elvers and II+ eels from Mill Pond, Featherbed Lane, and Belleville Pond stations.

Discussion

The distribution of age groups at the three sampling sites (Fig. 3) strongly suggests that most elvers progress no further than Mill Pond, and that the two upstream sites are populated mainly by eels age II+ and older. Elvers, which predominated at the Mill Pond station, were significantly smaller (mean TL = 70.1 mm), and probably represent glass eels that enter the river relatively late, are more abundant, but average smaller initially (Haro, first manuscript). Conversely, elvers from the Featherbed Lane (mean TL = 86.2 mm) and Belleville Pond (mean TL = 90.83 mm) stations probably represent glass eels that enter the river earlier and in smaller numbers, but that average larger initially and thus have greater swimming capability. Eels age II+ and older were more abundant at the two upstream stations. The absence of age V+ and VI+ eels at the Mill Pond station probably is not due to ageing error, since von Bertalanffy growth functions were similar for all three stations (Appendix I). Larger eels (> 210 mm TL) which represent these two age classes were also uncommon at the Mill Pond station.

Whether elvers or juvenile eels stop migrating upstream at a certain time of year (presumably winter) is not known; thus the exact time at which II+ eels arrive at the two upstream locations cannot be determined. It may take

several years for an eel to reach very remote upstream habitats. Since other studies have shown larger (older) eels with limited home ranges within a stream or lake (Gunning and Shoop, 1962; Helfman et al., 1984; Labar and Facey, 1983), most eels probably stop migrating upstream at some point in their lifetimes, but it is not clear at what age they do so. The changes in morphology of elvers during their upstream migration can be particularly dramatic. Elvers arriving in late winter and spring are initially semi-transparent, and accumulate pigment rapidly once they enter freshwater. However, elvers which attain "full" pigmentation (stage 7) by late spring are quite different in appearance from elvers collected in the late summer and fall; the latter being larger and more yellowish or greenish. Elver growth during the summer is also evident in the expanded transparent growth zone of the otolith margin (Fig. 2B). Absence of annuli and/or opaque zones near the margins of otoliths from late summer and fall eels suggests that annulus formation occurs during the winter, which is in agreement with Liew (1974).

The conclusions drawn so far in this study contrast many reports regarding the European eel, which describe lengthy migrations of elvers upstream for several kilometers or more. Clearly, elvers in the Annaquatucket progress upstream slowly, and their numbers become much reduced at upstream sites in comparison to their relative abundance in

the tidal zone. This disparity between Annaquatucket elvers and those from other systems which have little difficulty moving large distances upstream can probably be related to a fundamental difference in habitat types. Many European studies describing extensive elver migrations have taken place on large river systems (i.e. Deelder, 1952, 1958, 1970; Parsons et al., 1977), where current velocities are probably not great during the spring months in comparison with the Annaquatucket. Most of these studies do not provide information regarding what proportion of these migrations (in terms of distance) are facilitated by tidal transport, which could be a major factor of elver movement in larger rivers. Progress upstream by elvers in such systems is also likely to be enhanced by the lack of current near river banks; areas in which elvers have been noted to perform most of their migratory activity (Tesch, 1977). This habitat type is in direct contrast to the high gradient of the lower Annaquatucket system, which experiences great fluctuations in current velocity in response to changes in local precipitation. Fishways on the Annaquatucket seem to have little effect on assisting the upstream migration of elvers. In fact, they may be inhibitory in this respect in that they serve as attractors to elvers seeking flowing fresh water, yet elvers may have difficulty ascending fishways when current velocities through the baffles are high. Other studies in Europe have shown a similar inability of elvers to ascend fishways with high current

velocities (Tesch, 1977). The physical nature of elvers and their specific behavior during migration may exclude them from utilizing the fishways in a way that other species of upstream-migrating fishes do. Tesch (1977) has suggested that only larger eels are capable of ascending sections of streams which possess many dams, weirs, and other obstructions. It is possible that migrating elvers wait until water levels and current velocities drop before ascending fishways, or find other means of circumventing dams, such as climbing the wet concrete structures of the dams themselves. Also, the effect of standing bodies of water (i.e. lakes and ponds) on the progress of elvers through a river system is unknown. Elvers have been reported to wander randomly in still waters (Tesch, 1977), and thus would be expected to have difficulty locating an inlet stream once having entered an impoundment.

