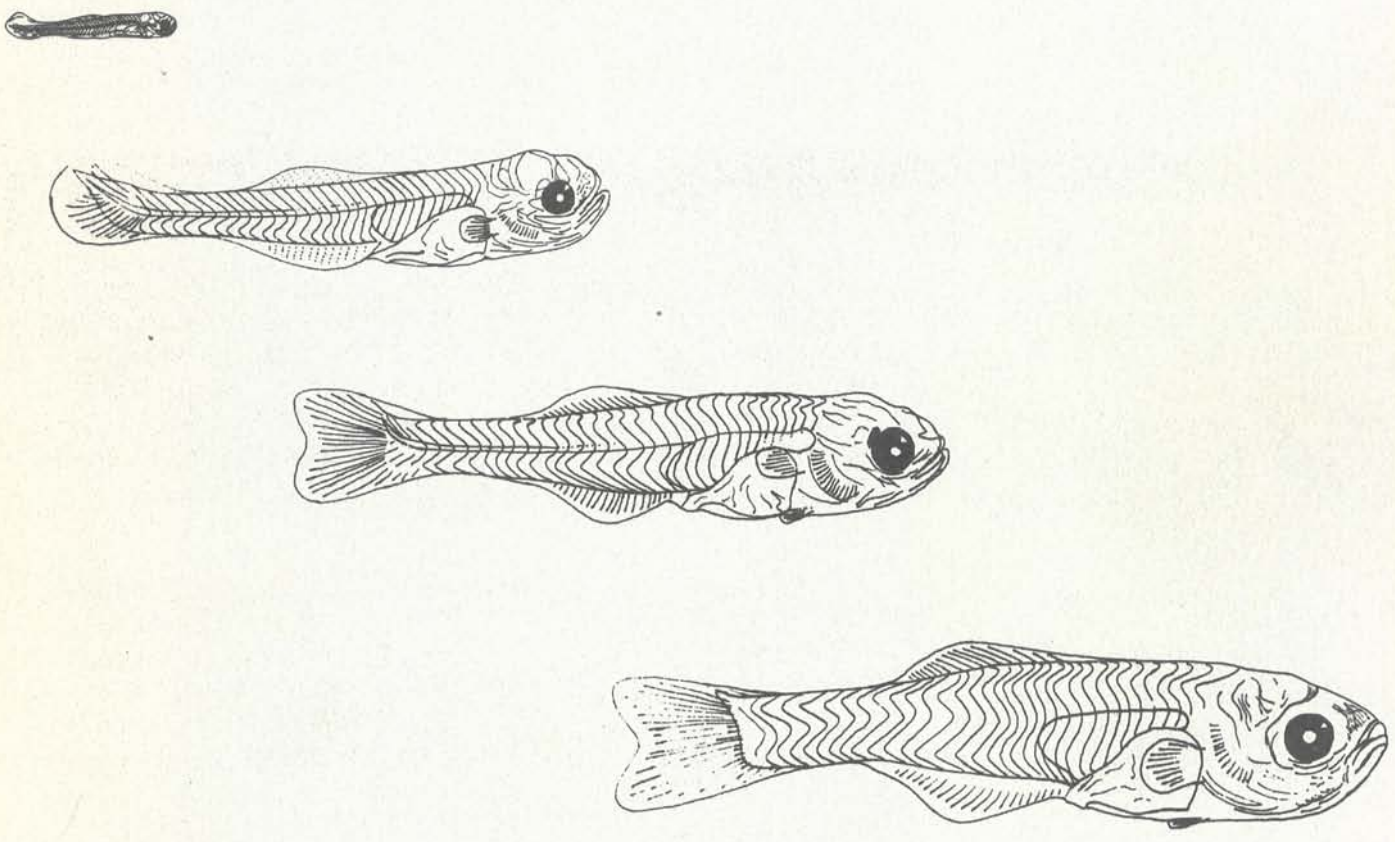
Proceedings of the

THIRD SYMPOSIUM ON LARVAL FISH



Western Kentucky University

DEPARTMENT OF BIOLOGY

PROCEEDINGS OF THE THIRD SYMPOSIUM ON LARVAL FISH

Robert D. Hoyt

Editor

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Hosted by the Department of Biology

CONTENTS

PREFACE

The Third Symposium on Larval Fish was sponsored and hosted by Western Kentucky University and the Department of Biology in Bowling Green, Kentucky on February 19-21, 1979. Benefits derived by the participants at the first two symposia, plus the continued interest in and need for further information regarding the biology of larval fishes provided the basis for this third conference.

To provide some direction in the development of the technical paper program, the theme "Larval Fish Taxonomy, Life Histories, and Methodologies" was established. This theme was generally a continuation of that of the second conference in Knoxville, Tennessee in 1978 and felt by participants of the third meeting to be relevant and beneficial. It was the concensus opinion of the 1979 group that the program should be continued and the suggestion made that salt water larval studies be encouraged and included in future programs.

It was the intent of the host in planning the 1979 meeting to provide a structured technical paper program in an informal atmosphere, allowing ample time for discussion and questions and answers. Directors and representatives of Regional Larval Fish Centers were invited to describe and update their respective facilities and services. Provisions were were made for several "taxonomic experts" to look at and examine specimens in a workshop setting. Participants were charged by the host at the outset to exchange information and ideas freely during the meeting and make whatever requests necessary to accomplish their goals.

Based on participant responses during the conference and letters received since, the above format was considered to be a success. In spite of inclimate weather conditions, 77 people were in attendence representing 12 universities, 6 power companies, 5 state conservation agencies, 2 federal agencies, and 12 environmental consulting firms.

Many people were involved in making this conference possible and are deserving of acknowledgment. Thanks are extended to the Dean's Office, Ogden College of Science and Technology for providing the resources necessary for travel to and from the Nashville Airport, the Director and Staff of the Florence Schneider Continuing Education Center, and the Office of Public Relations of Western Kentucky University. Graduate students Neil Fortner, Greg Kindschi, Gary Overmann, Allen Robison, Ben Del Tito, and Dennis Webb are deserving of special thanks for their many diverse efforts. Very special thanks go to Mr. J. R. McCurry for his tireless efforts and patience in photographing the figures for the proceedings. Mr. Robert Wallus, TVA, is deserving of special recognition for the direction, assistance, and inspiration he provided in the planning stages of the meeting. Part of the costs of printing the proceedings were provided by Grant No. 2-303-R (PL 88-309) from the National Marine Fisheries Service (NOAA) and the Kentucky Department of Fish and Wildlife Resources. Lastly, thanks are extended to Western Kentucky University for the excellent facilities and cooperation provided in planning for and hosting the meeting. This Proceedings Document is dedicated to James R. Charles, Kentucky Department of Fish and Wildlife Resources, whose technical and professional assistance and encouragement made our role in its development and completion possible.

OBSERVATIONS ON THE LARVAL ECOLOGY OF THE SMALLMOUTH BUFFALO

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ABSTRACT

Buffalo were first observed spawning in Rough River Lake on April 30, 1978, at 17.5 C. Larvae were first collected from the lake on May 6. A total of 52 larvae was collected from the lake from May 6 - May 30. Eggs from a second spawn were observed on May 19, but no larvae were collected from that spawn. Larvae were taken in all the upper reaches of the lake sampled. Larvae occurred chiefly on the surface at night. Growth averaged 1.6 mm per week with larvae being 5.1 to 9.1 mm total length. Buffalo larvae disappeared first from shallow water areas. Larval densities were highest at the start of the spawn and decreased thereafter. Densities averaged 0.257 fish/100 m^3. Based on densities observed in the study, larval recruitment at 10 mm length totaled approximately 320,000 fish for the entire lake. Forty-five of the larvae taken were pro-larvae while 7 were early postlarvae. Developmental patterns were similar to that reported in the literature. Food items, including rotifers and copepod nauplii, were observed in the stomachs of two postlarvae.

INTRODUCTION

The smallmouth buffalo, *Ictiobus bubalus* (Rafinesque), is an important freshwater commercial fish species. It has a widespread geographic distribution, high reproductive potential, reaches a large size exceeding 11 kilograms, and has a well established retail market value. Detailed studies have been made of the life history and various aspects of adults (Jester 1973, Hoyt *et al.* 1976), but its early

This study was supported by the National Marine Fisheries Service, NOAA, and the Kentucky Department of Fish and Wildlife Resources, under PL 88-309, Project Number 2-303-R.

larval and juvenile biology remains essentially unknown.

The objectives of this study were to determine the time of occurrence, distribution, density, food habits and early growth patterns of larval and juvenile smallmouth buffalo in Rough River Lake, Kentucky.

STUDY AREA

Rough River Lake is a small U.S. Army Corps of Engineers impoundment in the Green River watershed in west-central Kentucky (Figure 1). One permanent collecting station was established on the South Fork of the Rough River, 300 meters upstream from the mouth of Peter Cave Creek. This station was approximately 200 meters in length and was divided into 7 tow or net pull zones. Four tows were at the surface, 1 each along the shoreline, and 1 each one-third the width of the lake from each bank. Two tows were made along the floodplain bottom, approximately 6 meters in depth, 1 on each side of the river bed, while the last tow was made along the bottom of the river channel, or approximately 10 meters in depth.

Additional surface and bottom samples were taken weekly from the upper reaches of the lake in Peter Cave Creek and weekly surface samples were taken alternately from lake areas upstream and downstream from the main collecting station.

METHODS AND MATERIALS

Attempts to collect larval and juvenile smallmouth buffalo from Rough River Lake were made from November 4 to December 16, 1977, and from March 29 to August 31, 1978. Larval fishes were sampled with conical plankton nets 3 meters long with a 1-meter diameter circular mouth. Net mesh size was 0.8 mm. The net bridle consisted of a ring of 9.5-mm diameter

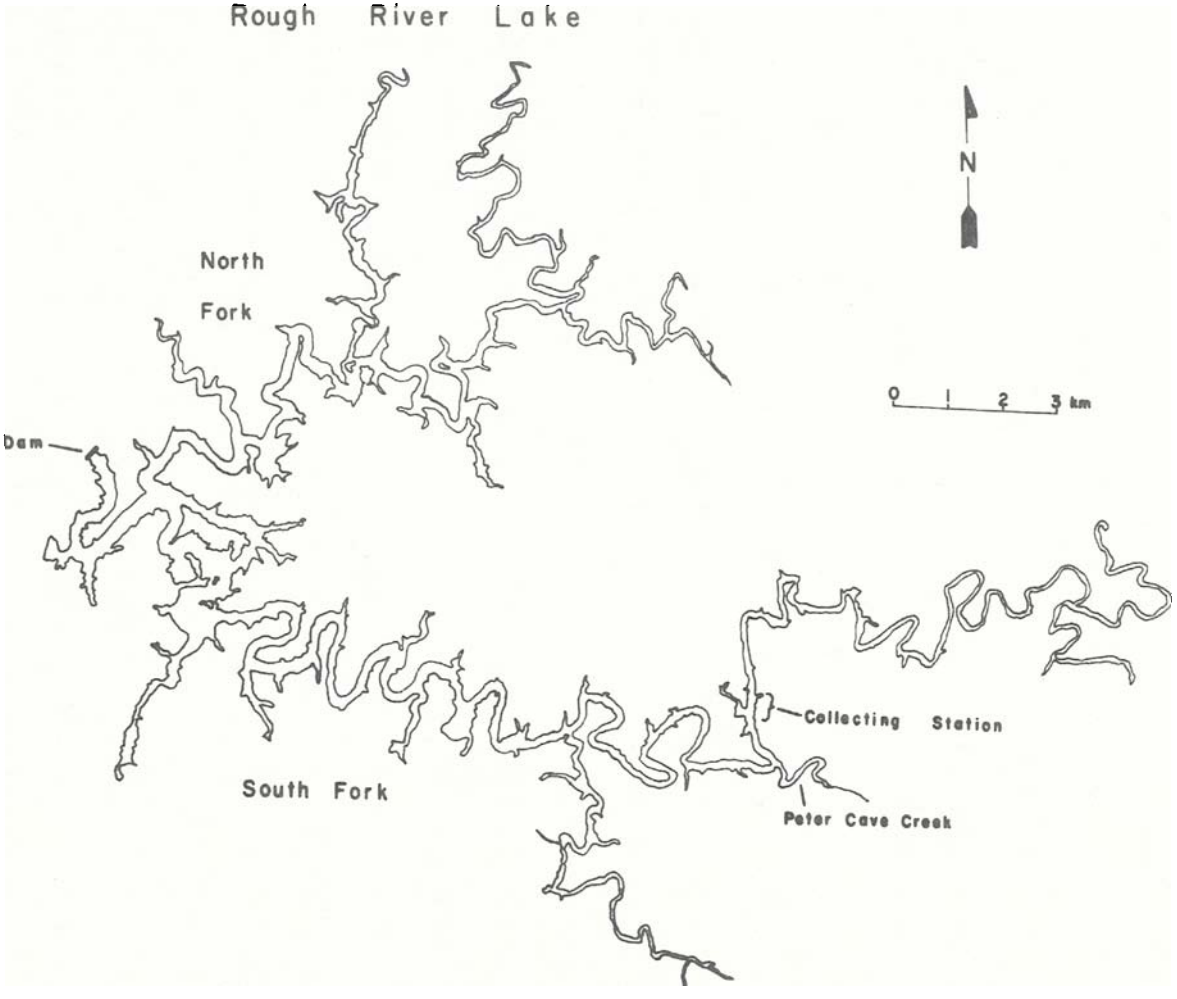

Figure 1. Map of Rough River Lake, Kentucky, showing the collecting station.

stainless steel rod tied inside the net mouth and three 1.3-meter lengths of nylon rope tied equidistantly around the net mouth and connected together in front of the net mouth. A 7.62-cm diameter, 35.6-cm long PCV collecting bottle was attached to the cod end of the net. A digital flowmeter suspended in the center of the net mouth determined the volume of water filtered. Nets were towed at approximately 0.5 m/s for 7 minutes and filtered approximately 250 m^3 of water.

Collections were made twice weekly from March 29, 1978 through May 26, 1978. One collection was made during daylight and one during dark periods. A day and night collection was taken once weekly from May 30 through August 31, 1978. Net tows were made on the surface by attaching a styrofoam block to the bridle ring, while bottom pulls were made with the aid of a 15 kg depressor. Specimens were washed from the net bottle into sampling jars and fixed in a 5% formalin solution.

Larvae were sorted using a dissecting microscope and identified with keys by May and Gasaway (1967), Nelson and Cole (1975), and Hogue *et al.* (1976). Specimens that could not be identified with the use of keys were sent to the Tennessee Valley Authority Larval Fish Laboratory in Norris, Tennessee. Larval drawings were made with a camera lucida mounted on a dissecting microscope.

Juvenile fishes were collected with a 4.9-m semi-balloon trawl with 3.8-cm mesh and 0.3 - 0.6-m otter boards. The trawl was pulled behind a 4.9-m boat powered with a 50-hp outboard. Surface tows were made by floating the otter boards with styrofoam floats, while bottom pulls were made by the normal action of the otter boards.

RESULTS

Spawning - Buffalo reproductive activity was first observed on April 30, 1978, when buffalo and carp were seen spawning along the banks of Peter Cave Creek. While both smallmouth and black buffalo were present in the lake, the spawning fish and their offspring were considered to be smallmouth buffalo on the basis of a known 25:1, adult smallmouth to black ratio in Rough River Lake. Activity was observed along the entire bank but was most intense along undercut banks where fine roots entered the water, in shoreline vegetation, and in and among fallen limbs and debris. Surface water temperature at the time of this observation was 17.5 C, while the bottom temperature was 14 C.

Egg samples were taken from several areas of the bank during this spawning activity and returned to the laboratory for incubation. Following this spawn, colder air temperatures lowered the water temperature to 16 C on May 3 and 6. By May 11, the water temperature had increased to 19 C and buffalo and carp eggs were again observed on May 19 at 25 C. This second evidence of spawning was again along shoreline areas but of much less magnitude than on April 30.

Appearance of Larvae - Twelve newly-hatched buffalo larvae were collected in the lake on May 6, 1978, apparent products of the April 30 spawn. These larvae were collected near the surface all along Peter Cave Creek and in the collecting station on the South Fork. The last larva to be collected was taken on May 30, 1978. As far as could be determined by total body lengths, no buffalo larvae from the May 19 spawn were collected.

Distribution - A total of 52 buffalo larvae were collected from the Lake during the study from May 6 through May 30, 1978. Thirteen were collected

from Peter Cave Creek, 38 from the collecting station on the South Fork, and 1 from a mile upstream from the station (Table 1). Forty-seven of the specimens taken were collected at the surface, while 28 of these were taken at the surface at night (Table 1). Larvae disappeared first from the shallower Peter Cave Creek and upstream lake reaches and then from the deeper main stream station (Table 1). Larvae collected showed no preference for shoreline areas over open water zones, 28 and 24 individuals, respectively (Table 2). Slightly more larvae were taken in night samples than day, 32 and 20, respectively (Table 2).

Density - The density of smallmouth buffalo captured per 100 cubic meters (m^3) of water sampled was greatest in night samples in the main body of the lake, 0.509 fish/100 m^3, followed by Peter Cave Creek, 0.288, and the upstream area, 0.100 (Table 3). At the collecting station, densities were much higher in night than day samples, 0.509 and 0.071, respectively (Table 3). Densities were greatest during the first two weeks of buffalo appearance, 0.419 and 0.498, and decreased progressively to May 30 when the density reached 0.022 fish/100 m^3. The average density of smallmouth buffalo larvae observed in this study was 0.257 fish/100 m^3. This density, when related to the lake capacity in number of cubic meters (123,152,640), indicated that approximately 320,000 smallmouth buffalo larvae survived hatching and early development to reach 10 mm total length.

Growth and Development - The first buffalo larvae collected on May 6 were newly-hatched specimens averaging 5.11 mm total length. By May 11, larvae averaged 7.17 mm, 7.42 mm on May 16, 9.1 on May 23, and 8 mm (1 individual) on May 30. No larvae were collected in the lake after May 30, or longer than 9.1 mm. Prolarvae dominated the samples with 45

Table 1. Number of larval buffalo collected from the South Fork Station, upstream area and Peter Cave Creek in daylight, dark, surface and bottom samples.

	South Fork				Upstream		Peter Cave Creek	
	Day		Night		Day		Day	
	S	B	S	B	S	B	S	B
May 6	1						11	
May 11	2	1	13	2			2	
May 16	2		14	1	1			
May 23			1					
May 30				1				
TOTAL	5	1	28	4	1	0	13	0

Table 2. Number of larval buffalo taken in shoreline versus open water samples in day and night samples on Rough River Lake, Kentucky.

	Shoreline		Open Water	
	Day	Night	Day	Night
May 6	10		2	
May 11		8	5	7
May 16	1	7	2	8
May 23		1		
May 30				1
TOTAL	11	16	9	16

Table 3. Number of larval buffalo collected per 100 cubic meters of lake water sampled at the South Fork Station, upstream area, and Peter Cave Creek in day and night samples.

	South Fork		Upstream	Peter Cave Creek	Total
	Day	Night	Day	Day	
May 6	0.059	0.00	0.00	0.939	0.419
May 11	0.163	1.111	0.00	0.243	0.498
May 16	0.122	0.890	0.227	0.00	0.399
May 23	0.00	0.062	0.00	0.00	0.023
May 30	0.00	0.061	0.00	0.00	0.022
TOTAL	0.071	0.509	0.100	0.288	0.257

specimens while 7 early postlarvae were taken.

Larvae raised in the laboratory at 19 C grew at a slightly faster rate than lake specimens early in development (6.86 mm on May 8, 7.5 on May 10, and 7.55 on May 13) and at a slightly slower rate later in development, 7.95 mm on May 23. Similarly, pro- and postlarvae developmental stages were accelerated in laboratory fish (first postlarvae observed at 7.1 mm and last prolarvae at 7.2 mm) over field specimens (first postlarvae at 7.6 mm and last prolarvae at 7.9 mm).

Average myomere counts for laboratory-raised versus field specimens were similar, 7.9 and 8.22 postanals, and 27.3 and 27 preanals, respectively. Although buffalo larvae were raised in the laboratory to a length of 60 mm by October 15, 1978, no specimens between 11 and 21 mm were preserved. Buffalo larvae were first observed in laboratory aquaria on May 8, eight days after being spawned in Rough River Lake and two days later than

lake larvae were observed. Aquaria temperatures were held constant at 19 C throughout the summer months. The most obvious early larval feature of the buffalo was the bi-lobed, linear yolk sac which maintained this shape to approximately 7 mm length (Figure 2). Pigmentation was lightly spread over the dorsum of the head at 6.5 mm and became increasingly intense dorsally such that by 11 mm, the body dorsad the lateral midline was covered with large pigmented blocks reaching posteriorally to just behind the dorsal fin (Figures 3 and 4). The air bladder first appeared at 7.6 mm, accompanying the development of the gut in lake specimens, and at 7.1 mm for laboratory-reared individuals. Fin ray elements were first observed in the ventral caudal fin and pectoral fins at 8.0 mm. Gill filaments appeared at 6.5 mm. The dorsal fin outline formed in the dorsal fin fold at 9.7 mm and the anal fin outline at 11 mm. The median fin fold between the dorsal and caudal fin and ventrally from the caudal fin to the pelvic fins persisted as a shallow ridge until 22 mm. By 25 mm, squamation was complete and the juvenile stage was attained.

Food Habits - Two of the seven early postlarvae taken had food items in the gut. One 8.5 mm specimen taken on May 16 contained one rotifer, *Keratella sp.*, and 2 copepod nauplii while a 9.1 mm larva collected on May 23 had 1 rotifer. In both specimens, the gut contents also included additional food material and/or detritus that could not be identified.

Juvenile Buffalo - No juvenile buffalo were taken in the study by the use of plankton nets or mid-water trawl gear.

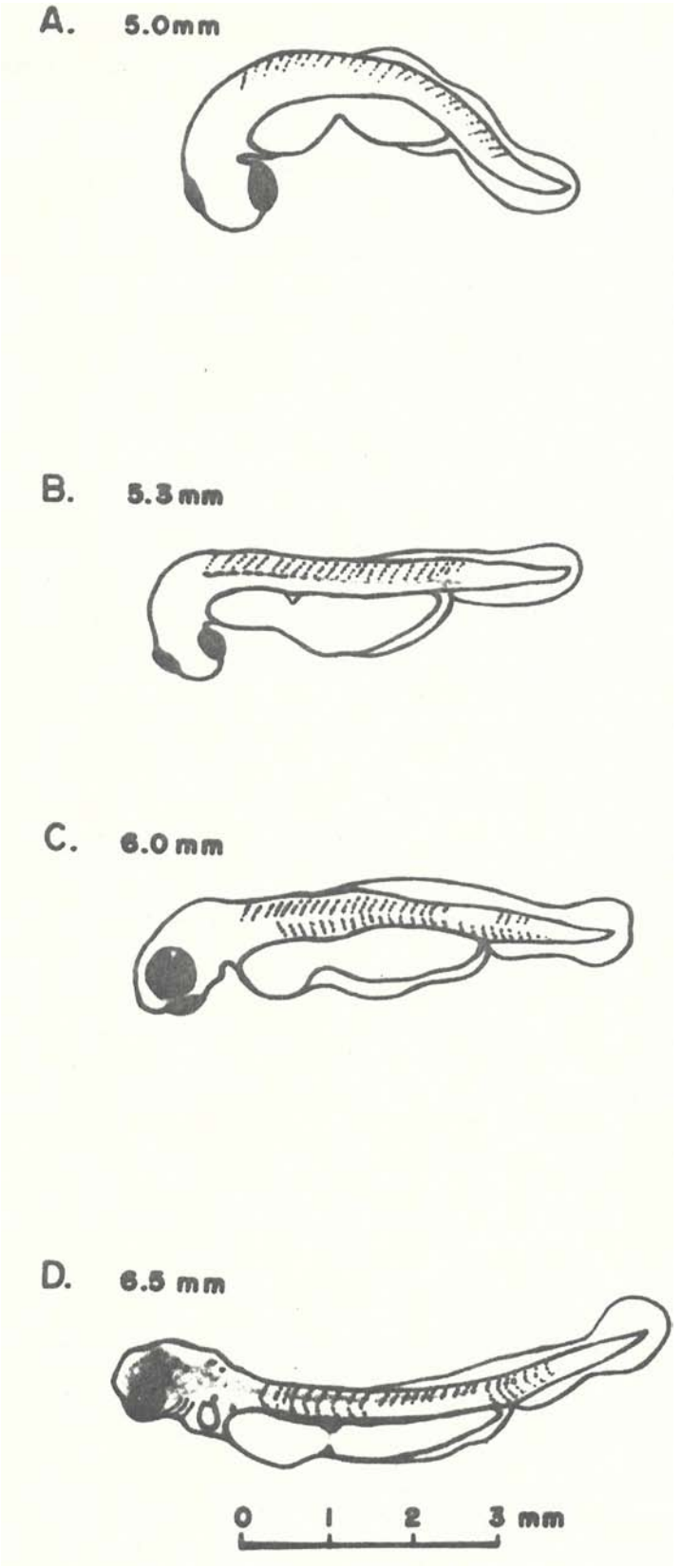

Figure 1. Developmental stages of larval buffalo, 5.0 to 6.5 mm total length, from Rough River Lake, Kentucky, May 1978.

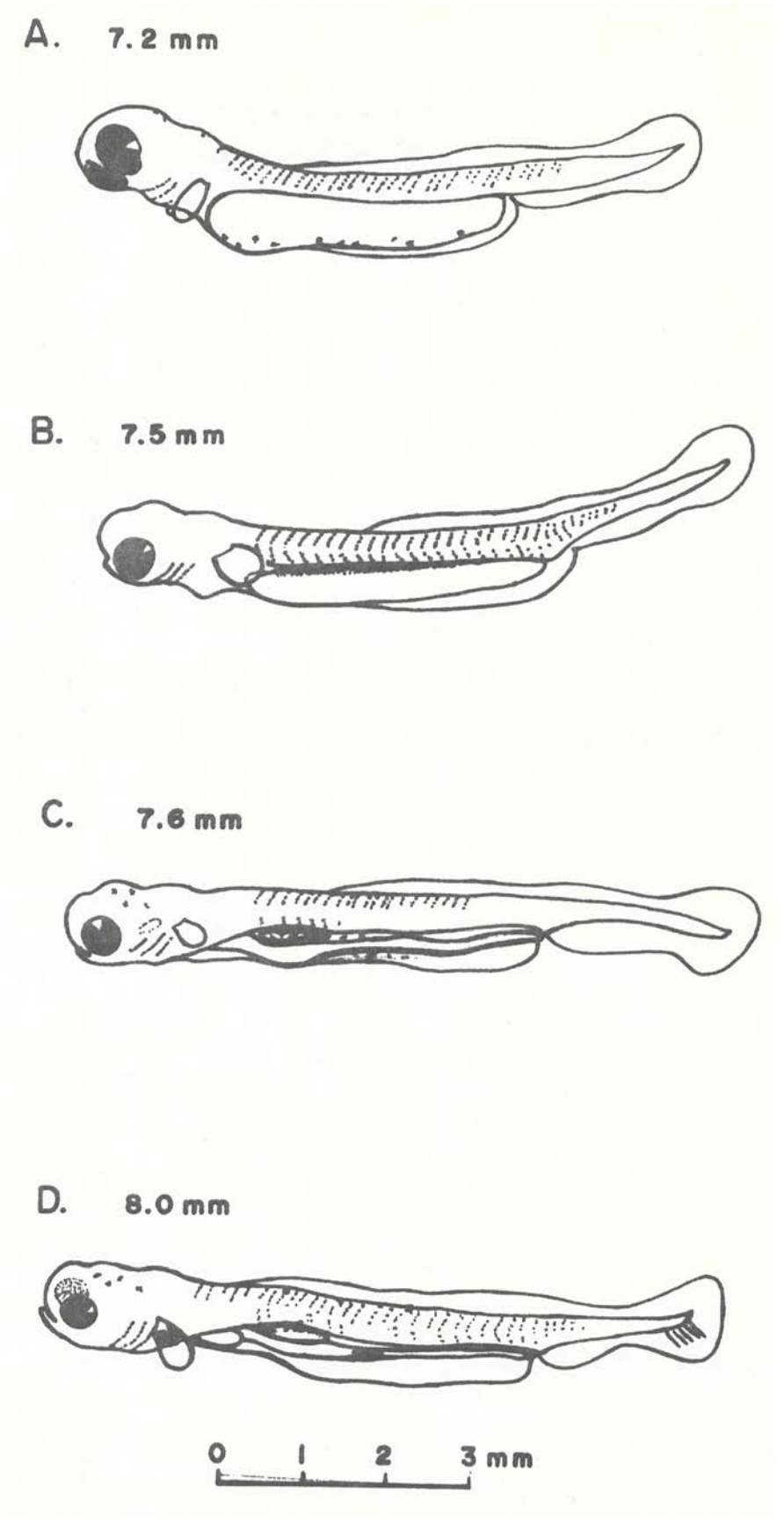

Figure 2. Developmental stages of larval buffalo, 7.2 to 8.0 mm total length from Rough River Lake, Kentucky, May 1978.

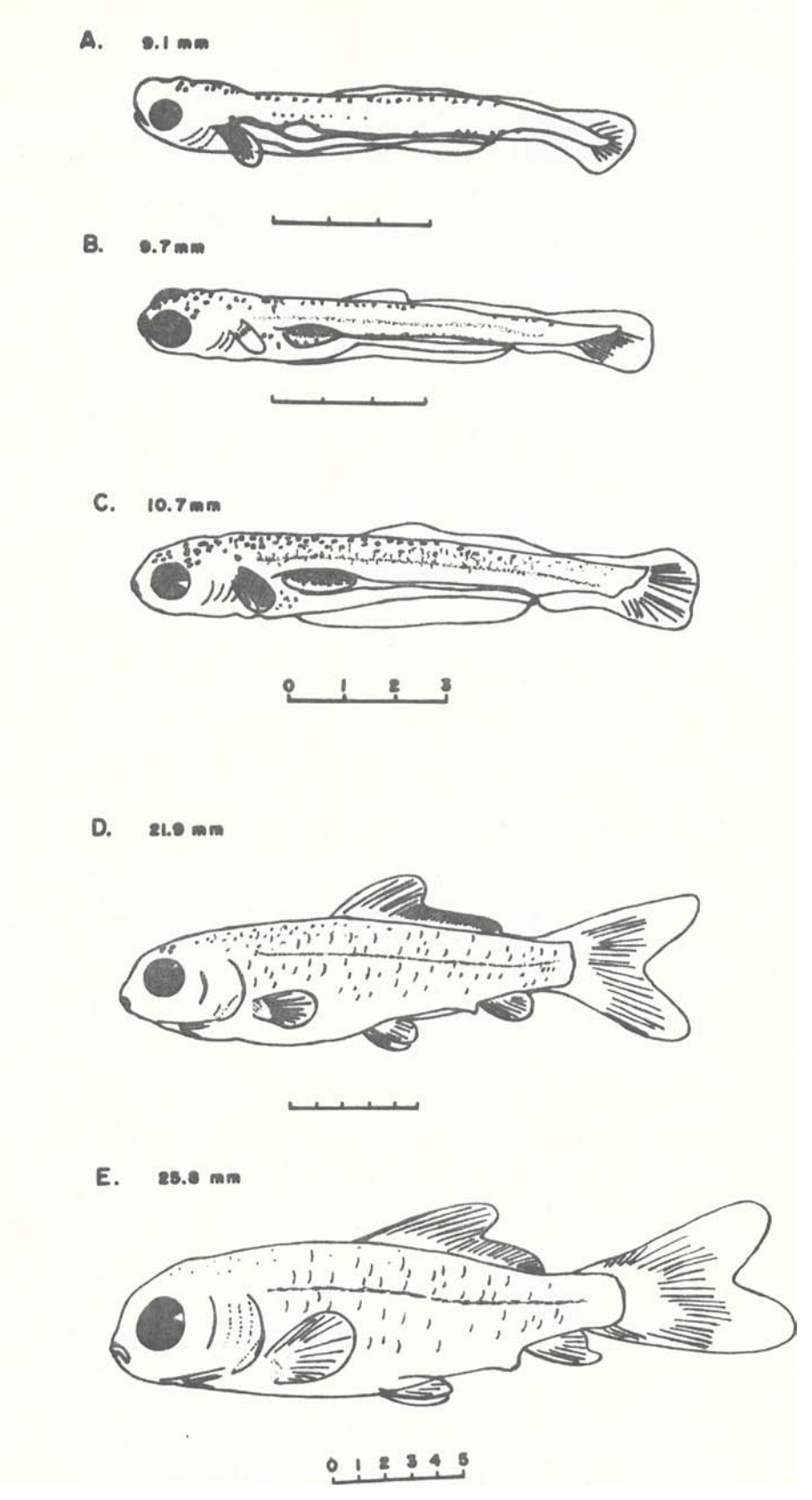

Figure 3. Developmental stages of young buffalo, 9.1 to 25.8 mm total length, from Rough River Lake, Kentucky, May 1978.

DISCUSSION

The onset of spawning activity by smallmouth buffalo in Rough River Late at 17.5 C water temperature conformed to the 15-23 C range reported for the species by Hoyt *et al.* (1976). However, the development of a cold front immediately following this spawning, and the subsequent lowering of the water temperature to 16 C four days later, could easily have increased the mortality during the egg stage, partially explaining the low number of buffalo larvae (52) observed in the study. In any case, spawning activity was altered and evidence of buffalo spawning was not noted again until 3 weeks later. The absence of prolarvae in samples following the May 19 spawn could not be explained.

Newly-hatched specimens were collected in the lake approximately 140 hours after the first observed spawning. These first specimens were collected at 16 C and may well have been hatched as early as 24-hours before capture. Eggs placed in laboratory aquaria did not hatch until 170 hours at 19 C. Wrenn and Grinstead (1971) reported smallmouth buffalo hatching to be completed at 108 hours at 22 C. Additional sources reported buffalo hatching to range from 24 hours at 23 C (Guidice 1964) and between 130-140 hours at 21 C (Heard 1958).

Spawning habitat observed in this study, in shoreline roots and vegetation and on submerged debris, was similar to that reported in the summary of Jester (1973). However, Padilla (1972) and Jester's (1973) report of buffalo spawning over all substrate types on the bottom to 6 meters deep were not evidenced by larval collections in this study.

The distribution of buffalo larvae in Rough River Lake in Peter Cave Creek, the South Fork Station, and one mile upstream indicated that the spawn occurred throughout the upper lake reaches. No

literature sources were available regarding the distribution of the species after hatching. It should be emphasized that, while the majority of specimens taken in this study were surface inhabitants, and that most open water surface individuals were taken at night, the total number of larvae taken was too low to use in defining strata preferences for the species.

The low density of buffalo larvae observed in this study appeared to be the result of undescribed behavioral patterns of the species early in the life cycle. Martin *et al.* (1964) and Hoyt *et al.* (1976) have both reported the species to represent sedentary, secretive populations for the first 2 years of life. In this study, larvae were taken throughout the sampling area up to total lengths of 9 mm. The absence of specimens larger than this might have been a function of the fish changing from endogenous to exogenous foods at this developmental stage and their movement into shoreline, inundated vegetated areas to feed. These shallow, obstructed areas precluded normal sampling procedures. After feeding in these areas for 3-4 weeks, their increased size and locomotor capabilities further prevented their capture. The size and developmental stages of the larvae taken in this study conformed to the above hypothesis.

The extent and success of the 1978 buffalo spawn in Rough River Lake was considered to be normal in spite of the low number of larvae observed. Conner (LSU, personal communication) has suggested a positive relationship between lake stage hydrography and reproductive success, the higher the water level above normal, the greater the inundated, vegetated "nursery areas". Although normal water levels were present, the amount and quality of substrate in Rough River Lake in 1978 was sufficient for spawning as observed.

The absence of food in 5 of the 7 postlarvae was most likely a function of the changing from yolk stores to foreign food sources rather than the absence of available food in the lake. Although no food data were collected from the lake to identify the availability of food organisms, larval crappie stomach contents analyzed in this study indicated the main food items to be copepods and cladocerans, implying an adequate food supply in the lake. McComish (1964) reported Age Group 0 buffalo to contain 99% copepods and cladocerans in their diet.

Average densities of buffalo larvae, as observed, when applied to the total lake volume, if used to predict the size of the young-of-the-year group, provided a very low 320,000 individuals less than 10 mm total length. These data, if even close to being reasonably accurate, describe a weak future year class.

Growth of buffalo larvae in the lake and laboratory in this study generally agreed with that of Wrenn and Grinstead (1971). Developmental features were likewise similar and no marked variations were noted.

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IDENTIFICATION OF LARVAL SUNFISHES (CENTRARCHIDAE, ELASSOMATIDAE) FROM SOUTHERN LOUISIANA

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ABSTRACT

Confident separation and identification of wild-caught larval and early juvenile sunfishes remains difficult despite the availability of an extensive literature. Some of the classically "diagnostic" characters for generic separation of larval sunfishes (e.g., gut architecture, gas bladder morphology, myomere counts, pigment) exhibit extreme variation and overlap in material from southern Louisiana. Using combinations of these features, however, it is possible to recognize the following genera within certain intervals of development: Pomoxis, Centrarchus, Lepomis (including Chaenobryttus), Micropterus, and Elassoma. Previously undescribed larvae of the flier (Centrarchus macropterus) are superficially similar to those of crappies (Pomoxis spp.), but are distinguished from the latter -- at least in early mesolarval and later phases -- by proportionally larger eyes and gas bladders. Insofar as confirmed identifications allow, it appears that the morphology of larval Lepomis spp. reflects the phylogenetic groups as currently appreciated by students of adult systematics. For example, the green sunfish and its relatives (L. cyanellus, L. symmetricus, L. gulosus) tend to be more similar to one another than they are to representatives of the longear, redear, and bluegill groups. For certain taxa of confirmed identity, pronounced differences are noted between wild-caught and lab-reared specimens. The latter tend to be larger, more robust, and more heavily pigmented at comparable stages than wild-caught material. Relative abundances of larval sunfishes as evidenced by conventional ichthyoplankton sampling may not always reflect adult densities in a given environment. The extensive variation and overlap in morphology of larval sunfishes indicates a need for more emphasis on the comparative approach in preparing descriptions.

INTRODUCTION

The purpose of this paper is to summarize the "state of the art" with respect to identification of larval sunfishes from southern Louisiana. A review of the descriptive literature may give the impression that these fishes are fairly well known (Table 1). Of the 16 native sunfish taxa occurring in southern Louisiana, for example, nine have been characterized throughout most of their larval development by illustrations and/or narrative descriptions. Three more are illustrated as juveniles and only four are completely undescribed in any of their immature phases. The latter are all members of the genus *Lepomis* and two of these (*humilis*, *symmetricus*) are more or less confined to the central and south-central United States, where relatively few larval fish investigations have been reported.

With the exception of the four obscure *Lepomis* spp., therefore, the larval sunfishes should be relatively easy to sort and identify. But the available literature still does not afford reliable taxonomic discriminations, sometimes even at the generic level.

There are several possible explanations for these problems. Many southern Louisiana water bodies have sunfish faunas that are somewhat richer than those for which most larval fish keys and/or manuals have been published. Much of my sampling activity is concentrated in non-pelagic situations where I encounter taxa and/or developmental stages that are rare in open-water plankton communities. Because much of the material comes from relatively turbid water it tends to be somewhat less pigmented than the lab-reared or clear-water specimens upon which most keys and

Table 1. Descriptive/comparative literature relevent to larval and early juvenile sunfishes of southern Louisiana (E=eggs; P=protolarvae; MS=mesolarvae; MT=metalarvae; J=juveniles, after Snyder 1976).

TAXON	PHASE E	P	MS	MT	J	REFERENCES
Ambloplites ariommus					X	10
Centrarchus macropterus					X	7,9,11
Elassoma zonatum	X	X	X	X	X	15
Lepomis cyanellus	X	X	X	X	X	4,11,16,24
Lepomis gulosus		X	X	X	X	11,13
Lepomis humilis						
Lepomis macrochirus	X	X	X	X	X	1,3,11,14,16,17,23,26
Lepomis marginatus						
Lepomis megalotis			X	X	X	11,23
Lepomis microlophus		X	X	X	X	6,11,14,16,26
Lepomis punctatus						
Lepomis symmetricus						
Micropterus punctulatus					X	19
Micropterus salmoides	X	X	X	X	X	1,2,5,11,12,14,16,19,20,23
Pomoxis annularis	X	X	X	X	X	1,11,18,21,22,23
Pomixis nigromaculatus		X	X	X	X	8,10,11,22,25

LITERATURE CODES

1. Anjard 1974
2. Carr 1942
3. Carver 1976
4. Champion and Whitt 1966
5. Chew 1974
6. Childers 1967
7. Conley and Witt 1966
8. Faber 1963
9. Fowler 19
10. Fowler 1945
11. Hardy 1978
12. Kramer and Smith 1962
13. Larimore 1957
14. May and Gasaway 1967
15. Metee 1974
16. Meyer 1970
17. Morgan 1951
18. Morgan 1954
19. Ramsey and Smitherman 1972
20. Reighard 1906
21. Siefert 1965
22. Siefert 1969
23. Taber 1969
24. Taubert 1977
25. Ward and Leonard 1952
26. Werner 1966

descriptions are based.

Sunfish larvae are encountered over a fairly protracted period of the year (March through October) in some southern Louisiana environments. Certain taxa (especially some *Lepomis* spp.) tend to spawn through most of the spring and summer, so that their eggs and larvae are exposed to a wide variety of water-quality conditions (*e.g.*, temperature). Substantial morphological variation is to be expected among such fishes (Barlow 1961).

Sunfish (especially *Lepomis* spp.) have a proclivity for natural hybridization (Hubbs 1955). Inasmuch as several hybrid combinations have been found as adults in southern Louisiana (*e.g.*, Guillory 1974, Saul 1974), it is reasonable to suppose that hybrid larvae might be encountered.

MATERIALS AND METHODS

About a thousand larval and early juvenile sunfish were critically examined and compared with respect to several meristic and morphometric features. Many additional specimens were checked for consistency of binary or unquantifiable characters such as pigment patterns, gut architecture, or size at the achievement of developmental "milestones".

All of the material used for compilation of the underlying descriptive and comparative information was wild-caught from a variety of riverine, floodplain swamp, backwater, and lake environments in southern Louisiana, mainly in the lower Mississippi Drainage. Identifications were based primarily on the process of "back-tracking" from recognizable juveniles, although in the case of certain fairly distinctive taxa, determinations were based on literature descriptions (*e.g.*, warmouth, pygmy sunfish). Lab-reared series of four *Lepomis* spp. (longear, redbreast, bluegill,

redear sunfishes) were also consulted.

The wild-caught material was initially fixed in 10 percent formalin and later transferred to 3-5 percent buffered formalin. All specimens were unstained. The material is housed, and will ultimately be formally cataloged, in the Louisiana State University Fisheries Collections, which are administered under the School of Forestry and Wildlife Management.

