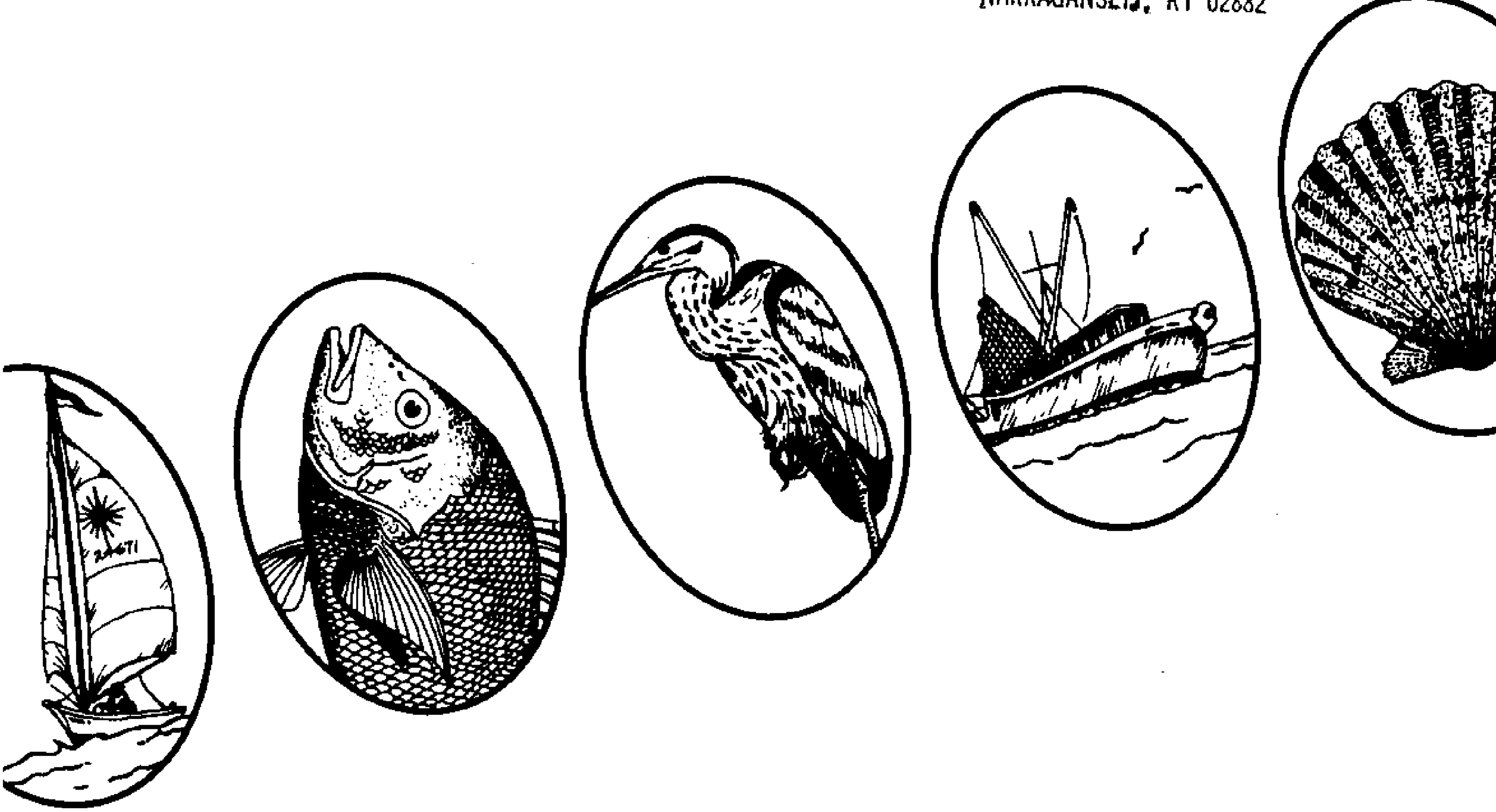
Working Paper 81-5

Migration and Development Of Young American Eels, *Anguilla rostrata* In Coastal North Carolina

Daniel P. Sykes



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MIGRATION AND DEVELOPMENT OF YOUNG AMERICAN EELS, *Anguilla rostrata*, IN COASTAL NORTH CAROLINA

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Editorial Preface

This UNC Sea Grant Working Paper contains the nearly completed and finalized results of the author's masters degree thesis. Because the results, conclusions and other thoughts expressed herein are those of the author, editorial and review actions were taken only to make it more easily read and understood. The editors made no attempt to expand the thoughts or data interpretations of the author.

Because of its relevance to studies of eel and elver biology currently underway in several other states, it was decided that this material should appear in printed form without further delay. Thus, the thesis draft has been prepared as a working paper even though defense of the thesis is pending.

William L. Rickards
Melvin T. Huish
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Introduction

The migration of the post-larval American eel *Anguilla rostrata* (LeSeuer) or elver in fresh water in the spring is the subject of this study. The biological condition of the elvers and the physical, climatological and biological condition of the sampling site preceding, during, and immediately following the spring upstream migration are the important aspects of this study which will help further the knowledge of fresh water eel biology.

The approximate arrival time and peak of migration of the elvers was determined by conducting an intensive trapping survey. Fish trapped along with the elvers were identified and are also reported. Length, weight, pigmentation stage and a condition factor based on length and weight were investigated to determine the biological condition of the elvers through the season.

Air temperature, direction and velocity of the wind and amount of daily precipitation were the climatological factors surveyed. Water analysis also included oxygen content, pH, temperature, level and velocity. The phase of the moon, general weather conditions and physical characteristics of the sampling site were observed and are reported because of their assumed influence on elver behavior.

The migration of the elvers of the genus *Anguilla* into fresh water is a well known phenomenon in many countries (Jellyman, 1977b). Migration of elvers of the American eel has been reported and discussed by various authors including Angel and Jones (1974), Groom (1975), Hornberger (1978), Jeffries (1960), Sheldon (1974), Smith (1968) and Wenner (1972). Environmental conditions at the time of elver migration for both North Atlantic species, the American and European eel, *Anguilla anguilla*, have been investigated by Creutzberg (1961), Deelder (1958), Groom (1975), Lowe (1951) and Menzies (1936).

The objectives of this study were to document the occurrence and approximate date of the 1978 spring upstream migration of American eel elvers in one location using data collected by intensive monitoring of traps designed for their capture. It was thus possible to determine the time of maximum elver movement. The environmental conditions which existed and the biological condition of the elvers before, during and after the peak of migration were examined in order to determine any correlation existing between them and the time of maximum elver movement.

Literature Review

Large gaps exist in our knowledge of life histories of Atlantic eels of the genus *Anguilla*, and Smith (1968) emphasized that much remains to be learned about the American eel since it has been the subject of very little direct work. His research in Florida supports the theory of the famous Danish scientist Johannes Schmidt, who mainly studied the European eel, *Anguilla anguilla* (Linnaeus), that there are two distinct species of north Atlantic fresh water eels. The extensive research of Schmidt and excellent brief histories of early investigations are reported in Bertin (1956). The issue over whether A. rostrata and A. anguilla are distinct or merely ecophenotypes is addressed by Harden Jones (1968) and contains arguments both for and against the theory.

Wenner (1972) stated that many aspects of American eel biology are extrapolations of results collected for the European eel. He concluded from results of his investigation combined with those of other authors that A. rostrata elver size and time of inshore migration were related to latitude, those in southern estuaries arrived earlier and were smaller. Smith (1968) made similar conclusions and stated the ascent into fresh water undoubtedly began earlier in Florida than it did farther north, and thus involved younger eels. Although no metamorphosing individuals were found, the larvae disappered from the water during September through December. Citing evidence based on the European eel, the conclusion was made that the disappearance is a period spent passing through the edge of the Gulf Stream and the approach of the continental shelf triggers the metamorphosis. The nearly metamorphosed elvers probably spend the rest of the autumn burrowing in the bottom, before beginning their ascent into fresh water.

The initial invasion of fresh water by "glass eels" (transparent elvers), which look like small eels, but lack pigment, is the first stage of migration (Jellyman, 1977b). This, Jellyman (1977a) claimed, is distinct from summer upstream migration of elvers. The distinction then between glass eel and elver is important and the physiological process which occurs as an eel makes this change is the extension of pigment. The extension of pigment which consists of a constantly increasing deposit of melanin in the melanocytes and melanophores according to Bertin (1956) is particularly useful in classifying the successive stages of metamorphosis. This is especially useful when dealing with such a wide variety in terminology. A deep nerve-cord pigmentation is followed by superficial pigmentation developed from tail towards head. Boetius (1976) gave simplified classifications for pigmentation development which were used in the present study.

Sheldon (1974) made the distinction between glass eels and elvers and stated that elvers invade eastern Maine rivers and streams in the spring and usually there are many in the glass eel stage when the run begins. The time, duration and extent of the upstream elver run are variable. The Maine runs investigated in 1971 and 1972 began around mid-May and continued through mid-June. A small wooden-frame trap used to capture elvers was described. This trap has been modified for use in other investigations.

On January 19, 1966, elvers captured in Florida for inspection by Smith (1968), ranged from 46 to 54 mm. Glass eels from Florida were also described by Eldred (1968) and had inconspicuous pigment and mean total lengths from 49.5 to 52.2 mm. Hornberger (1978) reports the first catch of small unpigmented glass eels in South Carolina on January 3, 1978. Mean length ranged between 52.8 and 55.8 mm, while mean weight varied between 1.5g and 1.8g for ten specimens. A target date set in 1974 for the capture of elvers by Angel and Jones (1974) was given to them as March 27. The first sighting of elvers in Broad Creek (Carteret County, N. C.) was on February 20, 1974. Commercial quantities were not taken until March 5. The Sheldon trap design was described as promising. Wenner (1972) captured elvers that were in various degrees of superficial pigmentation and had a mean length of 55.6 mm in Virginia on March 17, 1970. Elvers appeared in New Brunswick (Canada) in late April and May according to Groom (1975). Large masses began to appear on the spring tides as the water temperature approached 10^{o} C. Sample weights taken at that time were reported. Scoop net samples were taken in order to determine the time best suited for commercial harvest of elvers. Elvers were captured in coastal fresh water streams using fine mesh dip nets and traps by Rickards et al. (1978), and similar traps were used by Jellyman (1977b).

Studies of factors which affect the migration of elvers into fresh water and farther migration upstream are often inconclusive and at times conflicting. Invasion periodicity of the European eel was discussed extensively by Menzies (1936) and Lowe (1951). The earlier study stated that spring tides are more often used for invasion by glass eels than neap tides. The latter showed that this is not necessarily true. The influence of the moon and precipitation resulting in increased water flow and level on migration was not significant according to Jellyman (1977b). However, Cremer (1976) stated that elver invasion occured during the rainy season and that increased flow stimulated migration. General weather conditions and slight increases in catch correlated with the full moon were reported by Groom (1975). The accumulation of elvers was found not to correlate with temperature even though low temperatures sometimes meant few numbers (Creutzberg, 1961). Lindquist (1976) indicated that increased west wind was a stimulation to migration.

Study Area

The study area was located in the Newport River watershed and all sampling sites were located on Black Creek (Fig. 1). Black Creek is a small stream originating in the Croatan National Forest. In periods of reduced precipitation and subsequent low water level, the impoundment locally known as "Mill Pond" is the only source of water for Black Creek. A survey and classification of the Newport River watershed and Black Creek tributary was made by Davis and McCoy (1965) who showed that the central area soil of the lower coastal plain contained a high percentage of organic matter and the waters of most streams exhibit a dark brown stain resulting from leaching of humic acids from swampy areas. The Newport River was classified as a tidal stream and according to the report, Black Creek is not far from what appears to be a transition zone between fresh and salt water.

