First Feeding and Growth of Elvers of the American Eel (*Anguilla rostrata* (Lesueur)) at Several Temperature Regimes

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ABSTRACT

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Newly caught estuarial elvers averaged 145-178 mg wet weight and 59-63 mm total length in early June. Elver growth rates were determined experimentally at a series of temperatures with means from 13.8-24.7°C for the first month of feeding. Highest growth occurred at a mean test temperature of 22°C with a specific growth rate 5.2%/d. Little growth occurred at 13.8°. Initial elver growth is characterized by an increase in condition factor and decrease in water content with no increase in length. These changes may be related to transformation from the migratory phase to the freshwater sedentary phase.

RÉSUMÉ

Peterson, R. H., and D. J. Martin-Robichaud. 1994. First feeding and growth of elvers of the American eel (*Anguilla rostrata* (Lesueur)) at several temperature regimes. Can. Tech. Rep. Fish. Aquat. Sci. 2013: iii + 11 p.

Des civelles qui viennent d'être capturées en estuaire pesaient en moyenne entre 145 et 178 mg (poids frais), et mesuraient entre 59 et 63 mm de longueur totale au début de juin. Leur taux de croissance a été établi expérimentalement pour une série de températures: les moyennes variaient de 13,8 à 24,7°C pendant le premier mois d'alimentation. La croissance maximale a été enregistrée à une température expérimentale moyenne de 22°C avec un taux de croissance spécifique de 5,2% par jour. La croissance était faible à 13,8°C. La croissance initiale des civelles est caractérisée par une augmentation du coefficient de condition et une diminution de la teneur en eau sans augmentation de la longueur. Ces changements peuvent être liés à la transformation occasionée par le passage de la phase migratoire à la phase sédentaire en eau douce.

INTRODUCTION

Various species of eel (*Anguilla* spp.) are extensively cultured, with Japan and Europe being the principal culture areas (Gousset 1990). This culture industry relies solely on exploitation of wild elvers, resulting in reduced numbers of returning elvers in heavily exploited areas (Heinsbroek and Kamstra 1990). Conversely, the American eel (*Anguilla rostrata*) is an underutilized species in eastern Canada, with an abundance of elvers entering estuaries of this geographic area (Groom 1975).

First feeding of elvers in culture situations is one of the problems in the culture of this genus. Frequently, less than half the elvers are successfully weaned onto artificial foods (Degani and Levanon 1987). Stress associated with starvation, overcrowding and, perhaps social interactions, results in mortalities of 40-80% during this phase of culture (Gousset 1990; Kuhlmann 1990; Kamstra and Heinsbroek 1991).

In contrast to the considerable literature on culture of European elvers, there is little information on the culture of American elvers. In view of the shortage of elvers in countries where they are cultured extensively, and their abundance in eastern Canada, it would seem prudent to learn more about the culture of *A. rostrata* in relation to a possible export enterprise. No data have been published previously on temperature optima for growth of the various stages of this species, although experiments with the European eel (*A. anguilla*) have reported optima from 20-26°C. In this paper, we examine the first feeding and growth of *A. rostrata* elvers in relation to ambient temperature. The elvers were provided shelter to reduce possible social interaction.

MATERIALS AND METHODS

About 200 elvers were netted during each of 1989, 1990, and 1991 in the tidal portion of the Lepreau River, N. B. (45°11'N, 65°28'W), in early June. The elvers were then transported to the laboratory and randomly distributed in lots of 20 to each of 3-5 growth changers made of plexiglass.

Fresh water from a reservoir flows through a screen (1-mm mesh) to the rearing compartment and exits through a bottom screen positioned across the back (Fig. 1). The water level was maintained at 9 cm by the outflow drain. In 1989, a rock substrate (5-7 cm mean diameter) provided shelter and the tanks did not have flanges (see Fig. 1) to prevent escape. Behavioral observations of elvers during that year resulted in tank modifications for future experiments. Tanks with flanges extending down into the tank successfully prevented elver escape. In addition, shelter was provided by darkened plexiglass blocks with 20, 0.5-cm holes with 3-cm centres in the experiments conducted in 1990 and 1991.