Measurements were made to the nearest 0.1 mm with an ocular micrometer mounted in a stereo-zoom dissecting microscope, according to criteria established in Hardy (1978). Specimens which could not be straightened with the aid of a coverglass were excluded from the morphometric analyses. Unless otherwise indicated, all specimen sizes referred to are total lengths (TL).

Myomere counts were made according to Siefert (1969). No difference was found in counts made with polarized versus non-polarized light, but discrimination of the first and last few segments was easier using the former. Incomplete myomeres were not included, which presumably accounts for the tendency of the numbers to increase from earlier to later developmental phases. Other meristic determinations (*e.g.*, fin rays) were made according to Hubbs and Lagler (1964).

Terminology for developmental phases generally follows Snyder (1976). However, the most useful application of this system for sunfishes involves subdivision at varying hierarchical levels. That is, for description and comparison, the following phases, subphases, or combinations of phases seem most appropriate:

1) protolarvae (P) - as per Snyder (1976);

2) early mesolarvae (EMS) - specimens with at least one complete caudal ray but fewer than the adult complement of principal caudal rays; and

3) late mesolarvae through early juveniles (MS/J) - specimens with adult complements of principal caudal rays (17 or 18 in centrarchids, 14 or 15 in elassomatids).

It should be noted that the wild-caught protolarvae used in this study did not include recently-hatched individuals with large yolk masses. Many protolarval (and early mesolarval, in the case of one *Lepomis* "type") specimens had vestigial yolk but they all had at least partially developed jaws and thus were presumably capable of using exogenous food sources. In other words, this study relates exclusively to so-called "swim-up" stage and older fish.

Illustrations are based on camera lucida tracings and are diagrammatic in the sense that several specimens were consulted for details of pigmentation at the stage in question. Moreover, the eyes are not shaded to facilitate emphasis of other features. All sunfish specimens at the stages treated here have heavily-pigmented eyes. Excepting those of *Centrarchus macropterus* (Figure 1), the illustrations are presented in a comparative format. Each drawing is accompanied by an indication of the size of the particular specimen traced and, parenthetically, the total length range through which representatives of the taxon or "type" resemble the illustration.

RESULTS AND DISCUSSION

Sunfish larvae are superficially similar to those of other regional freshwater percoids, but they are readily distinguished from temperate

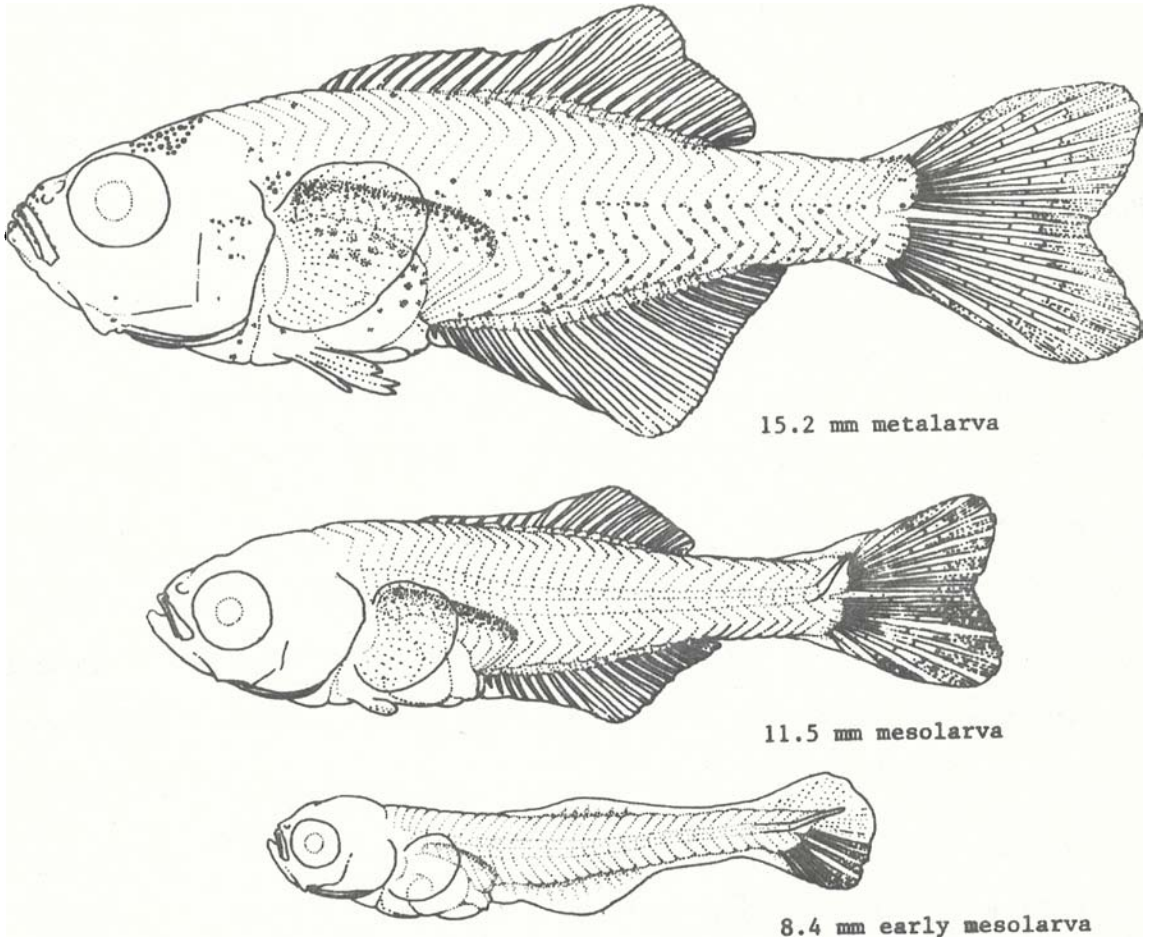

Figure 1. Three larval stages of the flier, *Centrarchus macropterus*, from southern Louisiana.

basses (*Morone* spp.) and the freshwater drum (*Aplodinotus grunniens*) by having more than 26 (27-36) total myomeres. Most larvae of the family Percidae have at least 40 total myomeres, but a few darters of the genus *Etheostoma* have myomere totals that overlap the high end of the sunfish range. Except as very recently-hatched protolarvae, however, the sunfishes have prominent gas bladders whereas this structure is absent in darters. Recently-hatched protolarvae of sunfishes may or may not have prominent oil globules in the yolk but if present they are not confined to the anterior third of the yolk mass. From the literature and southern Louisiana material examined to date, it seems that darter larvae consistently possess a prominent oil globule in the anterior third of the yolk mass.

Identification of Genera

The wild-caught sunfish larvae and early juveniles used in this study are referable to five genera, in accordance with the classification used in Special Publication No. 6 of the American Fisheries Society (1970): *Pomoxis; Centrarchus; Lepomis* (including *Chaenobryttus*); *Micropterus;* and *Elassoma*. Larvae and early juveniles of our local rockbass, *Ambloplites ariommus*, are not represented in LSU fisheries collections, but on the basis of their close phylogenetic affinities, it is reasonable to expect that they will strongly resemble the specimens of *A. rupestris* illustrated by Hogue *et al.* (1976: plates 12.0, 12.1).

Three recent publications (Anjard 1974, Hogue *et al.* 1976, Hardy 1978) provide useful descriptive and comparative information for the recognition of sunfish genera. However, these references contain certain inconsistencies and/or omissions that limit their reliability outside the geographic areas for which they were prepared. Gut shape and length; gas bladder position

and size; myomere counts; and certain aspects of pigmentation are the chief characters used for generic comparisons. For each of these characters, sufficient variation and/or overlap is evident among our material to warrent a brief discussion.

Gut Morphology - Preanal lengths expressed as percent of total length tend to be quite variable, even within a given developmental phase of a particular taxon (Table 2). Protolarvae of *Elassoma* and *Pomoxis* (presumably also *Centrarchus*) most often have preanal lengths less than 41 percent of TL, whereas the mode for this proportion in *Lepomis* and *Micropterus* lies well above 41 percent. In the range of proportional preanal lengths from 38 through 42 percent of TL, there is at least some overlap for protolarvae of all genera except *Micropterus*. For early mesolarvae and later phases, generic separation by preanal lengths becomes more reliable (again at *ca.* the level of 41 percent of TL), but note that as of the EMS subphase, *Elassoma* observations fall in the range exhibited by lepomines (*Lepomis*, *Micropterus*). Late mesolarval through early juvenile *Micropterus* tend to be fairly distinctive in having preanal lengths greater than 50 percent of TL, with overlap apparent only at the upper extreme for one "type" of *Lepomis*.

As noted by Anjard (1974) and Hardy (1978), *Micropterus* is readily distinguished from *Lepomis* and *Pomoxis* by its thicker, massively coiled gut (Figures 2, 3). Similar gut architecture is manifest in *Elassoma* and this feature, along with its robust head and trunk, relatively large eye, and anteriorly-placed gas bladder, results in strong superficial resemblance to protolarval and early mesolarval *Micropterus*. But there are pronounced differences between *Elassoma* and *Micropterus* in overall size and pigmentation at comparable stages (Figures 2, 3).

Table 2. Frequency distribution of preanal lengths expressed as percent of total length for larval and early juvenile sunfishes from southern Louisiana (P=protolarvae; EMS=early mesolarvae; MS/J=late mesolarvae through early juveniles; see text for definition of intervals).

	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Pomoxis spp. (crappies)																					
P	5	25	66	30	19	5															
EMS		5	11	18	14	3															
MS/J			3	8	8	6	2	1													
Centrarchus macropterus (flier)																					
P																					
EMS	1																				
MS/J			2		3	6	1	1													
Green sunfish "types"																					
P			1		7		5	2	3	2											
EMS							1	1													
MS/J								1	2	3		8	7	4							
Lepomis "A" (redear "type"?)																					
P					3	8	20	27	13	6	2										
EMS						1	10	13	9	5	1										
MS/J							2	5	2	2	1										
Lepomis macrochirus (bluegill)																					
P					3	9	18	42	21	11	2	1		1							
EMS							1	5	12	13	2	1									
MS/J						1	4	9	23	24	9	3									
Lepomis "B" (bluegill "type"?)																					
P									1	7	15	23	8	3							
EMS									1	5	16	14	7								
MS/J							1	4	10	11	6										
Micropterus spp. (black basses)																					
P										2	2	3	4	3	1						
EMS												1	2	1	2						
MS/J															2	4	8	5	5	5	3
Elassoma zonatum (pygmy sunfish)																					
P		1	4		2		2														
EMS									2		3	1	2								
MS/J								1	1	3	4	1	1	1							

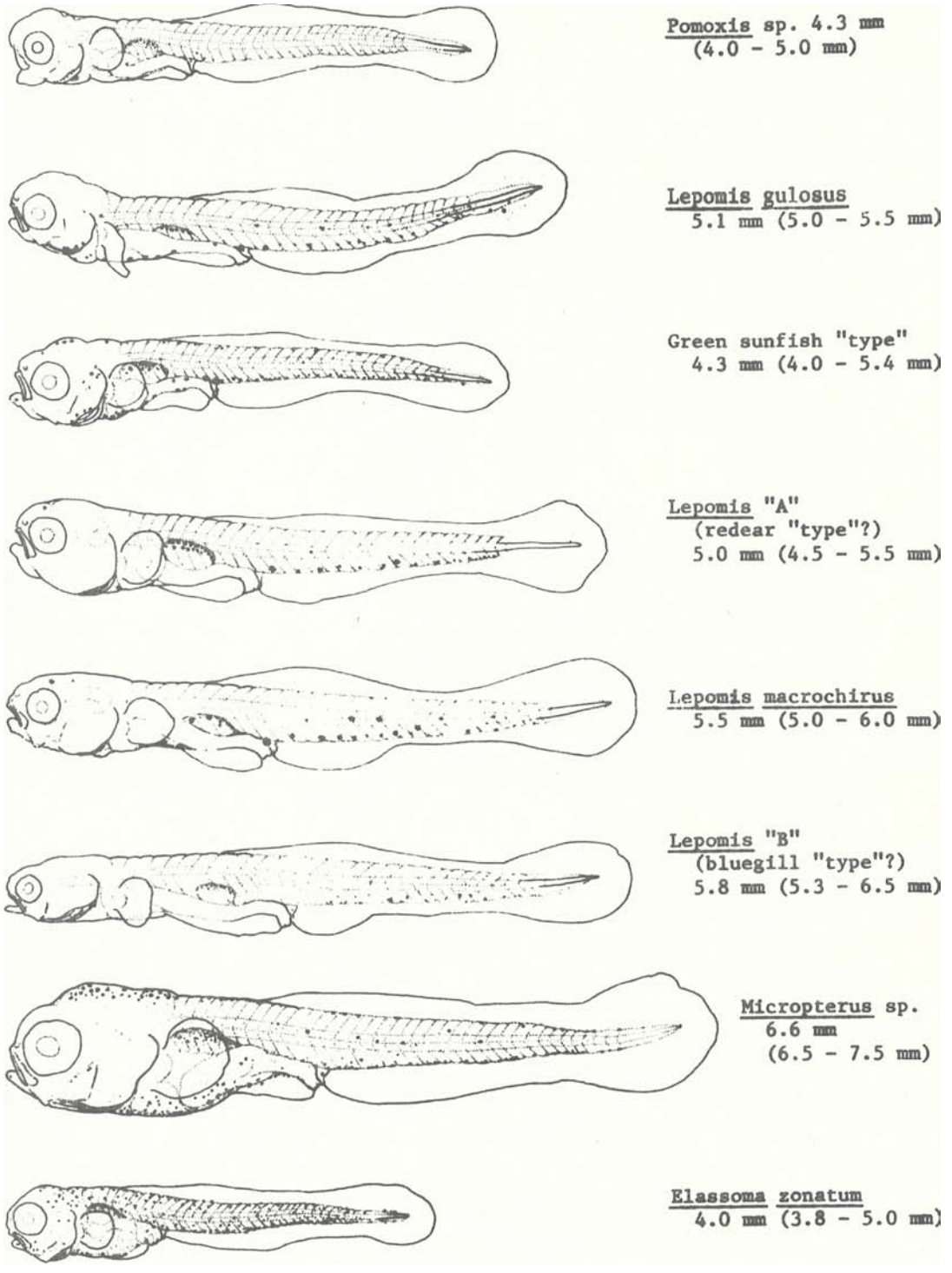

Figure 2. Representative sunfish protolarvae from southern Louisiana.

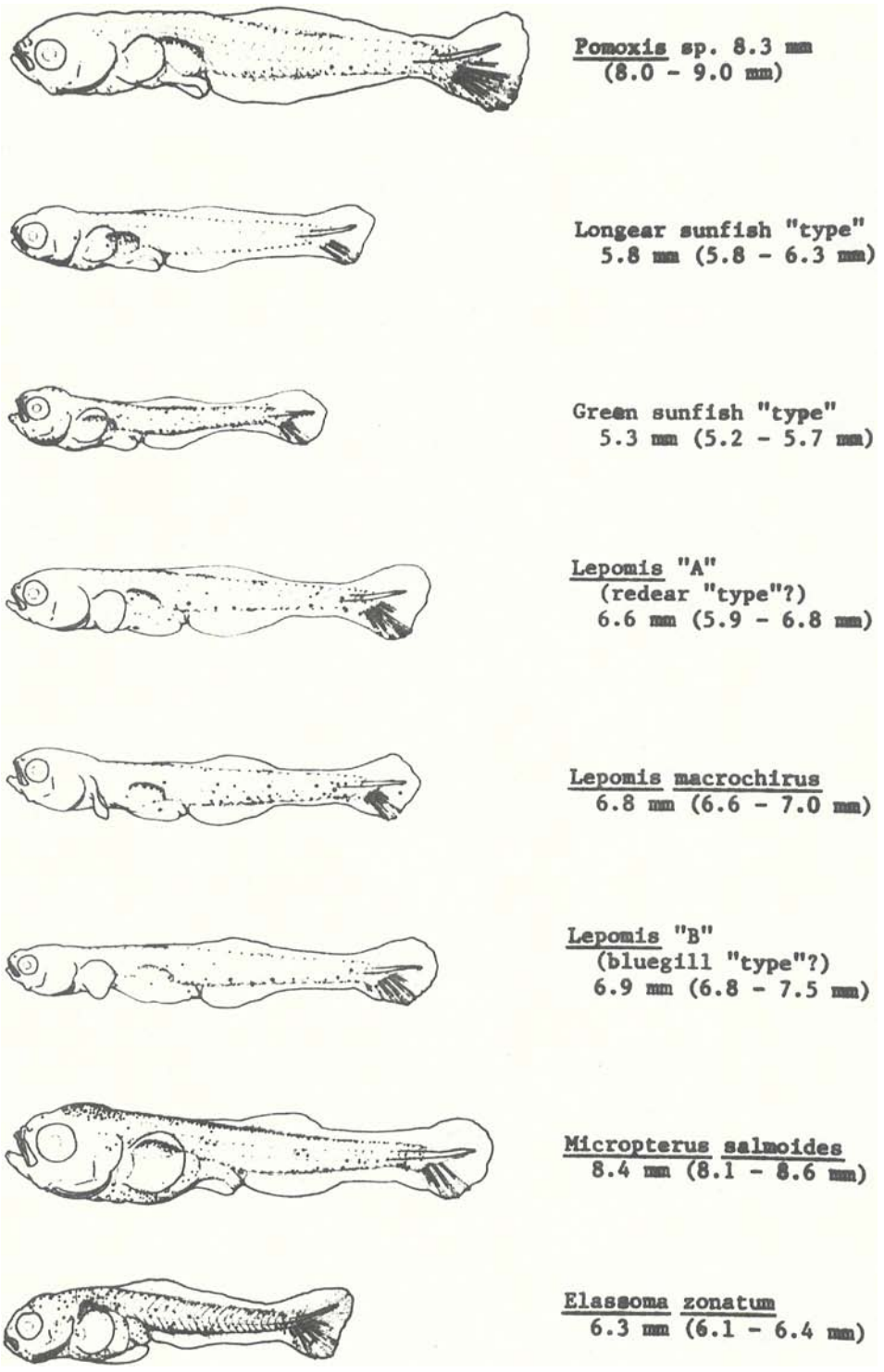

Figure 3. Representative sunfish early mesolarvae from southern Louisiana.

Extreme variation is evident in the gut shape of protolarval and early mesolarval *Lepomis* spp. (Figures 2, 3). This may be of some value in discriminating among the *Lepomis* "types" (see below), but it tends to confound the distinction of some specimens from *Pomoxis* on the basis of the comparative summaries prepared by Anjard (1974) and paraphrased by Hardy (1978). The difficulty arises especially when one is confronted with examples of *Lepomis* which have relatively short, anteriorly-coiled guts in samples which lack similar-sized *Pomoxis* for comparison.

Gas Bladder Morphology - Once the gas bladder is clearly defined (*i.e.*, in all but the most recently-hatched individuals) its position relative to the vent and other parts of the gut is perhaps more reliable than any other single character for the generic separation of sunfish in the protolarval and mesolarval phases. In larvae with massively coiled guts -- that is, *Micropterus* and *Elassoma* among ours (and, evidently from the literature, *Ambloplites* and *Enneacanthus*) -- the gas bladder is confined to the area above and anterior to the gut coils (Figures 2, 3). In all other P and EMS sunfishes, the gas bladder encroaches to some extent upon the space behind the section where coiling exists or is developing. As suggested by the literature, there is a strong tendency for the gas bladder of centrarchines (*Pomoxis*, *Centrarchus*) to extend posteriorly to or beyond the level of the anus, whereas in *Lepomis* it consistently terminates well in advance of the anus (Figures 1--3). In many of our very small crappies (less than 5.5 mm TL), however, the bladder fails to reach or even approach the anus (Figure 2).

Myomere Counts - Preanal, postanal, and total myomere counts afford some discrimination when certain phases of particular taxa or "types" are

compared, but extensive overlap tends to confound unqualified separation of genera (Table 3). Counts for *Lepomis* specimens omitted from the table (*i.e.*, the poorly represented warmouth and longear "types") all fall within the ranges recorded for the genus.

The geographically most relevant key to larval centrarchid genera (Hogue *et al.* 1976) relies heavily on myomere counts. Implicit in its basic dichotomy for "postlarvae" (*sensu* Hubbs 1943) is the separation of *Micropterus* from all other centrarchids on the basis of 14 or more preanal myomeres. Using this couplet we would have misidentified roughly 5 percent of our *Pomoxis*, 32 percent of our collective *Lepomis* (*ca.* 66 percent of *Lepomis* "B"), and 15 percent of our *Micropterus*. The TVA manual also separates *Pomoxis* and *Lepomis* on the basis of 18 or more postanal myomeres in the former. About 8 percent of our *Lepomis* have 18 postanal myomeres. Note, however, that our *Pomoxis* tend to have 19 or more (usually 20+) postanal myomeres prior to attainment of "complete" caudal fins and thus do not infringe upon the range exhibited by southern Louisiana *Lepomis* examined to date. The information compiled by Taubert (1977: Table 2) indicates a possible source of confusion -- namely, *L. gulosus* with 19 postanals -- but considering the preanal values reported (10 or 11), it seems unlikely that the warmouth counts were made in accordance with the procedure recommended by Siefert (1969). Indeed, our *L. gulosus* larvae examined to date have 12 or 13 preanal and 16-18 postanal myomeres.

Pigment - Many wild-caught *Lepomis* larvae with incomplete caudal fins from southern Louisiana do not exhibit the "supra-anal melanophore" cited as typical of the genus by Anjard (1974) and Hardy (1978). Its presence is limited to representatives of certain taxa or "types" (see below), and

Table 3. Frequency distribution of myomere counts for larval and early juvenile sunfishes from southern Louisiana (P=protolarvae; EMS=early mesolarvae; MS/J=late mesolarvae through juveniles; see text for definition of intervals).

	PREANAL									POSTANAL											TOTAL									
	10	11	12	13	14	15	16	17	18	14	15	16	17	18	19	20	21	22	23	24	27	28	29	30	31	32	33	34	35	36
Pomoxis spp. (crappies)																														
P	8	97	43	2												12	63	63	12					1	9	43	72	21	4	
EMS		1	40	15	1										1	19	14	21	11	1						6	13	22	14	2
MS/J			3	19	10									3	13	11	4	1							1	11	13	7		
Centrarchus macropterus (flier)																														
P																														
EMS		1															1									1				
MS/J		6	6	1											1	3	8	1							1	7	5			
Green sunfish "types"																														
P	3	15	2									2	14	4							2	15	3							
EMS		2											1	1								1	1							
MS/J				4	21						11	11	3										12	13						
Lepomis "A" (redear "type"?)																														
P		2	67	10							1	26	35	17								26	34	18	1					
EMS			8	30	1							2	30	7									1	30	8					
MS/J				18	14						4	18	10										12	19	1					
Lepomis macrochirus (bluegill)																														
P		9	55	24							6	26	43	13							1	24	42	21						
EMS			17	27	4						3	18	25	2									5	28	15					
MS/J			4	27	40	2					11	52	10										13	27	26	7				
Lepomis "B" (bluegill "type"?)																														
P				21	26					1	13	36	7								1	1	30	21	4					
EMS				3	25	2				1	12	24	3										16	22	2					
MS/J				3	35	3				2	25	14										2	25	14						
Micropterus spp. (black basses)																														
P			2	5	6	2						1	4	6	4									3	6	3	3			
EMS					1	5	1						5	2												5	2			
MS/J						2	9	13	2	5	5	16												1	5	13	7			
Elassoma zonatum (pygmy sunfish)																														
P	4	5											4	5							2	4	3							
EMS		2	4	3								2	4	3								1	6	1	1					
MS/J		1	1		2	2				1	1	3	1										3	2	1					

within these it is seldom consistently present throughout large samples. There is a definite tendency for the supra-anal melanophore to be more prevalent among specimens from clear or less-turbid waters. Indeed, there is a tendency for more prominent pigmentation in general among clear-water sunfish larvae as opposed to those from muddier riverine or swamp environments. Certain aspects of pigmentation are nevertheless useful in distinguishing some sunfish taxa or types (see underlying keys and discussion of *Lepomis*).

The five genera treated here are separable using essentially the same "classical" characters as the aforementioned publications if keys are derived for more narrow developmental intervals than those associated with presence or absence of yolk (prolarvae versus postlarvae). However, the reader should note that the following keys are complete only for the taxa and developmental phases available to this study.

Generic Key to Sunfish Protolarvae

1a. Gut massively coiled; gas bladder confined to area above and anterior to gut coils 2

1b. Gut uncoiled or, if coiled, gas bladder encroaches on space posterior to gut coils 3

2a. Larvae very small, (3.5-6.3 mm TL) and profusely pigmented with melanophores all over head and body. . . . . *Elassoma* (Figure 2)

2b. Larvae typically larger (5.5-8.0 mm TL) and sparsely pigmented or with melanophores concentrated on dorsum (mainly on head) and ventrum, widely scattered behind trunk . . . . . *Micropterus* (Figure 2)

3a. Postanal myomeres 14-18 . . . . . *Lepomis* (Figure 2)

3b. Postanal myomeres 19 or more . . . . *Pomoxis* and *Centrarchus* (Figure 2; see text for probable separation of centrarchine genera).

Generic Key to Sunfish Early Mesolarvae

1a. Gut massively coiled; gas bladder confined to area above and anterior to gut coils 2

1b. Gut uncoiled or, if coiled, gas bladder encroaches on space posterior to gut coils 3

2a. Larvae smaller (6.0-8.0 mm TL) and profusely pigmented with melanophores all over head and body *Elassoma* (Figure 3)

2b. Larvae larger (8.0 mm or longer TL) with pigment concentrated on dorsum and ventrum, widely scattered behind trunk . . . . . *Micropterus* (Figure 3)

3a. Postanal myomeres 14-18; gas bladder terminates well in advance of anus or, if approaching anus, specimens shorter than 8.0 mm TL *Lepomis* (Figure 3)

3b. Postanal myomeres 19 or more; gas bladder extends posteriorly to, or beyond level of anus . . . . . *Pomoxis* and *Centrarchus* (Figures 1 and 3; see text for probable separation of centrarchine genera).

Generic Key to Sunfish Larvae with "Complete" Caudal Fins

1a. Caudal fin emarginate or truncate, comprised of 17 or more principal rays 2

1b. Caudal fin rounded, comprised of 16 or fewer principal rays . . . . . *Elassoma* (Figures 4 and 5)

2a. Postanal myomeres 18 or more 3

2b. Postanal myomeres 17 or fewer 4

3a. In specimens shorter than 12.0 mm TL, eye diameter conspicuously greater than snout length (greater than 1.7 times snout length); in specimens 12.0 mm TL or longer dorsal spines number 10 or more .*Centrarchus* (Figure 1)

3b. In specimens shorter than 12.0 mm TL, eye diameter subequal to or only slightly greater than snout length (less than 1.5 times snout length); in specimens 12.0 mm TL or longer dorsal spines number 8 or fewer . . . . . *Pomoxis* (Figures 4 and 5)

4a. Larvae larger (11.5-16.0 mm TL); dark mid-lateral band of pigment well developed . . . . .*Micropterus* (Figures 4 and 5)

4b. Larvae smaller (6.5-13.0 mm TL); no dark mid-lateral band (although some may have mid-lateral streak or row of melanophores simulating a series of dots or dashes . . . . . *Lepomis* (Figures 4 and 5)

The material at hand does not allow confident separation of *Pomoxis* and *Centrarchus* protolarvae and mesolarvae. However, it seems highly probable that the pronounced difference in eye size will extend down through these phases. As a matter of practical consideration it should be noted that flier larvae may seldom, if ever, be encountered through conventional ichthyoplankton sampling procedures. We have towed or pushed plankton nets in a variety of water bodies known to contain *Centrarchus* populations and have yet to capture a single flier larva. The small series of *Centrarchus* specimens available to this study was obtained by dipnetting in very shallow littoral vegetation beds.

Intrageneric Identifications

Considering the difficulties noted above for recognition of sunfish genera, it is not surprising that precise species-level identifications are largely impossible at the current state of the art. Thesis research by Mark F. Chatry at LSU may ultimately lead to recognition of diagnostic

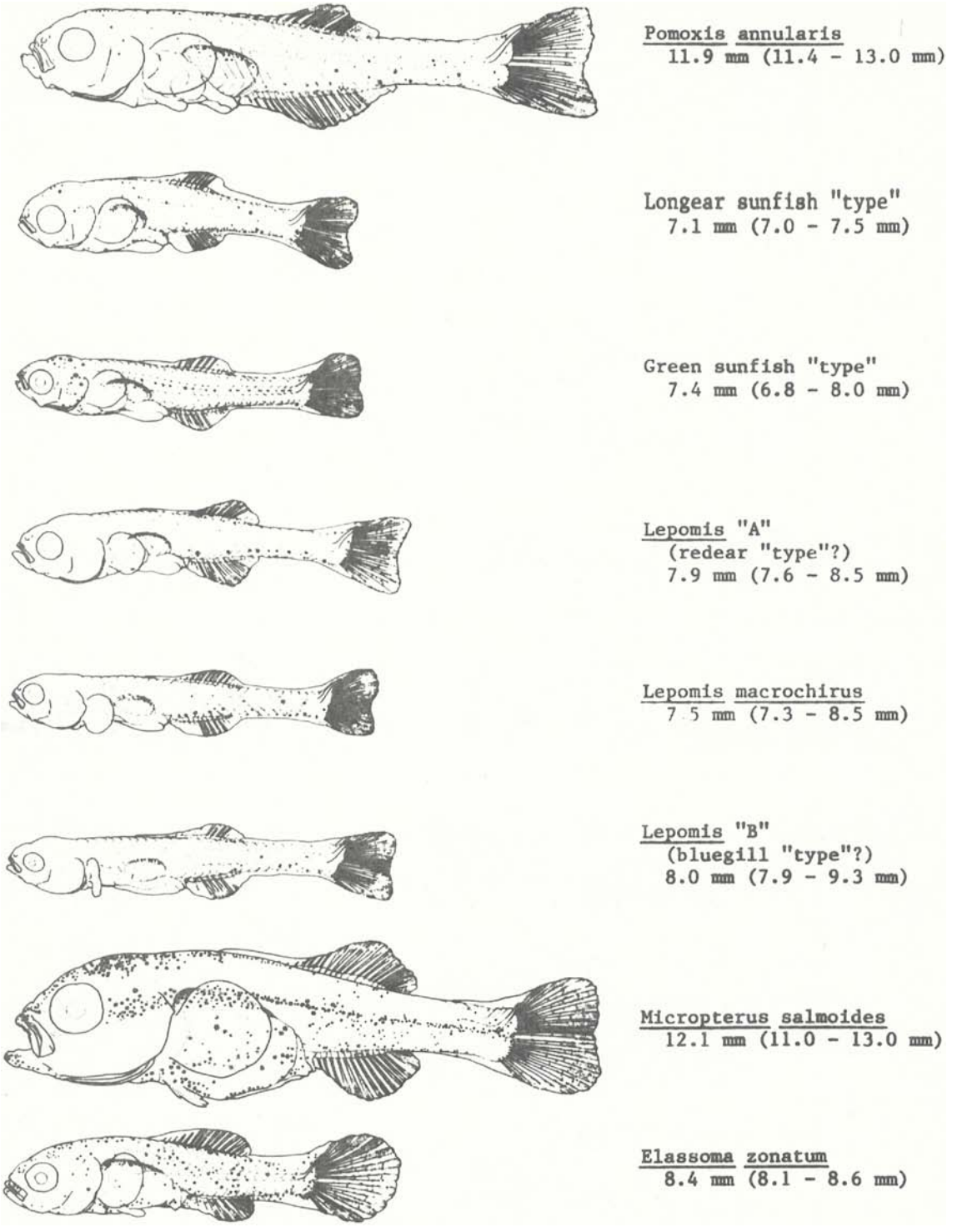

Figure 4. Representative sunfish mesolarvae with "complete" caudal fins from southern Louisiana.

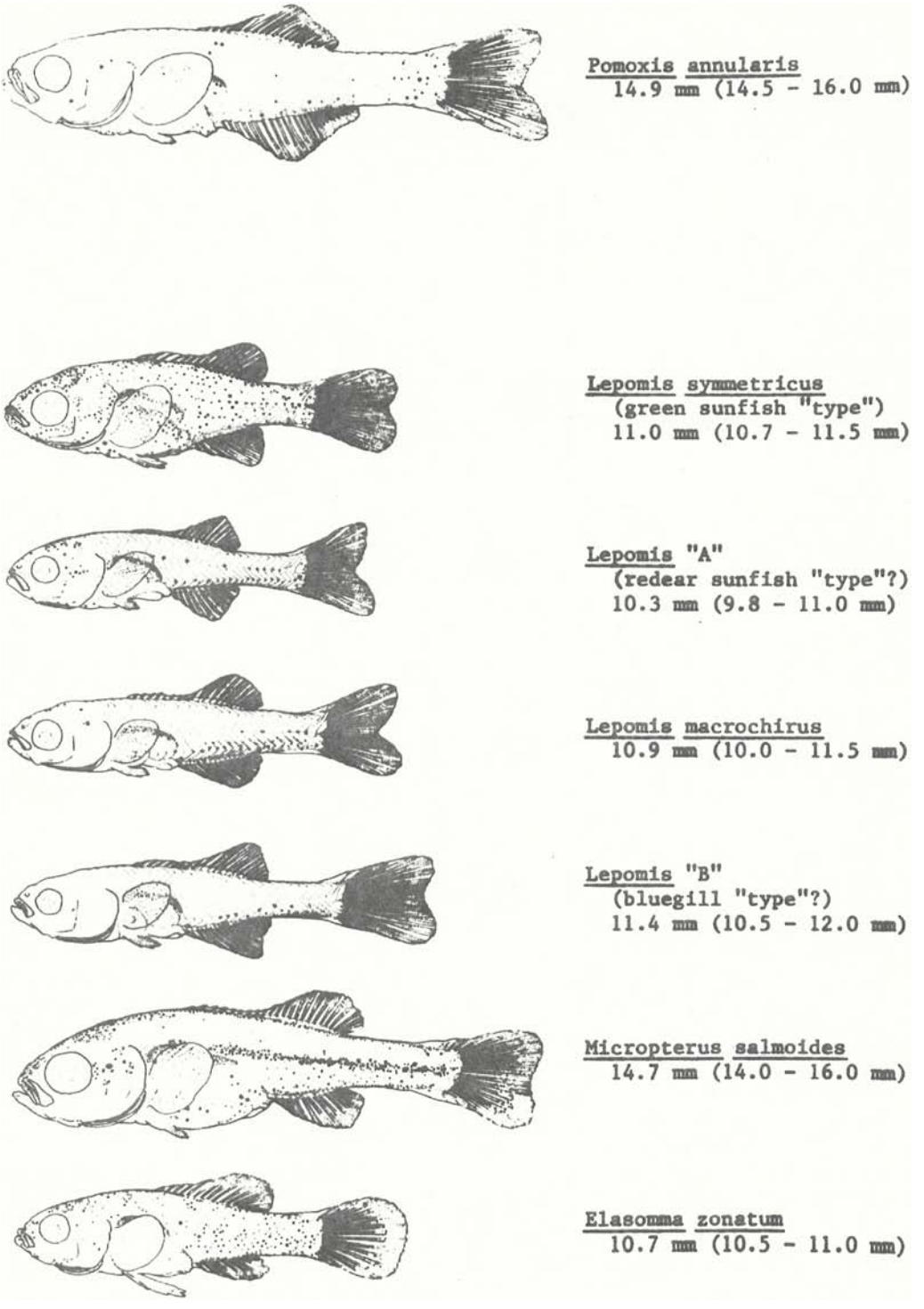

Figure 5. Representative sunfish metalarvae/early juveniles from southern Louisiana.

characters for black and white crappie larvae from southern Louisiana. Although the meristic trends identified by Siefert (1969) are evident in our *Pomoxis*, there are certain inconsistencies and variations of details. In any case, Siefert noted that the reliability of his myomere count differences breaks down with specimens shorter than 7 mm TL and, unfortunately, most of the crappie larvae we take in plankton samples fall into this small size group. Ramsey and Smitherman (1972) illustrated pigmentary differences between juvenile *Micropterus salmoides* and *M. punctulatus*, but no detailed descriptive information is available on larvae of the latter. Taber (1969:28) noted that largemouth and spotted bass longer than 15 mm could be separated on the basis of "body conformation and pigmentation patterns" but did not describe the differences.

Separation of *Lepomis* spp. - The *Lepomis* larvae used in this study are separable into a few more or less distinctive morphological types. Developmental series of some of these types are sufficiently complete to afford confident identification (*e.g.*, bluegill) or at least to indicate that they probably represent individual species (albeit of uncertain identity, such as types "A" and "B"). Representation for the other types is inadequate for confident determination of identity or even conspecificity.

As indicated in the introduction, there is a fairly extensive literature on the descriptive morphology of larval *Lepomis* spp. (Table 1). Aside from those pertaining to *L. macrochirus*, *L. gulosus*, and *L. megalotis* (as a "type"), however, the literature descriptions seem not to apply with much reliability to any of our unidentified forms. Several explanations are plausible and I suspect that there is some truth in each. First, it could be that some or all of our unidentified types will ultimately prove to be

larvae of the four hitherto undescribed *Lepomis* -- namely, *humilis*, *marginatus*, *punctatus*, and *symmetricus*. Also, infraspecific variation may be so extreme that descriptions based on localized populations are of limited relevance to wild-caught material from other regions. The tendency for rearing and studying series "one at a time" leads to a general lack of a comparative approach in preparing descriptions, which may limit the observers appreciation for salient differences and or similarities among taxa. The last is a reflection of very real logistical constraints, which also tend to limit the researchers ability to obtain sample sizes that are sufficient to reveal the extent of variation in a taxon. Finally, in some taxa, lab-reared material may be so different from wild specimens that their relationship is scarcely apparent.

There is at least some tendency for our recognizable types of *Lepomis* larvae to follow the major phylogenetic lines as currently appreciated by students of adult systematics. Four basic groups of *Lepomis* are recognized (Branson and Moore, 1962):

1) green sunfish group - including *cyanellus*, *symmetricus*, and (probably) *gulosus*;

2) longear sunfish group - including *megalotis*, *marginatus*, and *auritus*;

3) redear sunfish group - including *microlophus*, *gibbosus*, and *punctatus*; and

4) bluegill group - including *macrochirus* and *humilis*.

The groups are listed in their apparent sequence of evolutionary divergence (*sensu* Branson and Moore 1962) as representatives of morphological levels of organization. That is, the green sunfish group supposedly represents the basal, generalized stock that gave rise to remaining lepomines. The longear and its close relatives seem to represent a level

of organization derived directly from that of the green sunfish complex, whereas the redear and bluegill groups appear to constitute branches off the longear line. Within each of the last three groups there is a relatively generalized, geographically (and ecologically) ubiquitous taxon from which the other group members seem to have been derived -- namely, *L. megalotis*, *L. microlophus*, and *L. macrochirus*. The bantam sunfish (*L. symmetricus*) is almost certainly a specialized derivative of *L. cyanellus*, but the precise nature of the relationship between warmouth and green sunfish remains to be determined.

If larval morphology does "track" the phylogenetic relationships within and between taxonomic groups, it follows that members of a particular assemblage will be more similar to each other than to those of other groups. It is also reasonable to expect that there may be morphological continua (generalized to derived) for some characters which would allow recognition of organizational levels ("character states") that are representative of particular taxonomic groups.

Insofar as our developmental series of *Lepomis* afford accurate identification or at least strong suggestion of affinities, the above expectations are confirmed. For example, *L. symmetricus*, known by working backward from recognizable juveniles down through at least part of the EMS subphase, are more similar to confirmed or highly probable *L. cyanellus* and *L. gulosus* than they are to any other taxa or "types". In the lab-reared material soon to be described by Bruce Yeager of TVA, there is strong resemblance between *L. megalotis* and *L. auritus*, as indeed is evident upon close scrutiny of the published descriptions of these forms (Taber 1969, Anjard 1974, Hardy 1978, Buynak and Mohr 1978). That our

larval *L. macrochirus* and other recognizable but unidentified "types" are distinct from the aforementioned groups and more or less similar to one another is consistent with the above hypothesis.

After carrying identifications as far as possible with the literature, lab-reared series, and wild-caught samples at hand, I am able to recognize the following taxa or hypothetical "types".

Green sunfish "types" - Considering the widespread occurrence and abundance of their adults in our area, we probably have at least some larval examples of all three members of the green sunfish group. Once the yolk is mostly or entirely exhausted, the protolarvae and early mesolarvae referable to this type are characterized by relatively short preanal lengths (modally well under 45 percent of TL) and tend to have the lowest modal preanal myomere counts of our *Lepomis* spp. (Tables 2 and 3). Compared to other *Lepomis*, our P and EMS green sunfish types tend to have proportionally deeper heads (Table 4) and more extensive and prominent pigment, particularly in the head and trunk regions (Figures 2 and 3). At least in part (*L. symmetricus*?), they tend to be slightly smaller than other *Lepomis* at comparable stages. As regards specimens with more or less complete caudal fins, I am not sure if not all of our MS/J specimens of this type seem indistinguishable from those of the one confirmed series of *L. symmetricus*. In any case, the published illustrations of MS/J *L. gulosus* and *L. cyanellus* (e.g., Larimore 1957: Figures 14e and f, Meyer 1970: Figure 5, Taubert 1977: Figure 2b, see also Hardy 1978) are more similar to our unidentified "green" types and *L. symmetricus* (Figures 4 and 5) than to those of other taxa. Salient features of these older larvae include generally more profuse pigmentation than other *Lepomis*; especially

Table 4. Frequency distribution of head depths expressed as percent of total length for larval and early juvenile *Lepomis* spp. from southern Louisiana (P = protolarvae; EMS = early mesolarvae; MS/J = late mesolarvae through early juveniles; see text for definition of intervals).

Percent	Head Depth/Total Length													
	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Green sunfish "types"														
P						3	9	5	3					
EMS					5	3	1		1					
MS/J						2	1	3	1	4	2	8	9	2
Lepomis "A" (redear "type"?)														
P			11	32	25	10	1							
EMS				1	11	21	4	2						
MS/J						1	5	3	3					
Lepomis macrochirus (bluegill)														
P	2	24	48	23	1									
EMS		1	6	21	10	7								
MS/J				1	12	13	17	9	3					
Lepomis "B" (bluegill "type"?)														
P	19	16	5	1										
EMS	1	9	4	6	3									
MS/J			2	3	1									

well-developed head pigmentation (particularly in the cheek and postorbital areas); a characteristic mid-lateral streak of melanophores which often simulates a regularly-spaced series of "dashes"; and a tendency toward smaller size at comparable stages than other taxa or types.