In spite of all the potential restraints on their upstream migration, elvers are able to pass above the Mill Pond and Featherbed Lane dams by some means. Because eels were present in the Annaquatucket system before the fishways were built (J. O'Brien, pers. comm.), one can assume that their persistence in migrating upstream insures that some will arrive at the upper reaches of the system, regardless of obstructions. Therefore, the physical nature of the stream or river in question has an effect on how eels will populate it after migrating until they become sedentary in

their behavior. The next logical steps that should be taken in defining the upstream migration of elvers and eels involve the effects of stream gradient and obstructions, as well as comparisons of eel movements in large and small stream and river systems.

References

- Deelder, C.L. 1952. On the migration of the elver (Anguilla vulgaris Turt.) at sea. J. Cons. perm. int. Explor. Mer, 18: 187-218.
- _____. 1958. On the behaviour of elvers (Anguilla vulgaris Turt.) migrating from the sea into fresh water. J. Cons. perm. int. Explor. Mer, 24: 135-146.
- _____. 1970. Synopsis of biological data on the eel Anguilla anguilla (Linnaeus) 1758. FAO, EIFAC 70/Gen-6, 22.4.1970.
- Facey, D.E. and G.W. LaBar. 1981. Biology of American eels in Lake Champlain, Vermont. Trans. Am. Fish. Soc., 110: 396-402.
- Gray, R.W. and C.W. Andrews. 1971. Age and growth of the American eel (Anguilla rostrata (LeSueur)) in Newfoundland waters. Can. J. Zool., 49: 121-128.
- Gunning, G.E. and C.R. Shoop. 1962. Restricted movements of the American eel Anguilla rostrata (LeSueur), in freshwater streams, with comments on growth rate. Tulane Stud. Zool., 9(5): 265-272.
- Guthrie, R. and J. Stolgitis. 1977. Fisheries investigations and management in Rhode Island lakes and ponds. R. I. Dept. of Nat. Res., Fisheries Rept. No. 3. 256 pp.
- Helfman, G.S., E.L. Bozeman and E.B. Brothers. 1984. Size, age, and sex of American eels in a Georgia river. Trans. Am. Fish. Soc., 113: 132-141.
- Hurley, D.A. 1973. The commercial fishery for the American eel, Anguilla rostrata (LeSueur), in Lake Ontario. Trans. Am. Fish. Soc., 1973(2): 369-377.
- LaBar, G.W. and D.E. Facey. 1983. Local movements and inshore population sizes of American eels in Lake Champlain, Vermont. Trans. Am. Fish. Soc., 112: 111-116.
- Liew, P.K.L. 1974. Age determination of American eels based on the structure of their otoliths. In: The ageing of fish. J.B. Bagenal, ed. Unwin Bros., Surrey, England. 234 pp.
- McCleave, J.D. and R.C. Kleckner. 1982. Selective tidal stream transport in the estuarine migration of glass eels of the American eel (Anguilla rostrata). J. Cons. perm. int. Explor. Mer, 40: 262-271.