In 1989, two test temperatures, 14 and 16°C, yielded sufficient numbers of elvers to allow statistical analysis (ANOVA, Duncan's Multiple Range). Four test temperatures were investigated in each subsequent year (Fig. 2). Initial temperatures were set at the target temperatures in 1989 but, in 1990 and 1991, the initial water temperatures in the tanks were set at levels similar to that of the river at the time elvers were captured, 12 and 16°C, respectively, to eliminate possible stress associated with abrupt temperature change. Temperatures were then increased 1°C/d until the target temperatures were reached. Therefore, the mean temperatures during the 26- to 30-d growth period were less than the target temperature (Fig. 2). Temperatures and flow rates were recorded daily.

The elvers were fed every 2 h from 0830 to 1430 daily. The diet consisted of grated, frozen San Francisco Bay Brand brine shrimp and crumbled moist salmon pellets fed alternately. Uneaten food was siphoned out 15-30 min after feeding.

Elvers were starved for 24 h before final measurements. They were anaesthetized with tricaine methanesulfonate (MS 222) and total length determined to the nearest 0.5 mm. After blotting thoroughly, wet weights were measured to 0.1 mg and dry weights determined after drying to a constant weight at 60°C in a convection oven. A sample of 20 newly caught elvers, taken in grab samples from the total number captured, were similarly weighed and measured each year prior to use in experiments.

Specific growth rates were calculated according to the formula

$$G = \frac{\ln w_2 - \ln w_1}{t_2 - t_1} \times 100.$$

Because the variances in growth were proportional to the means for the different treatments, a square root transformation was performed on the data prior to statistical testing.

RESULTS

Elvers newly caught from the Lepreau River estuary averaged 145.5-178.1 mg wet weight and 59.1-61.3 mm total length (Table 1), and were quite uniform in size (Fig. 3a, f, k), with coefficients of variation of 15-20%. When classified according to the pigmentation stages of Boetius and Boetius (1989), most elvers were classed as stage D, with a few smaller ones classified to stage C.

After 27-30 d of feeding, mean elver size was greater than initial size at all test temperatures (Table 1, 2). Water content decreased and condition factor increased with increasing size. Due to variable growth rates among individual elvers (Fig. 3), standard deviations of size-related parameters increased in proportion to final size. Some starvation occurred at the three lowest test temperatures (Fig. 3b, c, g), as evidenced by one elver below the range of initial sizes for each of these test temperatures. It is probable that no starvation occurred at temperatures of 18.2°C and above. Characteristically, a few elvers grew rapidly enough at the four highest temperatures to separate from the rest of the distribution.

Elvers reared at the lowest test temperature (in 1989) were not significantly larger than initial weights (Table 3, 1989), nor had the condition factor changed significantly. In 1990 and 1991, significant increases in weight had occurred at all test temperatures. In 1990, elvers grown at 20.4°C were significantly larger and in better condition than those grown at 16.7 and 18.2°C. In 1991, elvers grown at 22.0°C were larger and in better condition than those grown at 23.5 and 24.7°C.

Specific growth rates (G, Table 2) expressed as % day^{-1} were higher at 20.4°C in 1990 than at the three lower temperatures, while a higher G was obtained at 22.0°C than at the three higher temperatures in 1991. The optimum temperature for first feeding of elvers would appear to be near 22.0°C. Because of slightly different culture conditions from year to year (as described in Methods), we do not feel justified in making quantitative comparisons between years.

Elver growth at first feeding is characterized by a change in shape. Initially, the elvers increase in weight with little or no increase in length as shown in Fig. 4, and also illustrated by the markedly higher condition factors for elvers at $\geq$16.7°C (Table 2). The dotted line in Fig. 4 encloses the weight-length data for newly caught elvers. The weight increase, with little or no concomitant increase in length, results in a discontinuity in the growth curve. The data points below the area enclosed by the dotted line represent elvers that lost weight. Most of these points are from 1989 experiments at 13.8°C in which no growth occurred. Associated with this rapid increase in condition is a decrease in water content (Fig. 5). At a length of about 60 mm, the water content decreases rapidly from greater than 80% to about 75%.

Only two mortalities occurred during the 3 years of experimentation (involving 200 elvers). Both occurred in 1991 at the two highest test temperatures.

DISCUSSION

First growth of elvers was characterized by an increase in condition with little or no increase in length. Brody (1964) considers discontinuities in growth curves to be indicative of "radical changes in mode of life." It is hypothesized that this is also the case for early elver growth when they are shifting from a migratory phase to a more sedentary benthic phase in streams or lakes.