Longear sunfish "types" - Naturally reproducing populations of *L. auritus* are as yet not established in our area, although extensive introductions have been made in neighboring regions. It is thus likely that our representatives of this type are all *L. megalotis* and/or *L. marginatus*. The longear type appears to be characterized by a lack of a free-swimming protolarval phase -- that is, they appear first in our collections as early mesolarvae (the smallest of which usually having remnants of yolk). This observation is consistent with those of the literature (*e.g.*, Taber 1969). Longear type larvae are extremely rare in our collections, which leads me to conclude that even as "free-swimming" individuals they may be much more nest-bound or at least much less prone to venture into pelagic areas than any of the other *Lepomis*. The few specimens we have are essentially like those of *L. megalotis* described and illustrated in the literature (Taber 1969: Figure 15, Hardy 1978: Figures 135-137). They are more robust and exhibit more pronounced thickening and coiling of the foregut at comparable stages than other *Lepomis* (Figures 3 and 4). No wild-caught metalarvae or early juveniles of the longear type are available from our study area.

Bluegill "types" - Sufficient wild-caught material is at hand to recognize *L. macrochirus* through all phases except perhaps the very earliest yolk-bearing protolarvae. A second form, which I call *Lepomis* "B", is more similar in many respects to the bluegill than to any other taxon or

"type". If this similarity does reflect phylogenetic affinity, then it is very likely that "B" will ultimately prove to be *L. humilis*.

Bluegill types are characterized by retarded thickening and coiling of the foregut. In our material, most *L. macrochirus* have an essentially uncoiled gut until very late in the EMS subphase and *Lepomis* "B" generally does not have a complete coil in the foregut until well after the full complement of principal caudal rays is attained. Protolarval and early mesolarval bluegill types also tend to have proportionally smaller eyes; greater preanal lengths (Table 2); more preanal myomeres (Table 3); and smaller, more posteriorly-placed gas bladders than other *Lepomis* (especially green and longear types). Also, prior to caudal fin "completion", bluegill types are markedly larger at comparable stages than green or longear types (Figures 2 and 3). As late mesolarvae through early juveniles, the bluegill types tend to become much less distinctive, particularly with respect to meristics and morphometrics. The later bluegill types are best distinguished from other *Lepomis* by certain details of pigmentation. For example, if a mid-lateral streak of "dash"-like melanophores develops at all (occasionally in *L. macrochirus*; almost never in *Lepomis* "B") it tends to be much less prominent than in the green sunfish types and is usually confined to the caudal peduncle. From about 9.5 mm TL onward, *Lepomis* "B" has dark pigment concentrated in the vertical intermuscular septum of the lower part of the caudal peduncle. Viewed from below this pigment creates the impression of a darkened underside of the caudal peduncle. Other *Lepomis* spp. (especially very late mesolarvae-juveniles) may develop dark pigment on the underside of the caudal peduncle but it is always superficial (integumentary) as opposed to extending up into the intermuscular septum. Prior to the appearance of juvenile coloration (vertical bars narrower than the interspaces)

no completely diagnostic characters are apparent for the MS/J *L. macrochirus* examined to date. As a matter of practical consideration, however, it may be noted that, in our study area at least, *L. macrochirus* is by far the most frequently occurring and abundant *Lepomis* encountered in conventional plankton samples (as MS/J specimens), regardless of the type of water-body involved. The only other MS/J *Lepomis* that is relatively common and abundant in plankton collections is "B", which is easily recognized by the pigment differences noted above.

Lepomis "A" - At least one other unidentified type is recognizable among our wild-caught specimens. *Lepomis* "A" larvae seem to represent a single species, but they are very difficult to diagnose because they are essentially intermediate with respect to bluegill types and green sunfish types (insofar as the latter are known). In meristics and pigmentation, *Lepomis* "A" larvae are closer to the bluegill types (especially *L. macrochirus* proper), but in respect to morphometrics and gut/gas bladder architecture they tend to resemble the green sunfish types as herein understood. Of the resident *Lepomis* spp. which are as yet unaccounted for as larvae, *Lepomis* "A" is most similar, at least at earlier stages, to TVA lab-reared specimens of *L. microlophus*. The resemblance is too slight for confirmation of identity, but it does suggest a strong possibility that *Lepomis* "A" represents an hypothetically-expected "redear type". That is, it might prove to be either *L. microlophus* or the closely related spotted sunfish, *L. punctatus*.

Protolarvae and early mesolarvae of *Lepomis* "A" are most easily distinguished from our green and longear sunfish types (as well as the published descriptions of *L. cyanellus*) by a virtual absence of pigment in the head region (Figures 2 and 3). *Lepomis* "A" differs from protolarval

and early mesolarval bluegill types in having a relatively thickened (usually coiled) foregut and a more anteriorly-placed gas bladder. Specimens of *Lepomis* "A" at comparable stages also tend to be smaller; have larger eyes; and have deeper, more robust heads (Table 4) than bluegill types. *Lepomis* "A" larvae with "complete" caudal fins are extremely difficult to recognize unless they are directly compared to similar-sized examples of the other taxa or types. At comparable sizes, *Lepomis* "A" MS/J specimens tend to be less strongly pigmented than the green and longear types (Figures 4 and 5). They lack the pigment concentrations in the ventral intermuscular septum of the caudal peduncle as described for *Lepomis* "B". In contrast to *L. macrochirus* the MS/J specimens of *Lepomis* "A" exhibit retarded development of pigmentation in the interradial membranes of the soft anal and dorsal fins. Once most of the rays are ossified in the soft anal and dorsal fins of MS/J bluegills there tend to be at least a few (usually several) prominent melanophores scattered through the interradial membranes, and this "speckling" increases with development of the fish until many specimens have well-defined bands crossing the fins near their midpoints. *Lepomis* "A" MS/J specimens tend to have virtually immaculate soft anal and dorsal fins until very late in the metalarval phase or beyond. When pigment does develop it tends to be in the form of very tiny melanophores distributed along the rays, giving an overall "dusky" appearance to the fins as opposed to speckling or banding.

Notwithstanding the fact that the above taxa or types are recognizable among our wild-caught material it should be emphasized that a great deal of additional study is required before we can account for, and adequately characterize, all larval and early juvenile phases of most of our resident

Lepomis spp. The present state of the art is synoptically summarized below:

Lepomis gulosus - has been tentatively distinguished as protolarvae on the basis of strong similarity to published photographs (Larimore 1957: Figures 14 b and c); EMS and MS/J specimens seem to be absent from our collections, but it is possible that they are represented among some of the unidentified "green sunfish types".

L. cyanellus - may be represented among our unidentified "green sunfish types".

L. symmetricus - has been distinguished from EMS specimens with nearly "complete" caudal fins up through early juveniles; it is also highly probable that the protolarvae and recently-transformed EMS specimens illustrated as "green sunfish types" (Figures 2 and 3) are *symmetricus* (the latter are almost certainly not *L. gulosus* and they differ in several respects from the published descriptions of *L. cyanellus*).

L. megalotis/L. marginatus - recognizable as a "type" only, from a few early and late mesolarvae.

L. microlophus/L. punctatus - one or the other of these species (probably the former) may be represented by what I call *Lepomis* "A", which is recognizable from protolarval through metalarval phases.

L. macrochirus - recognizable from protolarval through early juvenile phases.

L. humilis - probably represented by *Lepomis* "B", which is known from protolarval through early juvenile phases; rationale is based largely on the process of elimination and the superficial similarity to the bluegill.

Lab-Reared Versus Wild-Caught Specimens

In comparing specimens reared in captivity with those of confirmed identity from field samples (*e.g.*, bluegill and "longear types") I noticed some rather striking differences. Of course, the lab-reared material available to this study represents different genetic stocks and the physico-chemical conditions of their captivity may have been quite different from those of southern Louisiana wild-caught material. That certain morphological differences would occur is thus to be expected, but at least some general mention of the observed discrepancies seems relevant.

The lab-reared specimens were consistently larger and more robust at comparable developmental stages, prior to the juvenile phase, than any of the wild-caught fish. The impression is created that the lab-reared individuals represent "healthier" fish. Inasmuch as the captive larvae are held under more or less ideal conditions with no food competitors other than their own siblings this might be expected. The possibility also exists that our field sampling methods tend to be selective for the weaker individuals in the populations.

The lab-reared specimens were much more heavily pigmented than any of the wild-caught fish, including even those which came from relatively clear water. Some of the wild-caught specimens were examined in a very fresh condition -- that is, within hours after initial fixation -- so that the differences are probably not entirely attributable to conditions and duration of storage. The supposedly diagnostic (for 7-9 mm specimens) "supra-anal melanophore" was consistently evident in the lab-reared material while, as noted above, its occurrence was highly variable among wild-caught specimens.

Correlation of Larval and Adult Abundances

We have found that relative abundances of larval and early juvenile sunfishes, at least as reflected by conventional ichthyoplankton sampling methods, do not necessarily reflect adult densities in a given environment. This may be contrasted with the findings of Dorr *et al.* (1976), who showed that, in terms of percentage of total catch, there was close agreement between larval and adult species composition in a part of Lake Michigan.

It appears that early life-history phases of the different sunfish taxa vary considerably with respect to their vulnerability to ichthyoplankton sampling gear. For example, in one floodplain swamp environment that we routinely sample warmouth and largemouth bass adults rank among the top five centrarchids in terms of both overall catches/effort and mark/recapture density estimates, but their larvae are very poorly represented in plankton samples. Both longear and dollar sunfish are relatively common and abundant as adults in this swamp but as yet no "longear type" larvae have been encountered. On the other hand, the larval form referred to as *Lepomis* "B" ranks second to the bluegill in frequency of occurrence and relative abundance in plankton samples. The most probable identity of "B" is *L. humilis*, a species which is seldom encountered as adults in the swamp.

CONCLUSIONS AND RECOMMENDATIONS

One of the more striking recurrent themes of the above results is the extreme morphological variation exhibited by many taxa both within and between environments. Considering that the wild-caught material all came from a relatively limited geographic area, one is forced to conclude that many traditional characters that have been used to "diagnose" sunfish

taxa are very environmentally plastic. The essentially typological approach used in much of the descriptive literature may thus lead to its diminished reliability for practical purposes of identification.

Notwithstanding the urgency for preparation and dissemination of descriptive information and the logistical constraints on obtaining representative samples, it is recommended that more emphasis be placed on the comparative approach in the future. This study is an attempt at such an approach. Similar studies in other geographic areas will facilitate the ultimate compilation of comparative information that may have general application. For the time being, at any rate, it appears that larval sunfishes will have to be "learned" on almost a fauna-by-fauna basis.

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MYOMERE AND VERTEBRA COUNTS OF THE NORTH AMERICAN CYPRINIDS AND CATOSTOMIDS

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ABSTRACT

Myomere counts, which are valuable in larval fish identification, have been reported for only about 20% of the North American cyprinids and catostomids. Since there is a nearly direct correlation between total myomeres and total vertebrae, the latter, which are known for many more species, can be used to approximate the former. The range of total vertebra and/or myomere counts for 70 cyprinid species, 28 to 51, is larger and essentially includes that for 27 catostomids, 32 to 52. Preanal and postanal myomere counts ranged from 19 to 31 and 10 (9?) to 18, respectively, for cyprinids and 25 to 42 and 5 (3?) to 12 (14?) for catostomids. The two families can be readily distinguished by the proportion of postanal to preanal myomeres, about ½ or greater for cyprinids and 1/3 or less for catostomids, or preanal to total myomeres, about 2/3 or less for cyprinids and 3/4 or more for catostomids. The genera of each family are characterized by distinctive ranges of total myomeres or vertebrae which can be used to help determine the identity of unknown cypriniform larvae.

INTRODUCTION

Myomere counts are important in larval fish taxonomy, but they have been reported for only about 20% of North America's approximately 260 species of minnows (Cyprinidae) and suckers (Catostomidae). However, myomeres are directly associated with vertebrae and vertebra counts have been reported for most species. The purpose of this paper is to summarize myomere and/or vertebra counts for many cyprinids and catostomids and to compare and characterize these counts for the two families.

METHODS

Literature was surveyed extensively, but by no means completely, for records of total vertebrae and total, preanal, and postanal myomere counts. These counts were supplemented with unpublished data from several researchers. Vertebra counts were either assumed or adjusted to include the Weberian ossicles. Preanal and postanal myomere counts were either assumed or adjusted to conform with Seifert's (1969) method, *i.e.* all entire myomeres posterior to the posterior margin of the vent were considered postanal and the remainder preanal. Adjustment depended on the availability of reasonably accurate drawings from which revised counts were made. Some myomere counts were verified with personal reference specimens. A few highly unlikely counts or extremes were disregarded. Percentages or proportions of preanal to total and postanal to preanal myomeres were calculated using the median values of the typical ranges for each species. Total vertebrae (or myomeres when vertebra counts were not found) for all genera considered were summarized in range intervals of uniform size (*e.g.* 35-40 and 40-45).

RESULTS AND DISCUSSION

Extreme ranges for total myomeres were entirely included in the extreme ranges for vertebrae or vice versa in about 70% of the cases and at least partially overlapped in 90% of the cases for which both ranges were available (Table 1). Considering the paucity of data for some species and the probability of inaccurate data, there appears to be sufficient evidence to support the generalization that there is a nearly direct, one to one, correlation between total myomeres and total vertebrae, Weberian ossicles included. Accordingly, total vertebrae can be used with reasonable

Table 1. Typical myomere and vertebra counts for selected cyprinid and catostomid fishes. Reported or observed ranges, excluding unlikely extremes, are given in parentheses. Sources, coded by letters, are keyed below with the year of publication or, if the data used is unpublished, with an asterisk. Preanal and postanal myomere counts were either assumed or adjusted to conform with Seifert's (1969) method. Some counts were determined from drawings. Vertebra counts were either assumed or adjusted to include the Weberian ossicles.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Cyprinidae:				
Acrocheilus alutaceus				44-45 z
Campostoma anomalum	26-28 ekC	11-15 ekC	38-41 eC	
Carassius auratus	21-23 (20-24) qC	9-12 qC	30-34 (29-36) qC	28-32 qz
Clinostomus elongatus	20 e	15 e	35 e	40-41 (38-41) z
Clinostomus funduloides	22-25 k	11-14 k		
Couesius plumbeus				40-41 (39-43) z
Cyprinus carpio	24-26 (20-27)ekqsCGH	11-13 (10-15)ekqsCGH	35-38 (32-40)eqCGH	35-36 (32-39)qzH
Ericymba buccata	25-26 t	13 t	38-39 t	
Exoglossum maxillingua	24-27 hC	12-15 hC	38-39 hC	38 z
Gila cypha				46-47 (45-49) mz
Gila elegans				49 (47-51) m
Gila robusta	29-31 (26-31) C	16-17 (16-18) C	45-48) C	46 (45-48) m

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Gila seminuda				45 (44-47) m
Hybognathus hankinsoni				35-37 z
Hybognathus nuchalis	21-23 (21-26) qsH	13-15 (12-15) qH	35-37 (34-41) qH	37-38 (36-38)qzH
Hybopsis aestivalis	22-23 C	15 C	37-38 C	
Hybopsis gracilis				43-47 (40-47) z
Hybopsis storeriana	22-24 G	14-15 G	36-39 G	39 (38-41) z
Hybopsis x-punctata				37-39 z
Lavinia exilicauda		13? M		
Lepidomeda albivallis				43 (42-44) w
Lepidomeda altivelis				43 (42-44) w
Lepidomeda mollispinis				42-43 (42-44) w
Lepidomeda vittata				41-42 (41-43)uw
Leuciscus idus	27-29 d	16 d	43-45 d	46-47 d
Meda fulgida				40 (39-42) w
Mylocheilus caurinus				45 (44-46) z
Nocomis biguttatus				38 (37-39) z

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Nocomis micropogon	25-27 et	12-15 et	37-40 (-41?) et	38-39 z
Notemigonus crysoleucas	23-25 (22-26) ekqtCD	13-14 (12-15) ekqtCD	36-38 (35-40) eqtCDH	36-38 (35-40) qszH
Notropis anogenus				32-36 z
Notropis amoenus	23-27 qC	13-15 qC	37-41 qtC	38-40 (37-42) q
Notropis analostanus	22-24 (20-24) qE	13-14 (12-14) qE	35-37 (32?-37) qE	35-36 (35-38) E
Notropis atherinoides	25-26 (23-26) ekC	12-15 (10-15) ekC	38-41 (35-41) eC	39-42 (38-44) zHn
Notropis bifrenatus	19-20 (17-20) q	14-15 q	34 (32-34) q	34-36 q
Notropis blennius				36-37 z
Notropis buchanani	19-21 C	15-16 C	34-36 C	
Notropis chalybaeus	19-20 q	14-15 q	33-35 q	35 (33-37) q
Notropis cornutus	24-26 eCL	11-14 (11-16) eCL	36-39 (35-40) eCL	39-40 (38-43) z
Notropis dorsalis				34-36 (34-37) zH
Notropis emilae				37-38 z
Notropis girardi	24 x	13 x	37 x	
Notropis heterodon				35-36 z
Notropis heterolepis	21 e	14 e	34-35 e	34-36 z

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Notropis hudsonius	23-25 (22-25) eqstC	13-16 (12-18?) eqC	37-38 (36-40) eqC	37-38 (35-40) qszH
Notropis lutrensis	20-23 (19-23) yCG	12-14 (11-15) yCG	33-36 (32-37) yCG	
Notropis panarcys				35 (34-36) o
Notropis proserpinus				35-37 o
Notropis rubellus	26-27 et	13-14 et	39 et	39 (37-41) zH
Notropis spilopterus	22-24 (22-25) ktCDE	13-15 (11-15) ktCDE	36-38 (35-40) CDE	37-39 zE
Notropis stramineus	20-23 C	12-13 C	33-35 C	35 (33-36) z
Notropis umbratilis				35-36 z
Notropis venustus	23 (20-24) G	12-15 G	35 (33-38) G	
Notropis volucellus	20 C	14 C	34 C	36 (34-37) z
Phoxinus eos				37 (35-38) z
Phoxinus neogaeus				37-39 z
Pimephales notatus	22-24 etC	12-14 etC	34-37 etC	37-39 zH
Pimephales promelas	22-24 (20-25) ekCD	12-14 (11-15) ekCD	35-37 (34-38) eCD	36-37 (35-38) z
Pimephales vigilax	21-23 G	12-14 G	34-37 G	
Plagopterus argentissimus				40 (39-41) w
Ptychocheilus lucius	31-35 C	15-17 (14-17) C	48-50 (47-51) C	48 (47-48) A

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Ptychocheilus oregonensis				45-46 (44-46) F
Rhinichthys atratulus	24-25 (22-26) ght	15-16 t	38-39 t	38-39 (37-40) z
Rhinichthys cataractae	25-27 (24-27) eght	14-15 et	40-41 (37-41) et	38-40 (37-42) z
Rhinichthys falcatus				38-40 z
Rhinichthys osculus	24-25 C	13-15 C	37-39 (34-39) pC	37-38 z
Richardsonius balteatus	23-25 (23-26) rC	14-16 (13-17) rC	38-41) rC	38-43 z
Semotilus atromaculatus	25-26 eC	14-15 eC	39-42 eC	41-43 (39-44) z
Semotilus corporalis	29 t	17 t	46 t	42-43 (41-44) qzH
Semotilus margarita				39-40 (38-40) z
Tinca tinca				38-39
Catostomidae:				
Carpiodes carpio	30 C	8 C	38 C	
Carpiodes cyprinus	27-31 (26-32) fjqsC	8-9 (5-10) fjqsC	37-40 (32?-41) efjqC	38 (37-40) fjsz
Carpiodes velifer	26-27 (25-29) J	7-9 (6-11) J	33-37 (33-38) J	
Catostomus catostomus	37-38 (36-40) i	8-9 (5-12) i	46-48 (44-50) i	45-47 z
Catostomus clarki				46-49 (45-51) B

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Catostomus columbianus				46-49 (43-51) zB
Catostomus commersoni	36-39 (33?-42) efqC	8-9 (5-11) efqC	44-47 (41-52) efqC	44-48 qzH
Catostomus discobolus	37-38 C	9-11 C	47-48 C	45-49 (43-50) B
Catostomus fumeiventus	32?-34? v	9-10? v	41?-44? v	45-46 (44-48) v
Catostomus latipinnis	38-39 C	10-11 C	48-49 (48-50) C	
Catostomus macrocheilus				47-49 Z
Catostomus platyrhynchus				44-47 (42-48) zB
Catostomus plebius				43-44 (42-46) B
Catostomus santaanae	33? N	9? N	42+? N	43-44 (42-46) N
Erimyzon oblongus	30-31 (30-33) ft	8-10 (7-10) ft	39-41 (38-42) ft	
Erimyzon sucetta				35-36 z
Hypentelium nigricans	34-38 (33-40) aef	7-9 (3-11) aef	41-47 (39-49) aef	42-45 z
Ictiobus bubalus	25 K	8 K	33 K	
Ictiobus cyprinellus	30 C	7 C	37 C	36-37 z
Minytrema melanops	33-35 (30-35) klIJ	6-8 (3-9) (-14?) klIJ		43-44 z
Moxostoma anisurum	31 e	11 e	42-43 e	40 z

continued

Table 1. continued.

Species	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Total Vertebrae
Moxostoma carinatum				42 z
Moxostoma duquesnei				43 z
Moxostoma erythrurum	33-35 (31-37) i	7-8 (6-9) i	41-42 (39-45) i	40 z
Moxostoma hubbi				43 z
Moxostoma macrolepidotum	32-37 (30-39) bftC	6-8 (5-9) bftC	41-45 (38-45) bftC	42 (41-44) qzH
Moxostoma valenciennesi				42-44 z

Sources: a=Buynak and Mohr 1978, b=Buynak and Mohr*, d=Ehrenbaum 1909, e=Fish 1932, f=Fuiman 1978, g=Fuiman and Loos 1977, h=Fuiman and Loos 1978, i=Fuiman and Witman*, j=Gerlach 1973, k=Hogue *et al.* 1976, l=Hogue and Buchanan 1977, m=Holden and Stalnaker 1970, n=Hubbs 1922, o=Hubbs and Miller 1978, p=Hufzinger*, q=Jones *et al.* 1978, r=Lentsch*, s=Lippson and Moran 1974, t=Loos *et al.**, u=Miller 1963, v=Miller 1973, w=Miller and Hubbs 1960, x=Moore 1944, y=Saksena 1962, z=Scott and Crossman 1973, A=Seethaler 1978, B=Smith 1966, C=Snyder*, D=Snyder *et al.* 1977, E=Stone 1940, F=Suttkas and Clemmer 1977, G=Taber 1969, H=Werner and Young*, I=White 1977, J=Wiltz*, K=Wrenn and Grinstead 1969, L=Zicari*, M=Swift 1965, N=Greenfield *et al.* 1970.

confidence to approximate total myomeres.

Some variation in myomere counts is attributable to differences in techniques, difficulty in discerning the most anterior and posterior myomeres, and the specific stages from which the counts were determined. With respect to the latter, relative vent position may change somewhat during larval and early juvenile development, and the most posterior myomeres in protolarvae and early mesolarvae may be associated with the future or forming hypural complex and may cease to exist or be evident in later stages. In addition, some counts referenced herein may be based on erroneously identified specimens. Due caution is therefore advised in the use of the data presented, especially when total myomeres are notably different from total vertebrae (*e.g. Clinostomus elongatus*, Table 1).

The range of total myomeres or vertebrae for 70 cyprinid species, 28 to 51, is greater and in fact practically includes that for 27 catostomids, 32 to 52 (Figure 1). However, over 75% of the cyprinids have counts within the more restricted range of 34 to 43 and the catostomids within the more restricted range of 39 to 49, 33 to 38 for the ictiobinae and 41 to 49 for the catostominae. *Carassius* is responsible for the low end of the cyprinid range and *Gila*, *Mylocheilus*, *Leuciscus*, *Ptychocheilus*, and *Hybopsis gracilis* (*Platygobio gracilis* according to Scott and Crossman, 1973) for the upper end (Figure 2 and Table 1). The genera *Ictiobus* and *Catostomus* are respectively responsible for the lower and upper extremes of the catostomid range.

Ranges of preanal and postanal myomere counts are 19 to 31 and 10 (9?) to 18, respectively, for the cyprinids, and 25 to 42 (30 to 42 excluding Ictiobinae) and 5 (3?) to 12 (14?), respectively, for the catostomids (Figure 3). However, over three quarters of the cyprinids have preanal

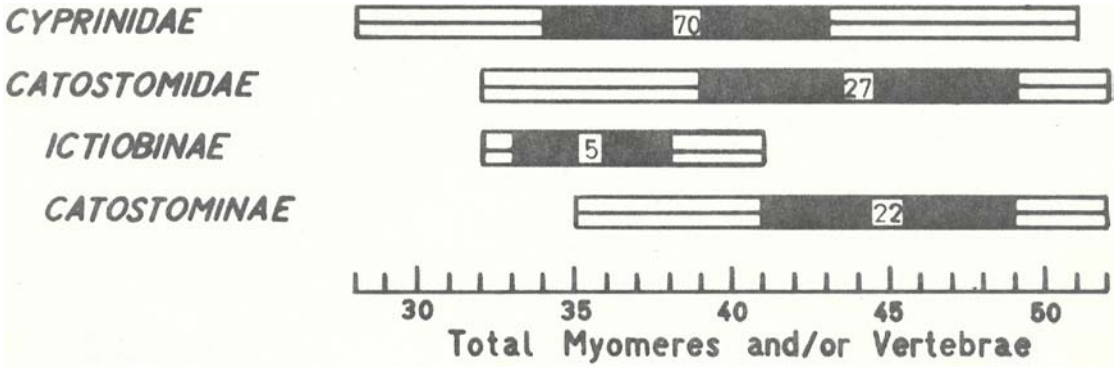

Figure 1. Cumulative ranges of total vertebrae and/or myomeres for the families Cyprinidae and Catostomidae, and the subfamilies Ictiobinae and Catostominae. Solid bars represent the modal ranges which include over 75% of the species. Numbers indicate the number of species on which the data are based. Based on data in Table 1.

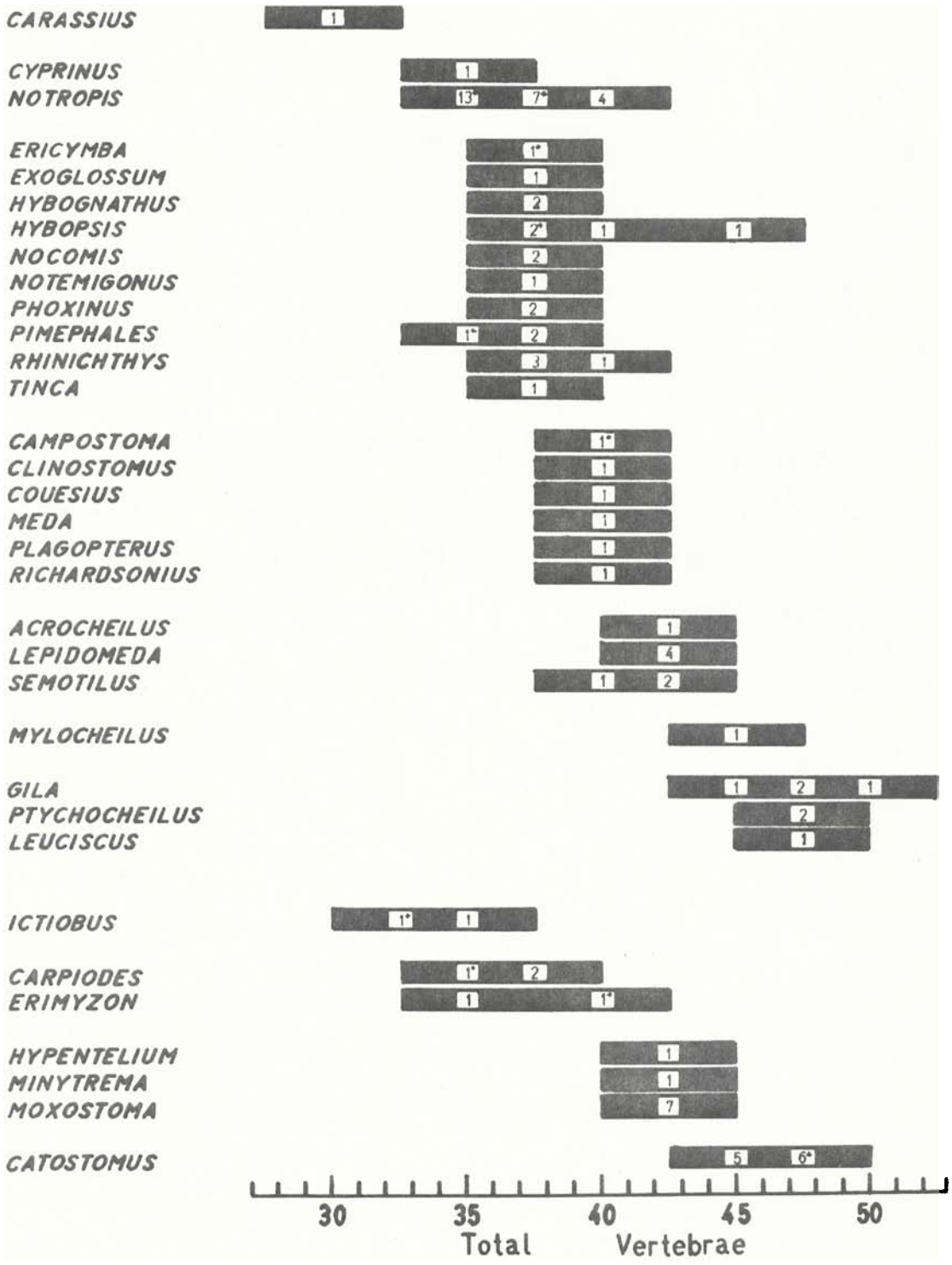

Figure 2. Total vertebrae summarized by genera in uniformly sized range intervals. Numbers indicate the number of species on which the data for one or more species is based on total myomeres rather than vertebrae. Based on data in Table 1.

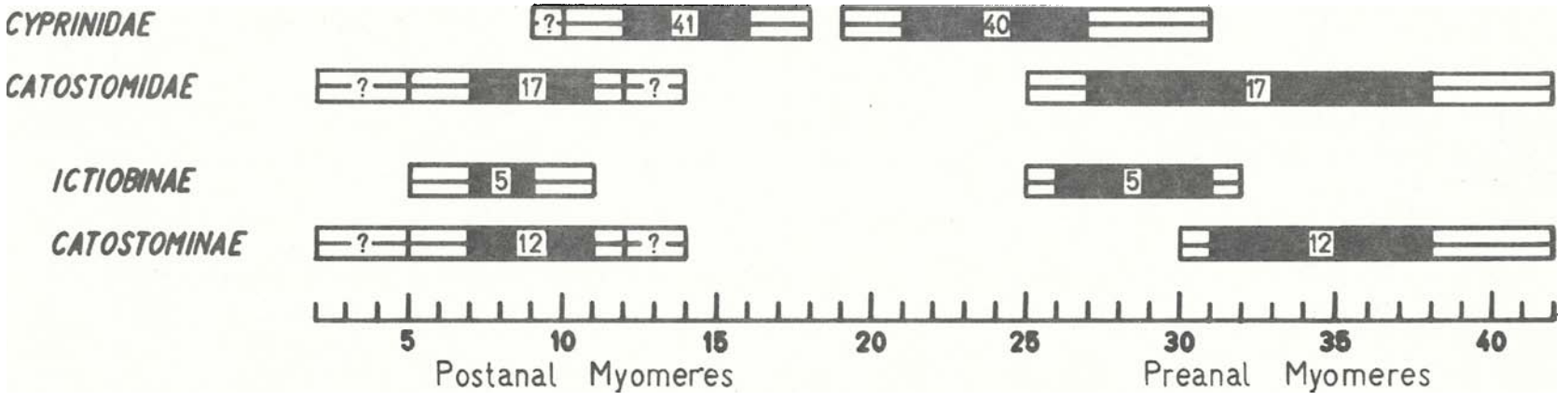

Figure 3. Cumulative ranges of preanal and postanal myomeres for the families Cyprinidae and Catostomidae and the subfamilies Ictiobinae and Catostominae. Solid bars represent the modal ranges which include over 75% of the species. Numbers indicate the number of species on which the data are based. Based on data in Table 1.

counts of 27 or fewer and postanal counts greater than 11, while over 75% of the catostomids have 27 or more preanal myomeres and 11 or fewer postanal myomeres.

Most larval fish biologists recognize vent position and the number of myomeres as key characters in distinguishing between cyprinid and catostomid larvae. Preanal lengths (snout-to-vent) relative to total length have often been reported as less than two-thirds for cyprinids and about two-thirds or more for suckers, but with some overlap. Likewise, as documented above, the ranges of total, preanal, and postanal myomeres for each family also overlap. The greatest degree of separation is found in the proportion of postanal to preanal myomeres which, based on the median values of the typical ranges (Table 1), is about ½ or greater for cyprinids (48 to 78%) and 1/3 or less for catostomids (20 to 35%). Good separation is also attained using the proportion of preanal to total myomeres, typically 2/3 or less for the minnows (57 to 69%) and 3/4 or more for the suckers (73 to 82%).

The genera within each family have more-or-less distinctive ranges of total myomeres or vertebrae (Figure 2). This information can be used, with care and an awareness of exceptions, to help determine the identity of some cypriniform larvae to at least a restricted group of genera and in a few instances to the specific level. As an example, consider an unidentified mesolarva with a myomere count of 29 preanal plus 16 postanal myomeres from the Upper Colorado River System. The high postanal count, and proportions of postanal to preanal (55%) and preanal to total myomeres (65%), place the specimen within the family Cyprinidae. Of the nine cyprinid genera known in the Upper Colorado River System, only *Semotilus*, *Gila*, and *Ptychocheilus* have ranges of total myomere counts that might

include the count for this specimen 45; Figure 2). The total and preanal myomere ranges for the specific species encountered in this river system are a bit low in *Semotilus atromaculatus* and high in *Ptychocheilus lucius* and *Gila elegans* (Table 1). These tentative eliminations leave *Gila cypha*, a rare and endangered species, and *Gila robusta*, common in most of the system, as the most probably identities.

ACKNOWLEDGEMENTS

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LARVAL DEVELOPMENT OF THE GREENSIDE DARTER, *ETHEOSTOMA BLENNIOIDES NEWMANII* (AGASSIZ)

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ABSTRACT

Larvae of the greenside darter, Etheostoma blennioides newmanii, were collected for this study from the Clinch River drainage in east Tennessee. Spawning by the greenside darter was estimated to extend from mid-March through April when water temperatures ranged from 10.2 to 19.0 C. Protolarvae examined ranged in length from 7.05 to 10.82 mm TL, mesolarvae from 11.23 to 16.87 mm TL, and metalarvae from 17.12 to 19.29 mm TL. Larval development, based on specimens examined, was compared with descriptions of larvae of E. b. blennioides by Fahy (1954). Of the five known sympatric darter species observed in this study, larvae of the redline darter, Etheostoma rufilineatum, were the most similar to those of the greenside darter.

INTRODUCTION

The greenside darter, *Etheostoma blennioides*, is a widely distributed species found in riffle habitats of the Mississippi River system from Illinois to New York and south to Alabama, Georgia, and North Carolina. West of the Mississippi River it occurs in the Ozark region of Missouri, Arkansas, and eastern Oklahoma. In the Great Lakes drainage, it occurs in the Ontario tributaries of Lake St. Claire, Lake Erie, and in the southern tributaries of Lake Ontario (Moore 1968). Four subspecies are recognized (Miller 1968); *E. b. blennioides* Rafinesque, *E. b. gutselli* (Hildebrand), *E. b. pholidotum* (Miller), and *E. b. newmanii* (Agassiz).

The latter is found throughout the Tennessee River system (except for those areas inhabitated by *E. b. gutselli*), the Cumberland River system, and west of the Mississippi River in the St. Francis, White, Arkansas and Ouachita River systems.

Larval fish drift was studied in Hinds Creek, a tributary of the Clinch River (Melton Hill Reservoir, Anderson County, Tennessee) from 1976 through 1978. Large numbers of larval greenside darters of the *newmanii* subspecies were identified from samples obtained. A series of specimens from protolarval through juvenile development periods was saved for reference material. No literature known to me is available concerning larval development of the greenside darter, with the exception of Fahy's (1954) description of two larval specimens of *E. b. blennioides*. As a consequence, it was the purpose of this paper to describe in detail larval development of the greenside darter *E. b. newmanii* (Agassiz) and to compare its development with larval development of *E. b. blennioides* as described by Fahy (1954). Reproductive habits for the greenside darter in Hinds Creek were also studied to a limited degree.

METHODS

Drift net samples were collected weekly at four locations on Hinds Creek (Table 1) from April 4 through September 1, 1976. Supplementary larval seine and dip net samples were collected periodically from 1976 through 1978. Larvae were preserved in the field in 10 percent Formalin and later transferred to buffered 5 percent Formalin for permanent storage.

Limited percid diversity in Hinds Creek made this a unique area for larval taxonomic study. Most percids captured, could be identified to the

Table 1. Total number of larval greenside darters (7 to 20 mm) captured with drift nets at four sampling stations on Hinds Creek in 1976. Number of samples is in parentheses.

Creek Mile Station No.	HCM 0.7 1	HCM 3.6 2	HCM 6.7 3	HCM 11.2 4
Total Larvae	0 (22)	23 (69)	238 (97)	15 (94)

species level by comparisons with specimens from a developmental series propagated and cultured from Hinds Creek parental stock.

Greenside darter larvae from Hinds Creek were identified by comparing them with a propagated series and by observing sequential development through the juvenile period. Taxonomic separation from other species was based on myomere counts, pigmentation patterns, yolk sac shape, number of rays and spines in the median fins, and development related to total length.

On March 28, 1977, gravid greenside darters from Hinds Creek were stripped and the eggs were fertilized and placed in vertical flow-through incubators at 13 to 15 C. Hatching occurred in 17 days. One egg was preserved in 5 percent buffered Formalin, and nine larvae, at hatching (three specimens) 1, 3 (two specimens), 4, 12, and 19 days post-hatching were also preserved.

Descriptions of greenside darters are based on a developmental series (63 specimens) encompassing protolarval through juvenile periods from Hinds Creek field collections. Specimens were examined with a stereomicroscope. An ocular micrometer was used for measurements and polarizing filters were used to facilitate myomere and ray counts. Illustrations were drawn with the aid of a camera lucida.

Morphometric and meristic characters examined (Figure 1; Tables 2, 3) include: total, standard, preanal, snout, and head length; length to the posterior margin of the yolk sac (YSL); head depth and body depth at the anus; orbit diameter; preanal and postanal myomere counts; numbers of myomeres anterior to the posterior margin of the yolk sac (YSM); and numbers of dorsal and anal fin spines and rays. Standard length was measured as the distance from the tip of the snout to the posterior tip of the notochord for specimens less than 13 mm total length. The hypural complex was used as the posterior limit of standard length for specimens 13 mm TL or greater. Head length on specimens less than 14 mm TL was measured from the tip of the snout to the posterior margin of the otic vesicle, for specimens 14 mm TL or greater the measurement was taken from the posterior margin of the opercular flap. Preanal myomeres included any myomeres touched by or anterior to an imaginary vertical line through the body at the posterior margin of the anus. Number of myomeres anterior to the posterior margin of the yolk sac included any myomere bisected by an imaginary vertical line through the body at that point.

Meristic and morphometric data were tabulated by length intervals. Developmental terminology used is that of Snyder (1976). Unless otherwise stated, lengths mentioned in the text are total lengths.

GREENSIDE DARTER SPAWNING

Of the four stations sampled with drift nets in Hinds Creek, one (Station 3) consistently yielded high numbers of greenside darter larvae (Table 1). This station was a pool having a substrate of bedrock overlain with gravel and rubble immediately below a shallow bedrock riffle covered with patches of filamentous algae. In late March 1977, gravid adult

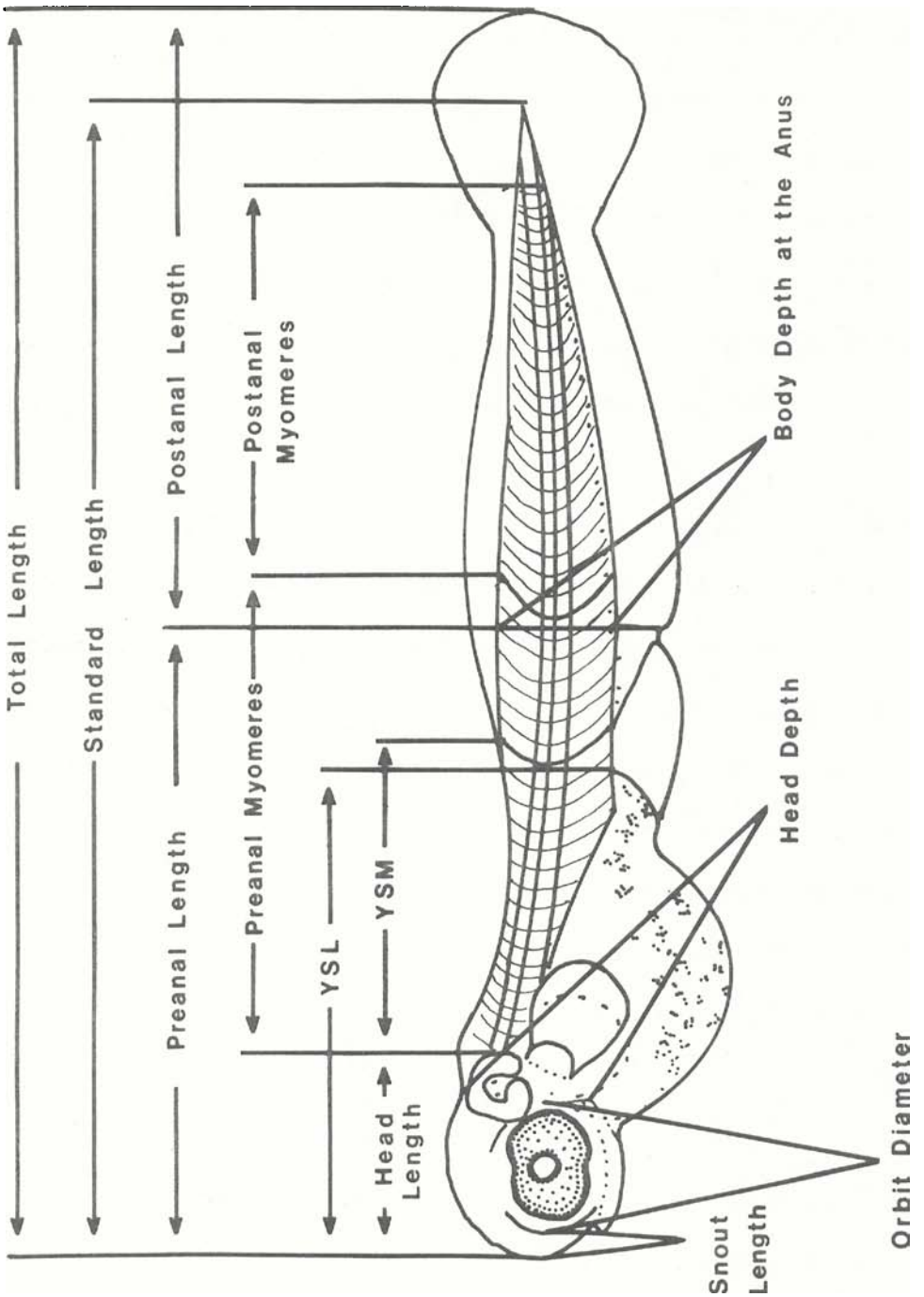

Figure 1. Morphometric and meristic characters examined for the greenside darter, *Etheostoma blennioides newmanii*.