Mill Pond, also known as Walker Pond, is approximately one mile long and one-quarter mile at its point of maximum width. Two small concrete spillways are the only links between the impoundment and Black Creek. The stream extends approximately two miles south from the spillway to the Newport River (Fig. 2).

This area was chosen because elvers of the American eel had been located and captured there (Angel and Jones, 1974 and Rickards et al., 1978) for several consecutive years. It was felt the stream would serve well in providing adequate quantities of elvers for study. Elvers were caught primarily in the modified Sheldon trap, and a few other species of fish were

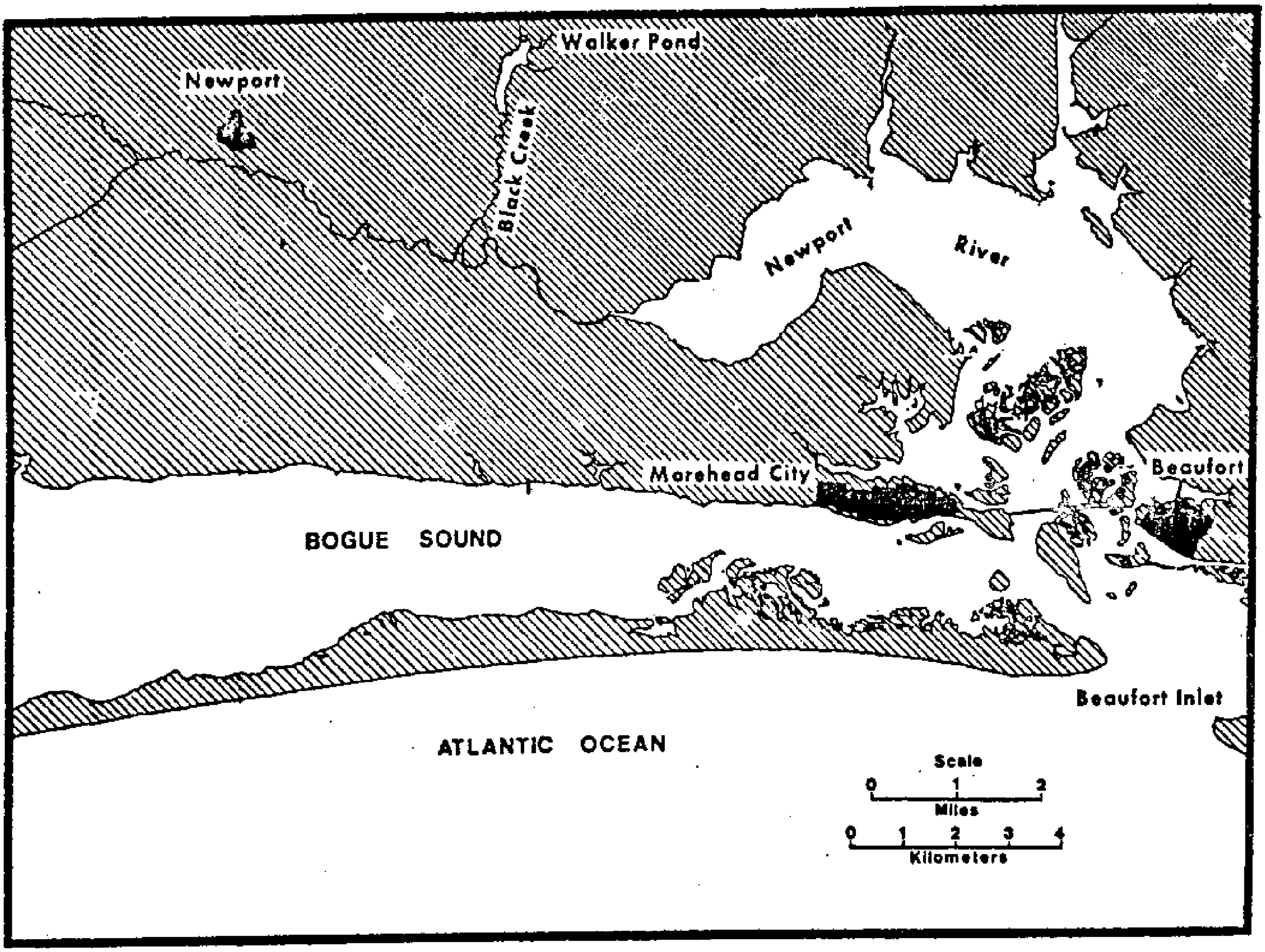


Figure 1. Location of the study site at Black Creek and nearby waterways by which elvers would have approached the site.

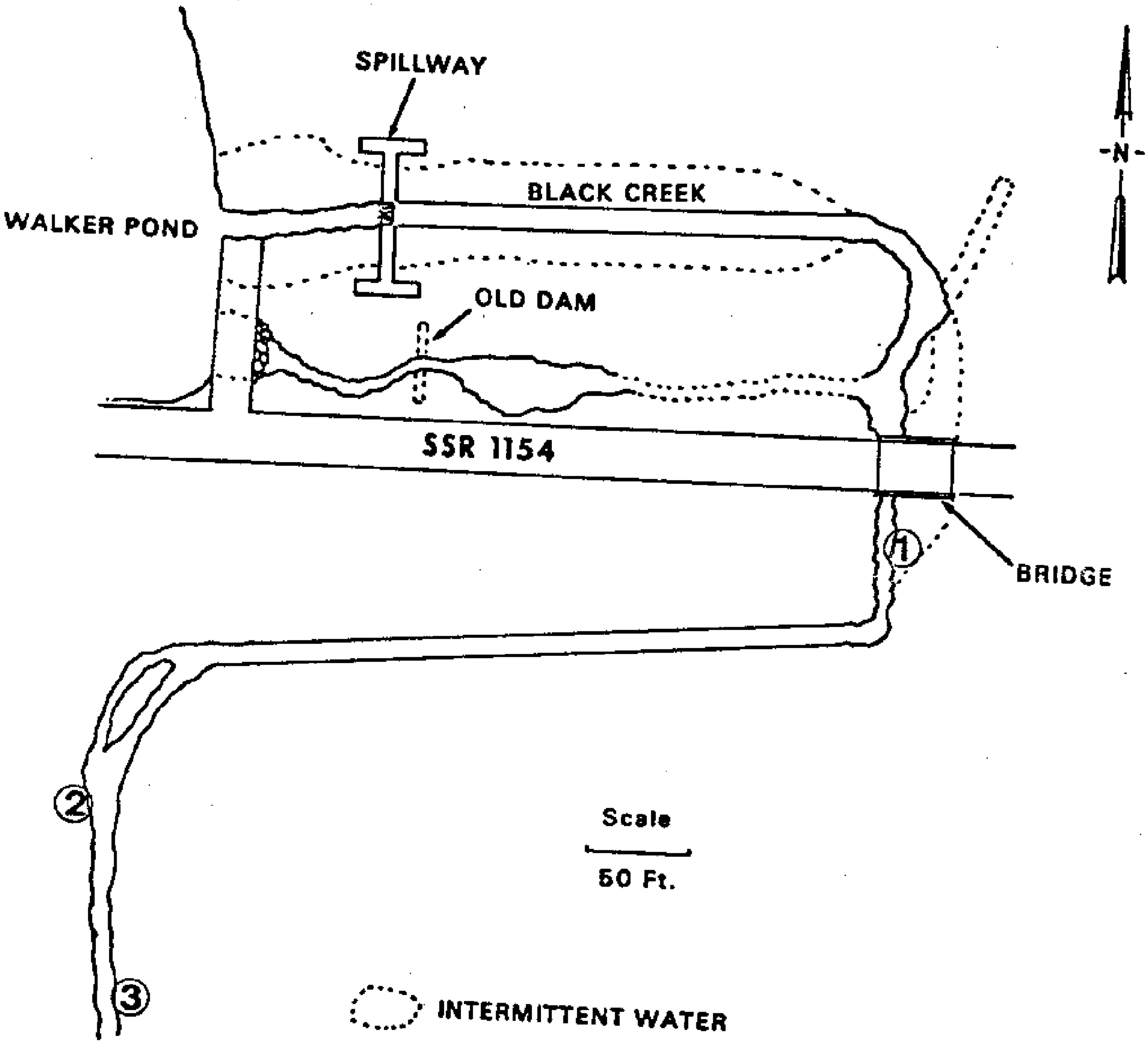


Figure 2. A more detailed map of Black Creek showing the three locations where elver traps were set.

caught as well (Table 1). Weather and water analysis data were collected at the site (Table 2). The water temperature ranged from 2.2 to 23.0°C and the air temperature from -5.5 to 20.5°C. Precipitation was infrequent and the largest downfall (3.10 inches) occurred the first day of this study. Water level and velocity increased during times of heavy precipitation ranging from 50 to 95 cm and 5 to 9 meters/second, respectively.

The oxygen content and pH of the stream water were nearly constant. Slightly acidic water (pH approximately 6.2) was measured every time and the oxygen content remained around 10 mg/ml. Moon and wind conditions are discussed later.

Methods and Materials

The method chosen for capturing elvers depends on such factors as water flow, tidal influences, physical shape of the water body, etc., and devices include dip nets, fyke nets, traps and channel nets. Each gear type may be modified for use under prevailing conditions, but fine mesh net is a common characteristic (Rickards et al., 1978).

A modified box trap was used in this study with a capture and holding chamber of 0.8 mm mesh netting. The mouth of the net leading into a tapered throat was on the downstream side, and operation of the trap took advantage of the elver's upstream movement (Fig. 3). The traps were set near the stream bank where there was slow water and in water deep enough to cover the mouth of the net yet shallow enough so there was no water flowing over the top edge. All sides were netting allowing water to flow through the trap. When the trap was left in the same location, the net mouth could be adjusted up or down depending on the water level. The three permanent trap locations are indicated (Fig. 2) by circled numbers 1, 2, and 3. A wing was extended from the holding chamber to the stream bank so that elvers moving along the stream edge were directed into the funnel mouth of the chamber. No elvers were seen escaping, and this was considered an effective elver capture technique. The biggest advantage of the trap was the minimal time spent tending the gear at the stream. The traps were fishing 24 hours per day, but only daily tending was necessary. Stakes and ropes were used to secure the net and fishing was possible under almost all conditions. The net was lifted out of the water and emptied every 24 hours and each 24 hour period was 1 trap day. The other fish captured were separated from the elvers and identified according to Eddy (1976).

The number and weight of the total catch were determined and a live subsample was taken for use in calculating fresh lengths and weights. The mean weights were usually based on 50 elvers, and individual lengths were determined to the nearest 0.1 mm by the use of calipers. After being measured, they were preserved in 5% buffered formalin. A condition coefficient (K) (Boetius, 1976; Jellyman, 1977b) was calculated using

$$K = \frac{W}{L^3} 10^3$$

Table 1. Common and scientific names of fishes in addition to elvers which were captured in the traps.