- Moriarty, C. 1978. Eels: a natural and unnatural history. Universe Books, New York. 192 pp.
- Neilson, J.G. and G.H. Geen. 1981. Method for preparing otoliths for microstructure examination. Prog. Fish Cult., 43(2): 90-91.
- Parsons, J., K.U. Vickers, and Y. Warden. 1977. Relationship between elver recruitment and changes in the sex ratio of silver eels Anguilla anguilla L. migrating from Lough Neagh, Northern Ireland. J. Fish Biol., 10: 211-229.
- SAS Institute Inc. 1982. SAS user's guide: Basics, 1982 edition. Cary, N.C. 923 pp.
- Sheldon, W.W. 1974. Elvers in Maine - Techniques of locating, catching, and holding. Sea Grant Pub. 4266.3030, 25 pp.
- Sloane, R.D. 1984. Upstream migration by young pigmented freshwater eels (Anguilla australis australis Richardson) in Tasmania. Aust. J. Mar. Freshw. Res., 35: 61-73.
- Sorensen, P. 1984. The use of olfaction by migrating elvers of the American eel, Anguilla rostrata (LeSueur). Ph.D. Thesis, Univ. of Rhode Island. 236 pp.
- Strubberg, A. 1913. The metamorphosis of elvers as influenced by outward conditions. Medd. Komm. Havunders. Ser. Fisk., 4(39): 1-11.
- Tesch, F.W. 1965. Verhalten der Glasaale (Anguilla anguilla) bei ihrer Wanderung in den Astuarien deutscher Nordseeflüsse. Helgolander wiss. Meeresunters., 12: 404-419.
- _____. 1967. Aktivitat und Verhalten wandernder Lampetra fluviatilis, Lota lota und Anguilla anguilla im Tidegebiet der Elbe. Helgolander wiss. Meeresunters., 16: 92-111.
- _____. 1977. The eel. John Wiley and Sons, New York. 434 pp.

BIBLIOGRAPHY

- Bertin, L. 1956. Eels, a biological study. Cleaver-Hume Press, London, 192 pp.
- Boetius, J. 1976. Elvers, Anguilla anguilla and Anguilla rostrata from two Danish localities. Size, body weight, developmental stage and number of vertebrae related to time of ascent. Meddr. Danm. Fisk. Havunders. 7: 199-220.
- Charlon, N. and J.M. Blanc. 1982. Etude des civelles d'Anguilla anguilla L. dans la region du bassin de l'Adour. 1. Caracteristiques biometriques de longueur et de poids en fonction de la pigmentation. Arch. Hydrobiol., 93(2): 238-255.
- Creutzberg, F. 1958. Use of tidal streams by migrating elvers (Anguilla vulgaris Turt.). Nature, 181: 857-858.
- Deelder, C.L. 1952. On the migration of the elver (Anguilla vulgaris Turt.) at sea. J. Cons. perm. int. Explor. Mer, 18: 187-218.
- _____. 1958. On the behaviour of elvers (Anguilla vulgaris Turt.) migrating from the sea into fresh water. J. Cons. perm. int. Explor. Mer, 24: 135-146.
- _____. 1970. Synopsis of biological data on the eel Anguilla anguilla (Linnaeus) 1758. FAO, EIFAC 70/Gen-6, 22.4.1970.
- Facey, D.E. and G.W. LaBar. 1981. Biology of American eels in Lake Champlain, Vermont. Trans. Am. Fish. Soc., 110: 396-402.
- Gilson, G. 1908. L'anguille, sa reproduction ses emigrations et son interet economique en Belgique. Annls. Soc. r. zool. malacol. Belg., 42: 7-58.
- Gollub, H. 1959. Uber die im Bezerk Schwerin durchgefuehrten Aalforderungsmabnahmen. Dt. FischZtg. Radebeul, 6: 86-89.
- Grassi, B. 1913. Metamorphosi dei Murenoidi. Jena. Verlag von Gustav Fischer.
- _____, and S. Calandruccio. 1897. Riproduzione e metamorphosi delle anguille. Giorne. ital. Pesca e Aquic., 7: 139-208.