Table 2. Morphometric characters of larval greenside darters, Etheostoma blennioides newmanii (Agassiz).

Size Range (mm TL)	N		Lengths						Body Depth at Anus	Orbit Diameter	Head Depth
			Total	Standard	Preanal	YSL*	Head	Snout			
7.0- 7.99	5	$\bar{X}$	7.35	7.10	3.66	2.74	1.20	0.88	0.63	0.70	0.86
		Range	7.05- 7.54	6.81- 7.30	3.61-3.69	2.72-2.80	1.12-1.26	0.08-0.12	0.58-0.70	0.68-0.70	0.80-0.94
8.0- 8.99	5	$\bar{X}$	8.45	8.21	4.10	3.11	1.36	0.14	0.75	0.66	0.95
		Range	8.04- 8.69	7.87- 8.28	3.98- 4.18	3.04-3.24	1.26-1.48	0.12-0.20	0.70-0.82	0.6 -0.70	0.88-1.10
9.0- 9.99	5	$\bar{X}$	9.29	9.02	4.67		1.47	0.18	0.83	0.67	1.08
		Range	9.06- 9.84	8.73- 9.55	4.55- 5.13		1.36-1.56	0.12-0.24	0.72-1.02	0.66-0.68	1.01-1.16
10.0-10.99	5	$\bar{X}$	10.44	10.08	5.32		1.68	0.22	1.07	0.76	1.31
		Range	10.0 -10.82	9.92-10.5	5.17- 5.49		1.64-1.72	0.20-0.24	1.00-1.14	0.70-0.80	1.26-1.38
11.0-11.99	5	$\bar{X}$	11.55	11.00	5.89		1.93	0.27	1.27	0.84	1.46
		Range	11.23-11.86	10.74-11.23	5.66- 5.99		1.84-2.00	0.20-0.36	1.20-1.34	0.82-0.84	1.40-1.54
12.0-12.99	5	$\bar{X}$	12.43	11.70	6.39		2.04	0.30	1.41	0.87	1.56
		Range	12.19-12.86	11.36-12.11	6.18- 6.68		1.88-2.16	0.24-0.40	1.32-1.48	0.82-0.90	1.44-1.64
13.0-13.99	5	$\bar{X}$	13.63	12.59	6.93		2.27	0.42	1.50	0.89	1.64
		Range	13.36-13.86	12.36-13.03	6.67-7.18		2.12-2.52	0.28-0.54	1.34-1.68	0.8 -0.96	1.52-1.76
14.0-14.99	5	$\bar{X}$	14.46	12.78	7.30		2.70	0.51	1.82	1.03	1.82
		Range	14.03-14.86	12.44-13.11	7.10-7.52		2.54-2.95	0.48-0.52	1.72-1.92	0.94-1.14	1.64-2.08
15.0-15.99	5	$\bar{X}$	15.28	13.36	7.7		2.91	0.54	1.95	1.09	1.87
		Range	15.03-15.53	13.03-13.69	7.52-7.85		2.79-2.99	0.52-0.56	1.88-2.00	1.08-1.10	1.80-1.96
16.0-16.99	5	$\bar{X}$	16.40	14.33	8.23		3.21	0.62	2.18	1.18	2.03
		Range	16.03-16.87	14.03-14.61	8.10-8.35		3.03-3.36	0.6 -0.64	2.16-2.28	1.16-1.24	1.88-2.12
17.0-17.99	5	$\bar{X}$	17.46	15.20	8.68		3.49	0.66	2.31	1.23	2.18
		Range	17.12-17.74	14.95-15.36	8.43-9.02		3.20-3.61	0.60-0.72	2.20-2.40	1.16-1.28	2.12-2.28
18.0-18.99	5	$\bar{X}$	18.22	15.82	8.85		3.63	0.70	2.42	1.27	2.30
		Range	18.04-18.45	15.61-16.03	8.68-9.52		3.53-3.77	0.68-0.76	2.36-2.48	1.20-1.30	2.24-2.32
19.0-19.99	2	$\bar{X}$	19.25	16.53	9.48		3.90	0.82	2.58	1.32	2.41
		Range	19.21-19.29		9.44-9.52		3.85-3.94	0.76-0.88	2.56-2.60	1.30-1.34	2.40-2.48

* Length to posterior margin of the yolk sac.

Table 3. Meristic characters of larval greenside darters, *Etheostoma blennioides newmanii* (Agassiz).

		Myomeres				Fin Rays and/or Spines		
Size Range (mm TL)	N	Total	Preanal	Postanal	YSM*	First Dorsal	Second Dorsal	Anal
7.0-7.99	5	45-48	21-23	23-26	13-14			
8.0-8.99	5	47-50	22	25-28	12-14			
9.0-9.99	5	45-47	21-23	24-25				
10.0-10.99	5	48-49	23	25-26				
11.0-11.99	5	44-49	22-23	22-26				
12.0-12.99	5	45-46	22-24	22-24				
13.0-13.99	5	43-46	22-23	21-23				
14.0-14.99	5	42-45	22-23	20-22		V-XI	11-14	II,8-9
15.0-15.99	5	42-45	22-23	20-22		IX-XIV	12	II,8-9
16.0-16.99	5	42-44	21-23	19-21		X-XII	12-13	II,8-9
17.0-17.99	5	40-44	21-23	19-21		X-XIII	13	II,8-9
18.0-18.99	5	41-43	21-22	20-21		X-XIII	13	II,8
19.0-19.99	2	42-43	21-22	21		X-XII	13	II,8-9

* Number anterior of the posterior margin of the yolk sac.

greenside darters were collected in this area, a habitat similar to that described by Fahy (1954) for the northern greenside darter.

Early protolarval greenside darters (7 to 8 mm TL) were captured in Hinds Creek from April 8 through May 7, 1976, at water temperatures ranging from 12.5 to 19.8 C. Eggs of the greenside darter, incubated at 13 to 15 C, hatched in 17 days in the laboratory. Therefore, the spawning season of the greenside darter in Hinds Creek probably extended from mid-March through April in 1976. Water temperatures ranged from 10.2 to 19.0 C during this two-month period.

DEVELOPMENT

Eggs and Protolarvae

Propagated greenside darter eggs were spherical, demersal, adhesive, and had a large yellow oil globule. One protolarval specimen, preserved at hatching from the propagated series, measured 7.22 mm TL. However, smaller protolarvae were collected from Hinds Creek. The smallest specimen measured was 7.05 mm TL.

Early protolarval greenside darters had a terminal, well-developed mouth and a rounded snout (Figure 2). No teeth were visible. The nares were formed and two small otoliths were present in each well defined auditory vesicle. The gill arches were partially covered by thin membranous opercula. Bony elements of the opercula were not present until 9 mm TL. By the end of the protolarval phase, the opercula covered the gill arches. Total numbers of myomeres ranged from 45 to 50 in the protolarval phase.

The early protolarval yolk sac was tear-drop in shape with a large anterior oil globule. It extended to approximately the 14th preanal myomere

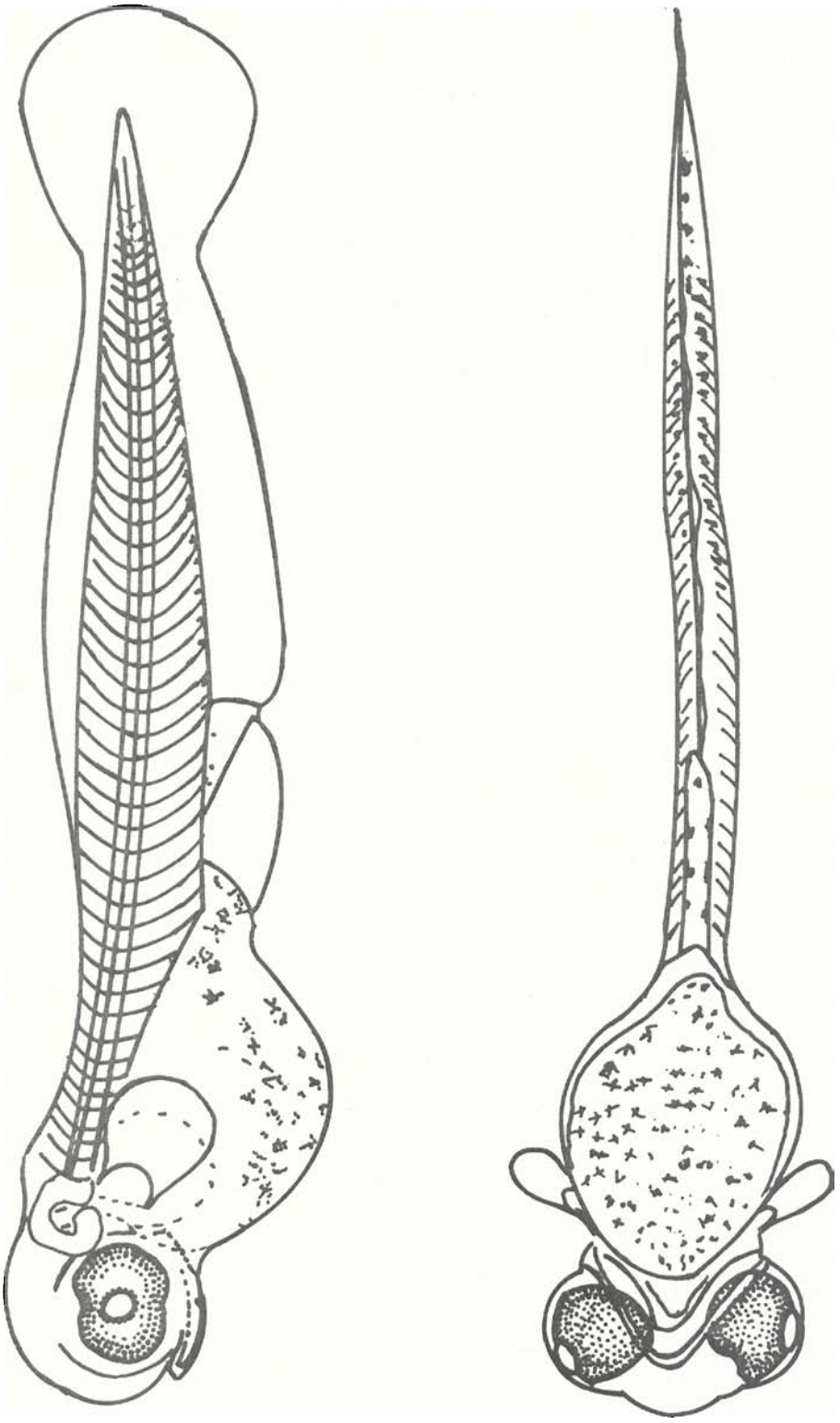

Figure 2. *Etheostoma blennioides neumanii* protolarva of 7.30 mm TL.

(Table 3) covering two-thirds of the straight gut. As yolk was absorbed, the yolk sac became more cylindrical in shape. Yolk absorption was completed by 11 mm TL. The oil globule was the last yolk component to be absorbed.

A reticulated network of vitelline veins was present ventrally and ventrolaterally on the yolk sac of early protolarvae (Figure 3). This network converged posteriorally into a single subintestinal vein which was present along the ventral surface of the gut to the anal pore. As yolk content diminished, the network of vitelline veins gradually became constricted into a tight mid-ventral bundle and began to deteriorate. By about 10 mm TL, the veins shifted to the right side of the yolk sac in the area of liver development. Anterior and posterior of the liver development area, the vitelline bundle retained its mid-ventral positioning. Immediately prior to total yolk absorption, the vitelline system was reduced to a single vein which disappeared with final yolk absorption.

Protolarval greenside darters had a large melanophore within each auditory vesicle. Most specimens had one melanophore immediately anterior to each pectoral fin base. There was a row of four to five melanophores along each side of the gut from the posterior margin of the yolk sac to the anal pore. One or two mid-ventral melanophores were usually present immediately anterior to the anal pore. Postanal pigmentation consisted of a mid-ventral row of indistinct melanophores and distinct ventrolateral rows of pigment. The ventrolateral melanophores were usually punctulate but occasionally appeared as short slashes of pigment along the myoseptae. Pigmentation on the caudal fin consisted of a few indistinct melanophores. No pigment was present on the dorsal surface. Early protolarval specimens

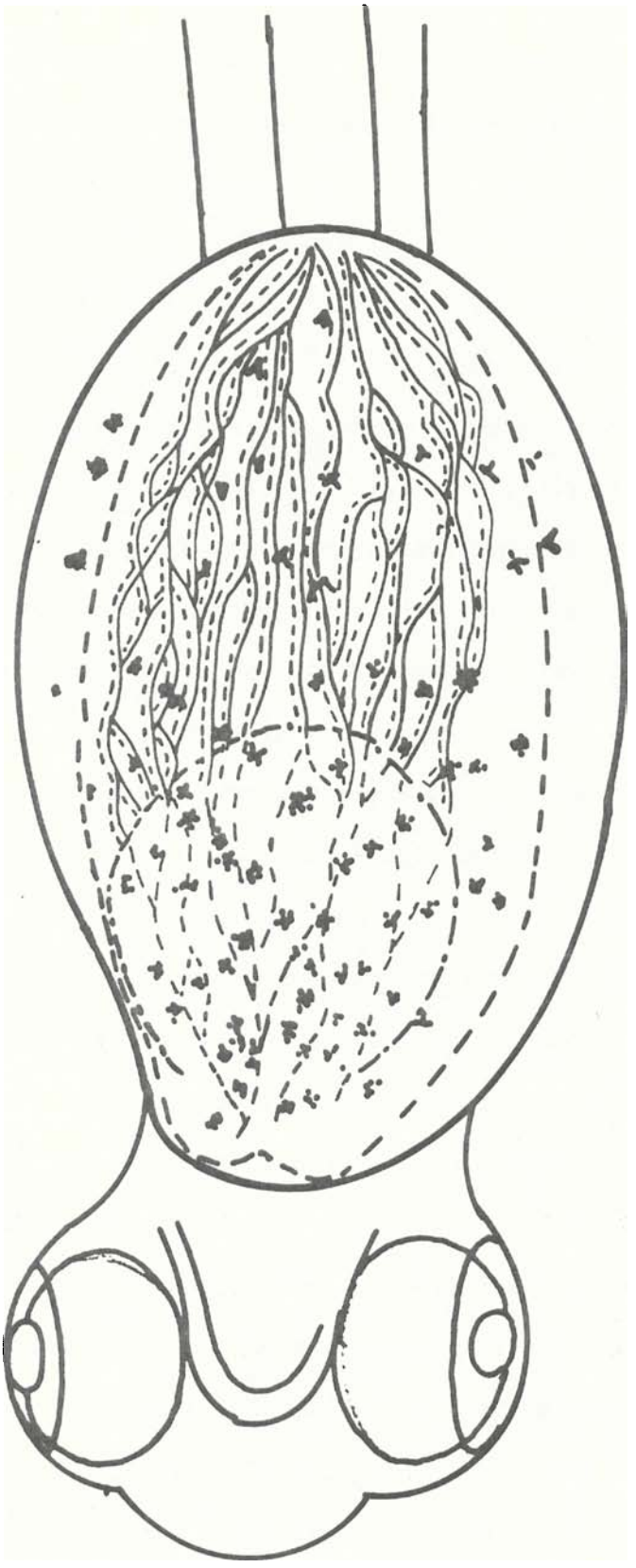

Figure 3. *Etheostoma blennioides newmanii* protolarva showing the vitelline vein system.

had a great deal of ventral pigment of the yolk sac in association with the vitelline vein system (Figure 3). Pigment diminished as yolk was absorbed and the vitelline system became constricted. By the time of total yolk absorption and subsequent disappearance of the vitelline system, the associated pigment was reduced to one large, usually stellate, melanophore between the pectoral fin bases and a few indistinct melanophores at intervals along the gut.

During the protolarval phase, the median finfold origin was dorsal near the fifth preanal myomere, was present around the urostyle, and extended ventrally to the posterior margin of the yolk sac. Undulations in the profile of the median finfold were present at the future locations of the second dorsal and anal fins. The pectoral fins were short and rounded. The onset of fin ray development was evidenced by an opaque area which formed in the caudal fin below the urostyle on specimens between 10 and 11 mm TL. Caudal rays were first observed on a 11.23 mm length individual, thus marking the transition to the mesolarval phase.

Mesolarvae

During the mesolarval phase of development, the mouth was moderately subterminal, and by the end of this phase, the snout was bluntly rounded and appeared almost square. The opercula gradually increased in length. On specimens greater than 14 mm TL, opercula extended to the pectoral fin bases and had distinct flaps.

The total number of myomeres gradually decreased through the mesolarval development phase. Counts on specimens between 16 and 17 mm length ranged from 42 to 44. The last three to five postanal myomeres on protolarvae gradually lost the myomere appearance as they became part of hypural musculature. The number of preanal myomeres also decreased slightly with

development. Two to three myomeres were visible anterior to the pectoral fins on protolarval and early mesolarval specimens. Usually only one was apparent on specimens greater than 14 mm TL. The anterior-most myomere on the smallest mesolarval specimens was occasionally incomplete and by 14 mm length had disappeared. The second and third myomeres anterior to the pectoral fin appear to fuse at approximately 14 mm and were counted as one.

Few changes in pigmentation occurred during the mesolarval phase of development. By the end of this phase, a few melanophores were present over the midbrain, the operculum was lightly pigmented, and the otic vesicle was more intensely pigmented. An indistinct mid-lateral line of pigment was present, particularly on the posterior half of the body, and the margin of the hypural complex was lightly outlined with small punctulate melanophores. On specimens less than 16 mm length, mid-ventral postanal pigmentation was confined posterior to anal fin development. For lengths greater than 16 mm, a double row of pigment was present around the anal fin with pairs of melanophores at the base of each ray.

The median finfold was gradually absorbed during the mesolarval phase. By 16.87 mm length, it disappeared dorsally. Ventrally, it was present as a thin line along the gut and a small flap immediately posterior to the anal fin.

At the onset of mesolarval development (11.23 mm), the urostyle was slightly upturned. Pelvic buds were in evidence between 12 and 13 mm length, as well as incipient rays in the second dorsal and anal fins (Figure 4). Development of dorsal spines and pectoral fin rays began between 13 and 14 mm length. Pelvic fin ray formation began between 14

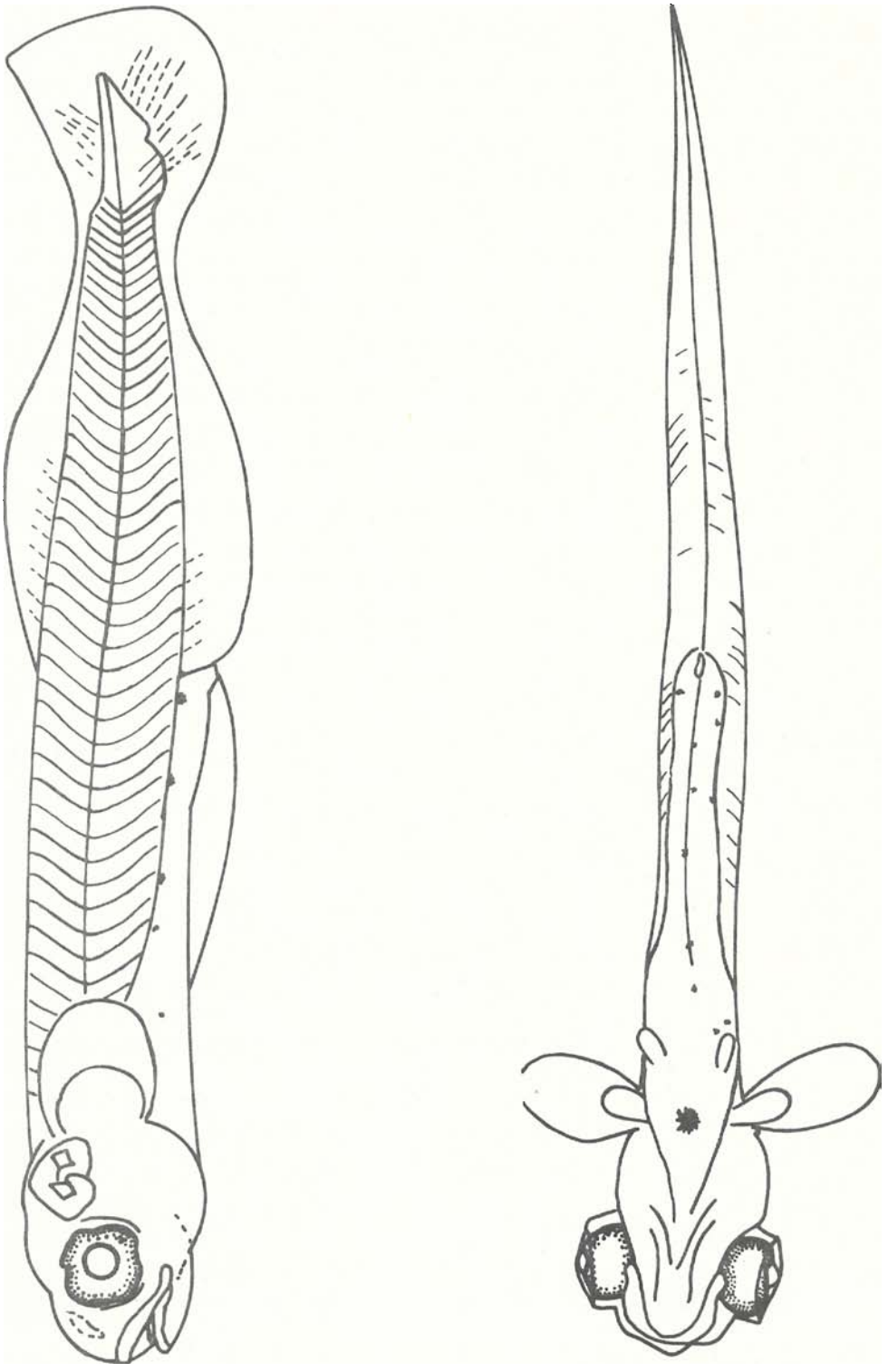

Figure 4. *Etheostoma blennioides neumanii* mesolarva of 12.36 mm TL.

and 15 mm length. The adult complement of fin rays appeared in the caudal and pectoral fins between 15 and 16 mm length; in the anal fin between 14 and 15 mm length; and in the second dorsal fin, marking transition to the metalarval phase, by 17.12 mm length (Table 3).

Metalarvae

During the metalarval phase, the mouth became distinctly subterminal. The bottom of the upper lip was in line with the ventral margin of the orbit and the snout was smoothly rounded.

Total myomere counts continued to decrease through the metalarval phase. Specimens greater than 18 mm length had 41 to 43 myomeres (Figure 5).

Between 18 and 19 mm length, two patches of pigment appeared dorsally on the torso, one between the dorsal fins and another at the posterior margin of the second dorsal fin. Between 19 and 20 mm length, six distinct dorsal saddles developed and mid-lateral pigmentation intensified in areas that later developed into the lateral blotches characteristic of adult greenside darters (Figure 6).

The pelvic fins were completely rayed but not fully formed by the onset of metalarval development. By 19.29 mm length, the median finfold was completely absorbed and the first dorsal fin had 10-12 spines. Although no specimens were available for verification, final development of the first dorsal fin, marking transition to the juvenile period, probably occurs shortly after 20 mm length.

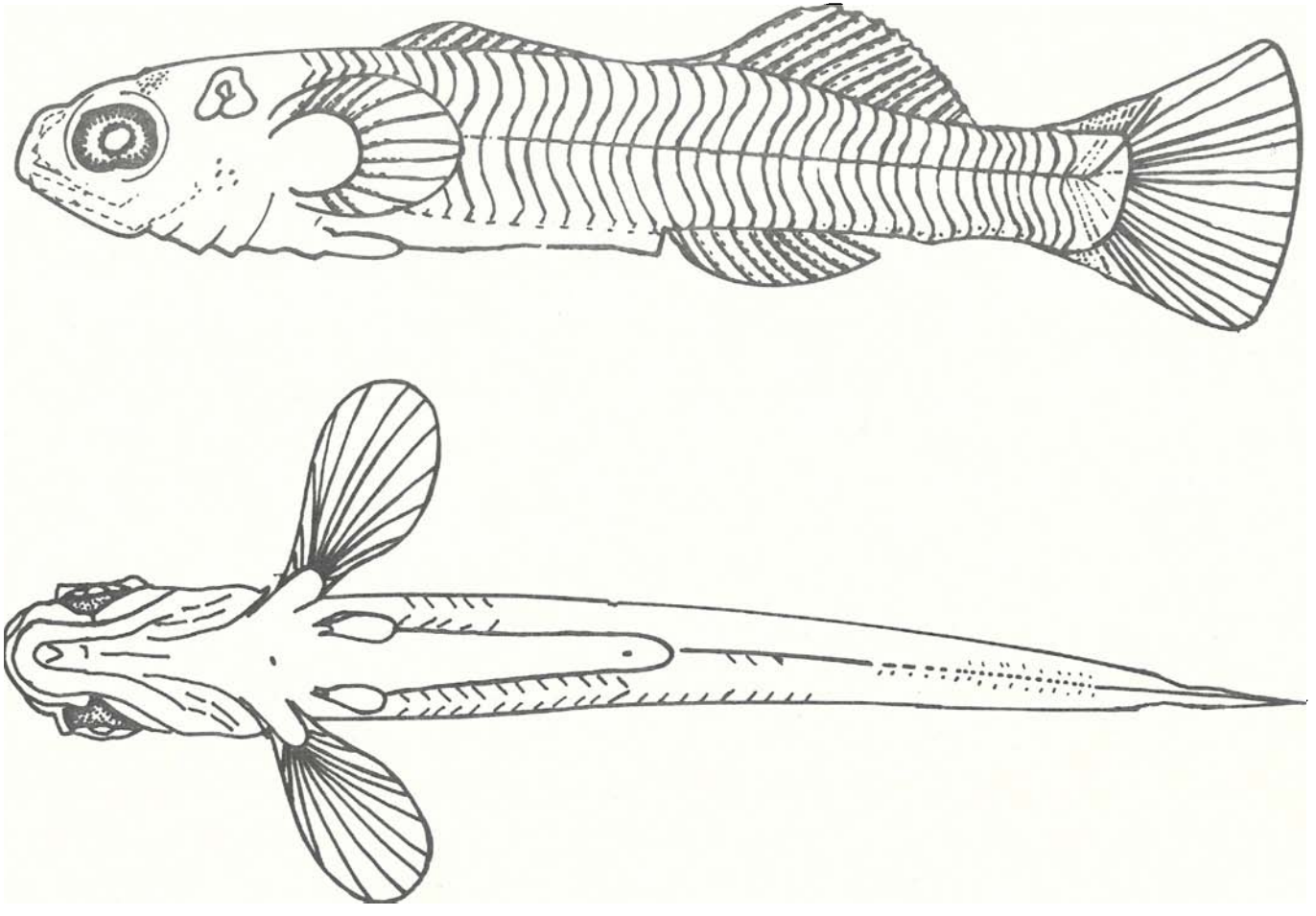

Figure 5. *Etheostoma blennioides newmanii* metalarva of 18.04 mm TL.

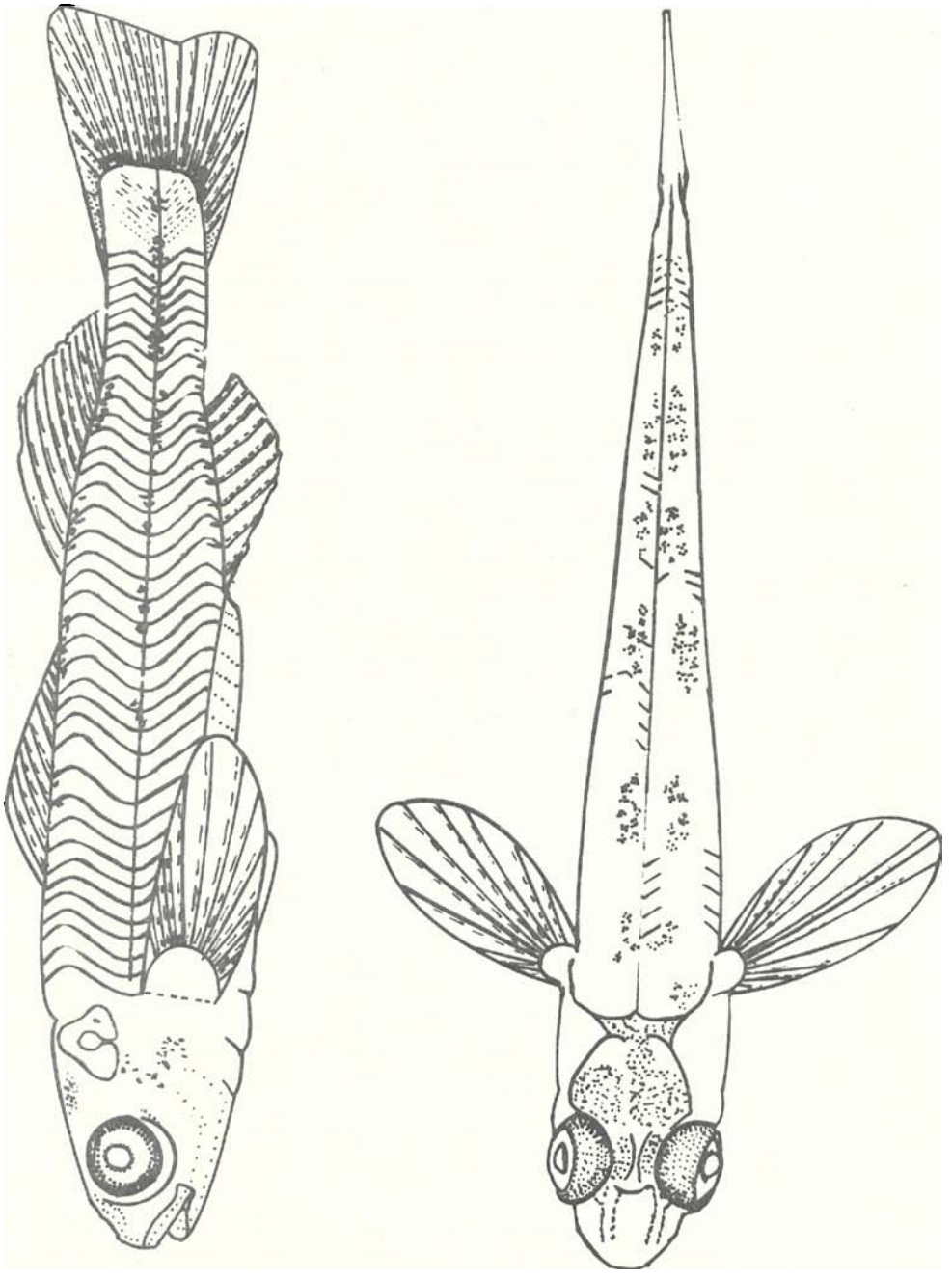

Figure 6. *Etheostoma blennioides newmanii* metalarva of 19.29 mm TL.

Juvenile

One juvenile specimen (Figure 7) was collected (25.89 mm length). It closely resembled the adult form in pigmentation patterns and mouth position. Lateral pigment consisted of six U-shaped blotches, a large blotch on the caudal peduncle, and a blotch above each pectoral fin. Six saddles were present dorsally. The mouth was inferior and the snout smoothly rounded. Squamation was complete and the adult complement of rays and spines was present in all fins (Table 4).

DISCUSSION

At least five species of darters are sympatric with the greenside darter in Hinds Creek. They are the Tennessee snubnose darter, *E. simoterum;* redline darter, *E. rufilineatum;* blueside darter, *E. jessiae;* stripetail darter, *E. kennicotti;* and logperch, *Percina caprodes*. The fantail darter, *E. flabellare*, and the dusky darter, *P. sciera*, may occur in Hinds Creek but were not captured during this study.

The redline darter is the only sympatric species in Hinds Creek with larvae that closely resemble those of the greenside darter. They differed in characteristics of the vitelline vein system, total myomere counts, and length for the various phases of development. Protolarval redline darters had a single serpentine vitelline vein. Total myomere counts ranged from 38 to 44 for protolarvae and 37 to 39 for metalarvae. Total length ranges for the three phases of larval development were; protolarval 6.2 to 8.5 mm TL, mesolarval 8.55 to 9.6 mm TL, and metalarval 9.9 to 13.36 mm TL (Baker and Whitaker 1979 MS).

Live eggs of *E. b. newmanii* observed during incubation in the

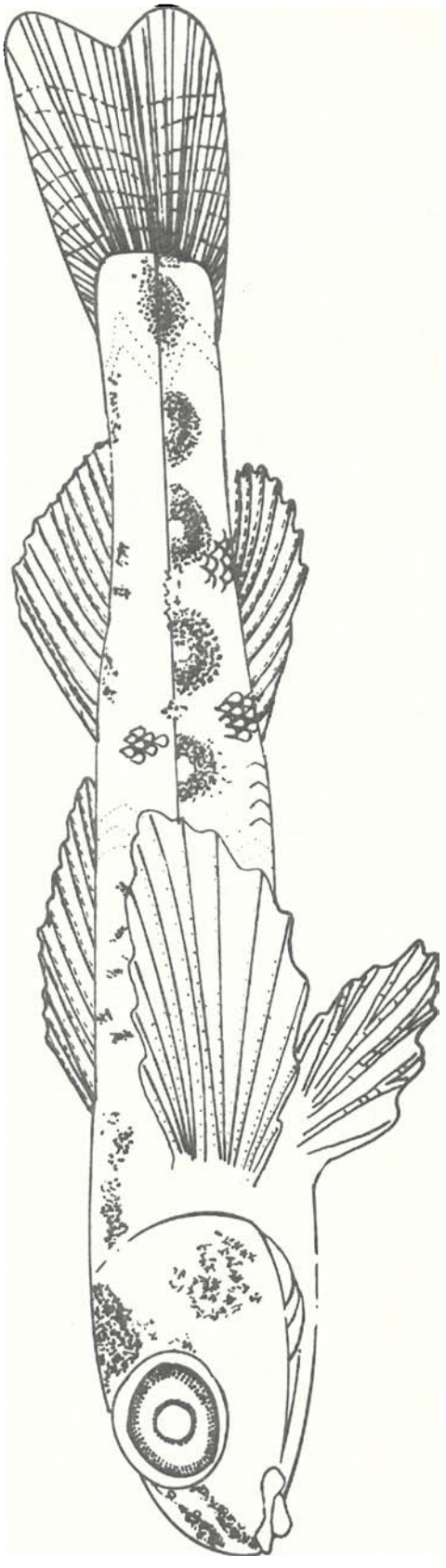

Figure 7. *Etheostoma blennioides newmani* juvenile of 25.89 mm TL.

Table 4. Morphometric and meristic characters of juvenile and adult greenside darters, *Etheostoma blennioides newmanii* (Agassiz).

		Myomeres			Rays and/or Spines					
	Length (mm TL)	Total	Preanal	Postanal	First Dorsal	Second Dorsal	Anal	Caudal	Pectoral	Pelvic
Juvenile	25.89	41	21	20	XIV	14	II, 8	17	14-14	6-6
Adult	89.50	42	20	22	XV	13	II, 8	17	14-14	7-7
Adult	81.00	42	21	21	XIV	14	II, 8	17	14-14	6-6
Adult	81.00	42	20	22	XIII	13	II, 8	17	14-14	6-6
Adult	70.00	42	21	21	XIII	13	II, 7	17	15-15	6-6

laboratory closely resembled Fahy's description for *E. b. blennioides* eggs. They were spherical, transparent, demersal, adhesive, and had a large yellow oil globule. The diameter of one dead and slightly deteriorated egg was approximately 2 mm. Fahy reported a range in egg diameter of 1.75 to 1.98 for *E. b. blennioides*. *E. b. blennioides* eggs incubated at 13 to 14.5 C hatched in 18 days, which is similar to the observed hatching time of *E. b. newmanii* (17 days at 13 to 15 C).

Fahy's illustration of a 7.5 mm northern greenside darter larva (24 hours old) is similar to larvae of comparable size described in this study with one exception. He observed rays in the pectoral fins at this length whereas the onset of pectoral fin ray development occurred between 13 and 14 mm length for our specimens. His 8 mm specimen (16 days old) differed considerably from 8 mm larvae examined in this study. At this length, Fahy reported total yolk absorption, well developed pectoral fin rays, the presence of fin rays in the caudal fin, and ray elements at the base of the second dorsal, anal, and pelvic fins. These findings disagreed markedly from those of this study. For specimens examined in this study, yolk absorption was not completed at less than 10 mm length. The onset of ray development occurred at considerably greater lengths; caudal fin at 10 to 11 mm TL, second dorsal and anal fins at 11 to 12 mm length, and pelvic fins at 12 to 13 mm TL. Pelvic buds did not appear on *E. b. newmanii* until after 11 mm length.

The 16 day old (8 mm) *E. b. blennioides* larvae illustrated by Fahy was shorter than the 19 day old (8.69 mm) *E. b. newmanii* larva cultured in this study. This is to be expected considering younger age and development at slightly lower water temperatures. It is at the same time more advanced in fin development and yolk absorption. This could be subspecific variation in developmental rates or abnormal development of Fahy's single cultured specimen. Cultured specimens of *E. b. newmanii* were very similar in

development to specimens of comparable length collected from Hinds Creek.

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MATERIALS FOR A DESCRIPTION OF LAKE CHUBSUCKER, (*ERIMYZON SUCETTA*), LARVAE

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ABSTRACT

Twelve lake chubsucker larvae were compared with descriptions of creek chubsuckers at equal developmental phases. Preanal myomere distributions for the two species showed no overlap. Modal values were 27 and 31 for lake and creek chubsuckers, respectively. Eye diameter, expressed as percent of total length, for metalarvae was the only significant (0.05 probability level) morphometric value. Pigmentary differences were essentially non-existent. Morphological changes, such as cleithrum ossification and formation of dorsal fin lepidotrichia, occurred at smaller total lengths in lake chubsuckers. Characters used in a previously prepared key to separate creek chubsucker larvae from those of other genera were also useful for separation of lake chubsuckers from these groups.

INTRODUCTION

Three species of *Erimyzon* are known. All are sympatric in parts of their distributions. Larvae of these species have not been compared and only those of the creek chubsucker, *E. oblongus*, have been described. (Carnes 1958, Fuiman 1978). Embryogeny and early posthatching stages (to 3 weeks) of the lake chubsucker, *E. sucetta*, have been documented (Shaklee *et al.* 1974).

Fuiman (1978) presented a key to catostomid larvae of the northern Atlantic slope of North America. He suggested that this key may be useful for generic identification of species occurring outside that

study area because the five species included in the key were in five genera. A small collection of *E. sucetta* are compared with published descriptions of *E. oblongus* in this paper. Differences are noted where present so as to suggest parameters for future, more detailed comparisons of these species. These larvae are also used to partially test the efficacy of Fuiman's key at the generic level.

METHODS

Twelve larval lake chubsuckers were dipnetted from Singletary Lake, Bladen County, North Carolina on 28 April 1976. Seven of these were preserved in five percent buffered formalin at the collection site. The remainder were reared in a laboratory according to details given by Fuiman and Loos (1978). Additional specimens were preserved on 24 May, 30 June, and 25 September. Larvae were known to be *Erimyzon* because of the long preanal distance (relative to that of cyprinids) and median pigment-free space on the occiput (Fuiman 1978). Specific identification of larvae was verified with scale counts of the largest specimen (35.7 mm TL) and by the fact that *E sucetta* is the only species of the genus known from Singletary Lake.

Morphometric measurements made on each specimen included: total length (TL), standard length (SL), preanal length (PAL), head length (HL), eye diameter (ED), body depth at the anus (BD), and ratio of lengths of posterior to anterior gas bladder chambers. These are defined and illustrated in Fuiman (1978). Measurements were made with a dissecting microscope equipped with an ocular micrometer (largest specimens with dial calipers) in November 1978. Preanal and postanal myomeres and median fin rays were counted using polarizing filters. Myomeres of two juveniles

were not easily enumerated and were omitted from the results. Significant differences (0.05 probability level) in body proportions between the species were tested using Student's "t" values derived from arcsin transformed ratios. Specimens were deposited in the Cornell University Ichthyological Collection (CU 55809). Terminology of larval phases follows Snyder (1976). Lengths are given as total length, unless otherwise noted.

RESULTS

A detailed description of lake chubsucker development was not justified because of the small sample size (12) and the lack of variability associated with geographic origin. Instead, preserved specimens were compared with Fuiman's (1978) description of creek chubsuckers. Results of a verbatim comparison follow.

Four protolarvae ranged from 6.8 to 7.4 mm. Total myomeres varied: 36 (3 specimens), 37 (4), and 38 (3). These were distributed as: preanal, 27 (5), 28 (2), and 29 (3), and postanal, 8 (2), 9 (4), and 10 (4). Myomeres in *E. oblongus* were approximately normally distributed; total: range 38 to 42, mode 40; preanal: range 30 to 33, mode 31; postanal: range 7 to 10, mode 9. No body proportions were significantly different between these species (Table 1).

Pigmentation was identical to that described for *E. oblongus* at 7.9 mm, except that melanophores were absent on the vertical myosepta of *E. sucetta*. Lake chubsuckers apparently absorb yolk at a smaller size. No individuals were found with yolk, yet it persisted in creek chubsuckers at 7.9 mm. Each protolarva had a partially filled gas bladder which did not inflate in *E. oblongus* until 7.8 mm. In *E. sucetta* it was located somewhat forward

Table 1. Morphometric and meristic data for *Erimyzon sucetta* (CU 55809). Abbreviations are explained in the text.