Although no data have been published previously on temperature optima for growth of this species, there have been several such studies on the European species (*A. anguilla*), with estimated optima ranging from 20.0-26.5°C (Kuhlmann 1979; Sadler 1979; Degani and Gallagher 1988; Penaz et al. 1988; Seymour 1989). We found little difference in specific growth rates over the range of 22.4-24.5°C in our experiments. Use of the lower temperature of this range would be more economical if heating were required.

The use of shelters may have an influence on optimum temperature of first feeding as the few studies using shelters report lower optima than for studies in which shelters were omitted (this study and Sadler, 1979).

First feeding of elvers in culture conditions has often been found to be a period of high mortality. Mortalities of 40-80% are frequently associated with this phase of culture (e.g., Degani and Levanon, 1987; Gousset, 1990; Kamstra and Heinsbroek, 1991). Possible reasons for this high mortality are stress on subordinate elvers due to aggressive behavior of dominants, and diets which are either inadequate nutritionally or are unattractive to the elvers.

Penaz et al. (1988) found aggression to begin at elver weight of 0.8-1.0-g. Aggressive behavior may not have been a factor in these experiments as none was observed, and the elvers in our experiments were less than 0.8 g.

Diet palatability is a problem with first-feeding elvers (Degani and Levanon 1987; Degani and Gallagher 1988; Gousset 1990). In our experiments, the *Artemia* was eaten voraciously. After a few days of feeding, the elvers had usually learned to come to the surface and take the *Artemia* from the knife used to scrap the block. The moist pellet was received with much less enthusiasm. While it appeared to be ingested to some degree, *Artemia* was undoubtedly eaten in far greater amounts. The two diets appeared adequate as the growth rates at near-optimal temperatures exceeded the usual values reported in the literature for *A. anguilla* (Sadler 1979; Penaz et al. 1988; Seymour 1989). None of the previous studies utilized frozen *Artemia*, and it may be too costly for commercial-scale rearing.

Knights (1985) found four daily feedings to be sufficient for maximal growth of elvers. The inactivity of elvers in shelters when not feeding may reduce the number of feedings required for maximal growth.

The question of whether provision of shelters in commercial scale operations is practical has been questioned. Knights (1985) considered shelters impractical in this regard. In view of the difficulties encountered with the first-feeding phase, however, perhaps they should be considered for commercial first-feeding operations. Studies on maximal rearing densities obtainable with shelters present are required. Mortality in our experiments was only 1% and there were no indications of stress-related pathologies such as enlarged gallbladders that has been reported by Willemse et al. (1984).

While our experimental procedure resulted in variable lengths of time at the final target temperature, we feel this is preferable to beginning growth experiments after target temperatures were attained. In the latter instance, experiments would have been performed with different initial elver sizes at available ages for each temperature. Use of mean experimental temperatures for the experimental period yielded unambiguous results.

Newly caught elvers used in our experiments averaged 57-61 mm in length and 145-178 mg wet weight. European elvers are about 1 cm longer when entering rivers (Boetius and Boetius 1989). These elvers apparently increase in length and lose condition as they migrate northward along the European coast from 68 mm and a condition factor (CF) of 1.0 in Spain to 71 mm and 0.55 in Denmark. Our elvers were intermediate in CF at about 0.77. Dutil et al. (1987) determined elvers entering streams of the St. Lawrence estuary to be 59 mm long and 150 mg wet weight (ca. 0.73 CF). These values are not greatly different from ours.

We conclude that, given adequate shelter and an optimal temperature near 22.0°C, an elver growth rate of about 5% day^{-1} can be achieved with little or no mortality. First elver growth is characterized by increase in condition and little or no increase in length.

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Table 1. Size-related parameters of elvers netted from the Lepreau estuary prior to growth experiments. Means with standard deviation are given in parentheses. L - mean length; WW - mean wet weight; DW - mean dry weight; H_2O - % water content; CF - condition factor (WW/L^3 x 1000); N - number of individuals measured.