- Gray, R.W. and C.W. Andrews. 1971. Age and growth of the American eel (Anguilla rostrata (LeSueur)) in Newfoundland waters. Can. J. Zool., 49: 121-128.
- Gunning, G.E. and C.R. Shoop. 1962. Restricted movements of the American eel Anguilla rostrata (LeSueur), in freshwater streams, with comments on growth rate. Tulane Stud. Zool., 9(5): 265-272.
- Guthrie, R. and J. Stolgitis. 1977. Fisheries investigations and management in Rhode Island lakes and ponds. R. I. Dept. of Nat. Res., Fisheries Rept. No. 3. 256 pp.
- Helfman, G.S., E.L. Bozeman and E.B. Brothers. 1984. Size, age, and sex of American eels in a Georgia river. Trans. Am. Fish. Soc., 113: 132-141.
- Hurley, D.A. 1973. The commercial fishery for the American eel, Anguilla rostrata (LeSueur), in Lake Ontario. Trans. Am. Fish. Soc., 1973(2): 369-377.
- Jeffries, H.P. 1960. Winter occurrences of Anguilla rostrata elvers in New England and middle Atlantic estuaries. Limnol. Oceanog., 5(3): 338-340.
- Jellyman, D.J. 1979. Upstream migration of glass-eels (Anguilla spp.) in the Waikato River. N. Z. J. Mar. Freshw. Res., 13(1): 13-22.
- _____, and C.M. Ryan. 1983. Seasonal migration of elvers (Anguilla spp.) into Lake Pounui, New Zealand, 1974-1978. N. Z. J. Mar. Freshw. Res., 17: 1-15.
- Kleckner, R.C. 1980a. Swimbladder wall guanine enhancement related to migratory depth in silver phase Anguilla rostrata. Comp. Biochem. Physiol., 65A: 351-354.
- _____. 1980b. Swim bladder volume maintenance related to initial oceanic migratory depth in silver phase Anguilla rostrata. Science 208: 1481-1482.
- _____ and W.H. Krueger. 1981. Changes in swimbladder retial morphology in Anguilla rostrata during premigration metamorphosis. J. Fish Biol. 18: 569-577.
- LaBar, G.W. and D.E. Facey. 1983. Local movements and inshore population sizes of American eels in Lake Champlain, Vermont. Trans. Am. Fish. Soc., 112: 111-116.

- Liew, P.K.L. 1974. Age determination of American eels based on the structure of their otoliths. In: The ageing of fish. J.B. Bagenal, ed. Unwin Bros., Surrey, England. 234 pp.
- Mann, H. 1963. Beobachtungen uber den Aalaufsteig in der Aalleiter an der Staustufe Geesthacht im Jahre 1961. *Fischwirt*, 13: 182-186.
- Matsui, I. 1952. Studies on the morphology, ecology and pondculture of the Japanese Eel (Anguilla japonica Temminck u. Schlegel). *J. Shimonoseki Coll. Fish.*, 2(2): 1-245.
- McCleave, J.D. 1980. Swimming performance of European eel (Anguilla anguilla (L.)) elvers. *J. Fish Biol.*, 16: 445-452.
- _____, and R.C. Kleckner. 1982. Selective tidal stream transport in the estuarine migration of glass eels of the American eel (Anguilla rostrata). *J. Cons. perm. int. Explor. Mer*, 40: 262-271.
- Menzies, W.J.M. 1936. The run of elvers in the River Bann, Northern Ireland. *J. Cons. perm. int. Explor. Mer*, 11: 249-259.
- Moriarty, C. 1978. Eels: a natural and unnatural history. Universe Books, New York. 192 pp.
- Neilson, J.G. and G.H. Geen. 1981. Method for preparing otoliths for microstructure examination. *Prog. Fish Cult.*, 43(2): 90-91.
- Ogden, J.C. 1970. Relative abundance, food habits, and age of the American eel, Anguilla rostrata (LeSueur), in certain New Jersey streams. *Trans. Am. Fish. Soc.*, 99: 54-59.
- Parsons, J., K.U. Vickers, and Y. Warden. 1977. Relationship between elver recruitment and changes in the sex ratio of silver eels Anguilla anguilla L. migrating from Lough Neagh, Northern Ireland. *J. Fish Biol.*, 10: 211-229.
- SAS Institute Inc. 1982. SAS user's guide: Basics, 1982 edition. Cary, N.C. 923 pp.
- Schmidt, J. 1906. Contributions to the life-history of the eel (Anguilla vulgaris Flem.). *Rapp. P.-V. Reun. Cons. perm. int. Explor. Mer*, 5: 137-264.