PHASE	TL(mm)	PERCENT OF TL					MYOMERES		FIN RAYS		
		SL	PAL	HL	ED	BD	PREANAL	POSTANAL	CAUDAL	DORSAL	ANAL
protolarva	6.8	94.6	68.6	17.9	7.3	9.5	27	9	0	0	0
	7.0	94.1	69.5	18.1	7.5	10.5	28	10	0	0	0
	7.3	94.4	69.9	16.4	6.7	8.4	27	10	0	0	0
	7.4	94.4	69.1	18.2	7.2	8.8	29	9	0	0	0
mesolarva	8.2	94.9	67.8	18.0	7.5	8.8	28	10	6	0	0
	9.1	91.1	67.1	18.4	7.2	10.7	27	10	18	0	0
metalarva	10.8	88.0	67.7	21.2	7.5	11.0	29	8	18	4	0
	12.1	84.5	64.0	21.7	7.8	10.9	27	9	18	11	6
	13.5	82.9	62.8	22.6	7.9	12.2	27	9	18	12	7
	14.5	82.1	62.3	22.9	7.9	11.7	29	8	18	12	7
juvenile	25.0	78.9	58.5	20.9	6.8	13.3	-	-	18	12	7
	35.7	78.8	58.1	21.0	6.4	12.9	-	-	18	12	7

of the position it occupied in the congener (between myomeres 7 through 11 versus 8 through 13, respectively).

Two mesolarvae were preserved (8.2 and 9.1 mm). These individuals had pigmentation and morphology as described for *E. oblongus*. Location of the gas bladder with respect to myomeres was similar to the *E. oblongus* description. Caudal fin rays developed between 7.4 and 8.2 mm, as evidenced by the first presence of rays (6 elements) in an 8.2 specimen. A more precise estimate might be prior to 7.9 mm (the size of caudal fin ray formation in *E. oblongus*), given the generally earlier development of features in *E. sucetta*. All 18 rays were present at 9.1 mm (again, earlier than the 10.1 mm for the creek chubsucker).

Four of the 12 preserved specimens were metalarvae ranging between 10.8 and 14.5 mm. Eye diameter averaged 7.8% TL. This was significantly greater (0.03 probability, $t_{18} = 2.6$) than the 7.1 value for *E. oblongus*. Other mean body proportions were similar for the two species.

Pigmentation of *E. sucetta* was the same as *E. oblongus* except for the lack of scattered melanophores on the operculum of the former. Morphology was not different between the two species. Four dorsal fin rays were present at 10.8 mm (0 rays through 9.1 mm). All rays were present at 12.1 mm. The corresponding values for *E. oblongus* were 13.9 and 14.4 mm, respectively. Anal rays of the lake chubsucker developed between 10.8 and 12.1 mm (when 6 elements were present).

The remaining specimens were juveniles (25.0 and 35.7 mm). Both were fully scaled, having the adult complement of 35 to 38 scales in a lateral series. Dorsal fin pigment was more scarce in lake chubsuckers. At least three interradial membranes were without melanophores in this species. Often cited differences in pigmentation between yearling

Erimyzon species (Hubbs and Lagler, 1958; Smith-Vaniz, 1968) were not evident at these sizes.

Keying of lake chubsuckers to genus was successful for all developmental phases. All protolarval and mesolarval characters used in Fuiman's (1978) key adequately described the appropriate larvae. Metalarval key characters included the presence of a medium pigment-free space on the dorsum, a prominent mid-lateral stripe, and small head and snout lengths. Two of the four metalarvae had relative head length measurements closer to those of *Carpiodes cyprinus* (the alternative species in the ultimate couplet) than *E. oblongus*. This character notwithstanding, identification as an *Erimyzon* species was inevitable because of the pigmentary characters used.

DISCUSSION

The most significant character for separating larvae of the two species of *Erimyzon* was preanal myomere number. There was no overlap of values in these species and it was based on the largest sample size (10) for quantitative data in this study. Vertebral number in adults can be used to verify this character but such data are available only for the lake chubsucker.

A recurring observation during the ontogeny of the lake chubsucker was the smaller size at a given developmental stage, as compared to its congener. This may be a result of smaller hatching sizes and equal developmental rates. *E. sucetta* eggs are two millimeters in diameter and larvae hatch at five to six millimeters, according to Cooper (1935) (hatching size was apparently incorrectly transcribed from Cooper by Scott and Crossman 1973). More precise measurement is necessary to detect differences from these values and the 1.9 mm eggs and 6.0 mm

newly hatched larvae (Fuiman 1978) of *E. oblongus*. An alternative explanation involves faster ontogenetic rates as compared to linear growth in the lake chubsucker.

Pigmentation patterns were essentially identical in the two species. The few exceptions noted may be an artifact of the small sample size. Metalarval eye diameter (as % TL) was the only significant morphometric parameter. This character may prove to be less valuable after more measurements are made (especially in the light of a lack of difference in eye diameters in the adult forms).

Fuiman's key to catostomid larvae successfully segregated *Erimyzon* from others. This is not unexpected because the ultimate couplet distinguishes *Erimyzon* from *Carpiodes*. The latter is in a different subfamily (Ictiobinae versus Catostominae).

Random variation, and variability associated with geographic origin, may have influenced the mean values observed in this study significantly. Therefore, one cannot accurately comment on valid characters for separating these species, given these data. *E. sucetta* is reported to be the only chubsucker in Singletary Lake. Therefore, the sample taken for this study was from a population which was allopatric with respect to local *E. oblongus* populations. Morphological character displacement may play a role in zones of sympatry of these two species. If so, differences between them will become more obvious and make the task of identification easier.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF THE YOUNG OF THE CREEK CHUB, *SEMOTILUS ATROMACULATUS*

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ABSTRACT

The development of larval and juvenile creek chub, Semotilus atromaculatus, is described. The description is based on field collected specimens from the Cipppewa River and Duscham Creek, a tributary, in west-central Wisconsin. Total myomere count, pigment patterns, and developmental phase transition lengths are the characters most useful in identifying young creek chub. The separation of young creek chub from other cyprinids is discussed.

INTRODUCTION

Cyprinidae, the most speciose family of North American freshwater fishes and often the most abundant in many habitats, has received little attention in the literature dealing with the taxonomy of the early development of freshwater fishes. Recent publications by Snyder *et al.* (1977), Fuiman and Loos (1977, 1978), and Loos *et al.* (1975) represent valuable contributions to larval cyprinid taxonomic literature.

Becker and Johnson (1970) reported that the creek chub (*Semotilus atromaculatus*) is abundant in small to medium size streams throughout Wisconsin, but is rare in large rivers and lakes. Specimens used in this study were collected primarily in Duscham Creek, which has a drainage area of approximately 28.5 km^2 (11 mi^2). Other cyprinids commonly collected with the creek chub included the golden shiner (*Notemigonus crysoleucas*), spotfin shiner (*Notropis spilopterus*), sand shiner (*N. stramineus*), fathead minnow (*Pimephales promelas*), blacknose dace (*Rhinichthys atratulus*) and longnose dace (*R. cataractae*).

This paper describes the early development of the creek chub and briefly compares it with literature accounts of similar species. The description is limited principally to those characters which the authors felt were distinctive.

METHODS

Specimens described in this paper were all obtained from field collections in Duscham Creek and the Chippewa River in west-central Wisconsin. Collecting gear included drift nets, dip nets and seines. A more detailed account of the sampling program was given in the project report (NUS 1978).

The developmental terminology used is that presented by Snyder *et al.* (1977) and is as follows:

> "Protolarva: The larval phase in which distinct median fin elements (dorsal, anal, or caudal spines or rays) are not yet apparent.

> Mesolarva: The larval phase in which at least one, but not the full complement of distinct principal rays in the median fins is apparent; or if the full complement is present and the adult possesses pelvic fins, the pelvic buds or fins are not yet apparent.
>
> Metalarva: The larval phase in which the full complement of distinct principal rays in the median fins, and if the adult possesses pelvic fins, the pelvic buds or fins are apparent."

Measurements were made with a dissecting microscope and ocular micrometer following those definitions given by Mansueti and Hardy (1967). Myomere counts were made for protolarvae, mesolarvae, and some early metalarvae with the aid of polarized light. Preanal myomeres were counted as defined by Mansueti and Hardy (1967) and Siefert (1969). Descriptions take the dynamic approach recommended by Berry and Richards (1973). Protolarvae are described in detail and from that point pigmentation, finfold and fins, and squamation are described throughout their developmental sequences.

DESCRIPTION

Only two protolarvae were collected (Figure 1). The specimens were 9.3 mm and 9.6 mm in total length (8.9 and 9.1 mm notochord length). Each specimen had some yolk material remaining. The size at hatching is unknown, but is estimated to be between 6 and 7 mm based on information supplied by Reed (1971) for the closely related fallfish (*Semotilus corporalis*).

The head length averaged 20 percent of the total length (Table 1). The eye was well formed and pigmented and its diameter averaged 8 percent of the total length. The mouth was slightly subterminal with the lower

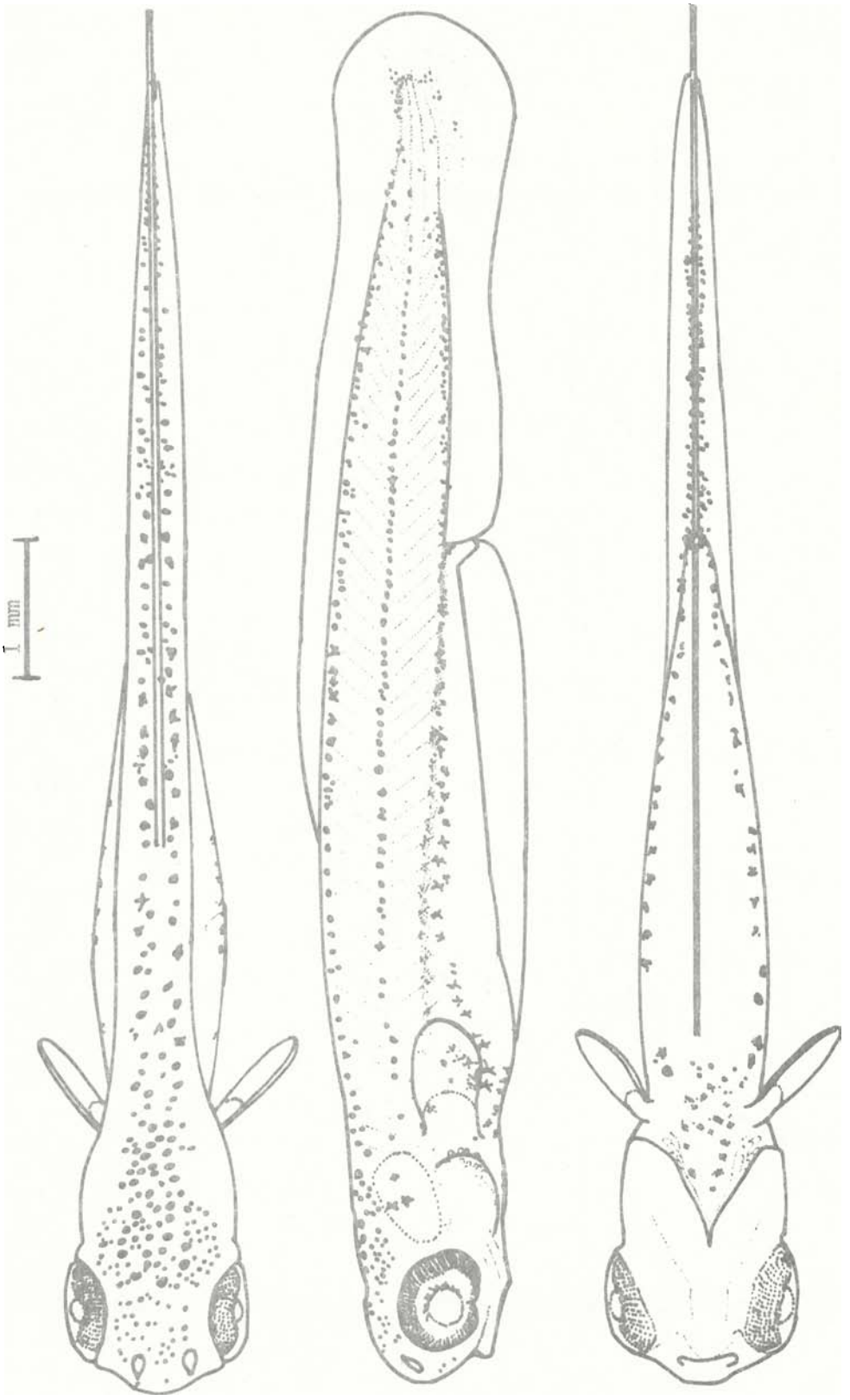


Figure 1. Protolarva, 9.6 mm TL.

Table 1 Selected morphometrics and meristics for protolarvae, mesolarvae and metalarvae of the creek chub.

PROTOLARVAE

	Morphometrics (as % of Total Length)									Meristics					
Length Interval	Total Length (mm)	Standard Length	Snout Length	Eye Diameter	Head Length	Prepelvic Length	Predorsal Length	Preanal Length	Body Depth at Anus	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Dorsal Fin rays	Anal Fin rays	Caudal Fin rays
9.0-9.9 mm															
Mean	9.4	95	2	8	20		47	64	10	28	13.5	41.5			
Range	9.3-9.6	95-96	2-3	7-8	-		-	62-65	-	-	13-14	41-42			

MESOLARVAE

	Morphometrics (as % of Total Length)									Meristics					
Length Interval	Total Length (mm)	Standard Length	Snout Length	Eye Diameter	Head Length	Prepelvic Length	Predorsal Length	Preanal Length	Body Depth at Anus	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Dorsal Fin rays	Anal Fin rays	Caudal Fin rays
9.0-9.9 mm															
Mean	9.6	93	3	8	20		46	63	10	28.5	14.5	43			13
Range	9.6-9.7	90-96	2-3	-	19-21		43-48	62-64	-	28-29	14-15	42-44			12-14
10.0-10.9 mm															
Mean	10.4	92	3	8	21		48	63	10	28	14	42	1	1	14
Range	10.0-10.9	91-94	2-4	7-8	20-23		44-50	62-64	10-11	26-29	14-15	41-43	0-6	0-4	2-19
11.0-11.9 mm															
Mean	11.6	91	3	8	22		49	63	11	28	14	42	3	2	18
Range	11.3-11.9	89-91	3-4	-	20-24		48-50	61-66	10-11	27-28	14-15	42-43	0-7	0-5	17-19
12.0-12.9 mm															
Mean	12.5	89	3	8	22		48	63	11	27	14	41	5	3	19
Range	12.1-12.9	88-90	2-4	7-8	20-29		46-49	61-64	10-12	25-28	13-15	38-43	0-7	0-6	-
13.0-13.9 mm															
Mean	13.0	89	4	8	21		47	65		27	14	42	3	2	18
Range	13.0-13.1	88-89	-	-	20-22		46-48	64-66		27-28	14-15	41-42	-	-	17-19
14.0-14.9 mm															
Mean	14.4	89	4	7	21	44	47	63	12	27	14	41	7	6	19
Range	14.0-14.9	88-90	3-4	7-8	19-22	42-45	46-48	61-64	11-13	26-28	13-15	40-43	5-8	5-7	-
15.0-15.9 mm															
Mean	15.3	88	4	7	21	44	49	63		27	14	41	7	5	19
Range	-	-	-	-	-	-	-	-		-	-	-	-	-	-

Table 1 (continued)

METALARVAE

Length Interval	Morphometrics (as % of Total Length)									Meristics					
	Total Length	Standard Length	Snout Length	Eye Diameter	Head Length	Prepelvic Length	Predorsal Length	Preanal Length	Body Depth at Anus	Preanal Myomeres	Postanal Myomeres	Total Myomeres	Dorsal Fin rays	Anal Fin rays	Caudal Fin rays
14.0 - 14.9 mm															
Mean	14.7	87	4	7	22	44	48	62	12	28	14	41	8	8	19
Range	14.3-14.8	86-88	3-4	-	20-23	43-45	47-49	61-64	12-14	26-28	13-14	40-42	-	-	-
15.0 - 15.9 mm															
Mean	15.7	88	4	7	22	45	48	62	13	27	15	42	8	8	19
Range	15.3-15.9	87-89	4-5	7-8	20-23	44-50	46-49	61-64	12-13	27-28	14-15	41-43	-	-	-
16.0 - 16.9 mm															
Mean	16.3	87	4	7	21	44	47	61	13	27	15	42	8	8	19
Range	16.0-16.7	86-88	4-5	7-8	20-24	42-45	46-49	59-62	-	26-28	14-15	41-42	8-9	-	-
17.0 - 17.9 mm															
Mean	17.4	86	5	7	21	44	47	60	14	27	15	42	8	8	19
Range	17.0-17.7	85-87	4-5	-	20-22	43-45	47-48	48-61	-	-	-	-	-	-	-
19.0 - 19.9 mm															
Mean	19.5	86	5	6	22	44	47	59	14				8	8	19
Range	19.2-19.8	85-87	4-5	6-7	19-23	43-45	47-48	58-60	14-15				-	-	-
21.0 - 21.9 mm															
Mean	21.4	86	5	7	23	44	47	58	15				8	8	19
Range	21.0-21.9	83-87	4-5	6-7	22-24	41-45	45-49	55-59	13-16				-	-	-
22.0 - 22.9 mm															
Mean	22.4	85	4	6	22	44	47	56	15				8	8	19
Range	22.1-22.9	84-86	4-5	6-7	21-23	43-44	46-48	56-58	14-15				-	-	-

(-) indicates single measurement or count.

jaw already developed. Other mouth parts were not discernable. The snout length was 2 percent of the total length. The opercle partially covered the gill chamber where several gill arches were barely visible. Otoliths were not evident.

The body depth at the pectoral fins was about 12 percent of the total length while the depth at the anus averaged 10 percent. A single chamber swim bladder was present in the smallest specimen. The median finfold arose dorsally at the fifteenth to seventeenth myomere and was continuous to the anus. The predorsal length averaged 48 percent of the total length. The finfold continued on the ventral surface from the anus to a point below the anterior end of the swim bladder. Pectoral fins were large, approximately 11 percent of the total length, but no rays were apparent. The urostyle on the 9.3 mm specimen was slightly flexed while that on the 9.6 mm specimen was straight. Hypochordal rays were beginning to form on both specimens.

Protolarvae were well pigmented. Numerous melanophores covered the dorsal surface of the head, between the eye and onto the snout. Dorsal body pigmentation consisted of scattered melanophores in the occipital region and a distinct double line of melanophores extending to the caudal region.

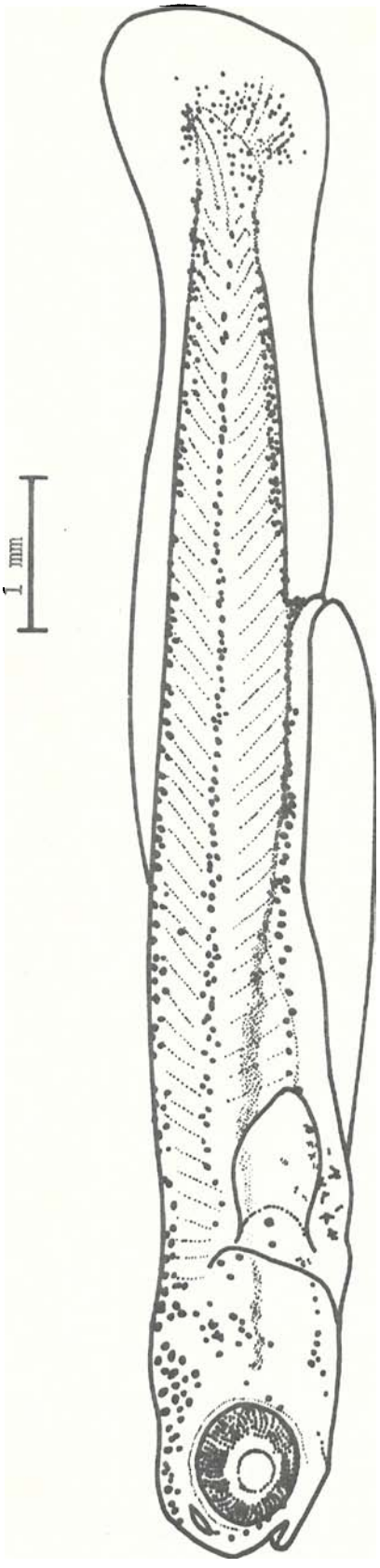
Laterally, a single row of melanophores on the midline extended from above the center of the swim bladder to near the caudal region. The caudal spot was beginning to form in the area of the flexed urostyle. A line of dark subsurface pigmentation was visible in the gill chamber. The dorsal surface of the swim bladder had a heavy concentration of melanophores which joined with a subsurface line of melanophores on the dorsal surface

of the yolk sac extending to the anus. A heavy concentration of melanophores occurred in the dorsal finfold near the tip of the urostyle and hypochordally between the developing caudal fin rays.

A prominent series of melanophores on the midline of the chin was present on the smallest protolarva as was a "V" or triangle shaped pattern of melanophores located ventral to the heart. These pigment patterns were not obvious on the larger protolarva. The vertex of the "V" was directed anteriorly and a series of melanophores extended posteriorly from the "V" onto the lateral surface of the yolk-sac to connect with the line of melanophores located on the dorsal surface of the intestine. A single line of melanophores extended from the anus to the caudal region along the ventral midline.

The protolarval phase was completed between 9.0 and 10.0 mm. Protolarvae had 28 preanal myomeres and 13 or 14 postanal myomeres (Table 1).

Finfold and Fins: Hypochordal rays were present in the caudal finfold at 9.6 mm (Figure 2). The complete complement of caudal fin rays and the bilobed outline of the caudal fin were attained between 11.5 and 12 mm (Figure 3). Dorsal fin rays began to form in the dorsal finfold between 10 and 11 mm. The dorsal finfold between the developing dorsal fin and the caudal fin diminished in size throughout the mesolarval phase and was not present on most specimens larger than 13 mm (Figure 4). Anal fin rays began to form at about the same length as did the dorsal fin rays, but developed slightly slower (Table 1). The complete complement of dorsal and anal fin rays was attained primarily between 14 and 15 mm (Table 1). The smallest specimen to develop pelvic fin buds was 13.2 mm;



√Figure 2. Recently transformed mesolarva, 9.7 mm TL.

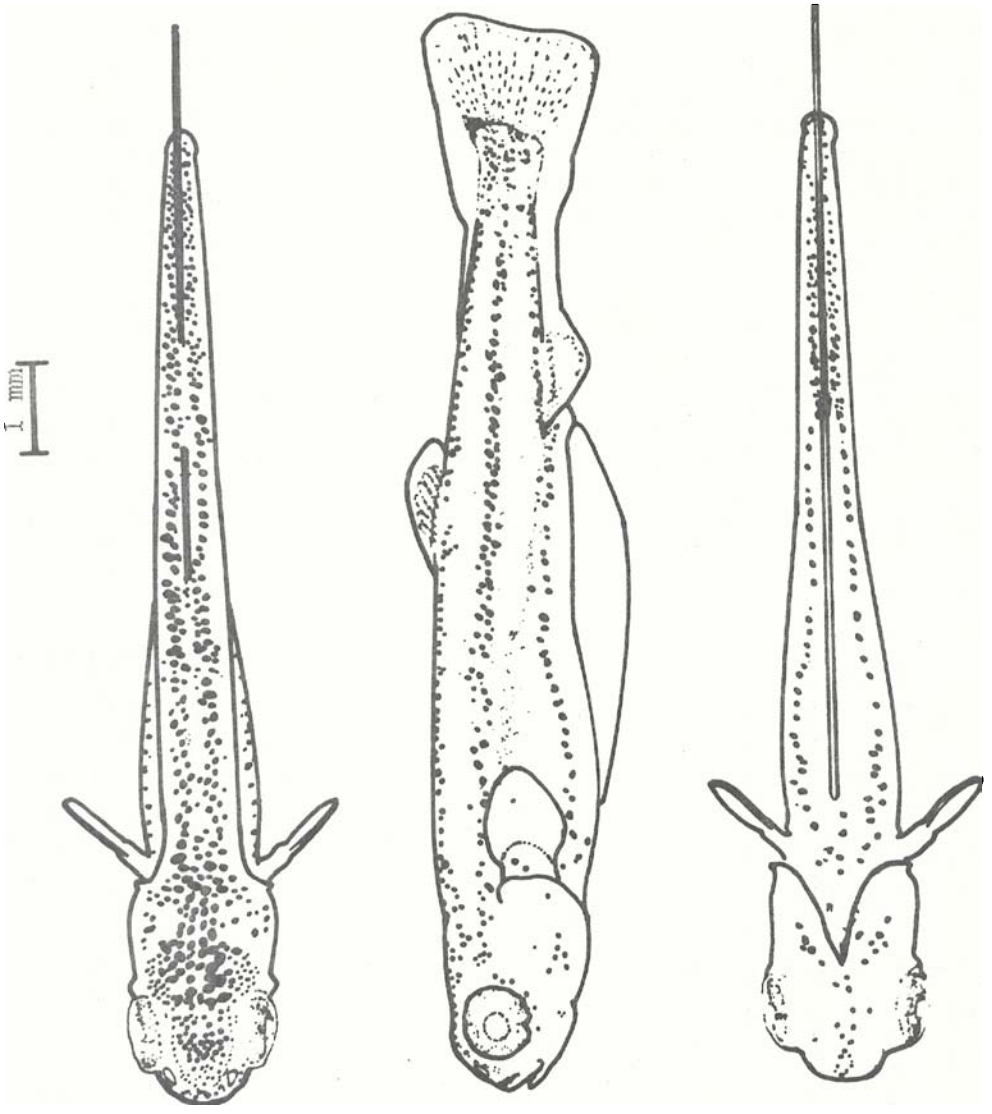


Figure 3. Mesolarva, 12.6 mm TL.

however, most specimens developed pelvic fin buds between 14 and 15 mm. The transition from the mesolarval to the metalarval phase occurred between 13.2 and 15.3 mm (Figure 4). The ventral portion of the finfold persisted to the end of the larval period which occurred at about 23 mm (Figure 6).

Pigmentation: The dorsal body pigment pattern on mesolarvae up to approximately 11 mm remained essentially the same as that described for protolarvae. On larger mesolarvae, the melanophores formed two distinct bands, each about 2 to 3 melanophores wide (Figure 3). Scattered between the bands and onto the dorsolateral surface to the mid-lateral band in the largest specimens were numerous smaller melanophores, giving the impression of a uniform dark coloration to the dorsal surface of the body (Figure 5). The double band pattern becomes less distinct after about 30 mm.

The line of mid-lateral pigment expanded to form a wide band of small chromatophores on specimens between 11 and 13 mm which was located below the midline of the body (Figure 3). The band extended anteriorly across the opercle, through the eye onto the snout, premaxillary, and the tip of the mandible. Posteriorly the band extended across the caudal peduncle. The caudal spot on mesolarvae greater than 13 mm and on metalarvae was more prominent than in protolarvae and smaller mesolarvae (Figures 3 and 4). The caudal spot was primarily on the caudal peduncle. The concentration of pigment at the tip of the urostyle formed a well defined elongated spot between 10 and 11 mm which persisted to the end of the metalarval phase at approximately 23 mm (Figures 2-5). Pigmentation on the caudal and pectoral fins continued to develop during the mesolarval

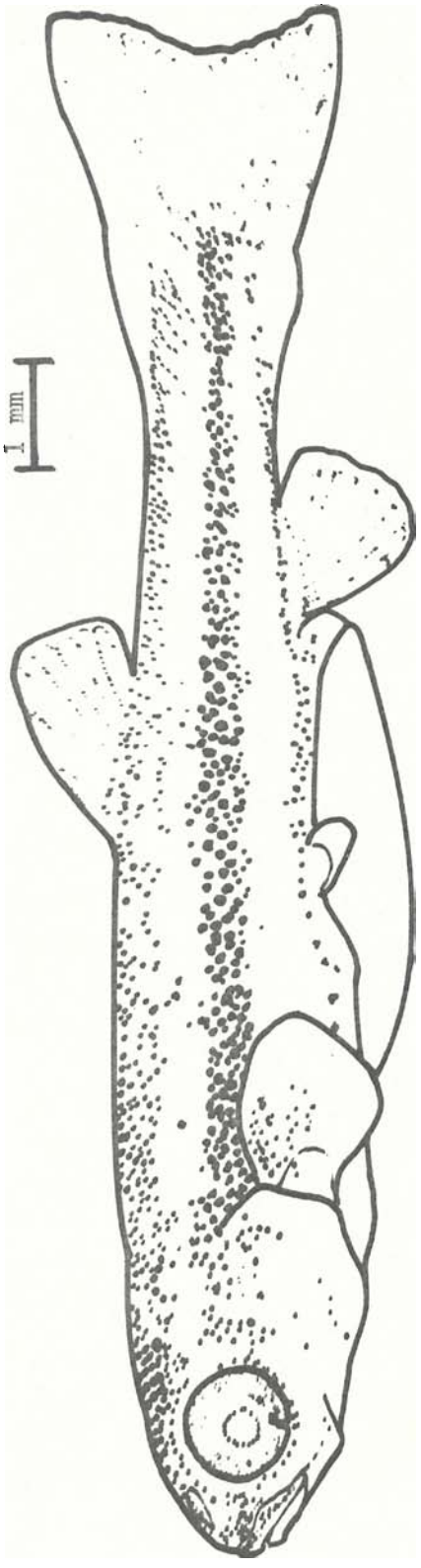


Figure 4. Recently transformed metalarva, 14.8 mm TL.

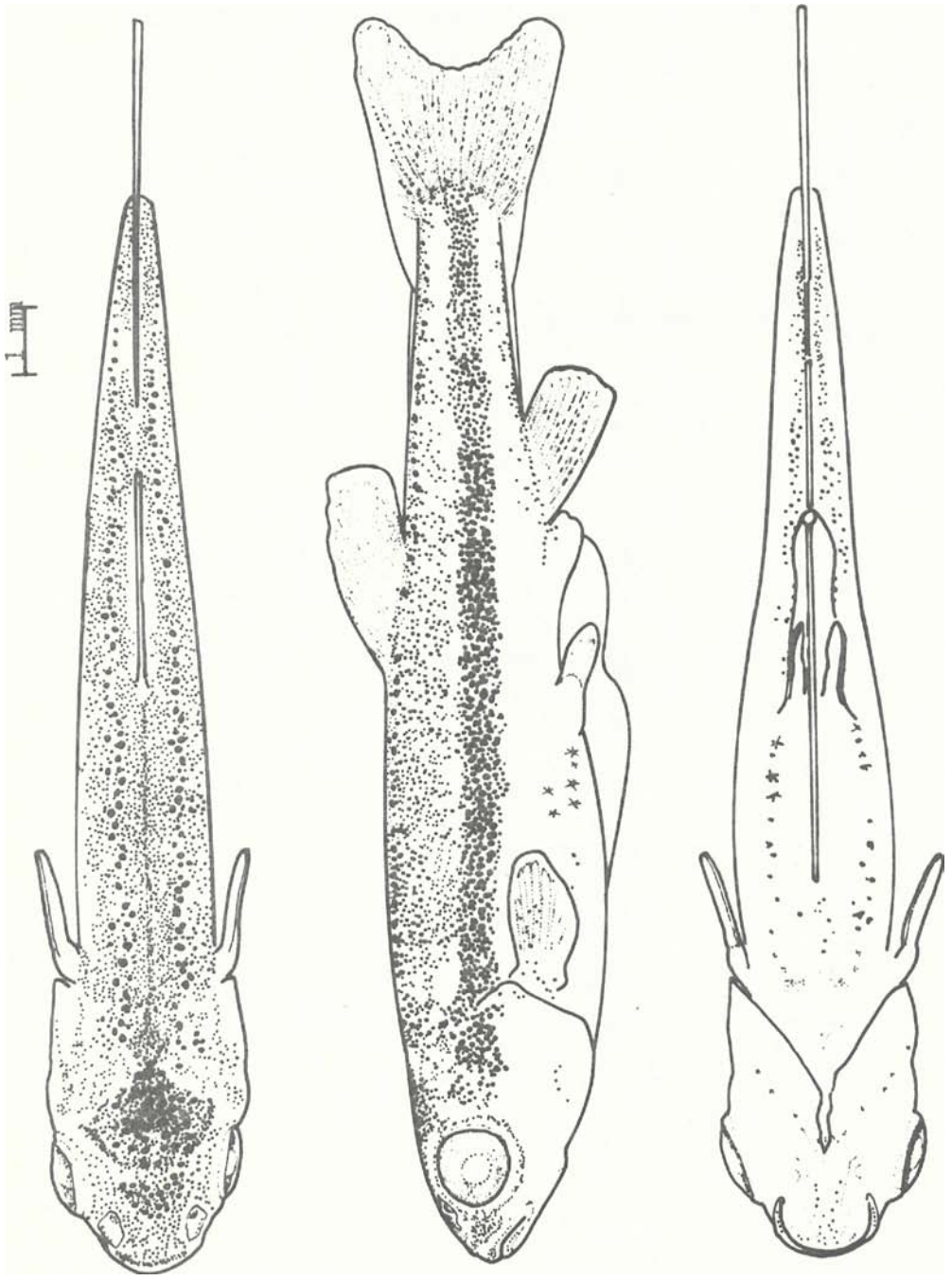


Figure 5. Metalarva, 19.2 mm TL.

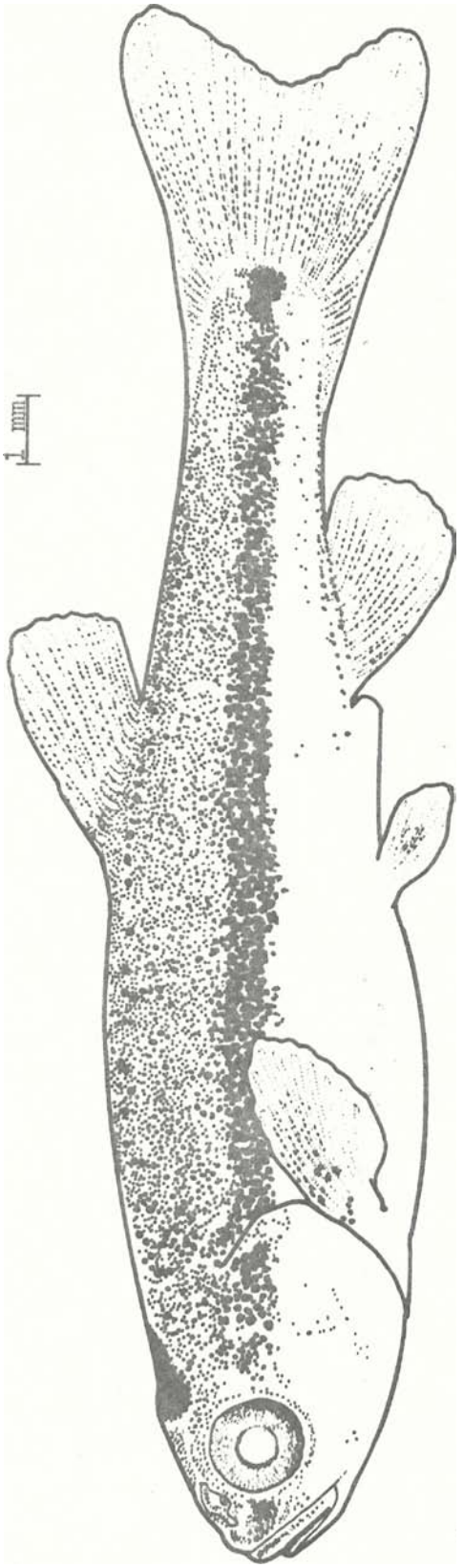


Figure 6. Recently transformed juvenile, 23.0 mm TL.

and metalarval phases. There was no pigmentation in the median finfold, in the future positions of the dorsal and anal fins prior to 12 mm when the first fin rays began forming. As fin ray formation progressed, pigmentation became more intense, particularly in the dorsal fin. Most melanophores in all fins were either on or closely associated with the fin rays and by about 17 mm, each fin ray was bordered with pigment (Figure 5).

Chin pigmentation, which was variable in protolarvae, was more prominent in the mesolarvae, metalarvae, and juveniles (Figures 3 and 5). The "V" pattern of melanophores ventral to the heart was present throughout the mesolarval phase, but disappeared during the transition to the metalarval phase between 13 and 15 mm. The prominent extensions of the "V" pigment pattern began to fade in early metalarvae (greater than 14 mm) and had completely disappeared at the end of this phase. Early in the mesolarval phase, a series of melanophores developed on the ventral, posterior edge of the opercle. This series was prominent throughout the mesolarval phase, but began to fade during the transition to the metalarval phase. It was completely absent by approximately 21 mm. The prominent mid-ventral line of caudal pigment was present on all specimens examined.

Squamation: Scales were first visible on the caudal peduncle of a 23 mm specimen. Scale coverage spread anteriorly and by 26 to 27 mm approximately 40 percent of the body surface was covered. Squamation was essentially complete by about 33 mm when scales were present over the entire body surface except the belly. The pattern of scale formation was essentially similar to that illustrated for the fallfish by Reed (1971).

DISCUSSION

The creek chub is readily separable from the golden shiner, spotfin shiner, and fathead minnow on the basis of its greater length at a given stage of development. Separation of creek chub from its congenor, the fallfish (*Semotilus corporalis*), during the larval period is not possible based on the information presented by Reed (1971). This was not a problem in this study because the fallfish does not occur in Wisconsin (Becker and Johnson 1970). Specimens larger than 18 mm may be distinguished on the basis of the size at transformation to the juvenile period and the onset of squamation both of which occur at 18 mm for the fallfish; whereas these events occurred at about 23 mm for the creek chub. At lengths greater than 23 mm, the position of the pelvic fin relative to the dorsal fin should be a useful distinguishing character. According to Hubbs and Lagler (1974), and Scott and Crossman (1973), the insertion of the dorsal fin is posterior to the base of the pelvics in the creek chub, but is directly over the pelvic fin base in the fallfish. The relative position of these fins in the creek chub became stable at about 16 mm, just after the appearance of the pelvic fin buds. Based on the illustrations presented by Reed (1971), it appeared that the dorsal and pelvic fins were still converging slowly between 18 mm and 32 mm. Juveniles larger than about 33 mm can be separated using the characters presented in Hubbs and Lagler (1974).

Protolarval creek chub have a higher preanal myomere count than the cutlips minnow, blacknose dace, and longnose dace; however, the difference is not large enough to differentiate it from the cutlips minnow or the longnose dace. The cutlips minnow absorbs its yolk sac and makes the

transformation to the mesolarval stage at a considerably smaller size than does the creek chub (Table 2). Longnose dace can be separated from the creek chub on the basis of its larger snout (5 percent versus 2 percent of total length) and its shorter preanal length (43 percent versus 47 percent of the total length) (Fuiman and Loos 1977). In general, after the protolarval phase, developmental events in the creek chub occur at greater lengths than do those in the cutlips minnow, blacknose dace, and longnose dace.

Mesolarval creek chub can be identified by their larger size and the presence of a well defined spot of pigment at the tip of the urostyle. This spot was not reported by Fuiman and Loos (1977) for the daces or by Fuiman and Loos (1978) for the cutlips minnow. Additionally, the caudal spot on the daces lies primarily at the base of the caudal rays while on the creek chub, it is at the end of the caudal peduncle. Fuiman and Loos (1977) observed that the protrusion of the snout of the longnose dace began in the mesolarval stage. In the creek chub, the snout never prominently overhangs the mouth.

Metalarval creek chub can be separated from the daces and the cutlips minnow by the absence of a frenum which is present in these three species. Additional distinguishing characters of the creek chub include the presence of a faint double band of melanophores on a background of small melanophores on the dorsal surface of the body, the absence of a concentration of melanophores along the base of the central rays of the dorsal fin (this pigment is present only in the daces), and the presence of a distinct patch of pigment on the chin.

As juveniles, these species may be identified using the cyprinid

Table 2 Preanal myomere counts and total length (mm) at the on set of selected developmental events for eight cyprinids.

Character	Semotilus atromaculatus	Semotilus corporalis[a]	Rhinichthys atratulus[b]	Rhinichthys cataractae[b]	Exoglossum maxillingua[c]	Notemigonus crysoleucas[d]	Notropis spilopterus[d]	Pimiphales promelas[d]
Protolarval phase	e	6.8 - 10.0	5.6 - 8.5	4.5 - 9.2	5.4 - 7.9	2.7 - 5.7	4.1 - 6.2	4.3 - 5.7
Preanal myomere count (Protolarvae)	28	29[c]	25 (24-26)	26 (26-27)	27 (26-27)	e	e	e
Mesolarval phase	9.0 - 10.0[f]	9.0 - 10.0	7.0 - 8.5	9.4	7.4 - 7.9	5.7	6.2	5.7
Yolk absorbed	9.6	9.0	ca 7.0	9.4	7.4	e	e	e
Caudal spot	9.3	12.0	11.0	-	9.9	-	-	e
Urostyle spot	9.6	e	-	-	-	-	-	ca 4.6
Metalarval phase	13.2 - 15.3	14.0	11.0 - 12.0	12.0	11.0 - 11.6	9.5	8.1	9.0
All fins complete	19.2 - 23.0	18.0	11.0 - 17.1	ca 17.0	14.9	e	e	e
Juvenile period	23.0	18.0	13.5 - 17.1	14.0 - 17.3	14.5 - 16.1	20.3	13.8	15.6
Squamation	> 23.0	18.0	-	-	14.9	e	e	e
Squamation complete	> 33.5	33.0	-	-	18.5	e	e	e

a. From Reed (1971)

b. From Fuiman and Loos (1977)

c. From Fuiman and Loos (1978)

d. From Snyder etal (1976)

e. Unavailable

f. Estimated

key in Hubbs and Lagler (1974) or that published by Becker and Johnson (1970).

In summary, the creek chub can be easily separated from golden shiner, spotfin shiner, and fathead minnow, species which commonly occur with it in Duscham Creek, based on the size at which most developmental events occur. As larvae, the creek chub and its congenor, the fallfish, cannot be distinguished based on available data at lengths less than 18.0 mm. The protolarvae of the cutlips minnow, blacknose dace, and longnose dace are similar to the creek chub, but can be separated using various morphological, morphometric, and meristic characters. After the beginning of the mesolarval stage, creek chub can be identified by their generally larger size at the onset of developmental events and the presence of characteristic pigment patterns.

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SPATIO-TEMPORAL DISTRIBUTION OF CLUPEID LARVAE IN BARKLEY RESERVOIR

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ABSTRACT

The spatio-temporal distribution patterns of clupeid larvae were described for a lotic area of Barkley Reservoir on the Cumberland River in 1976. Daytime clupeid catches were consistently higher than night catches. Peak clupeid densities for all larval size groups at the open water station (maximum bottom depth approximately 12 m), occurred at dusk in the upper strata (0-3 m). Day-night vertical distribution patterns were observed for even very small (2-5 mm) larvae. Evidence of a very abrupt cessation of clupeid spawning activity is presented and discussed. Turbidity, flow, temperature (i.e., thermocline), size class, diel period (overall light intensity as well as rate of change), gear type, and tow speed can all contribute to the observed distributional patterns of larval clupeids.