Year	L (mm)	WW (mg)	DW (mg)	H_2O (%)	CF	N
1989	61.3(3.3)	178.1(33.0)	33.4(9.5)	81.5	0.77	19
1990	57.1(2.3)	145.5(21.5)	28.7(4.8)	80.4	0.78	20
1991	59.1(3.5)	155.0(29.5)	30.1(7.0)	80.7	0.74	20

Table 2. Size-related parameters of elvers after 1 mo growth at various temperatures. t - experiment duration in days; T - mean temperature (°C); G - specific growth rate (percent wet weight per day and per degree-day); L - mean length, WW - mean wet weight; DW - mean dry weight; H_2O - % water content; CF - condition factor (WW/L^3 x 1000); N - number of individuals measured. Standard deviations given in parentheses.

Year	T	t	L	WW	DW	H_2O	CF	N	G(%/d)	G(%/°d)
1989	13.8	27	62.0(3.3)	189.7(50.8)	39.0(12.6)	79.7	0.79	26	0.7	0.06
	16.5	27	63.4(4.2)	234.5(86.4)	50.6(22.2)	79.1	0.89	30	1.6	0.11
1990	16.7	30	63.8(3.1)	267.4(61.0)	61.9(15.7)	77.0	1.01	21	2.6	0.17
	18.2	30	64.0(3.8)	263.4(57.3)	61.4(14.6)	76.8	0.99	17	2.5	0.15
	19.6	30	64.2(3.3)	278.0(63.3)	66.4(16.6)	76.2	1.04	22	2.8	0.15
	20.4	30	66.6(5.4)	314.5(87.9)	75.1(23.6)	76.4	1.03	20	3.2	0.16
1991	22.0	27	74.8(5.5)	495.8(130.6)	120.3(34.5)	75.7	1.17	19	5.2	0.23
	22.6	27	72.1(6.8)	438.1(143.7)	112.3(39.0)	74.6	1.13	18	4.9	0.21
	23.5	27	70.6(5.7)	391.0(123.8)	100.5(36.3)	74.6	1.08	18	4.5	0.19
	24.7	27	71.2(5.3)	394.2(121.1)	101.3(34.0)	74.5	1.06	20	4.5	0.18

Table 3. Statistical differences (after square root transformation) among final elver wet weights (mg) and condition factor for various experimental trials, as tested by ANOVA and Duncan's Multiple Range Test. Mean groups connected by underlining are not significantly different ($P \leq 0.05$).

A. Wet weight

Year	Mean test temperature (°C)					F	*P*
1989	Initial	13.8		16.5		4.2	0.02 (including initial weights)
1990	Initial	16.7	18.2	19.6	20.4	21.2	0.00 (including initial weights)
						2.26	0.09 (excluding initial weights)
1991	Initial	22.0	22.6	23.5	24.7	24.6	0.00 (including initial weights)
						2.70	0.05 (excluding initial weights)

B. Condition factor

Year	Mean test temperature (°C)					F	*P*
1989	Initial	13.8		16.5		3.33	0.01
						2.49	0.07
1990	Initial	16.7	18.2	19.6	20.4	17.8	0.00
						0.58	0.62
1991	Initial	22.0	22.6	23.5	24.7	45.7	0.00
						3.17	0.03