Redfin pickerel	*Esox americanus americanus*
Chain pickerel	*Esox niger*
Warmouth	*Chaenobryttus gulosus*
Bluegill	*Lepomis macrochirus*
Pumpkinseed	*Lepomis gibbosus*
Redbreast sunfish	*Lepomis cyanellus*
Mud sunfish	*Acantharchus pomotis*
Banded sunfish	*Enneacanthus obesus*
Pirate perch	*Aphredoderus sayanus*
Bluespotted sunfish	*Enneacanthus gloriosus*
Golden shiner	*Notemigonus crysoleucas*
Eastern mudminnow	*Umbra pygmaea*
Lake chubsucker	*Erimyzon sucetta*
Yellow bullhead	*Ictalurus natalis*
Tadpole madtom	*Noturus gyrinus*
Margined madtom	*Noturus insignis*
Swamp fish	*Chologaster cornuta*
Flier	*Centrarchus macropterus*
Swampdarter	*Etheostoma fusiforme*
Hogchoker	*Trinectes maculatus*
Mosquitofish	*Gambusia affinis*

Table 2. Weather and water conditions at Black Creek during sampling periods.

Date, 1978	Air temp (C)	Water temp (C)	Water level (cm)	Water velocity	Precipitation (inches)
Jan. 19	2.2	7.7	80	6	3.10
Feb. 4	-5.5	2.2	80	7	
10	-2.7	2.2	73	7	
12	-2.7	2.2	69	7	
17	2.7	4.4	65	8	.02
18	3.3	6.0	55	8	.07
25	4.4	7.7	55	8	
Mar. 3	3.8	7.2	55	9	.46
4	-0.5	5.5	75	6	
5	-3.8	4.4	80	8	
9	1.1	5.5	75	7	.15
10	5.5	7.4	85	6	.80
11	0.0	8.8	85	7	
12	10.0	11.1	80	8	
16	14.9	18.0	70	8	
17	4.4	14.4	65	8	
18	3.3	12.5	63	9	
19	10.0	12.7	60	9	
21	20.5	12.7	60	7	
22	19.9	13.3	58	7	

Table 2 (cont'd).

Date, 1978	Air temp (C)	Water temp (C)	Water level (cm)	Water velocity	Precipitation (inches)
Mar. 26	16.6	15.5	55	8	1.25
27	15.5	16.6	80	5	
31	9.4	16.6	65	7	
Apr. 1	16.6	17.1	62	8	
2	16.6	18.3	60	7	
7	17.2	21.1	52	9	
8	14.9	21.1	50	8	
9	15.5	17.7	50	9	
13	17.2	19.9	65	8	
14	15.5	19.9	68	8	
16	11.6	18.3	65	8	
21	10.5	18.8	90	5	
23	15.5	19.9	80	6	
24	17.7	18.8	78	6	
25	17.2	21.1	73	7	
26	19.9	19.9	73	7	.10
27	8.8	18.3	71	7	
29	11.1	18.3	67	8	
May 3	11.6	17.7	65	9	
13	20.5	23.0	95	5	

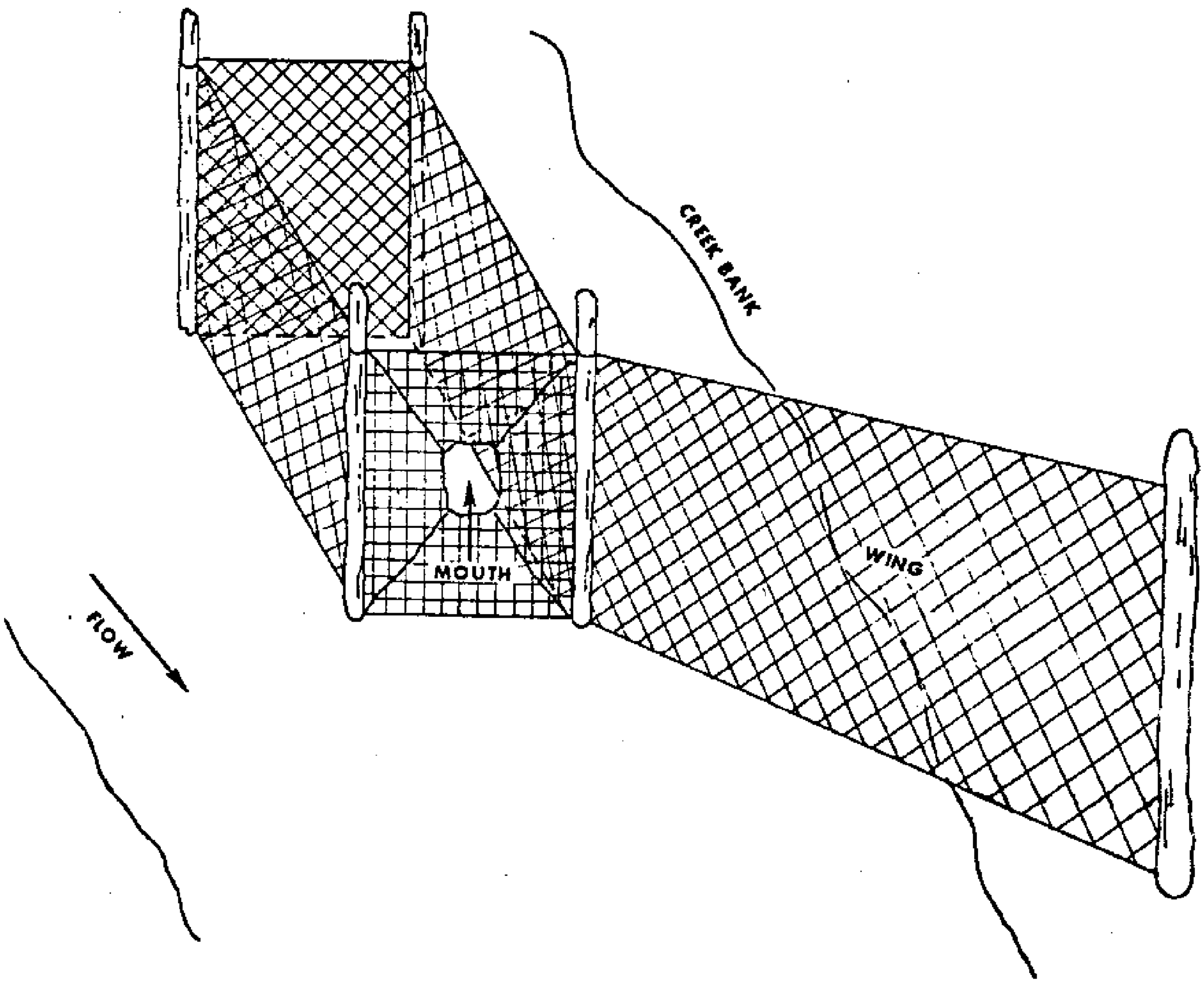


Figure 3. Drawing of an elver trap as it would appear when set to capture elvers. Note that the trap mouth is a funnel and not a flat panel.

where W = mean body weight (g), and
L = mean total length (cm).

The preserved samples were separated into both size categories and one of several stages of superficial or cutaneous pigmentation (examined with 12X magnification) according to the simplified scheme of Boetius (1976), (Fig. 4).

Observations of elver behavior were made in one location. It was hoped that this would make the results of the observations more consistent. Obstructions are known to hinder upstream travel by elvers, therefore, the spillway linking Walker Pond to Black Creek was the location used (Fig. 5).

Measurements of water level were taken from a permanent stake with increments marked in 10 cm intervals. The surface velocity was measured at the same location using a stopwatch and a floating object in meters/second. The air and water temperatures were also recorded at this point. The wind direction and velocity and precipitation were taken from records of the Atlantic Beach Policy weather station because large trees in the immediate vicinity of Black Creek prohibited accurate measurement. Oxygen content and pH of the water were measured beneath the SSR 1154 bridge using a Hache chemical analysis kit.

Results and Discussion

Thirty eight thousand one hundred elvers were captured during 150 trap days between January 19 and May 3, 1978 (Table 3). During this period, there was at least one elver trap in operation on thirty-seven separate sampling dates, of which thirty contained data from two traps (Table 4). Nineteen of these were taken after one trap day. The remaining 11 contained two or more trap days of catch.

Trap Number One caught 24,000 elvers during 53 trap days. Traps Two and Three caught fewer elvers on 33 and 64 trap days, respectively. Total catch was less for samples taken with one trap day (49 of the total 150 trap days contained a single 24 hour period's catch). Trap Number Three had 21, Number One had 17, and Number Two had 11 of the single trap day samples. Single trap day catch was highest for trap Number One while Number Three had the next highest total. Trap Number Two was eventually abandoned due to low success caused by unfavorable conditions. Traps Number One and Three showed peaks in catch in early March and late April. Number Three showed two very separate and distinct peaks while Number One showed greater fluctuation in four peaks. Two of these were associated with one of the more distinct peaks of trap Number Three, and the other two peaks were associated with the late April peak of trap Number Three (Figure 6).

Live mean weights (mg) are reported for 15 samples while mean total length and range are reported for these and three additional samples (two of the 18 samples were dipped at the spillway, the others are trap captures). Condition factors were calculated for those samples having both live fresh lengths and weights (Table 5). Distribution of developmental stages was calculated for 11 samples (Table 6).

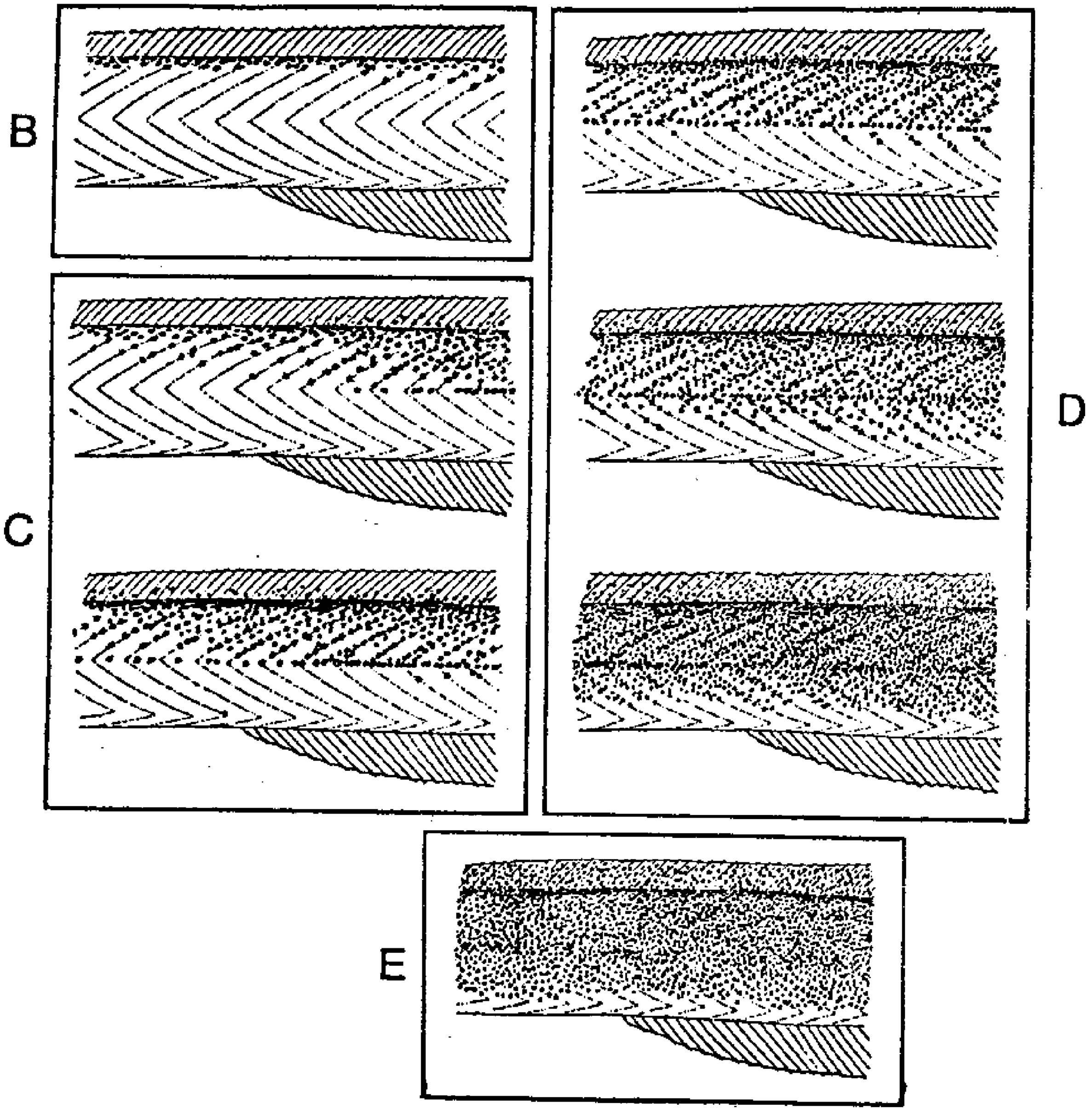


Figure 4. Developmental pigment stages (from Boetius, 1976) which were used to grade elvers into relative "age" groups.