INTRODUCTION

Early works (Bodola 1966, Houser and Dunn 1967, Moser 1967, and Taber 1969) have reported diurnal, horizontal, and vertical distributional patterns for young gizzard shad (*Dorosoma cepedianum*) and/or threadfin shad (*D. petenense*). Edwards *et al.* (1977) recorded the highest densities of larval shad (*Dorosoma spp.*) at the surface in Lake Norman, North Carolina, for both day and night sampling. This finding is in agreement with the

earlier work of Netsch *et al.* (1971) in Beaver Reservoir, Arkansas. Improved knowledge of these patterns was needed to refine entrainment predictions and describe actual and/or predicted impact assessments more accurately.

To define these types of distributional patterns more concisely, sampling for ichthyoplankton was conducted in 1976 at the Cumberland Steam-Electric Plant, Cumberland River Mile (CRM) 103.0 on Barkley Reservoir (Figure 1). A four-segment diel sampling schedule with defined vertical and horizontal sample partitioning was used to obtain information on the spatio-temporal patterns of clupeid larvae.

STUDY AREA

Barkley Reservoir is a Cumberland River impoundment approximately 103 km (64 mi) long with a surface area of 22,440 ha (57,920 acres) at normal full pool, 108 m (354 ft) above msl. At the study area, CRM 103.8 (Figure 2), the reservoir is approximately 400 m (1,312 ft) wide and 12 m (40 ft) deep. Mean annual flow at this location is approximately 656 m^3/sec (23,163 ft^3/sec). Flushing rate is approximately 16 days, and characteristically, no thermocline forms in the area of this study because of the lotic nature of the water body.

METHODS

During 1976, a four-segment sampling schedule was adopted. A set of samples was taken biweekly during dawn, mid-day, dusk, and night periods. Day samples were taken between 12 noon and 4 p.m., and night samples were taken between 12 midnight and 4 a.m. Twilight samples (the dawn and dusk

sets) were scheduled on a sliding timetable so that sampling began approximately one hour before first light or one hour before nightfall and then extended through the changing light period. There was a minimum of two hours between successive sample sets.

The gear employed was a 0.5 m square-beam net towed off the port side of the boat at 1.0 m/sec. A flowmeter mounted in the net mouth was used to measure volume filtered (approximately 150 m^3/10-minute sample). Net design and use in the field are such that essentially full vertical sampling integration of the chosen stratum was achieved with minimum (substantially less than 1 percent) contamination from undesired strata. Further details of this gear and sampling procedure are found in Graser (1977, 1978).

Each diel set consisted of six towed net samples which spanned the full depth of the water column. Stations at approximately 20 percent, 40 percent, 60 percent, and 80 percent of the river width were selected. Stations 2, 6, and 8 (Figure 3) were sampled with full stratum tows (bottom to surface). Station 4, the main channel of the river, was sampled with three consecutive tows; surface to 3 m, 3 m to 6 m, and 6 m to the bottom (approximately 11 to 12 m).

All samples were immediately preserved in 10 percent Formalin and transported to the laboratory. Eggs and all fish were identified to the lowest possible taxon using polarized stereomicroscopy and available taxonomic keys (*e.g.*, Hogue *et al.* 1976, May and Gasaway 1975, Taber 1967). Catch data were converted to densities (number per 1,000 m^3) based on volume filtered measurements and catch per haul.

This report focuses on the diel (dawn, day, dusk, and night)

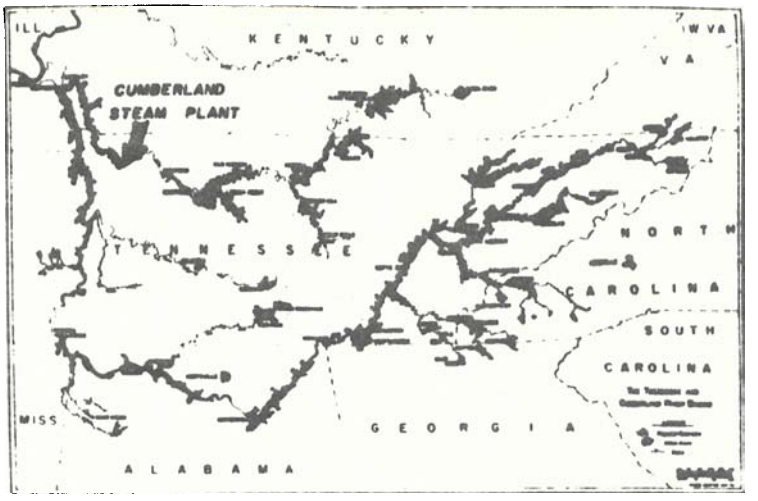

Figure 1. Location of the Cumberland Steam Plant Study Area in the Tennessee Valley.

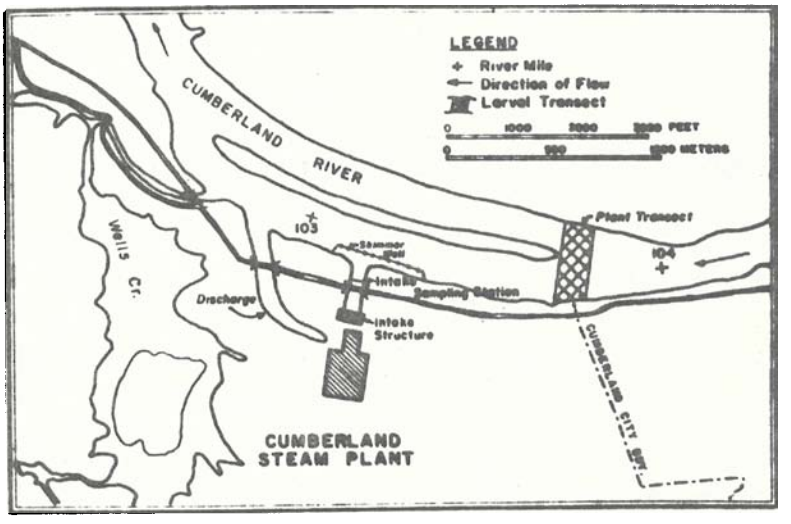

Figure 2. Location of the sampling station at Cumberland River Mile (CRM) 103.8.

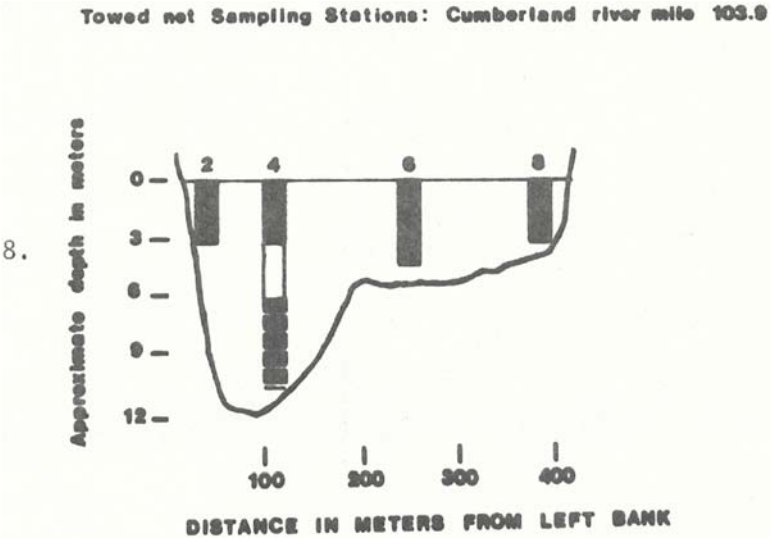

Figure 3. Stations and strata sampled at CRM 103.8.

distributional patterns observed at the combined stations with primary emphasis on day versus night catches of Clupeidae. The vertical distributional changes of clupeids observed at Station 4 will also be examined.

RESULTS

Examination of the towed net data showed that seasonal densities for total fish were highest for the day segment samples (Figure 4) reaching 5,934/1,000 m^3, while the night samples were recorded as 1,786/1,000 m^3. Shad (clupeids) contributed to the main portion of these numbers peaking at 5,828/1,000 m^3 for the day segment and 1,655/1,000 m^3 for the night segment. Non-shad were recorded at 105/1,000 m^3 during the day and 130/1,000 m^3 during the night with a peak of 162/1,000 m^3 during the dusk segment. Based on a mean of 30 cove rotenone samples taken during 1974-1976, the ratio of numbers per hectare of gizzard shad (*Dorosoma cepedianum*) to threadfin shad (*D. petenense*) to skipjack herring (*Alosa chrysochloris*) was 191:144:1 in Barkley Reservoir (Tennessee Valley Authority 1977). A comparison of day and night catch densities by sample period showed that daytime clupeid catches were consistently greater than night catches (Figure 5). The only sampling dates on which the ratio favored night catches (4-20 and 8-23) were times when extremely few individuals (fewer than 21) were captured. The greatest difference between day and night catches occurred on 15 June when the day catch was almost an order of magnitude (8.4 x) greater than the night catch. The seasonal peak of clupeids (110,360 fish) occurred during this same period (Table 1).

The catch during this single sample period (15 June) constituted 64 percent of the seasonal catch of clupeids. During this same period,

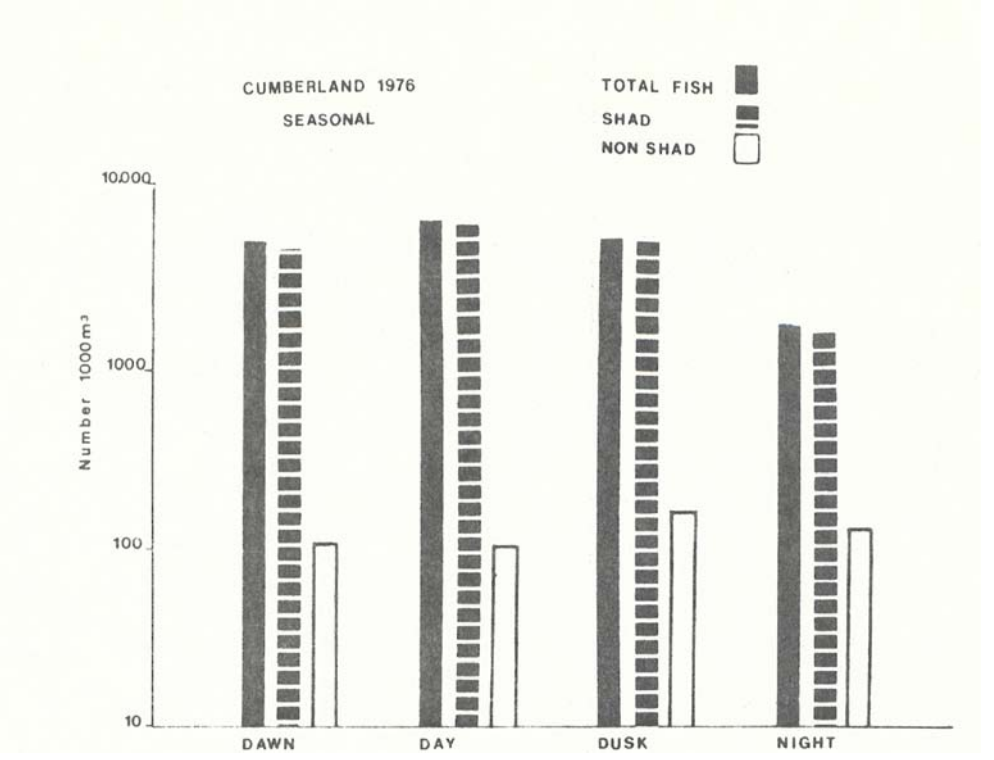

Figure 4. Seasonal densities of larval fish netted at all towed net stations.

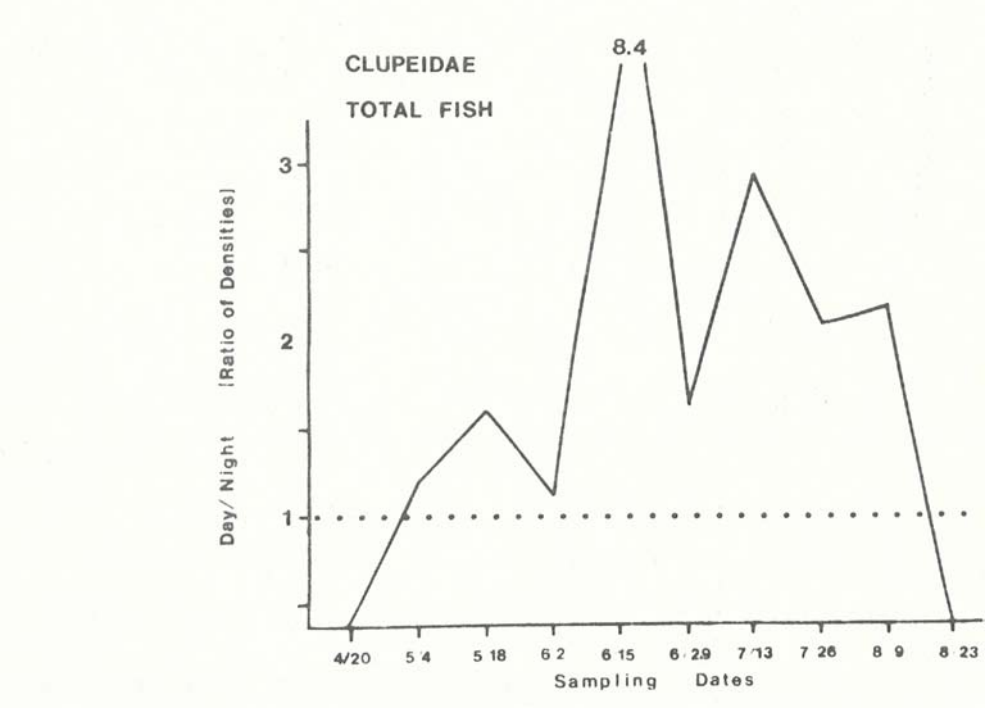

Figure 5. Day versus night (ratio of densities) for Clupeidae by sample period.

Table 1. Clupeid catch (numbers) by sample date and diel period for all towed net samples during 1976 at the Cumberland Steam-Electric Plant study area on Barkley Reservoir.

Date	Total Catch	Catch By Diel Period			
		Dawn	Day	Dusk	Night
3-23-76	1	-	1	-	-
4-7-76	1	-	-	1	-
4-20-76	169	51	14	83	21
5-4-76	10,000	4,436	1,969	2,115	1,480
5-18-76	24,311	4,229	8,913	6,006	5,163
6-2-76	21,785	5,822	5,878	4,566	5,519
6-15-76	110,360	26,515	49,228	29,473	5,144
6-29-76	4,885	1,106	1,321	1,810	648
7-13-76	1,526	317	484	562	163
7-26-76	306	76	60	142	28
8-9-76	58	19	18	14	7
8-23-76	25	5	3	3	14
9-8-76	7	-	1	-	6
9-22-76	1	-	-	-	1
TOTALS	173,435	42,576	67,890	44,775	18,194

catches of other taxa were observed to increase slightly (Figure 6) from day to night. Essentially, all the clupeid larvae caught during this time period were of two size groups, 0-5 mm and 6-10 mm. The greater portion of the decrease in catch was represented by the 2-5 mm group (approximately a 14-fold decrease from day to night).

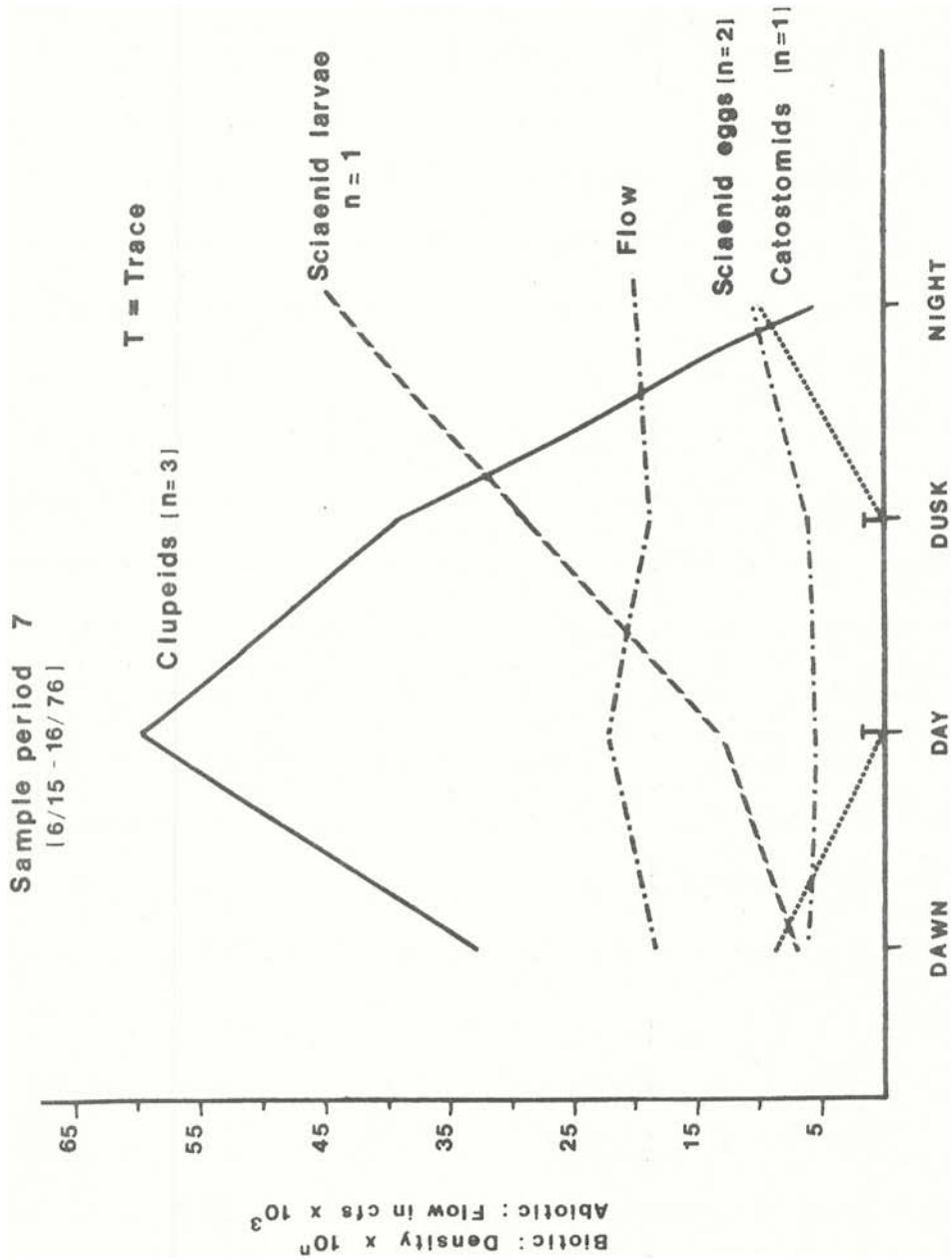

Figure 6. Densities of three taxa of larval fish and sciaenid eggs (all towed net stations), and river flow during sample period 7 by diel station.

The stratified sampling data from Station 4 were used to describe changes in vertical distribution. The sum of the day sample densities at Station 4 (surface, midwater, and bottom) was higher overall than the night sample sum (Figure 7). This trend is similar to that of the seasonal data for all stations (Figure 4). Seasonal clupeid densities in the surface and midwater strata were higher than those of the bottom strata during the day while the reverse was true at night (Figure 7). This same trend was observed for the vertical distributions for clupeid larvae of size groups 2-5 mm and 6-10 mm (Figure 8). The 11-15 mm clupeid group showed a shift toward more even distribution at night while the day segment samples still showed higher densities at the surface. The 16-20 mm and 21-30 mm clupeid groups showed a prominent peak at the surface for dusk segment samples (as did all the smaller size groups) and irregular catches in other strata and diel periods. Catch was zero for 21-30 mm larvae and was very irregular for 41-50 mm larvae. Larvae 50 mm and longer were recorded only at night in the surface and midwater strata (Figure 8). Vertical distribution examined by size group and sample period (for groups and periods of greatest abundance, Figure 9) showed that the previously noted surface and midwater shift of concentrations by day and the reverse at night was again the case.

The confusing picture of dawn and dusk distributional patterns may be clarified somewhat by a closer examination of the clock time for these respective sample sets as compared to actual sunrise or sunset. Dawn distributions which more closely resemble the night segment distributions (periods 5 and 6, 2-5 mm size group, Figure 9) were in fact sampled substantially earlier (before sunrise) than dawn sets of the period 7 sets.

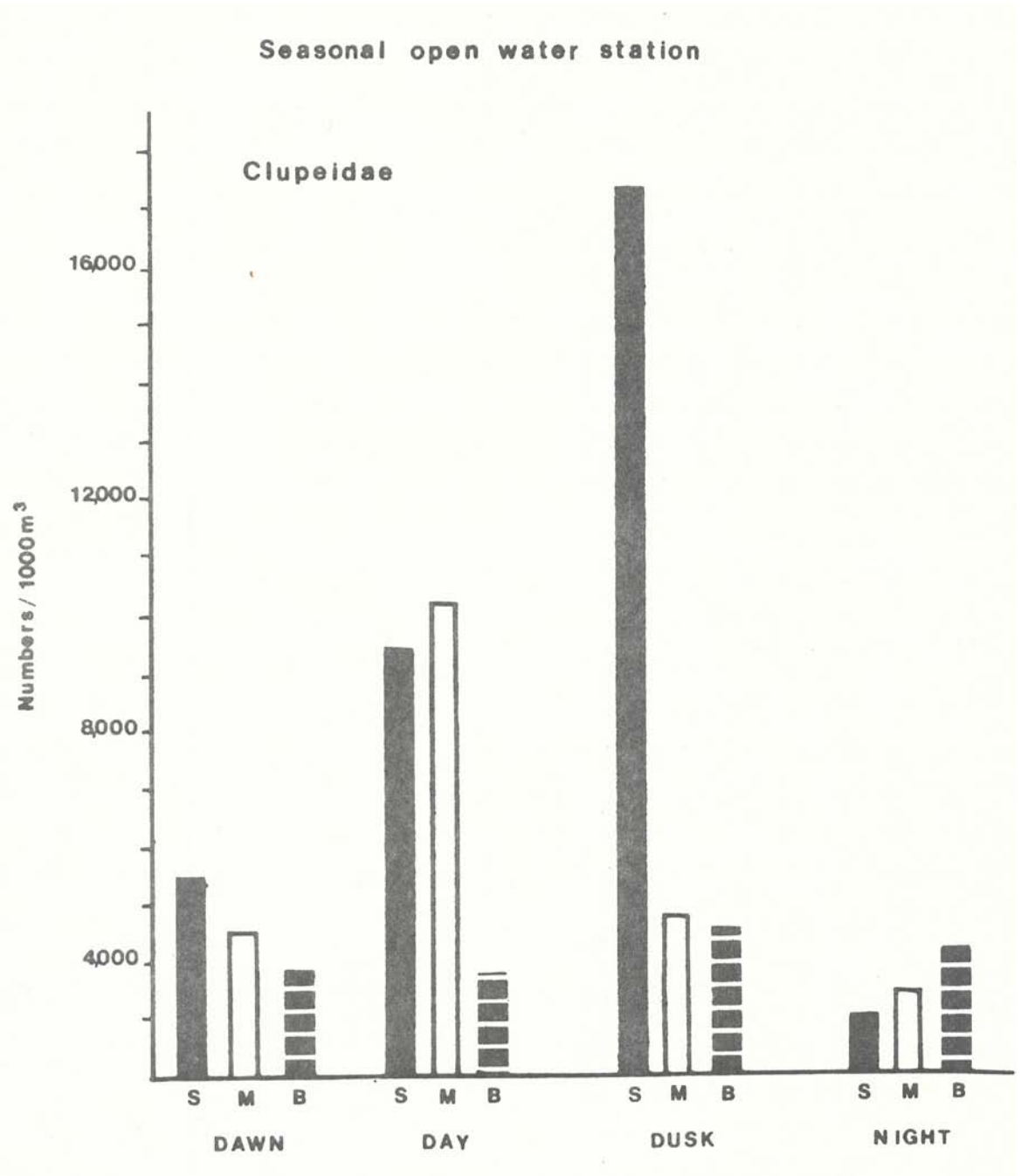

Figure 7. Seasonal distribution of all clupeid larvae sampled at Station 4 by diel period.

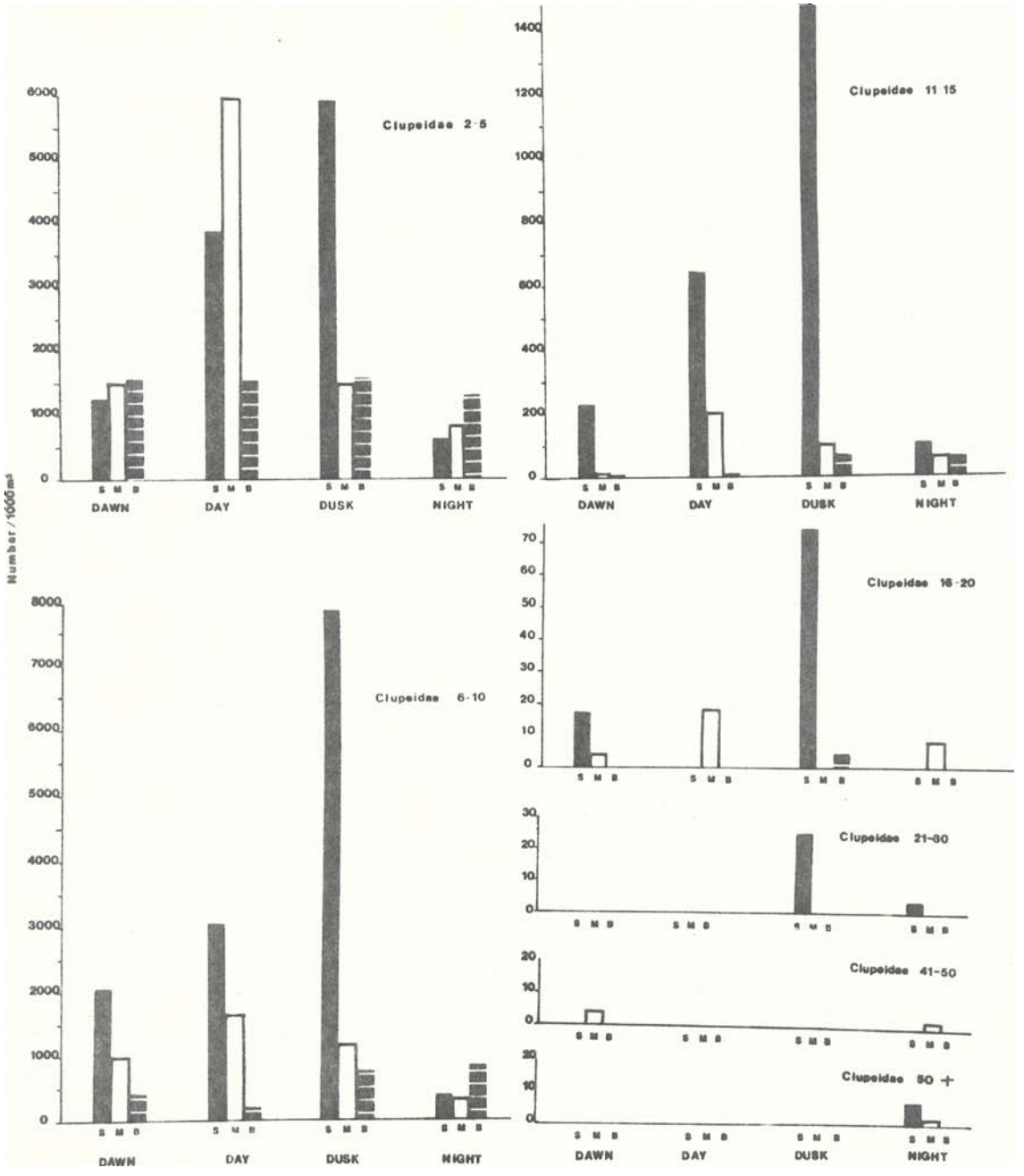

Figure 8. Seasonal distribution of clupeid larvae sampled at Station 4 by size group (mm) and diel period.

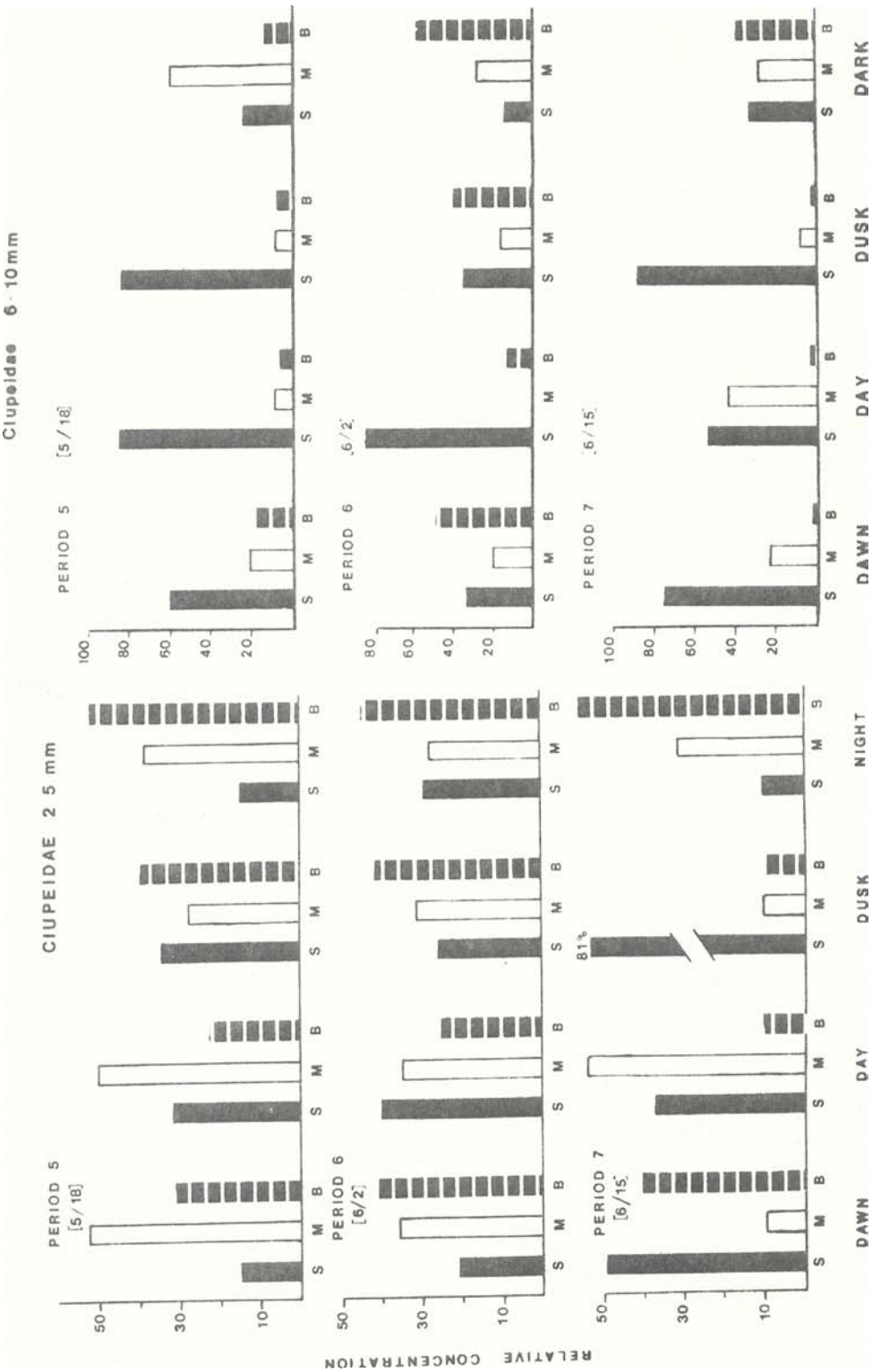

Figure 9. Distribution of two size classes of clupeid larvae at Station 4 during sample periods when clupeids were most abundant.

DISCUSSION

Larval shad were recorded first on 7 April (5 mm larvae) and were present in samples through 9 August (7 mm larvae), indicating an extended spawning season of 17-18 weeks. This is a more prolonged period than the 15-week period reported by Edwards *et al.* (1977) for Lake Norman in North Carolina and also longer than the 11-12 week period reported by Netsch *et al.* (1971) for Beaver Reservoir in Arkansas. Edwards *et al.* (1977) reported few newly hatched shad (4-6 mm) in his collections. Our collections showed high abundance of newly hatched shad (2-5 mm) as did those of Netsch *et al.* (1971) who reported concentrations as high as 90 percent for 3-6 mm shad from collections early in the spawning season.

Although mesh size of the net was a variable among these studies, it is not felt that this was the controlling factor. Edwards *et al.* (1977) and Netsch *et al.* (1971) both used 0.79 mm mesh while our study used 0.5 mm mesh. Subsequent sampling on Lake Norman (Cloutman, personal communication) with a finer mesh net (0.5 mm) has yielded the same lack of newly hatched shad (4-6 mm) as was previously reported. There seem to be basic differences among these three reservoir systems (Barkley Reservoir, Lake Norman, and Beaver Reservoir).

Netsch *et al.* (1971) and Edwards *et al.* (1977) both indicated that the shoreline areas were likely spawning areas because of higher densities of small larvae observed in these areas and low densities observed in channel areas. This is in agreement with the spawning behavior of *Dorosoma spp.* observed by Shelton (1972). The lotic nature of the Barkley Reservoir study area probably contributed somewhat to the high densities of larval

shad observed in the mid-channel area (Station 4). Horizontal (shore-to-shore) distributional patterns in Barkley Reservoir have not yet been analyzed.

In contrast to the findings of other authors (Netsch *et al.* 1971, Edwards *et al.* 1977) daytime clupeid densities in Barkley were consistently higher than nighttime densities. Several compounding factors may have been contributing to these observed differences. Netsch *et al.* (1971) noted less day-night density differences in the turbid, more lotic water of his upper two reservoir stations than from the clear lentic water of the lower stations. A similar observation was reported by Cloutman (personal communication). This may support the theory of poor visibility acting to reduce avoidance capability and thus increasing catch.

The study area on Barkley Reservoir was generally a lotic area. This is in contrast to Lake Norman (Edwards *et al.* 1977) and the Beaver Reservoir downstream stations (Netsch *et al.* 1971) which were more lentic in nature. The flowing water of our study area might have influenced distributional patterns.

As larval fish grow, their swimming mobility certainly increases and they may also change behavioral patterns as they progress through the various early life stages. Edwards *et al.* (1977) and Netsch *et al.* (1971) conducted their diel sampling over limited time periods. The data presented here span the entire season and therefore may be less affected by the prominence (*i.e.*, behavior) of a specific size class group.

Differences among the collection gear used may also have influenced the observed distributional differences. Netsch *et al.* (1971) and Edwards *et al.* both used a bridled net towed from the stern of the boat. Our study used a

bridleless net towed from the port side of the boat away from both boat and prop wash. Unbridled nets have been shown to yield significantly higher catches (Quirk *et al.* 1976, Smith 1972), most likely because (1) bridles vibrate and may cause pressure waves in the net mouth (Clutter and Anraku 1968, Fleminger and Clutter 1965), and (2) fish have been shown to be very sensitive to changes in pressure (Knight-Jones and Quasim 1955). The churning effect of the boat/prop wash (noted as a problem by Netsch *et al.* 1971b) combined with bridle effects may broadcast a considerable advance warning, thus allowing larvae to perceive and avoid the net. Such an avoidance capability would be expected to be greater during day periods when visual perception of the moving net would be easier. The tow speed used by Netsch *et al.* (1971) for the diel work was 0.8 m/s. A slow tow speed can undoubtedly increase avoidance success by larvae. A change in tow speed from 0.8 m/s to 1.2 m/s with a bridleless 1.0 m net has been shown to yield a significantly higher (approximately triple) catch (Texas Instruments, Inc., 1977). Tow speed thus appears to be a much more important variable than previously imagined.

Netsch *et al.* (1971) and Edwards *et al.* (1977) both reported an association between the depth of the thermocline (approximately 5 m in both studies) and the distribution of larval shad; greatest densities occurred at or above the thermocline. No thermocline was noted in this investigation.

The observation by Shelton (1972) that young *Dorosoma spp.* larvae exhibit a positive phototaxic response is supported by the distributional trends observed in this study (Figure 8). The day and dusk distributions illustrated a surface concentration of larval densities in contrast to

the bottom bias observed at night, thus indicating a capability for vertical migration by even very small larvae (2-5 mm). Houde and Forney (1970) observed a photopositive response for newly hatched walleye (*Stizostedion vitreum vitreum*) larvae and sustained surface-oriented photopositive swimming for early postlarvae (9.5 mm TL) walleye. The vertical density gradients (*i.e.*, vertical migrations) they observed were attributed to this swimming ability.

The striking difference between day and night catches (8.4 x observed on 15 June, Figure 6) could not be fully explained. Since other taxa from the same samples showed slight increases in density between the day and night catches, the clupeid decrease was apparently real and not an artifact of aberrent sampling technique or gear. River flow was fairly constant throughout the sampling period (Figure 6) and was not a likely causal factor. Water temperature also remained relatively constant through the sampling period (15-16 June).

The observed decrease may have resulted from an abrupt cessation of hatching, because the greater portion of this observed decrease was largely represented by newly hatched larvae (2-5 mm) which are less than one or two days old (Shelton 1972). Since these fish are at least one or two days old, this "cessation of hatching" must have occurred one to two days previous to the sample date. It may have been an artifact of an extremely intense short-term spawn or resulted from changing physico-chemical conditions of the water of 13-14 June (among them; temperature, O_2, chemistry (natural or man-induced), *etc.*) which either caused a cessation in spawning or caused eggs to cease development. The precise physico-chemical limits of the study area one to three days previous to the sample date were not definable.

Given the positive phototaxis of young shad larvae noted by Shelton (1972) and the capability for vertical migration suggested by the data from this study, it would follow that during periods of changing light (dawn and dusk), shad larvae would be actively "migrating" in response to the changing light stimulus. Thus, dawn and dusk would be transition periods between nighttime and daytime distributions. The distributional patterns during these periods (dawn and dusk) would therefore likely be very dependent upon the precise timing of samples taken with respect to the changing light conditions. For example, dawn samples taken early (during dark conditions) would be expected to reflect the night distributional pattern and conversely dawn samples taken later (during light conditions) would be expected to reflect the day distribution pattern. To an appreciable extent this was the pattern observed during sample periods 5, 6, and 7 (six of six dawn and dusk periods for 2-5 mm fish and four of six periods for 6-10 mm fish, Figure 9).

Distributional observations were further compounded by the fact that as larvae increase in size their swimming mobility greatly increases and these larger larvae might be expected to "react" more swiftly in changing from daytime to nighttime distributional patterns. Larger fish are also more capable of net avoidance. Thus, distributional patterns of fish larvae appear to be more highly size specific (*i.e.*, size dependent) than has been previously acknowledged.

There appear to be many interacting factors which must be understood before defining distributional patterns of fish larvae. Turbidity, flow, temperature (*i.e.*, thermocline), size class, diel period (overall light intensity as well as rate of change), gear type, and tow speed all seem to contribute to observed distributional patterns.

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SOME ASPECTS OF THE ECOLOGY OF LARVAL FISHES IN ROUGH RIVER LAKE, KENTUCKY

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ABSTRACT

Some aspects of the ecology of larval and juvenile fishes were investigated in Rough River Lake, Kentucky, from April through August, 1978. Larval fish were collected weekly from the upper reaches of the lake from the surface and bottom, during daylight and dark periods. Twenty-three species and 3 categories of unknown larval and juvenile fishes represented by 177,119 individuals were collected. White bass and logperch were the first to appear on April 15 with surface water temperatures of 18.5 C. Gizzard shad larvae dominated net collections while Lepomis spp. were the second most abundant. Larvae were primarily concentrated near the surface and taken mostly at night. Larval concentrations were greatest on May 30. Throughout the study, specimens were collected mainly along the shorelines. Growth rates of most taxa generally lagged early in life increasing greatly after the first 6-8 weeks. Light traps supported the surface - night distribution pattern for several species. Piscivory was observed in white bass 10.5-25 mm total length on gizzard shad, and logperch 16.5-17 mm total length on unknown larvae and suckers.

INTRODUCTION

In recent years, a greater demand has been placed on aquatic environments by energy needs, recreational interests and the necessity for regulating water levels and supplies. Because year class strength of fish is generally considered to be formed during the first year of life (Kramer and Smith 1962), these demands have placed increased stress on fish

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populations. Large numbers of larvae can be entrained at power plant intakes (Nelson and Cole 1975) and changing water levels can greatly alter the spawning success of certain species (Storck *et al.* 1978; Webb and Moss 1968). Additional knowledge of the early ecology of fishes will enable biologists to know the effects of these demands during critical periods of development and allow water level manipulations and other usage regimens that provide for more efficient fisheries management.

Developmental stages of certain larval fishes have been described by McCrimmon and Swee (1967), Cooper (1978), Wrenn and Grinstead (1971) and Meyer (1970) under laboratory conditions. Ecological studies concerning spawning chronology, distribution, occurrence and abundance of larvae are numerous but usually refer to one particular taxon (Morgan 1954, Hubbs 1921, Swedberg and Walburg 1970, Werner 1969) or make no mention of developmental stages, growth or behavioral relationships (Nelson and Cole 1975, Storck *et al.* 1978, Walker *et al.* unpublished report, and others).

This study was undertaken to investigate spawning periods, diversity, density, temporal and spatial distribution, developmental stages, piscivory, and observe growth patterns of larval and juvenile fishes in the headwaters of Rough River Lake, Kentucky.

STUDY AREA

Rough River Lake is a small impoundment in the Green River watershed in west-central Kentucky. The Lake was impounded in 1961 with the construction of an earthen-fill dam at River Kilometer 143.7. The lake impounds 62.8 km of the Rough River at seasonal pool with an average surface of 2,345 ha. and a total volume of 140 million m^3 of water. The lake has a drainage area of 1180 km^2 in Breckinridge, Grayson, and Hardin Counties.

METHODS AND MATERIALS

One permanent collecting station was established on the South Fork of the Rough River, 0.2 km upstream from the mouth of Peter Cave Creek (Figure 1). This station was approximately 200 meters in length and was divided into seven tow zones. Four tows were made at the surface, one each along the shoreline, and one each one-third the width of the lake from each bank. Two tows were made along the floodplain bottom, approximately 6 m in depth, one on each side of the river bed, while the last tow was made along the bottom of the river channel, approximately 10 m in depth.

Larvae and juveniles were sampled from March 29 through August 31, 1978 with conical plankton nets 3 m long with a 1 m circular mouth. Net mesh size was 0.8 mm. The net bridle consisted of a ring of 9.5 mm diameter stainless steel rod tied outside the net mouth with 3, 1.3 m lengths of nylon rope tied equidistantly around the net mouth and connected together in front of the net. A 7.62 cm diameter, 35.6 cm long PCV collecting bottle was attached to the cod end of the net. A digital flowmeter suspended in the center of the net mouth determined the volume of water filtered. Nets were towed at approximately 0.5 m/s for 7 minutes and filtered approximately 250 m^3 of water.