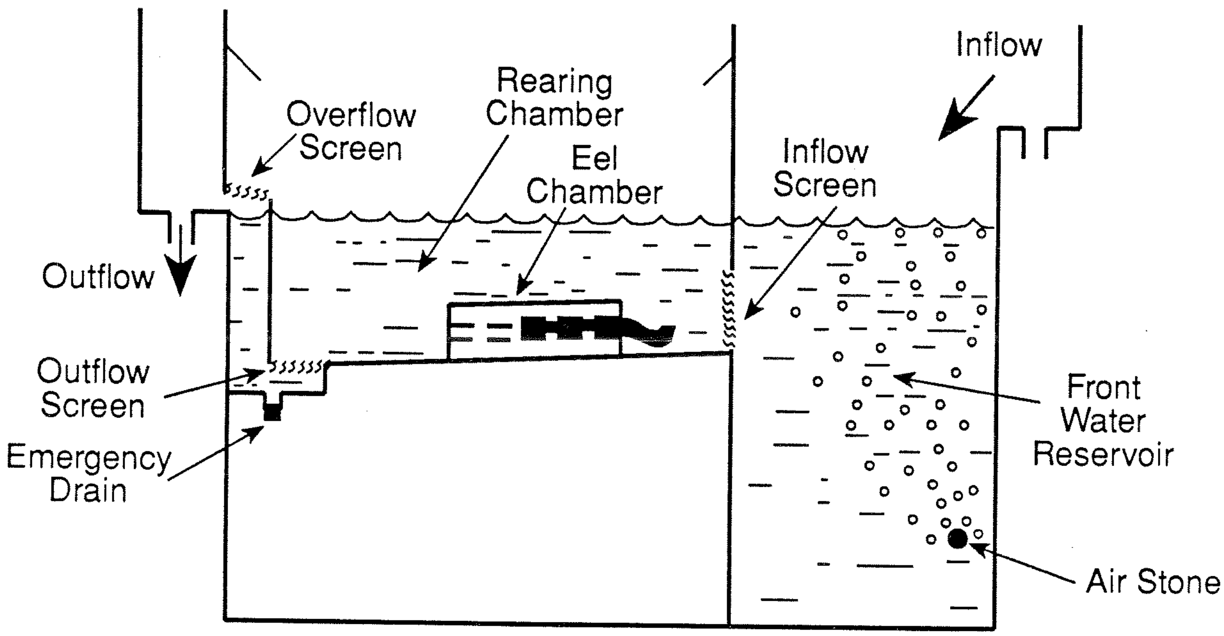

Fig. 1. Schematic of eel growth chambers used in 1990 and 1991. Overall dimensions are 61.5 cm wide x 51 cm x 36 cm high.