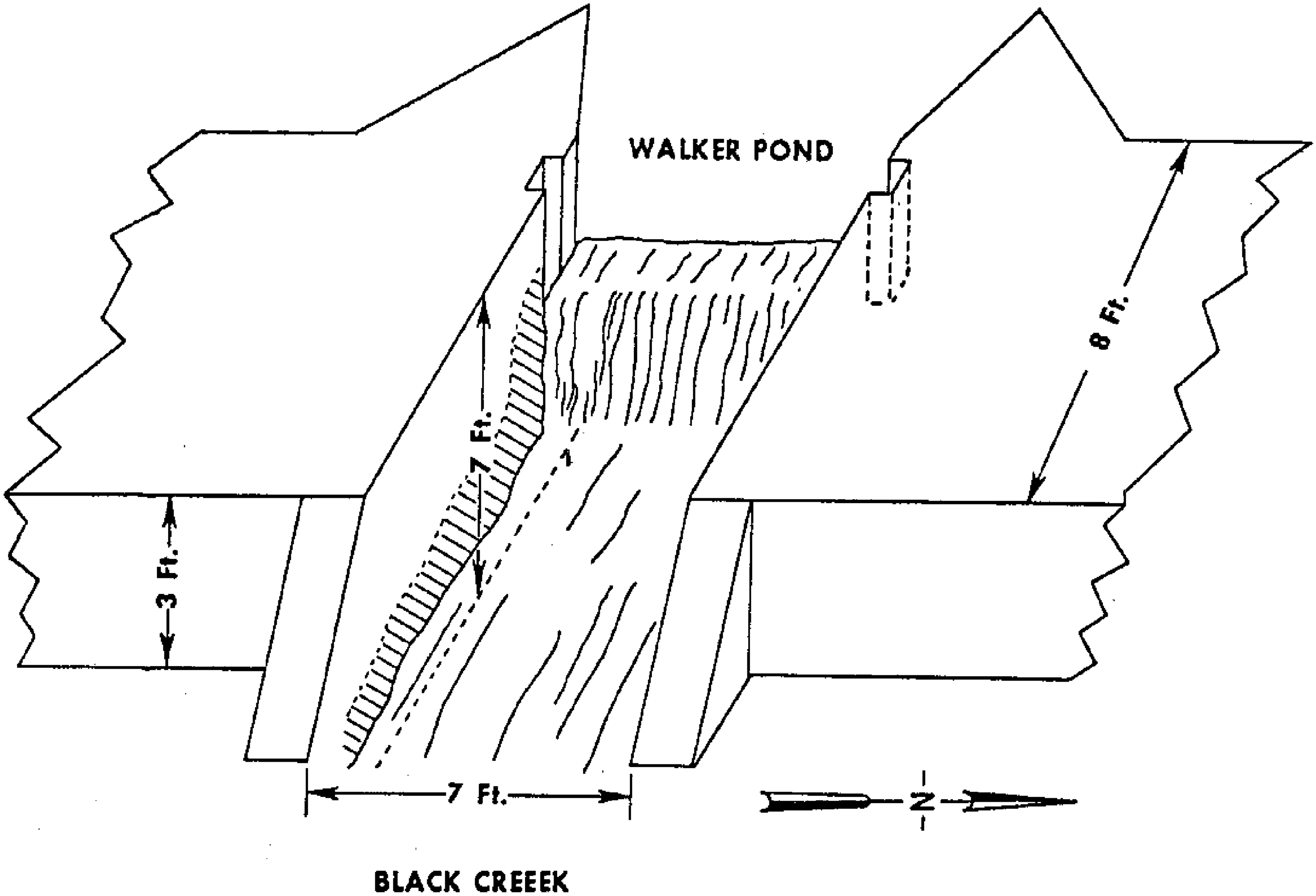


Figure 5. Detailed diagram of the spillway at Walker Pond where many elvers were captured with dip nets.

Table 3. Trap days, total numbers and total weight of the elver catch among the three trap locations.

Trap	Trap days	no. of elvers	weight (g)
no.1	53	24,087	5435
no.2	33	5,615	1252
no.3	64	8,399	1959
Totals	150	38,101	7646

Trap	Trap days	no. of elvers	weight (g)
no.1	17	9,254	2153
no.2	11	1,370	306
no.3	21	3,730	922
Totals	49	13,354	3381

Table 4. Numbers and weights of elvers captured by each trap.

Date, 1978	Trap days	Trap no. 1		Trap no. 2		Trap no. 3		Total	
		no. of elvers	wt. (g)	no. of elvers	wt. (g)	no. of elvers	wt. (g)	no. of elvers	wt. (g)
Mar. 26	3	702	120	*		7	2	709	122
27	1	350	85	25	6	10	2	385	101
31	3	100	23	33	8	1		134	31
Apr. 1	1	65	15	*		2		67	15
2	1	120	28	*		38	9	158	37
7	4	*		*		14	4	14	4
8	2	*		*		3		3	
9	1	*		*		40	9	40	9
13	3	*		*		20	5	20	5
14	1	*		*		15	3	15	3
16	2	0	0	*		50	11	50	11
21	1	1100	250	*		*		1100	250
23	2	2500	570	*		2053	480	4553	1050
24	1	645	140	*		23	5	668	145
25	1	1020	240	*		800	200	1820	440
26	1	1160	262	*		650	187	1810	449
27	1	2250	630	*		515	125	3065	755
29	2	2180	495	*		300	68	2480	563
May 3	5	3240	750	*		50	12	3290	762

Table 4 (cont'd).

		Trap no. 1		Trap no. 2		Trap no. 3		Total	
Date, 1978	Trap days	no. of elvers	wt. (g)	no. of elvers	wt.(g)	no. of elvers	wt.(g)	no. of elvers	wt.(g)
Feb. 4	1	8	2	75	17	85	19	168	38
10	1	1		5		0	0	6	2
12	1	*		1		0	0	1	
17	5	45	11	166	40	83	19	249	59
18	1	25	6	79	18	68	15	172	39
25	1	18	4	15	4	40	9	73	17
Mar. 3	4	1215	270	3240	720	38	9	4493	1000
5	2	655	126	6	2	12	3	673	131
9	3	354	79	71	15	230	56	655	150
10	1	*		23	5	115	26	138	31
11	1	*		170	39	410	92	580	131
12	1	800	180	900	200	800	192	2500	572
16	3	3015	670	50	11	820	150	3885	831
17	1	131	29	36	8	50	11	217	48
18	1	250	55	*		43	10	293	65
19	1	379	87	*		8	2	387	89
21	2	827	168	679	150	987	220	2493	538
22	1	630	140	41	9	18	4	689	153

* denotes no captures on this date

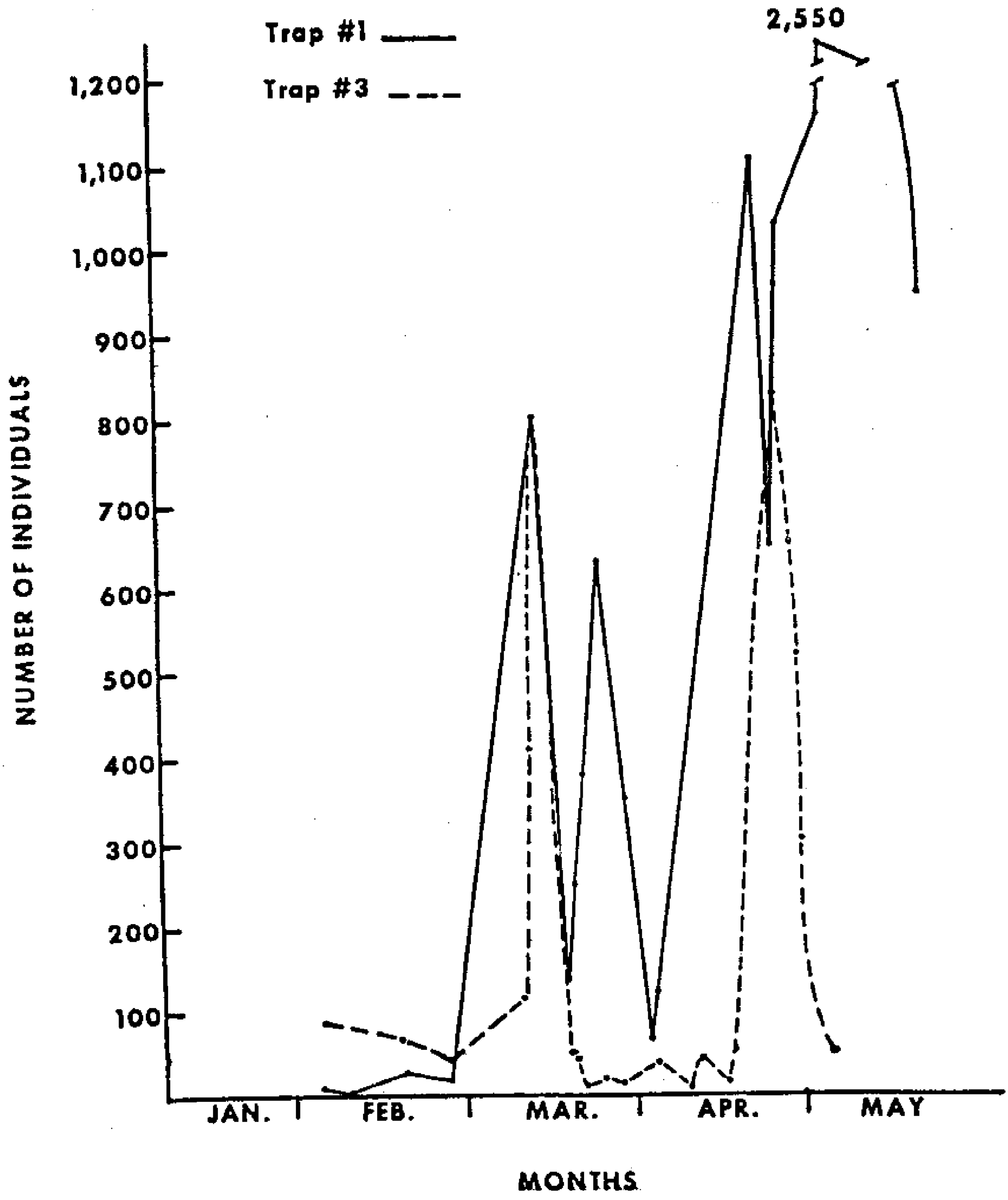


Figure 6. Distribution of the total numbers of elvers captured in Traps One and Three during the study.