Collections were made twice weekly from March 29 through May 26, 1978. One collection was made during daylight and one during dark periods. A day and night collection was taken once weekly from May 30 through August 31, 1978. Net tows were made on the surface by attaching a styrofoam block to the bridle ring, while bottom pulls were made with the aid of a 15 kg depressor. Specimens were washed from the net bottle into sampling jars and fixed in a 5% formalin solution.

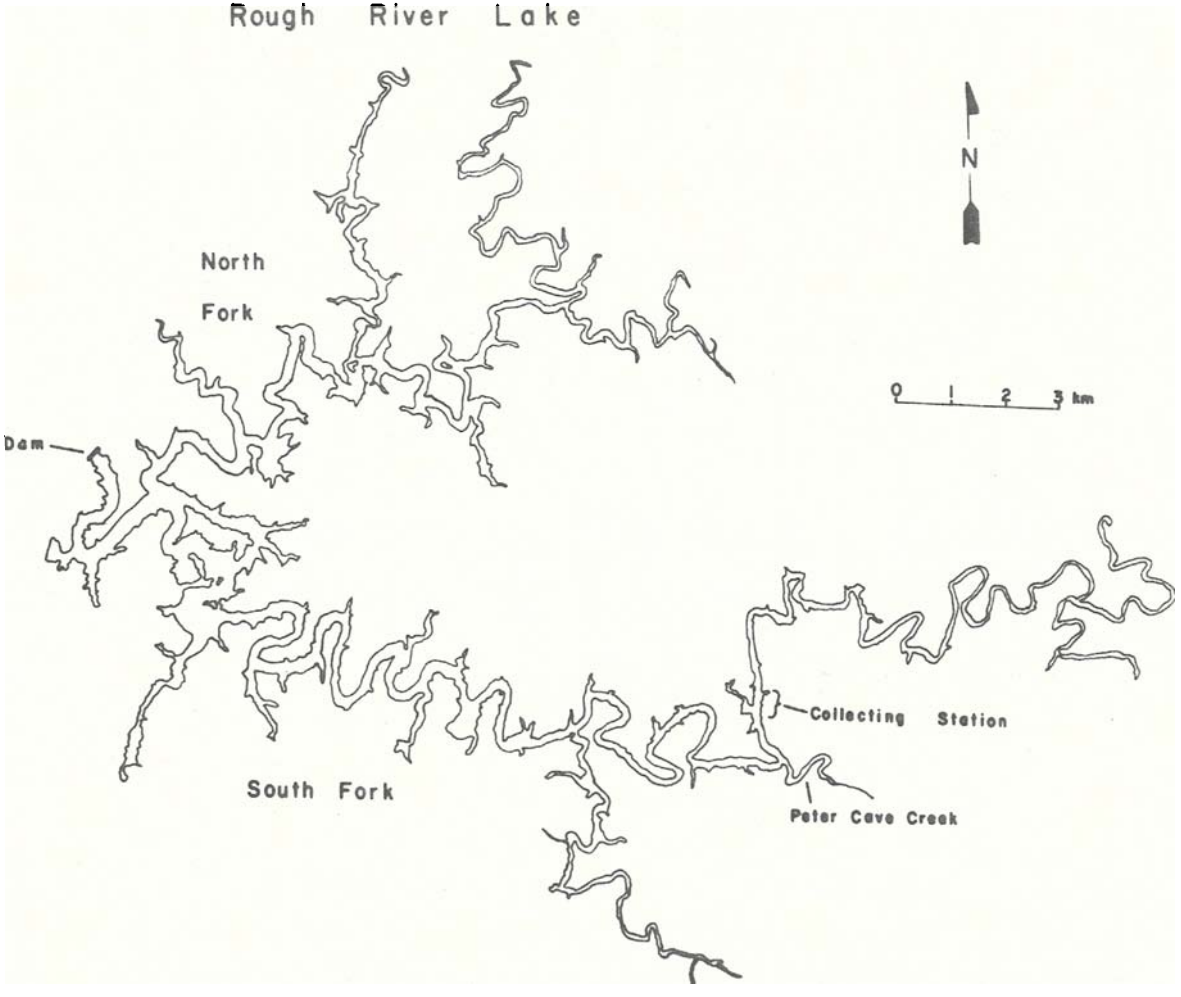

Figure 1. Map of Rough River Lake, Kentucky, showing the collecting station.

Larval traps were designed and used to determine nocturnal distribution patterns. Traps were constructed of wire screen, 0.3 m in diameter, 1 m in length with funnels in each end and having 1 mm mesh. Traps were set at the surface and about 6 m from April 12 through July 18, 1978. Two pairs of traps were set simultaneously, one pair lighted with a 12 volt, auto tail-light bulb and one pair unlighted.

Larvae were sorted using a dissecting microscope and identified with keys by May and Gasaway (1967), Nelson and Cole (1975), and Hogue *et al.* (1976). Specimens that could not be identified were sent to the Tennessee Valley Authority Larval Fish Laboratory in Norris, Tennessee. Closely related species groups such as smallmouth and black buffalo, black and white crappie, and bluegill and longear sunfish were combined into single categories because existing keys could not separate them.

Developmental stages used in the study were similar to those used by May and Gasaway (1967). Total lengths of from up to 15 individuals from each net tow were measured with a maximum of 75 measurements being used per collection. Growth statistics including standard deviation, standard error of the mean, range and median were calculated. Subsampling methods were used to count shad, white bass, crappie and sunfish species from samples collected from May 30 through June 20, 1978. Stomach contents were examined for piscivory from a subsample of all larval fish except shad.

RESULTS

Twenty-three species and three categories of unknown larval and juvenile fishes represented by 177,119 individuals were collected at the South Fork Station from April 15 through August 31, 1978 (Table 1). Four taxa represented more than 99% of the total including gizzard shad (79%),

Table 1. Larval species and number of individuals collected in day and night samples from Rough River Lake

Species	Day N	Night N	Total	% of Total
Morone chrysops	1547	4100	5647	3.2
*Percina caprodes**	64	44	108	tr
Dorosoma cepedianum	33788	106480	140268	79.2
Ictiobus spp.	5	31	36	tr
Cyprinus carpio	8	68	76	tr
Pomoxis spp.	3499	3870	7369	4.2
Unknown Darters	2	3	5	tr
*Etheostoma spp.**	0	2	2	tr
*Catostomus commersoni**	1	2	3	tr
*Minytrema melanops**	1	0	1	tr
*Moxostoma spp.**	0	1	1	tr
Unknown *Catastomids*	2	11	13	tr
Cottus carolinae	0	3	3	tr
Labidesthes sicculus	26	38	64	tr
Lepomis spp.	5292	17908	23200	13.1
Aplodinotus grunniens	73	8	81	tr
Aphredoderus sayanus	0	1	1	tr
Ictalurus punctatus	18	179	197	0.1
Micropterus salmoides	2	22	24	tr
Campostoma anomalum	1	0	1	tr
Unknown *Cyprinids*	1	1	2	tr

*Identified by personnel at the Tennessee Valley Authority Regional Larval Fish Laboratory, Norris, Tennessee.

Table 1. Continued.

Species	Day N	Night N	Total	% of Total
Pimephales notatus	0	6	6	tr
Noturus miurus	0	1	1	tr
Ictalurus natalis	1	0	1	tr
Ictalurus melas	2	5	7	tr
Ambloplites rupestris	0	2	2	tr
TOTAL	44,333	132,786	177,119	

sunfish species (13%), crappie (4%), and white bass (3%). Only nine species and/or taxa were represented by more than 60 individuals in the study. White bass and logperch appeared first while sunfish appeared last (Figure 2). Gizzard shad and crappie were present as larvae at the collecting station for the longest interval, 15 and 13 weeks, respectively.

The first larvae appeared on April 15 when water temperatures were 18.5 C and 15.5 C at the surface and bottom, respectively. Larvae continued to appear in the samples until August 31 when the surface temperature reached 28 C and the bottom temperature 24 C. Pool elevation reached normal summer pool level, 151 m msl, the week of April 30, but increased nearly 3 m during the week of May 14. Two weeks later, larval densities peaked at 3,689/100 m^3.

Larval and juveniles were most abundant at the surface throughout most of the study (Figures 3-6). Bottom densities exceeded surface densities on only four dates: April 15, June 20, June 27 and July 11. Generally, surface and bottom larval densities showed a similar pattern, but bottom

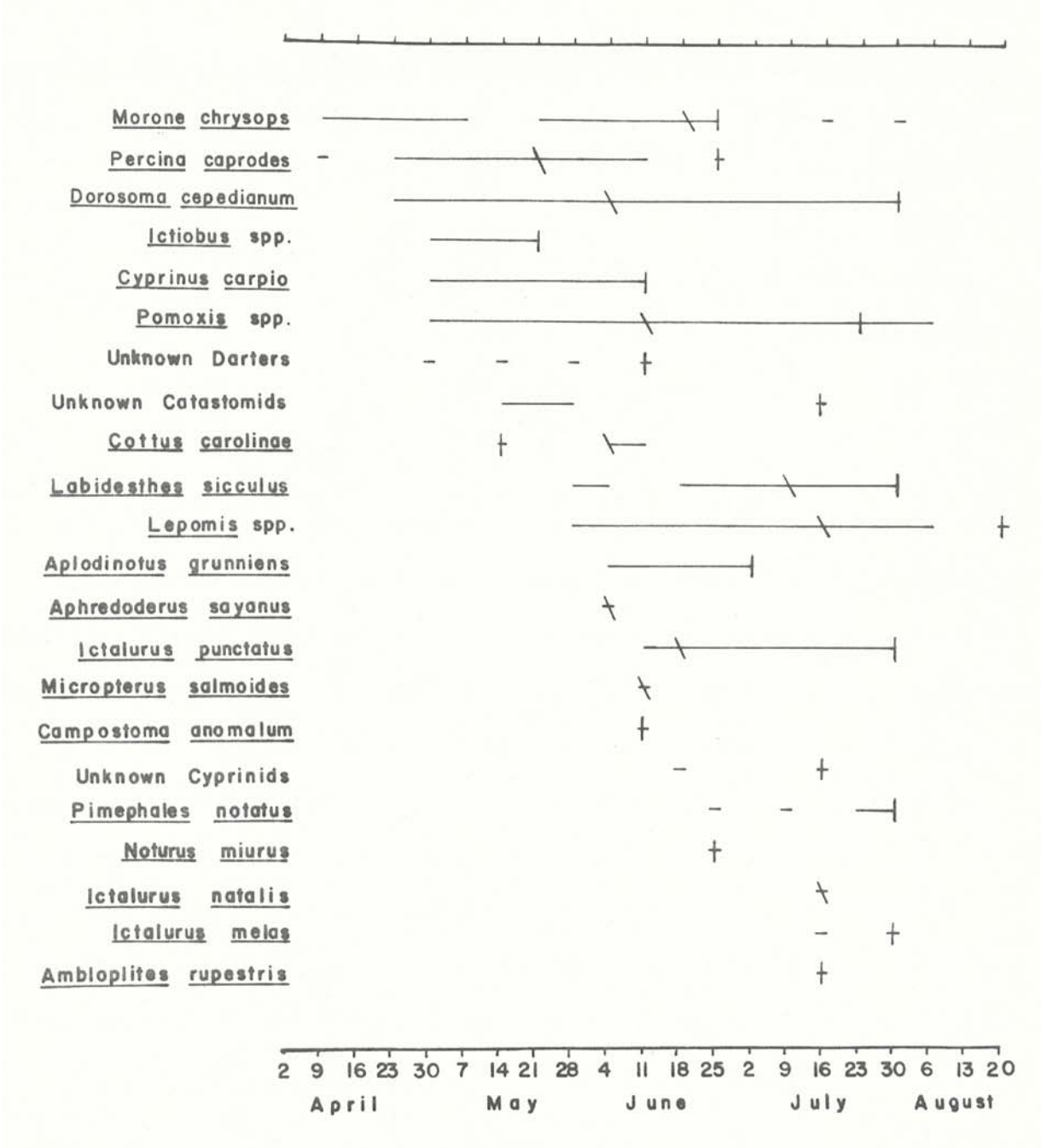

Figure 2. Time of occurrence and duration of larval species in Rough River Lake, Kentucky, April 15 through August 1978. Vertical lines represent last larvae to appear; slashed line represents first juvenile observed.

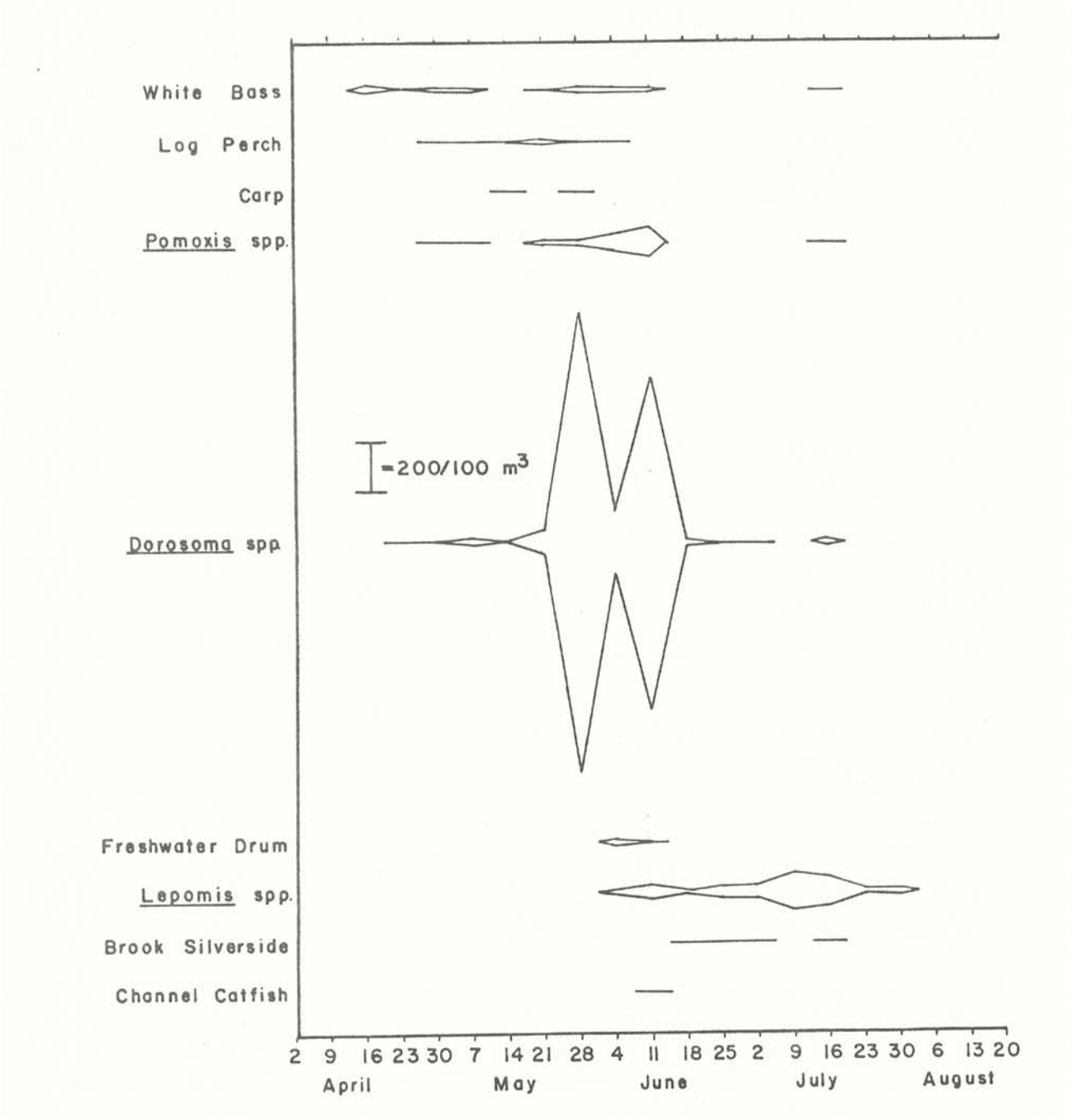

Figure 3. Densities of the major species collected at the surface during daylight hours on Rough River Lake.

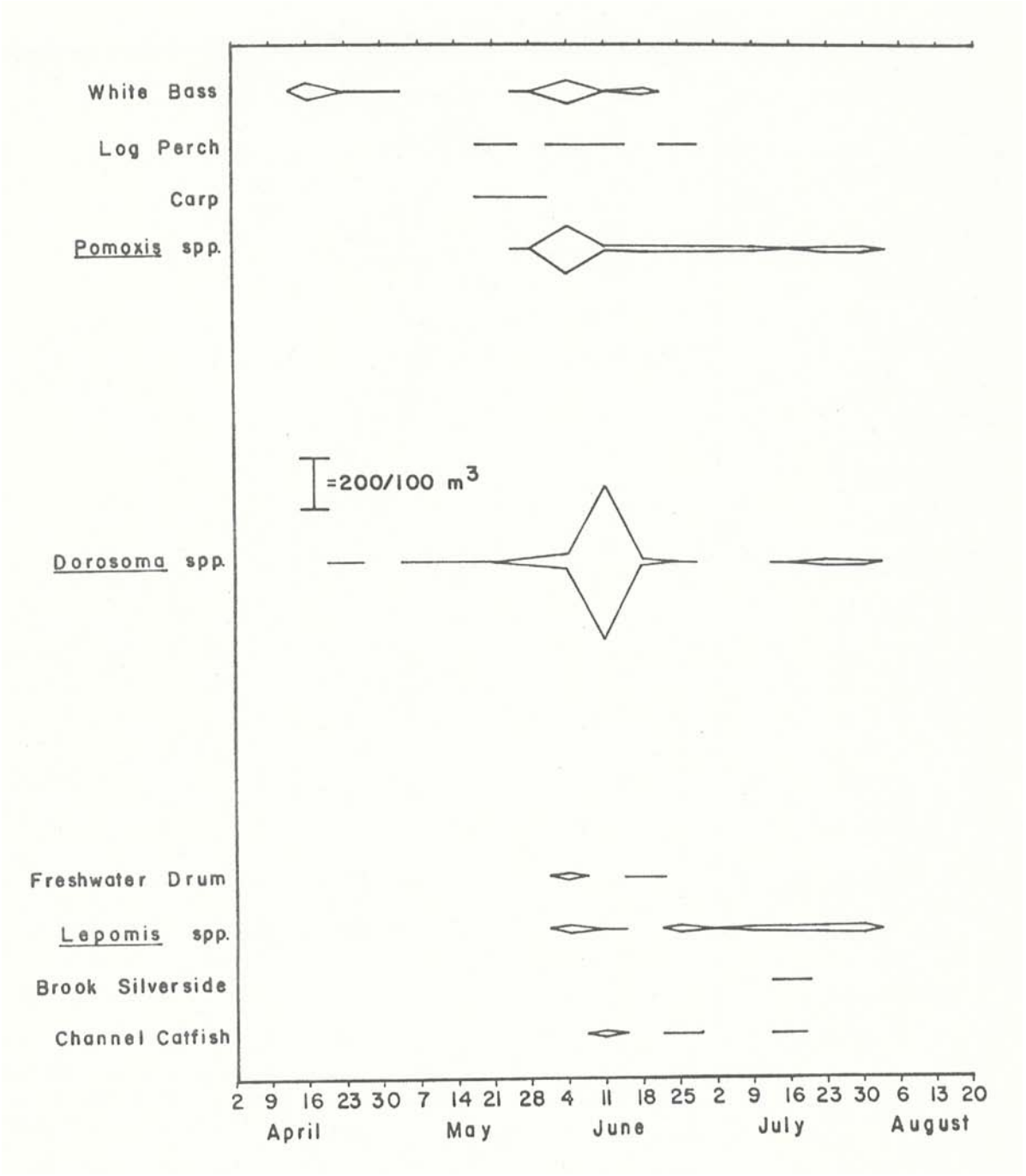

Figure 4. Densities of the major species collected at the bottom during daylight hours on Rough River Lake.

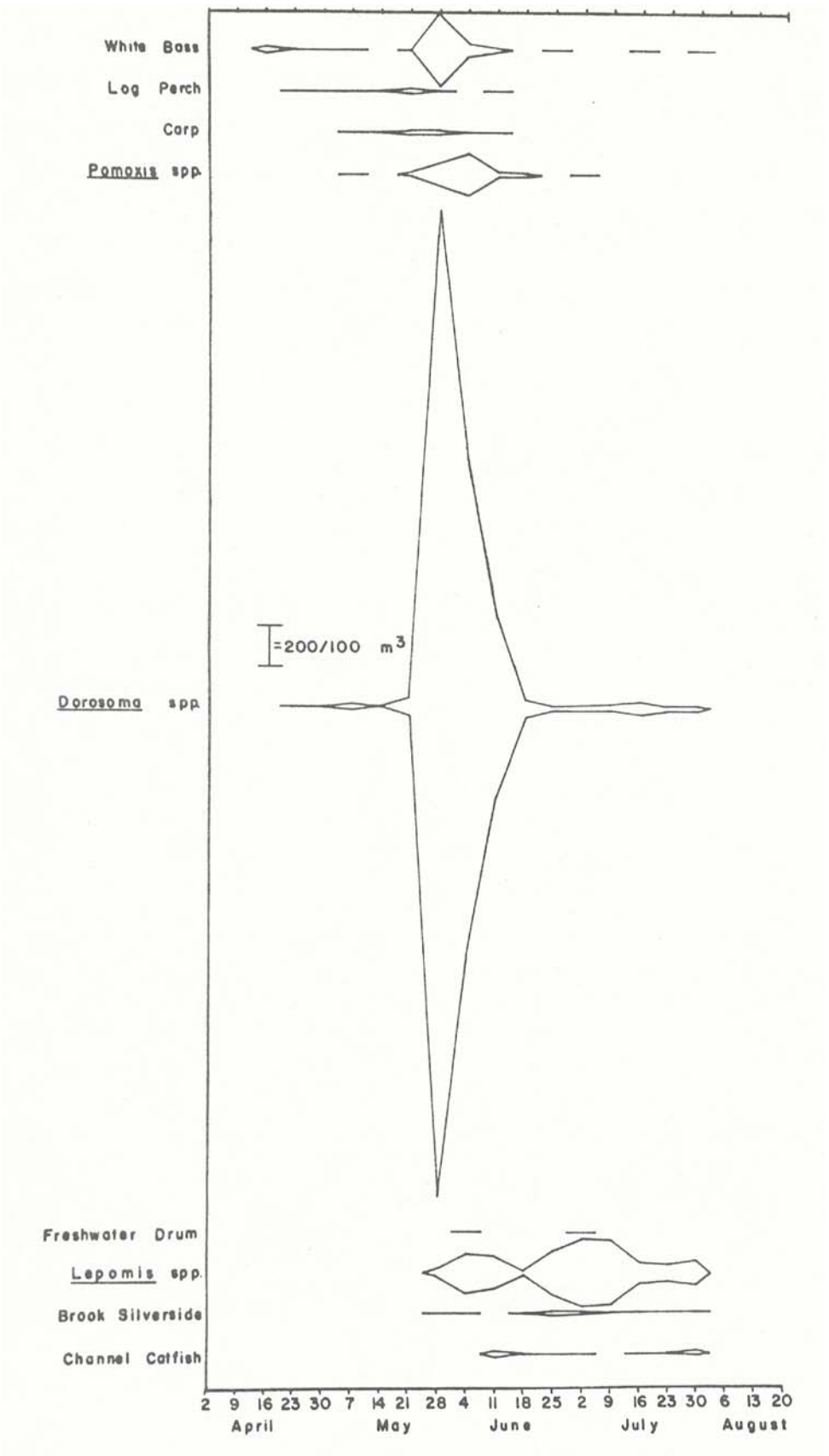

Figure 5. Densities of the major species collected at the surface during the night on Rough River Lake.

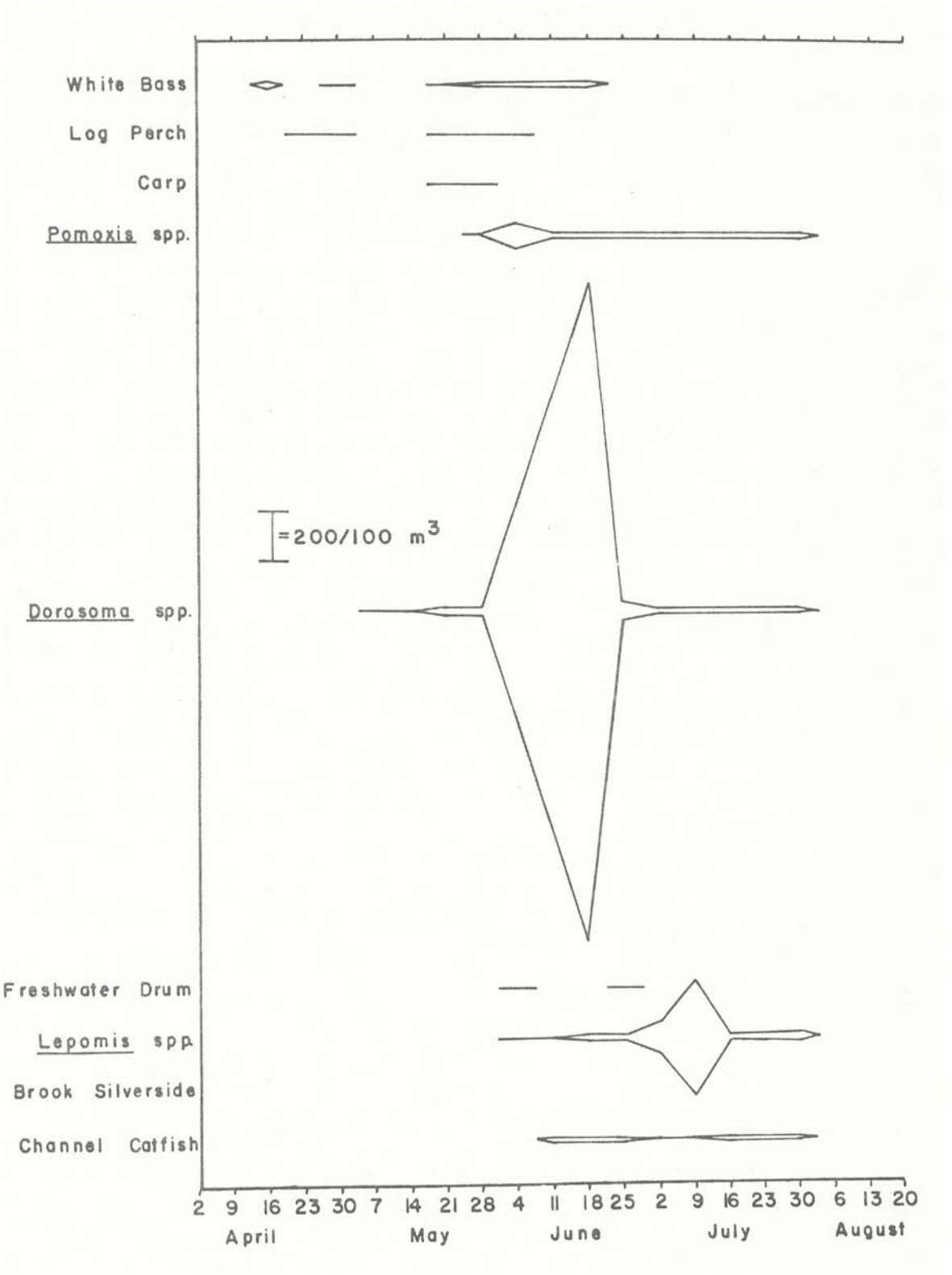

Figure 6. Densities of the major species collected at the bottom during the night on Rough River Lake.

densities were lower and lagged one week. Surface-bottom densities varied according to season, length and developmental stage of the larvae and species composition (Figures 3-6). Maximum densities in all surface-bottom and day-night samples occurred before June 20. Densities were greater at night than during the day for most species. Gizzard shad collected on the surface during the day and sunfishes on the surface at night exhibited a marked bimodal density pattern (Figures 3 and 5). Fish densities at night were three times greater than during daylight hours during the study.

Throughout the study, shad, sunfish species and white bass were most abundant along the shorelines. Catfish were always most abundant in bottom samples, while crappie occurred near the surface early in the study and deeper later.

White Bass - Along with logperch, white bass were the earliest appearing larvae (Figure 2). Larvae were collected from April 15 through June 27. Based upon total lengths, two apparent spawns occurred as small specimens were taken on April 16 and 23 and later on May 28 (Figure 7). They were commonly taken near the bottom during the day and at the surface at night (Figures 3-6). Maximum densities of 100/100 m^3 occurred on May 30. For the first 8 weeks, specimens averaged 0.56 mm growth/week. Prolarvae ranged from 4-7 mm, early postlarvae 7.5-12 mm, late postlarvae 13-32 mm and juveniles 27 mm and greater. Juveniles first appeared on June 20.

Logperch - Larvae were collected from April 15 through June 13 and were primarily taken at the surface in day and night samples (Figures 3-6). Densities were low, a maximum of 1.45/100 m^3 on May 23, and growth averaged 1.4 mm/week for the first 3 weeks. Prolarvae ranged from 7-10 mm, early postlarvae 8-14 mm, late postlarvae 14-19 mm and juveniles 19+ mm.

Juveniles were first observed on May 23.

Gizzard Shad - Prolarvae were first collected on April 26 at 15.5 C, while eggs were first collected on April 30 attached to shoreline vegetation and debris at 16.5 C. Prolarvae were collected from April 26 through June 20 and again on July 11. Larvae at some stage of development were present from April 26 through August 1 (Figure 2). Larval densities averaged 882/100 m^3 from May 23 through June 20 with the maximum, 1771/100 m^3, occurring on May 30. Prolarvae ranged from 5 to 10 mm, early postlarvae 9 to 19 mm, late postlarvae 14.5 to 25 mm and juveniles 23+ mm.

Buffalo spp. - Eggs collected from fish observed spawning in shoreline vegetation on April 30 at 17.5 C hatched in the laboratory in 170 hours at 19 C. Larvae were present from May 6 to May 30 and collected mainly at the surface. Prolarvae ranged from 5-7.9 mm and early postlarvae from 7.6-9.1 mm.

Carp - Eggs attached to shoreline vegetation and debris were collected on April 30. Larvae were collected from May 11 through June 13, mostly near the surface at night. Prolarvae ranged from 5.5-7.5 mm. No late postlarvae or juveniles were taken.

Crappie spp. - Larvae were collected from April 30 through July 25 (Figure 2). No prolarvae were taken. Early postlarvae ranged from 4 to 11 mm, late postlarvae 11.5 to 19.5 mm, and juveniles 19+ mm. Juveniles were first taken on June 13. The maximum density, 130/100 m^3, occurred on June 6. Specimens less than 20 mm total length were taken mostly in shoreline areas while larger individuals were collected in deeper water.

Brook Silverside - Specimens were taken from May 30 through August 1 (Figure 2). Growth averaged 1.6 mm/week for the first 5 weeks and the species required a length of 30 mm to reach the juvenile stage. No

prolarvae were taken and juveniles first appeared on July 11.

Sunfish spp. - This group included at least two species, the bluegill and longear sunfish. Larvae were taken from May 30 to August 25. Because of the protracted spawning period, 12 to 13 weeks for the collective species, average weekly total lengths never exceeded 12 mm (Figure 7). Densities averaged 71/100 m^3 per week with a maximum of 240/100 m^3 on July 11. Specimens were taken mostly along the shorelines at night. Prolarvae ranged from 4.5 to 6 mm, early postlarvae 5 to 12 mm, late postlarvae 10 to 19 mm and juveniles 20+ mm. Juveniles appeared first on June 20.

Freshwater Drum - Larvae were collected from June 6 through July 5 (Figure 2). Of 81 specimens, 78 were prolarvae taken mostly from surface, open water areas. Total lengths ranged from 4-16.5 mm and no juveniles were observed.

Channel Catfish - Specimens were taken from June 13 through August 1 with only late postlarval and juvenile stages represented. Most individuals were taken in bottom samples at night.

Largemouth Bass - Twenty-four larvae were collected on June 13. Twenty-two of these were taken at night, all but one on the surface. Total lengths ranged from 14.5-33 mm and no prolarvae were taken. Early postlarvae ranged from 14.5 to 16 mm, late postlarvae 16 to 22 mm and juveniles 21.5+ mm.

Light Trap Data - Two lighted traps set from April 15 to August 1 collected 1445 larval and juvenile fish (Table 2). Five taxa were taken with sunfishes comprising 80% of the total. All brook silversides, along with most sunfish, were taken near the surface. Gizzard shad, logperch and crappie were taken primarily on the bottom. No fish were taken in adjacent unlighted traps.

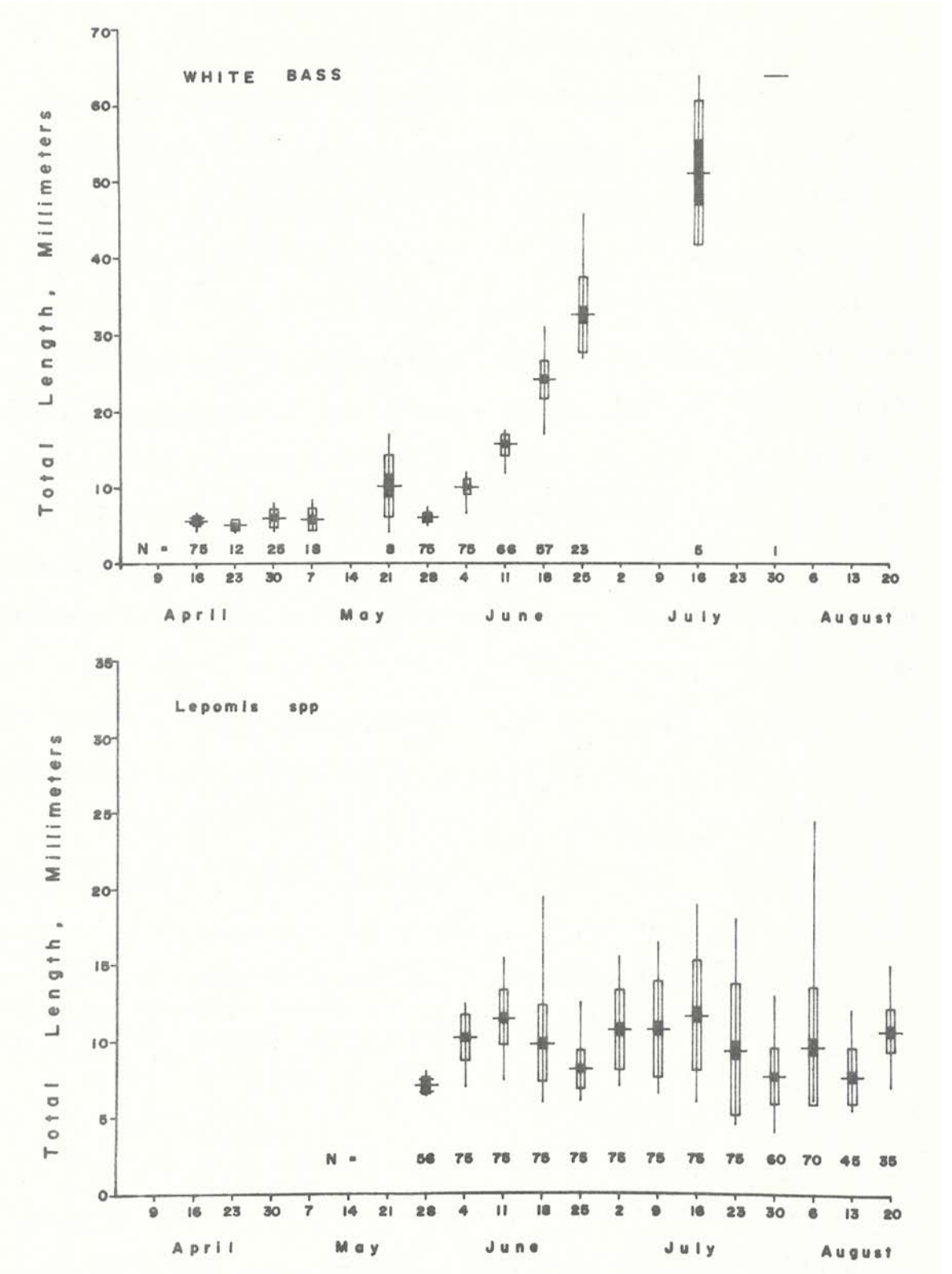

Figure 7. Weekly growth data of larval white bass and *Lepomis* spp. in Rough River Lake, Kentucky, April through August 1978. Horizontal line is the mean, vertical line the range, open box equals one standard deviation, and the darkened box equals one standard error of the mean.

Piscivory - All taxa, except gizzard shad, were examined for piscivory. Only white bass and logperch ingested other larvae. Sixty white bass stomachs representing four size groups collected on four different dates were examined. Of 15 larvae ranging from 10.5-12 mm total length collected on June 6, 1 gizzard shad was observed in the stomach of 1 individual (Table 3). Fifteen bass from 16-20 mm taken on June 13 had 11 gizzard shad in 11 stomachs, and 6 gizzard shad larvae were found in 6 stomachs from individuals 22-25 mm taken on June 20. When piscivory was observed in white bass, no other food items were present.

Twenty-three logperch stomachs were examined in individuals from 13.5-27 mm collected from May 19 to June 13 (Table 4). One unidentifiable sucker was found in a logperch 17 mm total length taken on May 19. On May 23, 2 unknown larvae were found in the stomach of 1 logperch 16.5 mm total length.

Table 2. Species and number of individuals taken in light traps at the surface and 6 m in Rough River Lake, April 15 - July 18, 1978.

Species	Surface		6 Meters	
	Lighted	Unlighted	Lighted	Unlighted
Logperch	0	0	2	0
Gizzard Shad	73	0	152	0
Crappie spp.	5	0	32	0
Sunfish spp.	920	0	255	0
Brook Silverside	6	0	0	0
TOTAL	1,004	0	441	0

Table 3. Piscivory observations in white bass from Rough River Lake, June 6 - June 27, 1978.

Date	N	Size Range (mm)	$\bar{x}$	Day	Night	Total
June 6	15	10.5 - 12	11.2	1	0	1
June 13	15	16.0 - 20	17.2	6	5	11
June 20	15	22.0 - 25	23.8	3	3	6
June 27	15	25.0 - 30	28.0	0	0	0
TOTAL	60			10	8	18

Table 4. Piscivory observations in logperch from Rough River Lake, May 19 - June 13, 1978.

Date	N	Size Range (mm)	$\bar{x}$	Day	Night	Total
May 19	5	13.5 - 17	15.5	1	0	1
May 23	6	14.0 - 20	16.9	0	2	2
May 30	5	15.5 - 19	16.6	0	0	0
June 6	3	15.0 - 16	15.5	0	0	0
June 13	4	13.0 - 27	21.2	0	0	0
TOTAL	23			1	2	3

DISCUSSION

Other investigators (Netsch *et al.* 1971, Nelson and Cole 1975, Hess and Winger. 1976, Walker *et al.* unpublished report, and Davis and Freeze 1978) have shown that clupeids dominate larval collections in both river and lake environments during the warmer months. Sunfish larvae were the second most abundant in this study, but species dominance may change from year to year (Faber 1967) depending on water temperature (Kramer and Smith 1962) and pool elevations (Walburg and Nelson 1966) during spawning periods. Failure to collect substantial numbers of species common to Rough River Lake such as buffalo and carp indicated perhaps a low spawning success, that spawning took place primarily in other areas of the lake, or that larvae moved to some undetermined habitat seeking food and/or protection.

White bass and logperch larvae were the first collected in this study on April 15. These same species were the first to appear in Nickajack Reservoir, Tennessee (Walker *et al.* unpublished report). The surface water temperature when the first larvae appeared (18.5 C) was slightly higher than that reported in studies by Davis and Freeze (1978) and Walker *et al.* (unpublished report). This was due to an early pre-spawn warming trend the end of March in Rough River Lake. *Lepomis spp.* had the most prolonged spawning period, with prolarvae present through August 10. A protracted sunfish spawn was also observed on the Cumberland River (Hess and Winger 1976).

Larval shad density was highest on 30 May, 5 weeks after the first appearance of shad larvae and two weeks after a 3 m increase in lake pool elevation. Netsch, *et al.* (1971) observed peak shad densities in mid-June

9 weeks following the onset of spawning. Hess and Winger (1976) observed greatest concentrations in late June through July, but this was in the Cumberland River where water temperatures rose less rapidly.

Three times more larvae were collected at night than day, possibly because of reduced visibility resulting in less net avoidance. Walker *et al.* (unpublished report) also reported greater densities of similar species at night, but Storck *et al.* (1978) noted greater concentrations of shad during the day.

The five most common species were most abundant along the shoreline areas in water 1.5-2 m deep. Similar shoreline findings were reported by Walker *et al.* (unpublished report). This was expected, because most taxa taken in this study spawn along the shoreline. Channel catfish were most abundant in bottom samples because they school in deeper water when young (Mansueti and Hardy 1967). Crappie were taken near the surface early in the study and deeper later. Nelson *et al.* (1968) reported that crappie commonly move from shallow protected nursery areas into deeper waters to feed as their size increased.

White bass were observed to have the fastest growth rate (3.89 mm/wk) during the sampling period which was similar to that noted by Ruelle (1971) in Lewis and Clark Lake. He also noticed a positive correlation between water temperature, food availability and growth. Sunfish appeared not to grow because the spawning season was protracted, several species were possibly included within this taxon and larger individuals were able to avoid the net. Channel catfish also appeared not to grow because of continuous spawning, sometimes extending into September (Mansueti and Hardy 1967).

Prolarval white bass were present from April 15 to June 6, indicating a

1.5-2 month spawning period at surface temperatures of 18.5-29 C. These findings generally agreed with those of Ruelle (1971) and Webb and Moss (1968). It appeared that the early warming trend at the end of March in Rough River Lake did not stimulate spawning but the cooling trend which followed possibly inhibited it. White bass hatch at 3 mm (Ruelle 1971), but the smallest individuals taken in this study were 4 mm. Smaller larvae may possibly have remained hidden in the substrate until reaching this length or stayed in areas not sampled by our nets.

During daylight hours, white bass were primarily taken in deeper, cooler water and at night came to the surface, probably to feed. From April 30 through May 30, white bass prolarvae were taken mostly along the east shoreline, an area having extensive gravel-rubble substrate areas, substrates on which white bass have been known to spawn (Pflieger 1975). For the remainder of the sampling period, individuals were taken in limnetic regions.