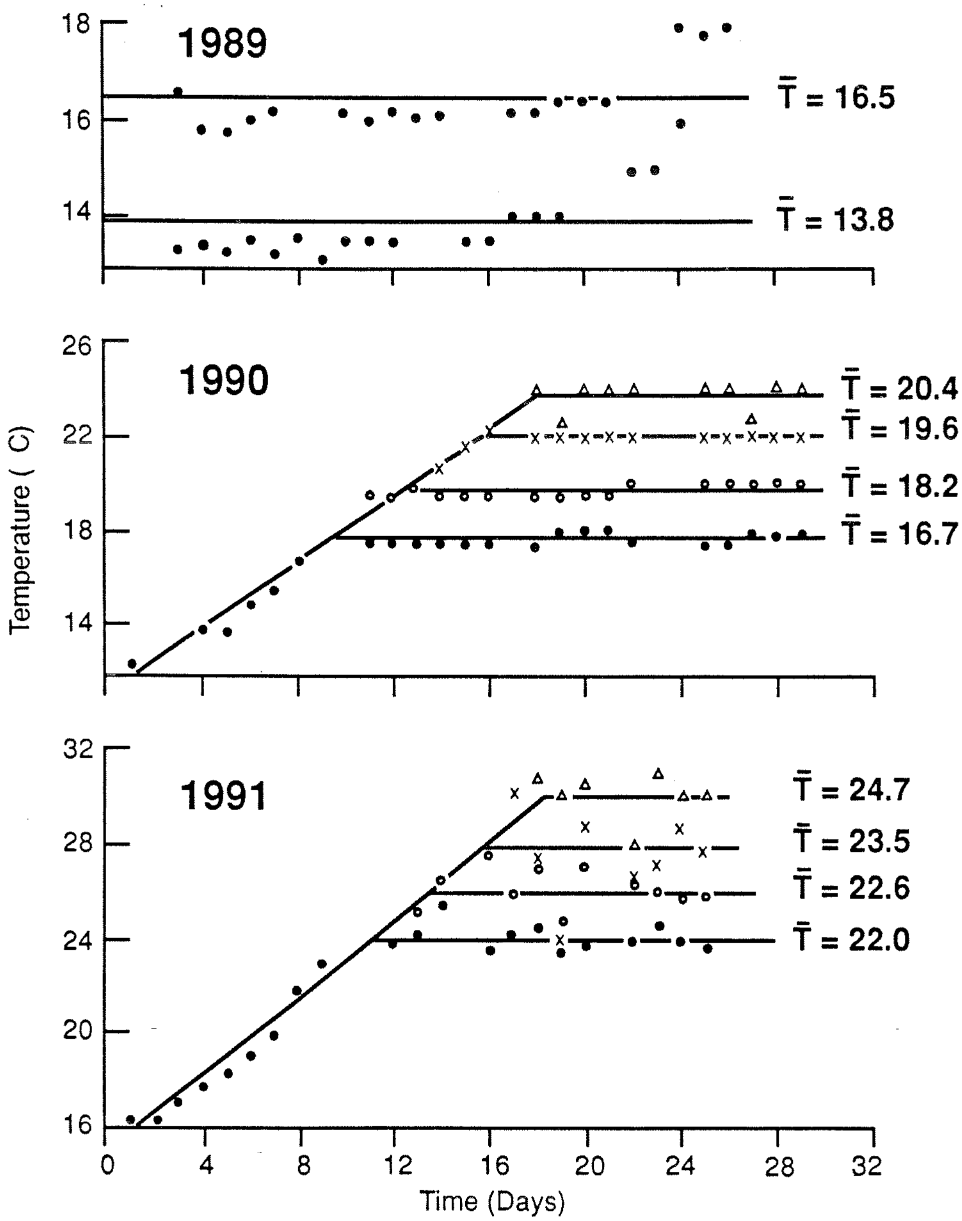

Fig. 2. Temperature regimes used for the various elver growth experiments. Symbols indicate daily measured temperatures. Lines are fitted by eye. $\overline{T}$ - mean experimental temperature for the entire experiment.

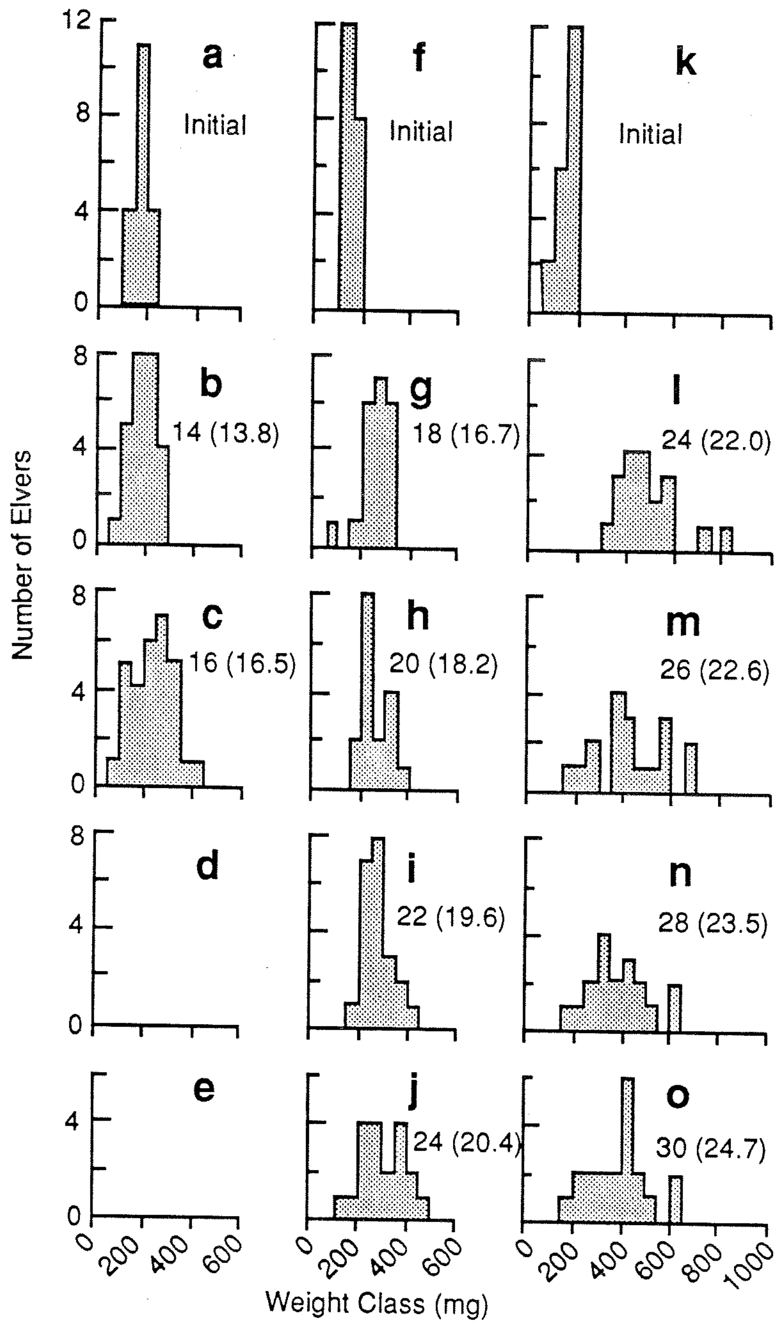

Fig. 3. Frequency distributions of elver wet weight classes before ("initial" panels) and after growth experiments. Experiments for 1989 are represented by panels a-c; for 1990 by f-j; and for 1991 by k-o. Numbers of elvers in each distribution are given in each panel, with mean experimental temperatures in parentheses.