- _____. 1922. The breeding places of the eel.
Phil. Trans. Ser. B., 211: 179-208.
- Sheldon, W.W. 1974. Elvers in Maine - Techniques of locating, catching, and holding. Sea Grant Pub. 4266.3030, 25 pp.
- Sloane, R.D. 1984a. Invasion and upstream migration of glass eels of Anguilla australis australis Richardson and A. reinhardtii Steindachner in Tasmanian freshwater streams. Aust. J. Mar. Freshw. Res., 35: 47-59.
- _____. 1984b. Upstream migration by young pigmented freshwater eels (Anguilla australis australis Richardson) in Tasmania. Aust. J. Mar. Freshw. Res., 35: 61-73.
- Smith, D.G. 1968. The occurrence of larvae of the American eel, Anguilla rostrata, in the Straits of Florida and nearby areas. Bull. Mar. Sci., 18: 280-293.
- Smith, M.W. 1955. Control of eels in a lake by preventing the entrance of the young. Can. Fish Cult., 17: 13-17.
- Sorensen, I. 1951. An investigation of some factors affecting the upstream migration of the eel. Rep. Inst. Freshw. Res. Drottingholm, No. 32, 126-172.
- Sorensen, P. 1984. The use of olfaction by migrating elvers of the American eel, Anguilla rostrata (LeSueur). Ph.D. Thesis, Univ. of Rhode Island. 236 pp.
- Strubberg, A. 1913. The metamorphosis of elvers as influenced by outward conditions. Medd. Komm. Havunders. Ser. Fisk., 4(39): 1-11.
- Tesch, F.W. 1965. Verhalten der Glasaale (Anguilla anguilla) bei ihrer Wanderung in den Astuarien deutscher Nordseeflüsse. Helgolander wiss. Meeresunters., 12: 404-419.
- _____. 1967. Aktivitat und Verhalten wandernder Lampetra fluviatilis, Lota lota und Anguilla anguilla im Tidegebiet der Elbe. Helgolander wiss. Meeresunters., 16: 92-111.
- _____. 1977. The eel. John Wiley and Sons, New York. 434 pp.

Vladykov, V.D. 1966. Remarks on the American eel (Anguilla rostrata LeSueur). Sizes of elvers entering streams; the relative abundance of adult males and females; and the present economic importance of eels in North America. Verh. Internat. Verein. Limnol., 16: 1007-1017.

Winn, H.E., W.A. Richkus and L.K. Winn. 1975. Sexual dimorphism and natural movements of the American eel (Anguilla rostrata) in Rhode Island streams and estuaries. Helgolander wiss. Meeresunters., 27: 156-166.

APPENDIX I

Length and age data from the Mill Pond, Featherbed Lane, and Belleville Pond collections were used to estimate growth of eels at the three sites. Nonlinear regression was used to estimate growth parameters of the von Bertalanffy function:

$$L_t = L_{\infty} (1 - e^{-k(t-t_0)})$$

where

L_t = length at time t

L_{∞} = asymptotic length

k = growth rate coefficient

t_0 = hypothetical time at age 0

The following table gives growth parameters for von Bertalanffy functions calculated for the three collection sites:

	<u>Mill Pond</u>	<u>Featherbed Lane</u>	<u>Belleville Pond</u>
n	99	44	45
L_{∞}	1063.5970	1144.7872	819.0822
k	0.04352	0.0358	0.0553
t_0	-0.0049	-0.1247	0.0379

Analysis of asymptotic 95 percent confidence intervals of the three estimates of k showed no significant difference in growth rate between the three collection sites (at the 5 percent level). It should be noted that the estimates of growth parameters provided here are based on fish of age VI+ and younger from the Belleville Pond and Featherbed Lane sites, and on fish IV+ and younger from the Mill Pond site. Growth of older eels may not be accurately described from these estimates.