Table 5. Average total length, live weight and condition factor for elvers captured by dip net at the Walker Pond spillway.

Date 1978	Jan. 19	Feb. 24	Feb. 25	Mar. 3	Mar. 5	Mar. 10
Total no.	44	22	11	43	50	31
Mean total lengths (mm)	54.91	57.95	60.60	57.95	57.84	58.77
Total lengths (range)	50-60	54-61	53-63	51-64	54-65	52-65
Mean body fresh weight (mg)				144.2	164.0	156.4
Condition*				.740	.849	.769

Date 1978	Mar. 16	Mar. 17	Mar. 18	Mar. 22**	Mar. 22	Mar. 26
Total no.	50	50	50	50	50	50
Mean total lengths (mm)	58.08	57.80	57.78	60.20	58.96	56.36
Total lengths (range)	52-63	53-64	53-62	56-67	55-65	52-62
Mean body fresh weight (mg)	143.6	144.0	145.0	141.5	137.4	137.8
Condition*	.733	.746	.752	.646	.668	.765

Table 5 (cont'd).

Date 1978	Mar. 31	Apr. 1	Apr. 16	Apr. 24	Apr. 25	May 13
Total no.	50	50	50	50	50	50
Mean total lengths (mm)	56.54	56.78	57.62	57.62	58.46	60.02
Total lengths (range)	51-61	51-63	53-63	52-65	53-64	55-65
Mean body fresh weight (mg)	146.0	154.7	96.6	124.3	160.8	160.4
Condition*	.808	.842	.505	.648	.801	.741

* $\frac{W}{L^3} \times 10^3$ (W=body weight, gms. L=total length, cm.)

**dipped at dam

Table 6. Percent distribution of each pigment stage present in eleven dip net samples.

	Percent of total no. in stage			
Sample no.	B	C	D	E
1		19	81	
2	9	75	16	
3		41	53	6
4		60	40	
5		57	43	
6		48	48	4
7		42	58	
8		41	59	
9		25	73	3
10		33	67	
11		13	72	15

Mean length made a discontinuous increase from January until a peak (about 59 mm) in mid-March. The following sample mean was next to the lowest (about 56 mm), and the rest of the samples increased through April and May (Figure 7). The mean weight (Figure 8) decreased to its lowest value (100 mg) slightly later than the corresponding decrease in length. The condition factor (Figure 9) is a direct reflection of fish weight; therefore, length, weight and condition were at their lowest prior to the sample on March 24.

The distribution of pigment development stages (Figure 10) was determined on the following sample dates:

Sample	Date
1	1/19
2	3/9
3	3/16
4	3/17
5	3/18
6	3/26
7	3/31
8	4/1
9	4/13
10	4/24
11	5/14

Sample one contained a larger percentage of D stage elvers than any other. Samples two, three, four and five all contained at least equal numbers of elvers in stage C. Six, seven and eight also contained high percentages of stage C elvers, but more were in stage D. Very few stage C elvers exist in samples nine, ten and eleven while most were in stage D.

The least pigmented elvers sampled (stage B) were taken on March 9, and they comprised nine percent of the total sample. This same sample contained the highest stage C percentage of all eleven samples. Samples three, six, nine and eleven contained stage E elvers.

Environmental variables were investigated in order to determine relationships with change in elver length, weight or catch. From General Linear Models (Service, 1972), water temperature and level were indicated as variables needing closer attention. High correlation between air temperature and water temperature was also indicated. When moon phase, water velocity, oxygen, pH and wind direction and velocity were eliminated, the correlation of water temperature and level with elver length, weight and catch was greater.

Figure 7. Progression of the mean total length of elvers captured during the study period.

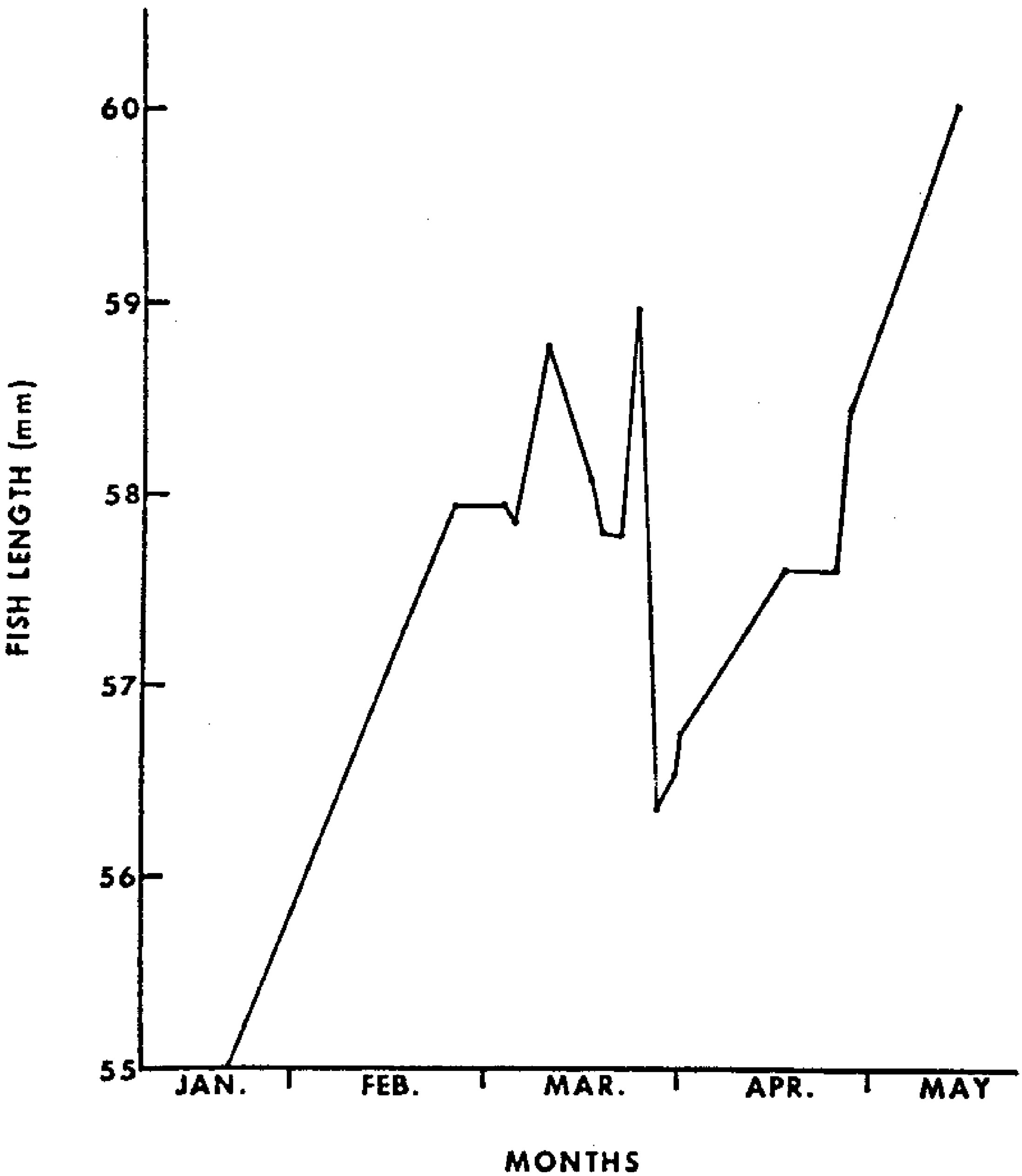


Figure 8. Progression of the mean live weight of elvers captured during the study period.

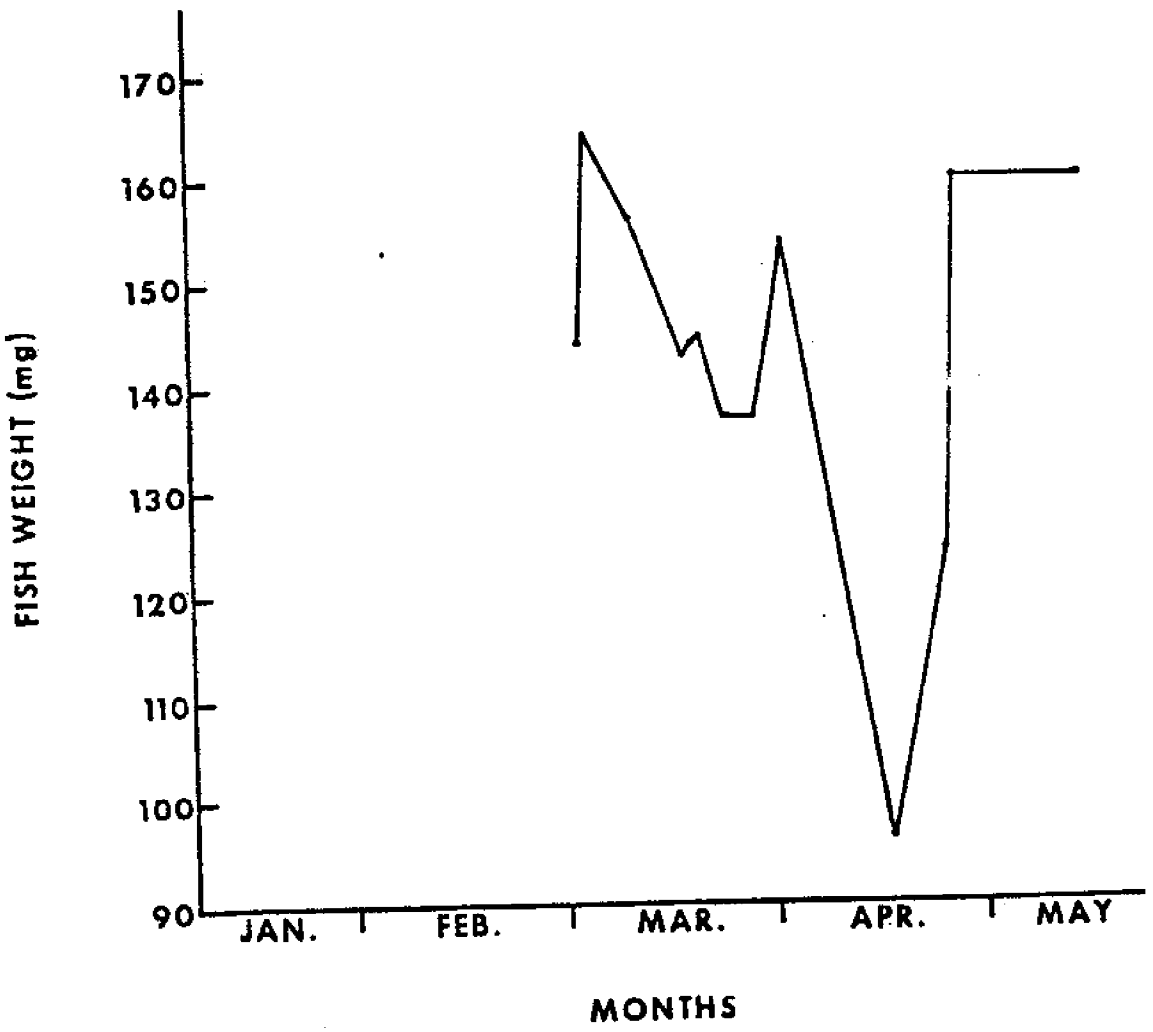


Figure 9. Progression of the condition factor (K) for elvers captured during the study.