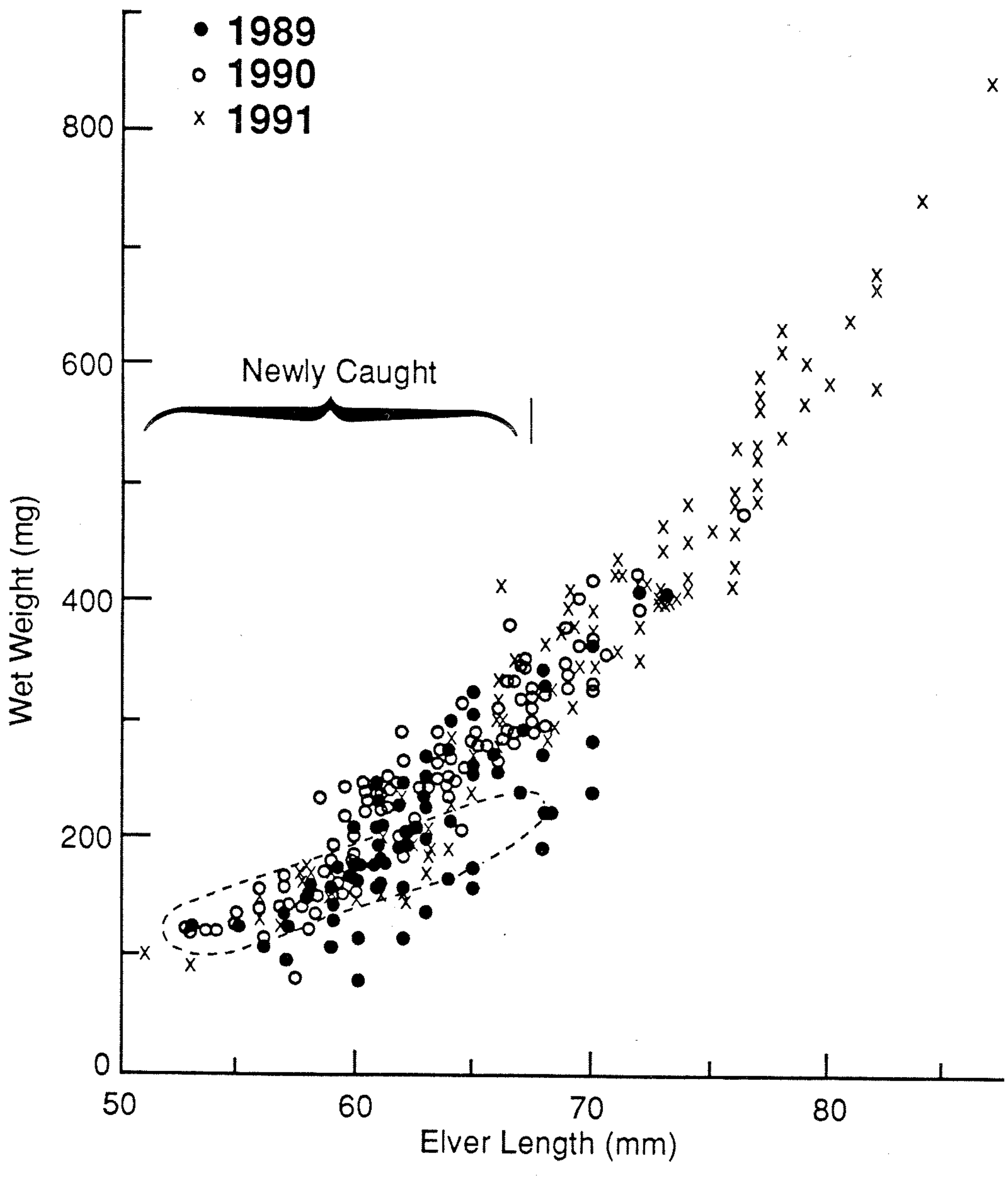

Fig. 4. Weight-length relationships shown for all elvers used in growth experiments for the 3 yr. The dotted line encloses values for elvers when initially caught. Elvers with wet weights below the area enclosed by the dotted line may not have fed during the growth experiment.

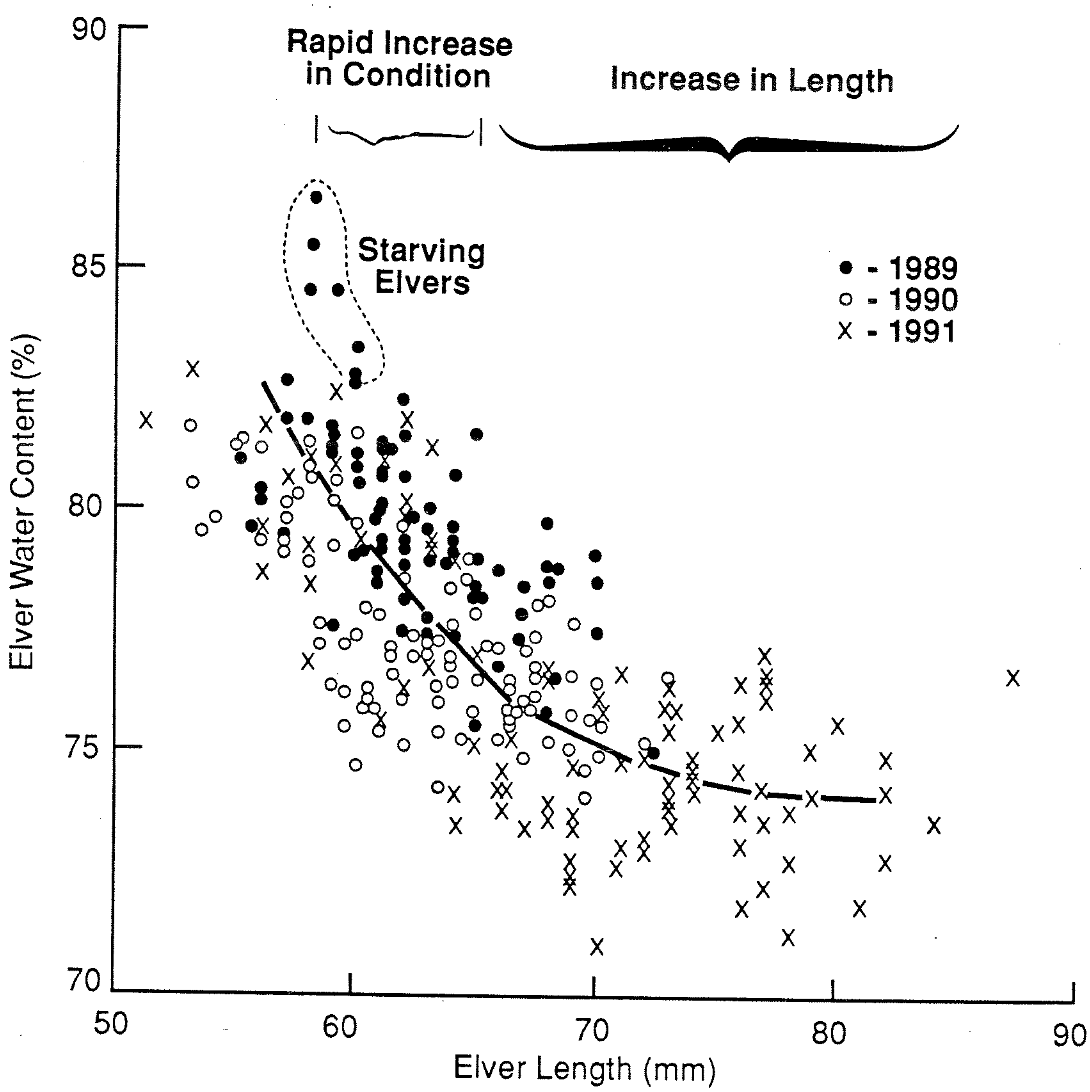

Fig. 5. Elver water content (%) is shown in relation to elver length. Line fitted by eye. Bracketted comments above the data highlight the relationship to Fig. 4.