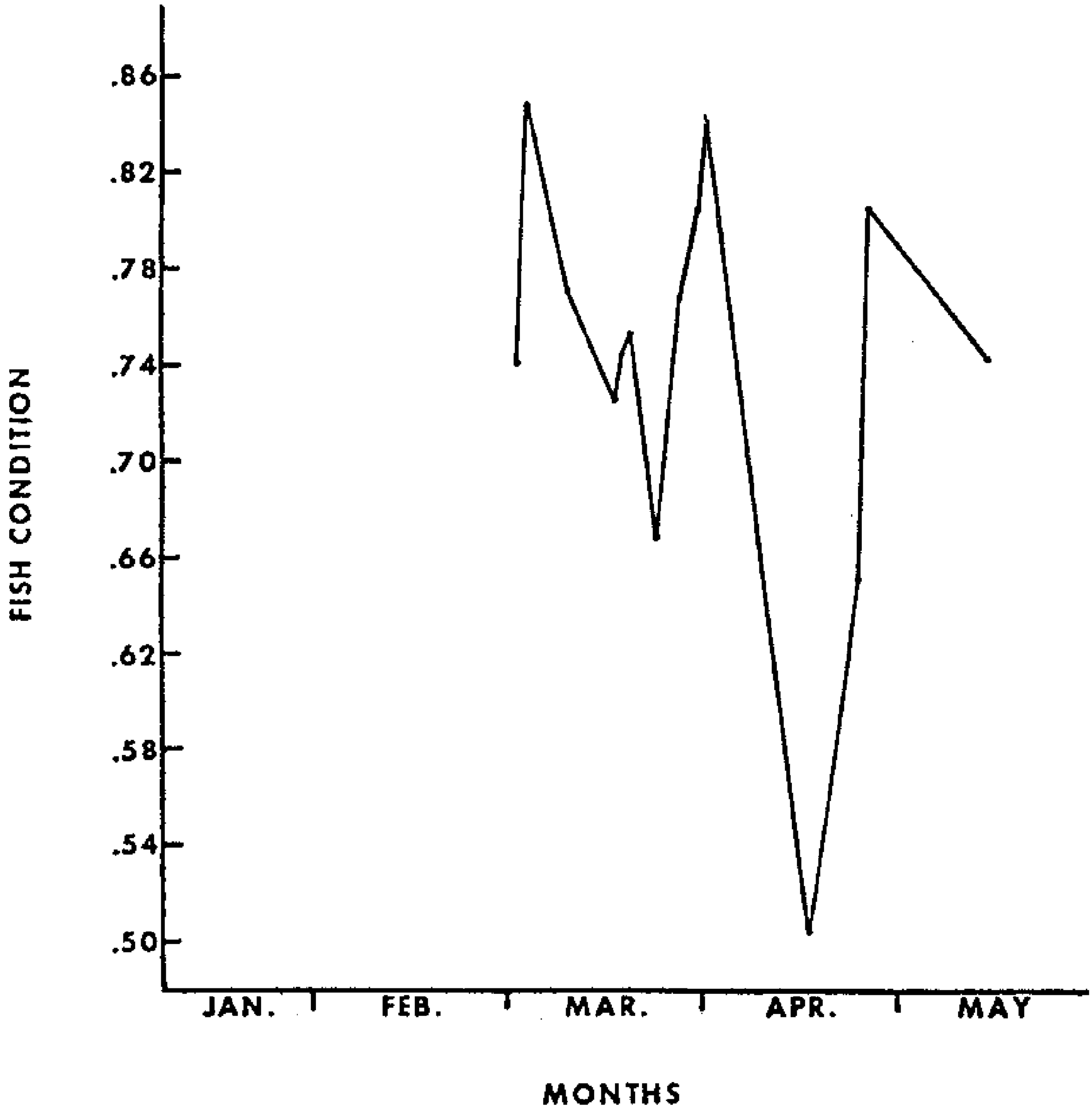


Figure 10. Percent distribution of pigment stages within each each of the eleven samples examined by length classes.

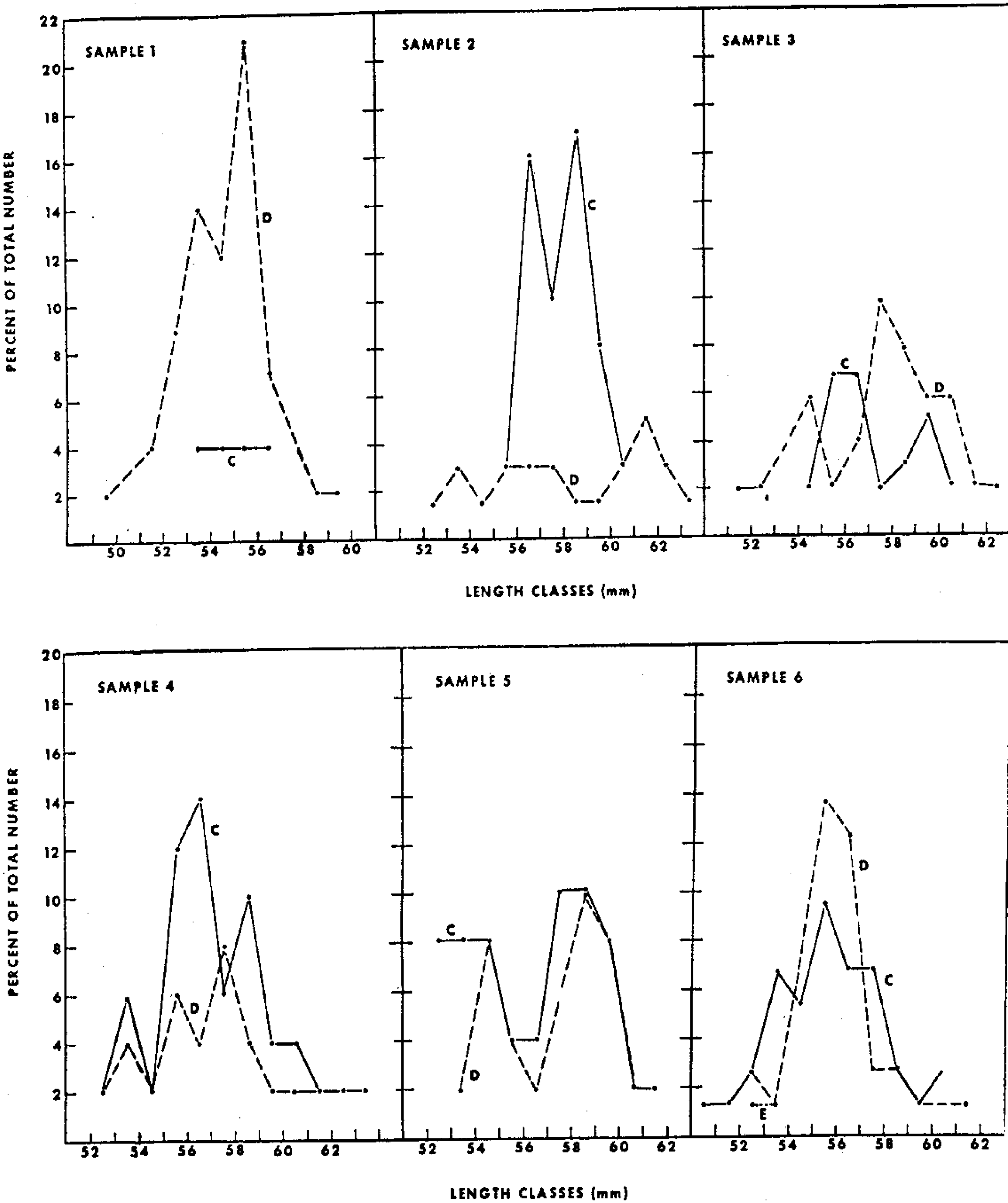
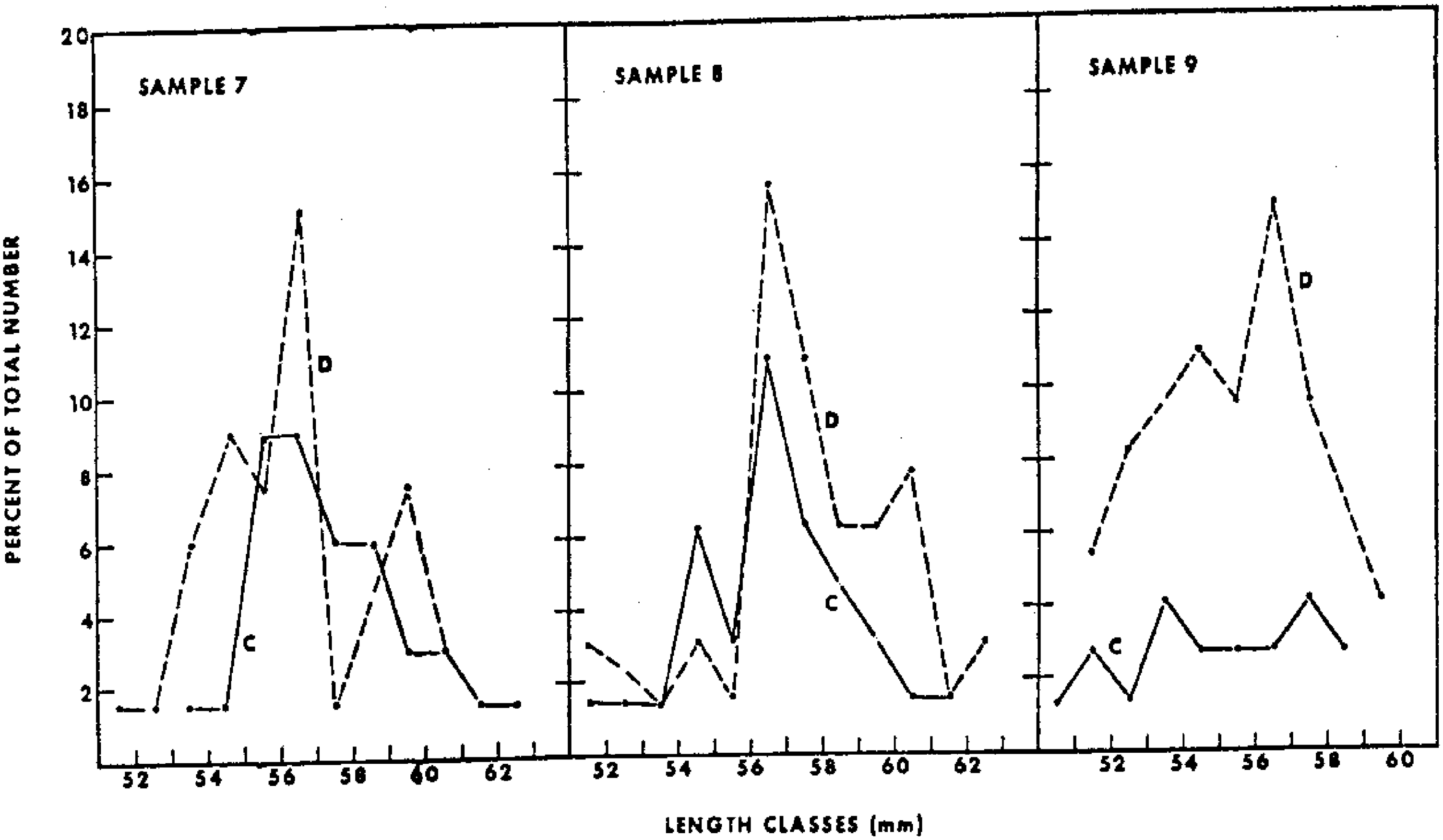
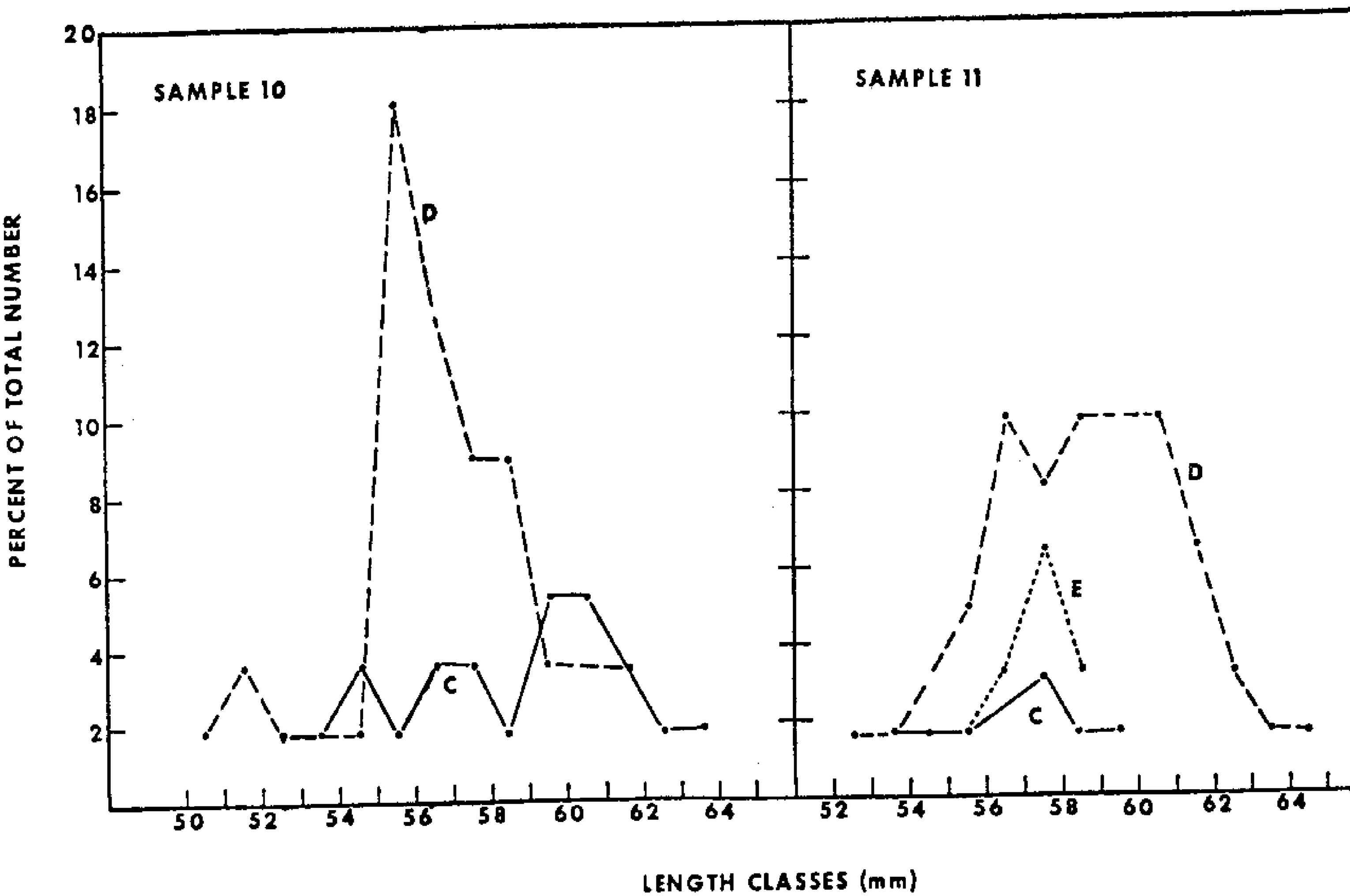


Figure 10 (cont'd).





There were three periods of falling water temperature and three peaks, one in mid-February and two in March (Figure 11). The trap sites on Black Creek were not influenced directly by tides even though the mouth is located in a tidal area. Measurable precipitation occurred eight times and water level fluctuated accordingly (Figure 12). There were four periods of low water ranging between 50 and 100 (cm) depth. The first was in late February, the second and third were separated by a peak level in late March, and the fourth occurred in late April.

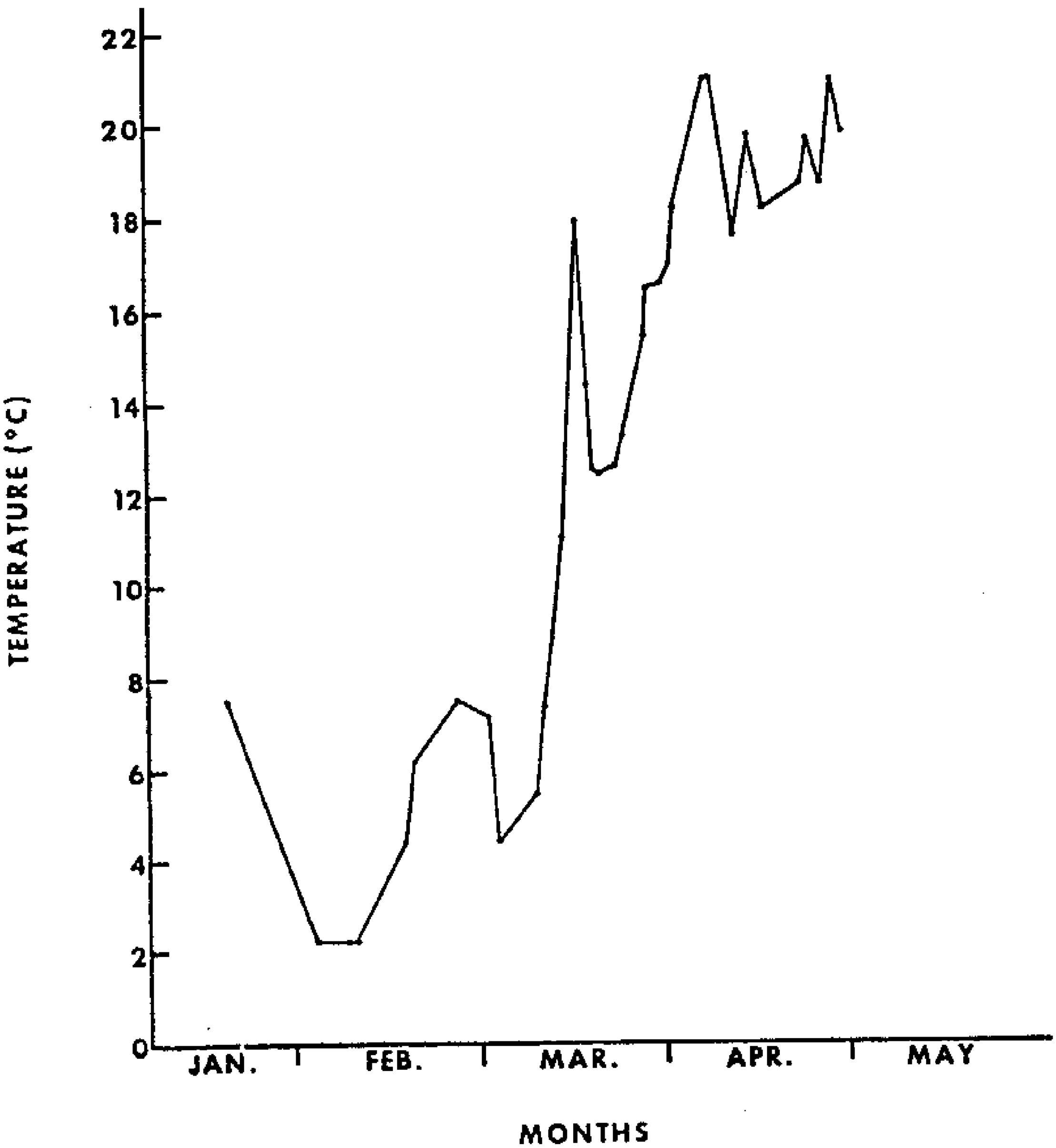
Along with daily trap fishing, observations were made of elver behavior at the spillway which separates Walker Pond and Black Creek since this is the point where upstream movement by the elvers is interrupted. These observations were begun on January 19, 1978. At that time, only sporadic, small numbers of elvers were seen. This was the case for both day and nighttime observations until noon on March 16, when the first "swarming" behavior (i.e. thigmotaxis according to Jellyman (1977a). Trap catch increased along with this heightened elver activity and abundance at the spillway. At this time, a single scoop with a dip net yielded several hundred elvers. Such behavior continued through the daylight hours and ceased at dusk. No elvers were seen during the night or early morning, but at dawn (March 17) elvers began to appear once again. This diurnal rhythm with (at least, initially) no activity at night continued through March 26.

On the afternoon of March 24, a new activity was observed. The elvers moved up and onto the damp, mossy surface of the spillway just above the water line (shaded area, Fig. 5). There was little movement once the elvers clung to the surface. At this same time, a reduction in observable numbers at and around the spillway occurred. As diurnal swarming and climbing continued, the reduction in numbers continued until April 2. Many elvers were seen on this day as swarming and climbing appeared to be at a peak level. No observations were made until April 7 when swarming and climbing were again observed along with a great reduction in numbers. Such small-scale activity continued until the third week in April.

Following a considerable increase in water level on April 21, many elvers were seen. Elver activity on the next two days was diurnal with increasing observable numbers. The elvers were active during the daytime on April 23. However, on this day, they did not disappear at dusk. They remained active, and upon darkness became more active than before. The elvers were not only climbing out of the water and onto the spillway walls, but they were also moving along the wet surface of the concrete towards the water rushing over the spillway. An area of spillway surface remains damp above the water line due to splashing, and elvers moved as high as about 12 inches above the water line. There were no bare spots, and every inch appeared to be covered with elvers. No elvers were seen gaining entry into the pond. Jellyman (1977a) described the method that elvers used in moving along a concrete spillway, appearing to cling by friction and surface tension.

After 9:30 PM, elver activity decreased, and abundance dropped off through the night. Elver activity was lowest after dawn and through the day even though they were abundant along the edges of the stream. At dusk on April 24, climbing and moving towards the pond were again observed. This

Figure 11. Progression of water temperatures in Black Creek during the study period.



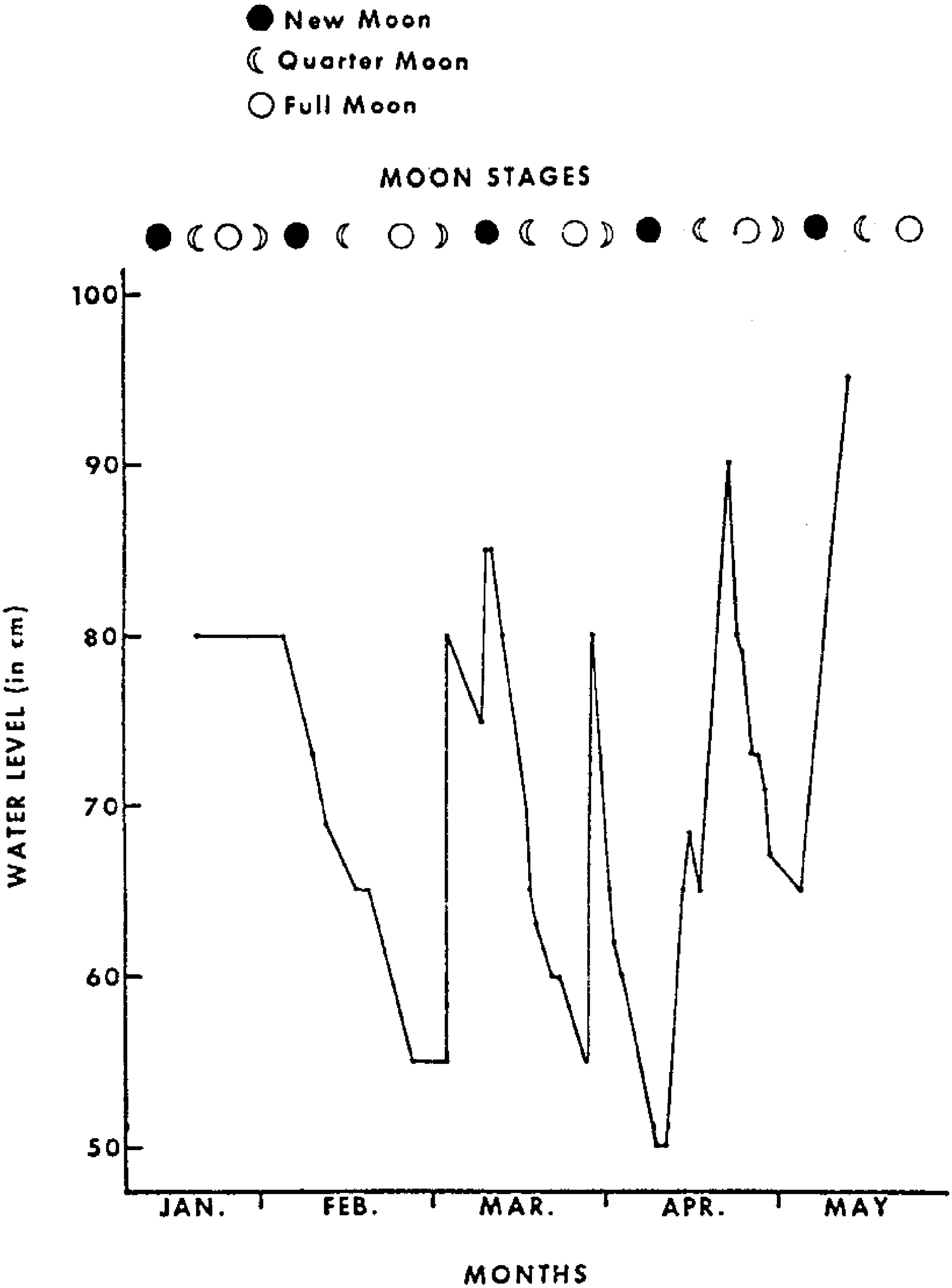


Figure 12. Water levels and moon phases which occurred during the study period.

nocturnal pattern continued for twelve consecutive nights until May 4. There were two peak periods during this time. The nocturnal activity and climbing peaked April 25, and several thousand elvers swarmed over the moist concrete of the south wall of the spillway. There were fewer elvers climbing April 26 through 28, but just as many were in the calm water below the spillway as on the previous nights. The second, but lesser peak occurred shortly after dark on April 30 as 200 elvers were counted climbing on the south spillway wall. There were 75 elvers climbing the preceding night and 25 the following night. The next four nights, May 1 through 4, only a few elvers were seen and none during the day.

The site was not checked until May 12 at which time the largest mass of elvers was congregated at the spillway. This was at noon, and there were no elvers moving at all that night. This reversal to diurnal behavior continued May 13 through 16 and numbers of elvers observed decreased every day. Another two-week break in site visitation occurred after which elvers were rarely seen, throughout the summer.

Elvers moved upstream from the estuary throughout the spring. Large masses were clearly seen in the level of catch (Figure 6), and it is felt that the two peaks associated with trap Number Three were those elvers heading up Black Creek after migration from the estuary had been triggered. According to behavior observed by Deelder (1958), these elvers had been in the area for some time because they exhibit rheotaxis and thigmotaxis (Jellyman, 1977a) which are not exhibited by elvers encountering fresh water for the first time. Thus, the elvers in this case had been in fresh water for an undetermined amount of time and had become darker with the acquisition of pigment (Figure 13).

The two environmental factors which most influenced the migration as indicated from General Linear Models were water level and temperature. Upon closer general inspection, it appears that an increase in water level is accompanied by not only an increased catch, but length and weight of elvers appears to change accordingly. There is obviously a lag time between precipitation and rise in water level, and water temperature changes accordingly. Therefore, exact correlations between these factors and elver length, weight, and catch are not seen.

Generally, however, there were lower values for length, weight and condition when the large declines in water level and temperature occurred. Length and weight are reflected in the condition factor; and even though a decrease in length occurs with developmental pigment stage (Table 7) the condition does not regress throughout the season. This can be explained by the fact that elvers congregating below an obstruction could be actively feeding as the temperature increased and would be in better condition. Boetius (1976) confirmed this by stating that elvers do increase in weight and length as they pass from stage B through E, but as elvers arrive along the coast the mean length in each of the stages decreases through the season.

There has been no previous intensive elver trap study like this one. Nor have there been studies which have conclusively identified those factors which actually trigger migration. A number of factors have been proposed. Cremer (1976) suggested that rainfall stimulates migration since catches

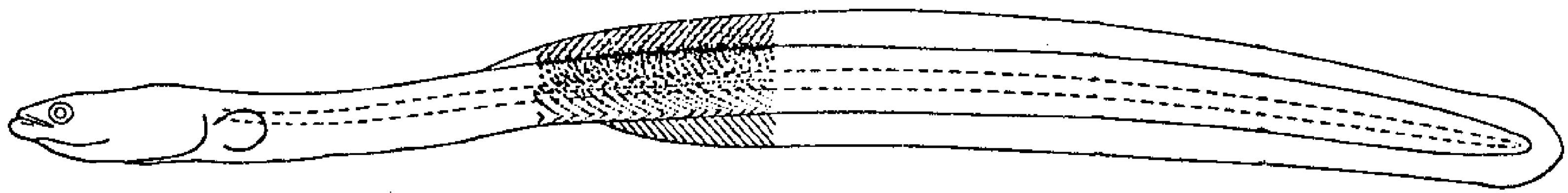


Figure 13. An elver on which the region of cutaneous pigment inspection is indicated by shading (Stage D).

Table 7. Average elver length for pigment developmental stages B, C, D and E encountered during the study period.

	Average length in stage (mm)			
Sample no.	B	C	D	E
1		54.5	51	
2	58.3	57.6	56.9	
3		57.1	56.8	56
4		56.5	56.5	
5		56	56.7	
6		54.6	55.4	53.6
7		56.8	55.7	
8		55.9	58.6	
9		54.4	54.5	54.5
10		57.1	55.9	
11		56.8	58.1	56.7

were greatest during periods of high tide and on overcast or moonless nights. Groom (1975) stated, however, that greater concentrations of elvers on dark, cloudy, windy nights were not confirmed from his study. The present study can neither confirm nor deny their suppositions.

The full moon on April 23, even though not visible due to cloud cover, corresponds to the peak catch in trap Number One. It also occurred at the same time the elvers changed from diurnal to nocturnal behavior.

The only way to accurately determine the condition of elvers at time of entry into fresh water would be to capture them close to that area. When elvers arrived at Walker Pond, they were presumably in a more developed stage than when they entered the sound from the ocean. Therefore, the condition of the elvers upon entering the sound was unknown. No elvers of the very early stages were captured although several elvers of Stage B were found in Sample Two. It is reasonable to assume that catching elvers of stages A and B would indicate a very short period of time for movement from the ocean to the headwaters of Black Creek. Since only a few Stage B elvers were caught, it is apparent that glass eels do not occur this far inland. This study has presented a view of the condition, length, weight and stage of the pigmented elvers as they migrate upstream throughout the spring (Jan. 19 through May 15).

Literature Cited

Angel, N. B., and W. R. Jones. 1974. Aquaculture of the American eel (Anguilla rostrata). Industrial Extension Service, School of Engineering, North Carolina State Univ., Raleigh, N. C. 43 pp. Project completion report to the Coastal Plains Regional Commission.

Bertin, L. 1956. Eels: A Biological Study. Cleaver-Hume Press Ltd. 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. Medd. Dan. Fisk. - Havunders. N. S., 7:199-220.

Cremer, M. C. 1976. Eel culture in the Philippines. Proc. World Mariculture Soc., 7:129-136.

Creutzberg, F. 1961. On the orientation of migrating elvers (Anguilla vulgaris Turt.) in a tidal area. Netherlands Journal of Sea Research, (3):257-338.

Davis, J. R., and E. G. McCoy. 1965. Survey and classification of the New- White Oak- Newport rivers and tributaries, North Carolina. Final Report, Federal Aid in Fish Restoration. North Carolina Wildlife Resources Commission, Raleigh, N. C. 25 pp.

Deelder, C. L. 1958. On the behavior of elvers (Anguilla vulgaris Turt.) migrating from the sea into fresh water. Journal du Conseil, 24(1):135-146.

Eddy, S. 1976. How to Know the Freshwater Fishes. Wm. C. Brown Company Publishers. Dubuque, Iowa. 286 pp.

Eldred, B. 1968. Larvae and glass eels of the American freshwater eel, Anguilla rostrata (LeSeuer, 1817) in Florida waters. Fla. Board Conserv., Mar. Res. Lab., Leafl. Ser. 4(9, pt. 1):1-4.

Groom, W. 1975. Final report on elver observations in New Brunswick waters, 1975. N. B. Dept. Fisheries, Caraquet. 156 pp.

Harden Jones, F. R. 1968. Fish Migration. Arnold, London. 325 pp.

Hornberger, M. L. 1978. Coastal Plains American eel study. Pages 42-50 in Progress Report for October 1977 through January 1978. South Carolina Wildlife and Marine Resources Department, Charleston.

Jeffries, H. P. 1960. Winter occurrences of Anguilla rostrata elvers in New England and Middle Atlantic estuaries. Limnol. Oceanogr., 5(3):338-340.

Jellyman, D. H. 1977a. Summer upstream migration of juvenile freshwater eels in New Zealand. N. Z. Journal of Marine and Freshwater Research, 11(1):61-71.

Jellyman, D. J. 1977b. Invasion of a New Zealand freshwater stream by glass-eels of two Anguilla spp. N.Z. Journal of Marine and Freshwater Research, 11(2):193-209.

Lindquist, A. 1976. Observations on glass eels in the Skagerak and Kattegat. ICES/EIFAC Symp. on Eel Research and Management. Paper No. 48. 17 p.

Lower, R. H. 1951. Factors influencing the runs of elvers in the River Bann, Northern Ireland. Journal du Conseil, 17(3):299-315.

Menzies, W. J. M. 1936. The run of elvers in the River Bann, Northern Ireland, Journal du Conseil, 11(2):249-259.

Rickards, W. L., J. E. Foster and W. R. Jones. 1978. Techniques for culturing the American eel. Proc. World Mariculture Society, 9:641-646.

Service, J. 1972. A user's guide to statistical analysis system. Student Supply Stores. North Carolina State Univ., Raleigh. 260 pp.

Sheldon, W. W. 1974. Elvers in Maine: techniques of locating, catching and holding. State of Maine, Department of Marine Resources. 25 pp.

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.

Wenner, C. A. 1972. Aspects of the biology and systematics of the American eel, Anguilla rostrata (LeSeuer). M. A. Thesis. College of William and Mary, Williamsburg, Virginia. 109 pp.