Logperch larvae, although not abundant, were taken mainly along both shorelines. Walker *et al.* (unpublished report) observed a similar distribution pattern. Their occurrence in the limnetic habitat, as shown by Fish (1932) and Faber (1967), was not observed in this study, possibly because of the small size of the collecting station. Cooper (1978) noted prolarval development from 4.5-6.9 mm under laboratory conditions at 16.5 C. In this study, yolk and oil were present in individuals up to 10 mm long and none were taken less than 7 mm. Late postlarval development (14-19 mm) appeared earlier in this study than in Cooper's (1978) study (21 mm).

Spawning dates and water temperatures for gizzard shad appear to vary yearly with latitude, but can occur from March to at least August 20 at water temperatures from 10 to 21 C (Miller 1960). Prolarvae were present

in this study from April 26 through June 20 indicating a 9 to 10 week spawning interval at water temperatures from 15.5 to 29 C.

The peak gizzard shad density in this study occurred on May 30, 2 weeks later than noted by Houser and Netsch (1971) in northwest Arkansas. During day and night collections, gizzard shad were taken mostly at the surface which was also observed by Walker *et al.* (unpublished report), but differed from Nelson and Cole (1975) and Houser and Netsch (1971).

Developmental stages for gizzard shad were generally similar to those observed by Mansueti and Hardy (1967), however they indicated prolarval development to be from 3.25 to 6.5 mm. A yolk sac was still present in individuals up to 10 mm in this study. Although no prolarvae less than 5 mm total length were collected, larvae hatched at 3.25 mm in the laboratory.

Spawning by the smallmouth buffalo in Rough River Lake at 17.5 C surface temperature conformed to the 15-23 C range reported for the species by Hoyt *et al.* (1976). Eggs collected from the lake hatched in laboratory aquaria in 170 hours at 19 C. Wrenn and Grinstead (1971) observed that smallmouth buffalo hatched within 108 hours at 22 C. The low number of buffalo taken was most likely the result of net avoidance due to the movement of larvae into some undescribed habitat not sampled in the study.

Although the number of smallmouth buffalo taken was too small to define strata preferences, 31 of the 36 collected were taken near the surface at night. Walker *et al.* (unpublished report) observed highest numbers below 7.5 m during the day and random distributions at night. Developmental stages and growth were similar to that reported by

Wrenn and Grinstead (1971).

Carp were also present in numbers too small to establish their distribution patterns. The greatest number of carp were taken on May 23, 1 week following peak pool elevation, indicating the spawning was triggered by rising water. Storck *et al.* (1978) reported a similar response to rising water. Prolarval development between 5.5 and 7.5 mm was similar to observations by McCrimmon and Swee (1967).

No prolarval crappie were taken in this study possibly because they remained in shallow water, less than 1 m deep, until reaching 4.1 to 4.6 mm. Our gear could not sample these areas. Morgan (1954) reported similar observations in describing prolarvae from 3 to 3.9 mm.

Young crappie were taken the first 4 weeks, mostly at the surface as they left shoreline areas. Larger larvae were collected in deeper water, possibly because of their feeding behavior and preference for cooler water. Nelson *et al.* (1968) reported similar distribution findings.

Our observations on the brook silverside were in agreement with the findings of those of Hubbs (1921). He reported the limnetic presence of postlarvae to be due to their leaving the shoreline for the protection afforded by the open water. Prolarvae were not taken, probably due to their shallow water nursery areas. In August, juveniles returned to littoral areas as their diet changed from microcrustaceans to aquatic and terrestrial insects (Pflieger 1975).

Lepomis spp. had the longest spawning season of all the species in the study, May 30 to August 10. Bluegill eggs have been known to hatch by June 24 and become free-swimming 3 days later (Meyer 1970). Consequently, longear and other sunfish species probably represented the majority of the

larvae taken in this category in the latter weeks of the study. Greater sunfish densities at the surface at night in this study were similar to findings of Werner (1969) who noticed a vertical migration following plankton movements at dusk. Storck *et al.* (1978), however, reported greater densities during the day at the surface. Prolarval lengths were the same as those noted by Werner (1969).

Most drum collected on June 6 were prolarvae, indicating this to be near the peak spawning period. Specimens were taken mostly in deeper samples during the day similar to findings of Walker *et al.* (unpublished report) and Swedberg and Walburg (1970).

No prolarval or early postlarval channel catfish were collected since they are known to remain in secluded, shallow nests for 7-8 days after hatching (Pflieger 1975). Most individuals were taken at night, similar to the report of Walker, *et al.* (unpublished report), but differed by occurring mostly in deep samples.

Larval and juvenile largemouth bass were taken only on June 13, mainly at night. Their capture came at a period of increased turbidity following a rain, possibly explaining their increased vulnerability to capture.

Lighted traps proved to be an effective attractant for 5 taxa of larval and juvenile fish. These particular species were more active at night and/or were stimulated by light. Sunfish species, which are known to actively feed on plankton at dusk near the surface (Werner 1969), made up the majority of trap specimens. The low number of shad, when compared with net catches, indicated the species to be less active at night or not highly responsive to light stimulii. This observation might also explain the greater night catches of larval and juvenile fishes, net catch success

being a function of fish inactivity as well as reduced net avoidance due to poor vision.

Piscivory was observed only in white bass and logperch. This larval trait was probably the result of bass and logperch being present in an advanced developmental state when the other larval forms appeared. Other studies have shown that piscivory occurs in white crappie greater than 75 mm (Morgan 1954) or not less than 100 mm (Nelson *et al.* 1968) and in largemouth bass greater than 20 mm (Kramer and Smith 1962). None was noted in bluegill fry (Werner 1969), in young-of-the-year drum (Swedberg and Walburg 1970) or in channel catfish less than 100 mm (Bailey and Harrison 1948). These observations agreed with the findings of this study, although piscivory was not noted in largemouth bass from 20 to 33 mm.

White bass piscivory was observed in specimens 10.5 to 25 mm total length, mostly 10.5 to 20 mm. This length limit for maximum piscivory on gizzard shad was a function of shad size being optimal for ingestion by bass during that period and decreased as shad size increased. Clark and Pearson (1978) noted that prolarval carp were the major food source for white bass 7 to 12 mm standard length in the Ohio River, but observed no piscivory in individuals larger than 12 mm. This abrupt change in the diet was attributed to the lack of sufficient numbers of vulnerable size larvae at that stage or an increase in zooplankton concentrations. Stomachs of white bass from Rough River Lake contained no other food items when shad were present. The energy provided by one large food item, plus the energy saved in catching several small prey forms could be an important factor in the development of this feeding behavior. Zooplankton was the

major food category in the stomachs of individuals larger than 25 to 30 mm, similar to the findings of Clark and Pearson (1978).

Piscivory has not been reported for logperch. This species reportedly feeds mostly on midge larvae (Clay 1975) and snails and small crustaceans (Turner 1921). Gizzard shad capable of being ingested (6-10 mm) were present at the time of piscivory by logperch, but apparently occupied habitats preventing their coming into contact.

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TEMPORAL AND SPATIAL VARIATIONS IN ABUNDANCE AND SPECIES COMPOSITION OF LARVAL FISHES IN CENTER HILL RESERVOIR, TENNESSEE

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ABSTRACT

Larval fish were collected bi-weekly at five main channel sites of Center Hill Reservoir from May through August 1978 to assess spatial and temporal variations in abundance and species composition. Larval Dorosoma spp., Lepomis spp., and Pomoxis spp. comprised over 97% of all specimens collected. Analysis of variance indicated that Dorosoma abundance varied significantly between sample sites, but density was not related to an upstream-downstream gradient within the reservoir. Lepomis and Pomoxis showed significant spatial differences in abundance within some sample periods, but low catch rates during several periods made overall analyses inconclusive. Localized variations in spawning stocks, water quality, or other environmental factors appear to have been more important regulators of larval fish density than upstream distance from the dam.

INTRODUCTION

Surveys of larval and early juvenile stages of fish can be used to trace fluctuations in spawning stocks, forecast year-class strength (Hempel 1973), and assess the impact of water quality or other factors on biological productivity. Knowledge of spatial and temporal variations in abundance of larval fishes not only contributes to an understanding of life history and population dynamics, but it can also lead to development of management procedures for enhancing recruitment of young fish into adult stocks.

This study was conducted to describe spatial variations in abundance and species composition of larval fishes that occupied the limnetic habitat of Center Hill Reservoir, Tennessee. Emphasis was placed on variations of larval fish abundance between sites within specific sampling periods and upstream versus downstream areas of the reservoir.

STUDY AREA

Center Hill Reservoir was impounded in 1948 by the U.S. Army Corps of Engineers for flood control and power generation. The reservoir has a surface area of 7,373 ha and a mean depth of 29 m at maximum power pool. The reservoir has a narrow, meandering mainstream channel and several large embayments associated with major tributaries (Figure 1), but hydraulic and water quality characteristics are dominated by inflow of the Caney Fork River. Center Hill is monomictic and undergoes temperature-density stratification from March through November (U.S. Army Corps of Engineers 1976). Water levels are usually lowest in winter and early spring, and wide variations of inflow can cause extreme fluctuations of water level during the spawning seasons of most game and forage fishes.

METHODS

Five mainstream sampling sites were established along the length of the reservoir (Figure 1), and each was sampled bi-weekly at night from early May until mid-August 1978. A 0.25 m^2 Tucker trawl with a 505 micron Nitex net was towed from the stern of a 5.75 m boat powered by a 85 hp outboard motor. Two 6-minute tows were made at each site and time. The net was lowered to a depth of 10 m, opened, and then raised 2 m at 1-minute intervals. From 4 May until 12 July, tows were made at a speed

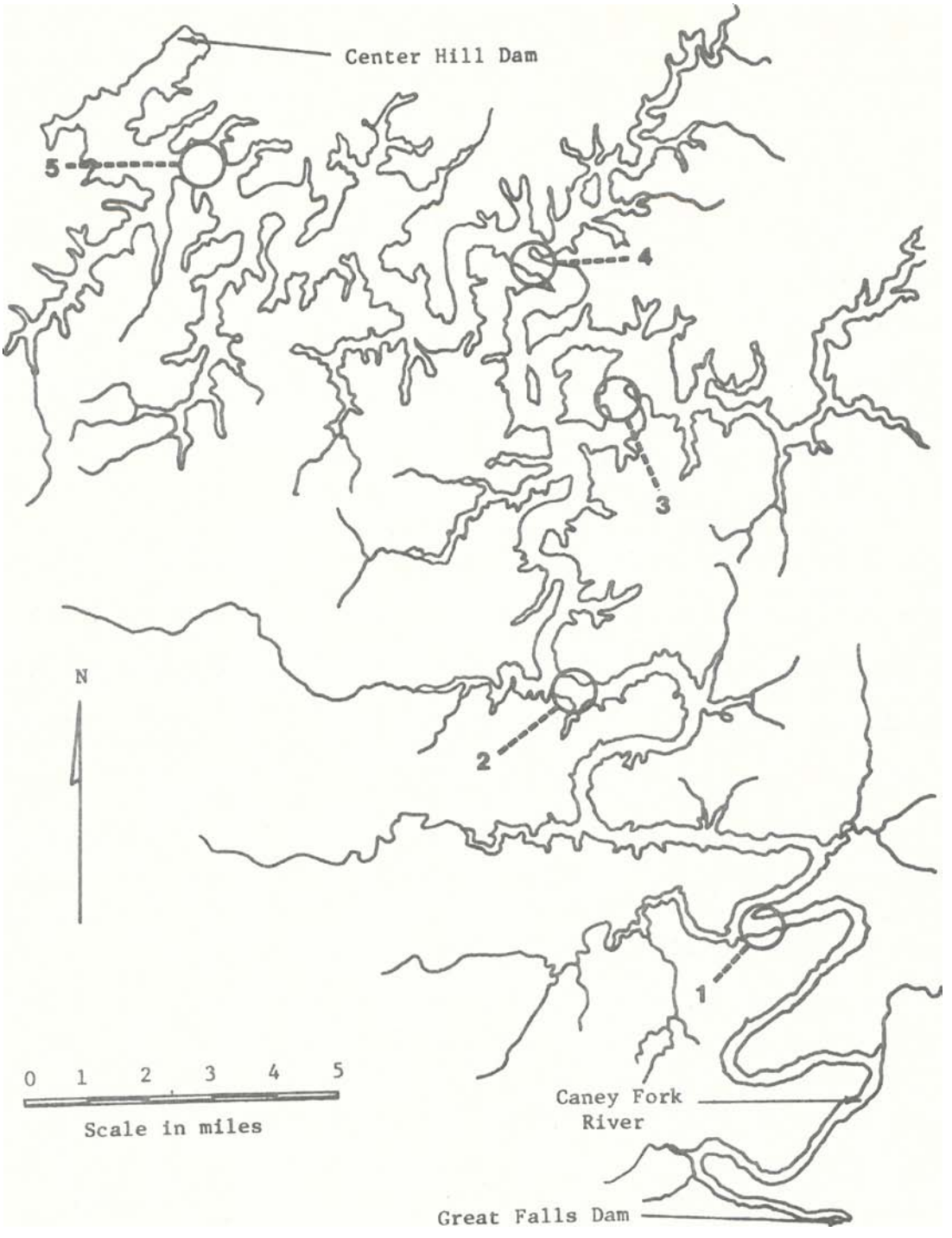

Figure 1. Map of Center Hill Reservoir, Tennessee, showing sample sites.

of 1.0 m/s, and all subsequent samples were collected at 1.5 m/s. A flowmeter suspended in the mouth of the net was used to estimate the volume of water filtered during each tow.

Samples were initially fixed in 10% formalin. After sorting in the laboratory, the larvae were stored in a solution of 5% buffered formalin. Specimens were identified to the lowest possible taxon using polarized-light stereomicroscopy and the taxonomic key developed by Hogue *et al.* (1976). All larvae were enumerated and measured to the nearest mm total length.

Catch rates were expressed as number of larvae per 1000 m^3, and analysis of variance was used to compare densities between stations for the entire study and within each sampling period. Examination of the relationship between the variances and means of replicate density estimates (n = 2) indicated a contagious distribution of the data for each genus. In this situation, a logarithmic transformation is recommended (Taylor 1953) to equalize the variances within the treatments (in this case, sites) for the analysis of variance. Due to the presence of observations with values of zero, $\ln(X + 1)$ was used, where X was the observed number of larvae per 1000 m^3 in each tow. When analysis of variance indicated a significant difference (0.05 probability level) in mean density between sites, the individual station means were compared using Duncan's new multiple range test (Steel and Torrie 1960).

RESULTS

Shad (*Dorosoma spp.*), sunfishes (*Lepomis spp.*), and crappies (*Pomoxis spp.*) collectively comprised over 97% of all larvae collected (Figure 2), and subsequent analyses will be restricted to these groups. Shad over 18 mm

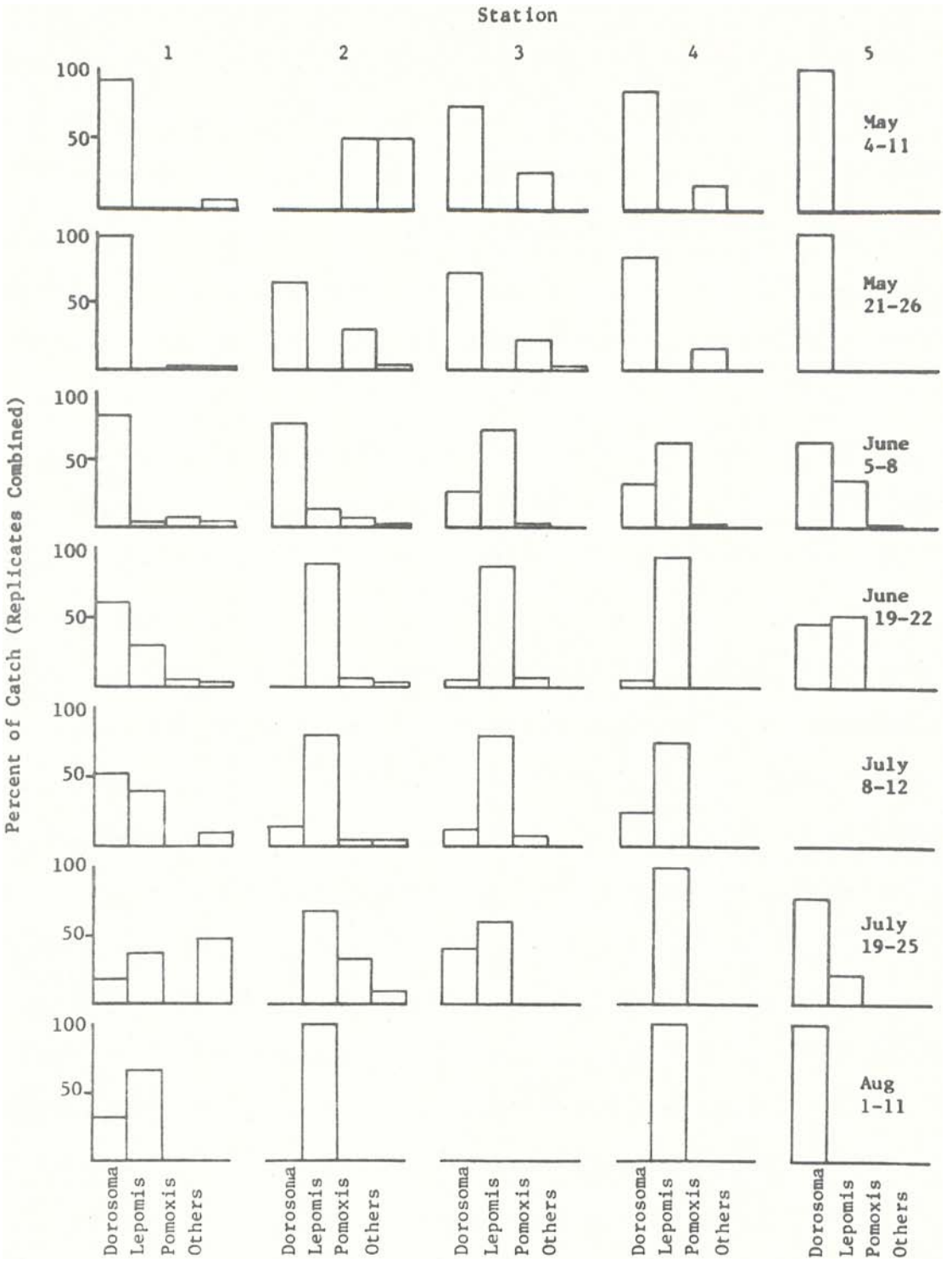

Figure 2. Species composition of larval fish collected from five sites in Center Hill Reservoir, May-August 1978.

total length were usually identified to species, however, due to the inability to separate smaller gizzard (*D. cepedianum*) from threadfin shad (*D. petenense*), data from both were pooled in all analyses. No attempt was made to identify sunfishes and crappies beyond the genus level.

In general, *Dorosoma* predominated the collections prior to mid-June, and *Lepomis* was the most abundant group thereafter (Figure 3). *Pomoxis* was intermediate in ranking before June, after which the group was rarely collected.

Seasonal patterns of density were similar between stations for each species group, which indicated that spawning occurred at approximately the same time at all sites (Figure 3). *Dorosoma* may have spawned earlier at Station 1 than at the others, as indicated by the high density (1617 larvae per 1000 m^3) during the first sample period. At all other stations, shad abundance was highest during early June. *Lepomis* abundance was highest during mid to late June at all stations. Comparisons of average lengths and length ranges for each species group showed no pronounced differences in size between stations during the May and June sample periods (Figure 4). Although mean lengths of *Dorosoma* were more variable between sites after July 8, the ranges generally overlapped. Therefore, the length data also suggested that spawning times did not vary with reservoir position.

For *Dorosoma*, a two-factor analysis of variance using transformed data indicated that time, stations, and a time-station interaction significantly affected mean density (Table 1). Duncan's new multiple range test showed that Station 1, which was the farthest upstream, had significantly higher mean catch rates than all other sites (Table 1). Station 5, which was nearest the dam, was ranked second highest in abundance, which indicated that there was no pronounced gradient of shad density with reservoir length.

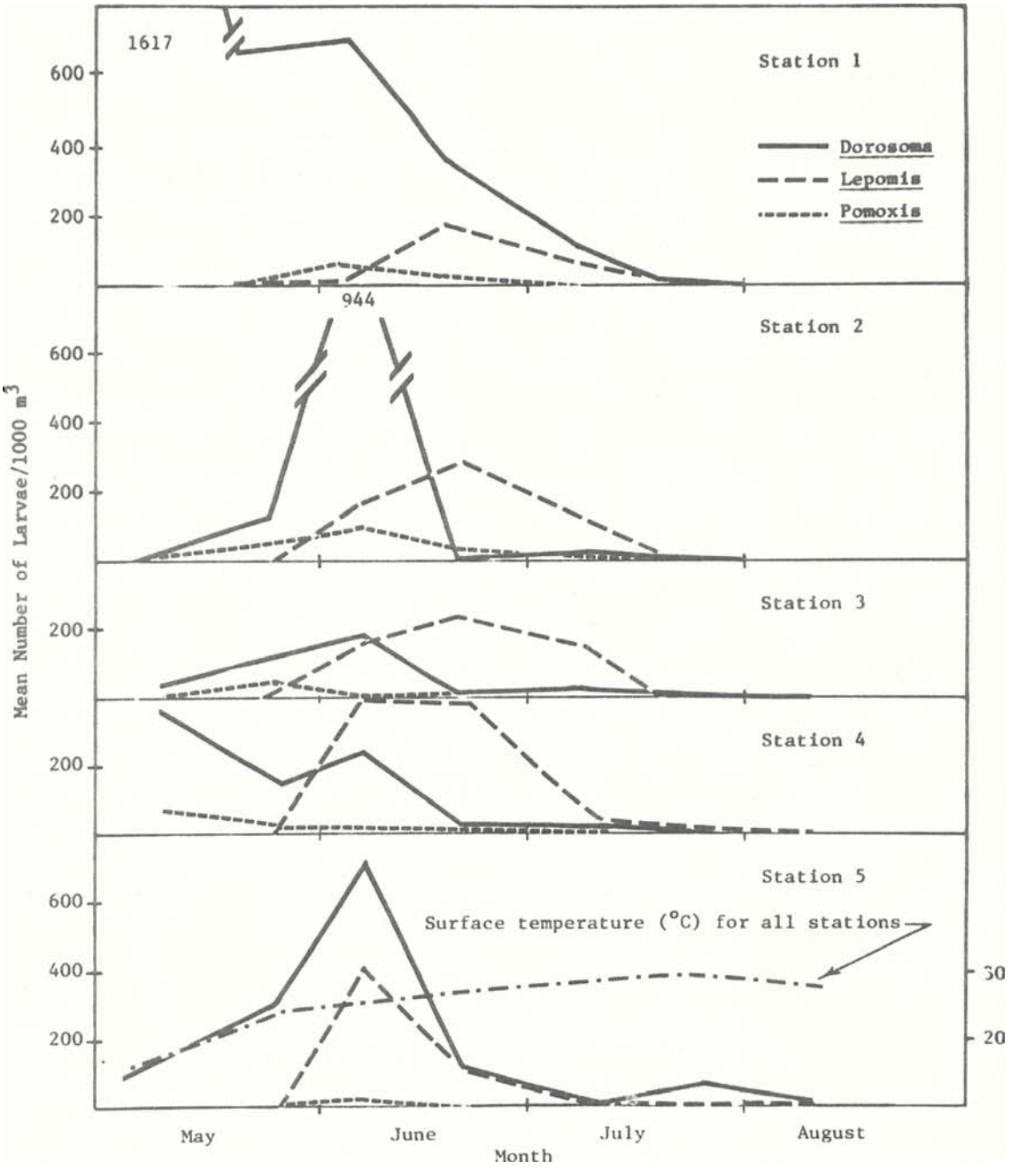

Figure 3. Density of larval *Dorosoma* spp., *Lepomis* spp., and *Pomoxis* spp. at five sites in Center Hill Reservoir, May-August 1978.

Table 1. Two-factor analysis of variance and multiple range tests for density of larval *Dorosoma spp.* in Center Hill Reservoir, May-August 1978.

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Time	6	40.72	44.0*
Stations	4	14.50	15.7*
Time-Station Interaction	24	4.63	5.0*
Error	35	0.92	
TOTAL	69	6.46	

Multiple Range Test**

Station	2	3	4	5	1

* Statistically significant at 0.05 probability level.

**Mean densities at stations underscored by the same line were not significantly different.

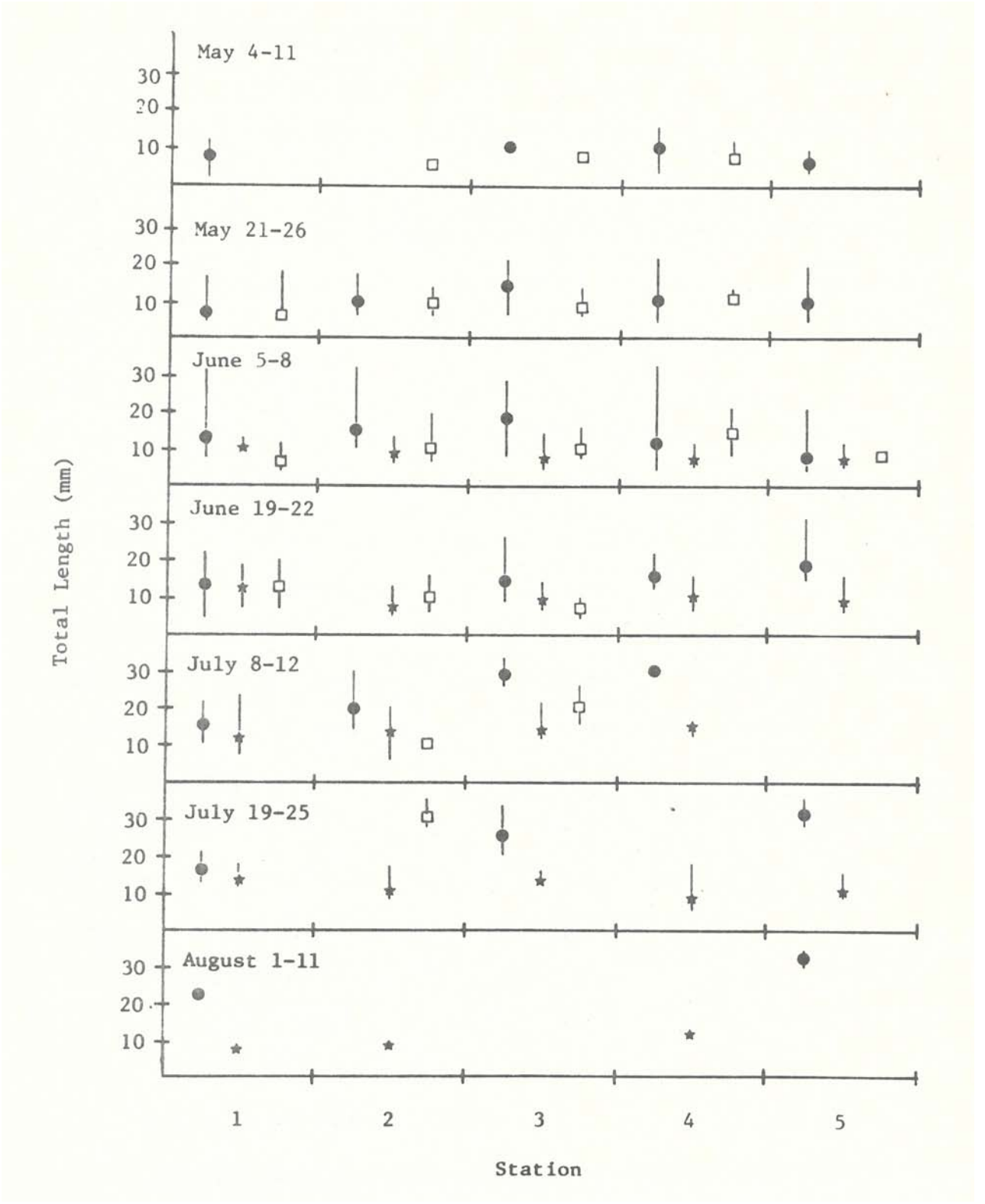

Figure 4. Mean lengths of larval *Dorosoma* spp. (●), *Lepomis* spp. (*), and *Pomoxis* spp. (■) collected from five sites in Center Hill Reservoir, May-August 1978. Vertical lines indicate ranges of observed lengths.

The presence of a significant time-station interaction indicated that the degree to which sites differed in density varied over time. Thus, to further examine variability among sample stations, one-way analyses of variance and multiple range tests, using transformed data, were used for each sample period. Significant differences in mean density between sites were indicated during five of the seven sample periods (Table 2). In Table 2, the arithmetic, rather than transformed mean numbers per 1000 m^3 are shown to permit easier interpretation of the results. These analyses support the results of the overall analysis of variance by showing that Stations 1 and 5 generally were ranked high in density while Stations 2 and 3 usually were the lowest.

For *Lepomis*, the two-factor analysis of variance also showed significant effects of time, station, and a time-station interaction on mean density (Table 3). The ranking of stations by density was different from that observed for *Dorosoma* (Tables 1 and 3). Stations 2, 3, and 4 showed the highest mean density, while Stations 5 and 1 were lowest. Analyses of variance of the transformed data indicated significant differences between sites during only two of the five sample periods in which *Lepomis* were collected (Table 4). In these two cases, extremely low or zero catches at one station were primarily responsible for obtaining significant results. This fact, in combination with the low catch rates after mid-July and a significant time-station interaction indicate that the overall analysis of variance did not properly reflect spatial variations in abundance throughout the sampling period and that the results should be interpreted with caution.

The two-factor analysis of variance for *Pomoxis* again showed significant time, station, and time-station interaction effects (Table 5). The ranking of stations by mean density was similar to that observed for

Table 2. One-way analysis of variance and multiple range tests for density of larval *Dorosoma spp.* during each sample period in Center Hill Reservoir, May-August 1978. All hypotheses were tested using transformed data, but mean densities shown are the arithmetic averages (number per 1000 m^3).

Sample Period	F*	Multiple Range Test**				
May 4-11	10.05***	Station	2	3	5	4	1
		Mean Density	0	28	83	350	1617
May 21-26	4.42	Station	2	3	4	5	1
		Mean Density	134	134	144	294	656
June 5-8	17.92***	Station	3	4	1	5	2
		Mean Density	172	233	694	706	944
June 19-22	6.94***	Station	2	3	4	5	1
		Mean Density	0	16	22	100	362
July 8-12	5.41***	Station	5	4	3	2	1
		Mean Density	0	11	22	22	94
July 19-25	5.38***	Station	4	2	3	1	5
		Mean Density	0	0	7	7	37
August 1-11	0.77	Station	2	3	4	1	5
		Mean Density	0	0	0	4	11

* Indicates the F-value calculated to test whether mean densities were equal among stations, with 4 d.f. in the numerator and 5 d.f. in the denominator.

** Stations underscored by the same line were not significantly different.

***Statistically significant at the 0.05 probability level.

Table 3. Two-factor analysis of variance and multiple range tests for density of larval *Lepomis spp.* in Center Hill Reservoir, June-August 1978.

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Time	4	35.02	56.8*
Stations	4	3.38	5.5*
Time-Station Interaction	16	2.88	4.7*
Error	25	0.62	
TOTAL	49	4.39	

Multiple Range Test**

Station	5	1	3	2	4

* Statistically significant at the 0.05 probability level.

**Mean densities at stations underscored by the same line were not significantly different.

Table 4. One-way analyses of variance and multiple range tests for density of larval *Lepomis spp.* during each sample period, June-August 1978. All hypotheses were tested using transformed data, but mean densities shown are the arithmetic averages (number per 1000 m^3).

Sample Period	F*	Multiple Range Test**				
June 5-8	15.15***	Station	1	2	5	4	3
		Mean Density	16	166	406	428	461
June 19-22	1.56	Station	5	1	3	2	4
		Mean Density	116	178	228	272	394
July 8-12	72.54***	Station	5	4	1	2	3
		Mean Density	0	33	72	122	150
July 19-25	0.51	Station	3	5	1	2	4
		Mean Density	11	11	14	22	22
August 1-11	1.36	Station	5	3	2	1	4
		Mean Density	0	0	4	7	7

* Indicates the F-value calculated to test whether mean densities were equal among stations, with 4 d.f. in the numerator and 5 d.f. in the denominator.

** Stations underscored by the same line were not significantly different.

***Statistically significant at the 0.05 probability level.

Table 5. Two-factor analysis of variance and multiple range tests for density of larval *Pomoxis spp.* in Center Hill Reservoir, May-July 1978.

Analysis of Variance

Source	Degrees of Freedom	Mean Square	F
Time	5	10.97	11.6*
Station	4	6.92	7.3*
Time-Station Interaction	20	3.49	3.7*
Error	30	0.94	
TOTAL	59	3.06	

Multiple Range Test**

Station	5	1	4	2	3

* Statistically significant at the 0.05 probability level.

**Mean densities at stations underscored by the same line were not significantly different.

Lepomis, but for *Pomoxis*, the mean density at Station 5 was significantly lower than at all other sites. This resulted because *Pomoxis* were collected at Station 5 during only one of six sample periods (Table 6). Analyses of variance within each sample period were significant only during the first half of May, and catch rates were extremely low or zero after mid-June. During late July, only two *Pomoxis* specimens were captured at Station 2. Thus, as with *Lepomis*, significant spatial variations in abundance of *Pomoxis* were not consistently observed, and the results of the overall analysis of variance probably are reflective only of the May and early June samples.

DISCUSSION

Although the two-factor analyses of variance for *Dorosoma*, *Lepomis* and *Pomoxis* indicated significant differences in density between stations, we believe that the results were conclusive only for *Dorosoma*. The low or zero catches of *Lepomis* and *Pomoxis* during several sample periods made detection of significant differences difficult and caused the overall analyses to be reflective only of sample periods in which catches were highest. The results do suggest, however, that between-site variations could exist throughout late spring and early summer and that future sampling programs should account for this possibility. Since *Lepomis* and *Pomoxis* spawn in littoral regions and the larvae subsequently disperse into the limnetic zone (Faber 1967, Werner 1967), higher catches than were observed (hence, more precise density estimates) might be obtained by sampling nearer the shoreline.

The presence of significant time-station interactions for all species groups indicated that the degree to which stations differed and/or the

Table 6. One-way analyses of variance and multiple range tests for density of larval *Pomoxis spp.* during each sample period in Center Hill Reservoir, May-July 1978. All hypotheses were tested using transformed data, but mean densities shown are the arithmetic averages (number per 1000 m^3).

Sample Period	F*	Multiple Range Test**					
May 4-11	10.21***	Station	5	1	2	3	4
		Mean Density	0	0	6	11	67
May 21-26	4.99	Station	5	1	4	3	2
		Mean Density	0	11	28	44	62
June 5-8	4.82	Station	5	3	4	1	2
		Mean Density	6	11	22	67	100
June 19-22	2.72	Station	5	4	3	2	1
		Mean Density	0	0	16	22	28
July 8-12	4.66	Station	5	4	1	2	3
		Mean Density	0	0	0	6	16
July 19-25	1.00	Station	5	4	3	1	2
		Mean Density	0	0	0	0	6

* Indicates the F-value calculated to test whether mean densities were equal among stations, with 4 d.f. in the numerator and 5 d.f. in the denominator.

** Stations underscored by the same line were not significantly different.

***Statistically significant at the 0.05 probability level.

ranking of the stations by larval density were not considered throughout the sampling period. Although average lengths and the synchrony of catches for each group suggested that spawning times did not vary between sample sites, it was possible that spatial variability in spawning times and density of the species within each genus could have contributed to the interactions. This also indicated that information for a particular group (*i.e. Dorosoma*) may not have adequately represented each of the component species (*i.e.*, gizzard and threadfin shad). For example, since gizzard shad spawn at cooler temperatures than threadfin shad (Kimsey 1958, Miller 1960), data from the early sample periods may refer primarily to gizzard shad while threadfin shad may have predominated in the later collections.

Variations in mean density of each species group apparently were not related to an upstream-downstream gradient within the reservoir. *Dorosoma* was most abundant at Station 1, which was the farthest upstream, and at Station 5, which was nearest the dam, while *Lepomis* and *Pomoxis* were most abundant at the intermediate stations. Localized variations in spawning stocks, water quality, or other environmental factors appear to have been more important regulators of larval fish density than upstream distance from the dam.

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VERTICAL DISTRIBUTION OF ICHTHYOPLANKTON IN UPPER NICKAJACK RESERVOIR, TENNESSEE, WITH COMPARISON OF THREE SAMPLING METHODOLOGIES

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ABSTRACT

Vertical distribution of clupeid and drum, Aplodinotus grunniens larvae in upper Nickajack Reservoir was determined using a highly stratified sampling regime. Clupeid larvae showed a preference for surface waters, especially during day. Most length groups of drum larvae were much more abundant at 3 to 6 m than at other depths during day, but more abundant in deeper waters at night. Results were compared to those obtained by Walker (1975) and TVA in 1977. Results were generally similar for clupeids, but the discrete-depth sampling conducted by Walker (1975) appeared to be less efficient in describing the distribution of drum larvae than stratified oblique sampling.

INTRODUCTION

Ichthyoplankton sampling was conducted in upper Nickajack Reservoir in 1973 and 1974 by Walker (1975) and in 1977 by TVA to determine the distribution and abundance of ichthyoplankton during the preoperational phase of the Raccoon Mountain Pumped Storage Project. In 1977, in addition to TVA's standard sampling methods, limited but highly stratified sampling was conducted during June and July with the objectives of : 1) identifying trends in vertical distributions that could be masked by normal sampling methods, and 2) relating these distributional trends to those described by

Walker (1975) and the standard samples of 1977.

STUDY AREA

Nickajack Reservoir is a mainstream reservoir on the Tennessee River in eastern Tennessee. It is 86 km long with a surface area of 4,415 hectares. Surface elevation is controlled between 192.6 m (632 ft) and 193.2 m (634 ft) msl for navigational purposes. All but the lower third of the reservoir is highly riverine in nature with little or no overbank. In the study area (Figure 1), the reservoir is approximately 200 m wide with a maximum depth of 30 m. Depth at the stratified sampling station was a maximum of 18-20 m. The sampling station (TRM 445.4) is 32 km (about 20 mi) downstream from Chickamauga Dam. Average discharge past the site is approximately 950 m^3/s (33,000 cfs) with a mean velocity of 30 cm/s (about 1 ft/sec). The river is well-mixed thermally and chemically (TVA 1976).

METHODS

Stratified samples were taken at a transect at Tennessee River Mile (TRM) 445.4. Samples were collected June 1, June 28, and July 27, 1977, at mid-channel (Figure 2). Single samples were taken within each of six 3 m strata from surface to 18 m by towing a 0.5 m beam net (0.5 mm bar mesh) obliquely through each stratum (Graser 1977). Towing speed was about 1.0 m/s and volume filtered per sample was approximately 150 m^3. The standard sampling technique used in 1977 was similar except that sample strata were fewer and the sampling frequency was biweekly from mid-March through mid-September.

A mid-channel station and two shoreline stations were sampled by the standard technique. The mid-channel station was the same station at which

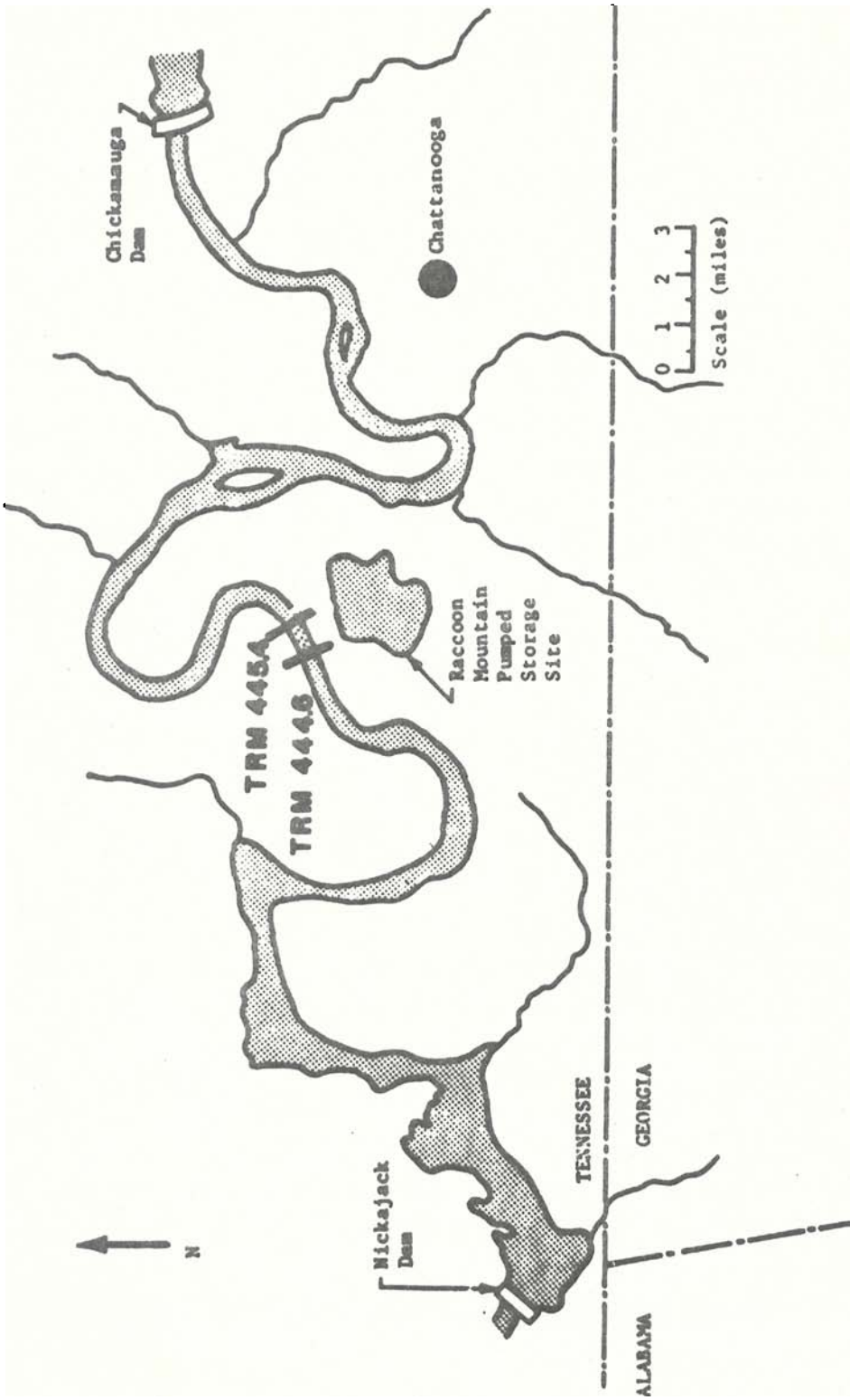

Figure 1. Location of study sites on Nickajack Reservoir, Tennessee (from Walker, 1975).

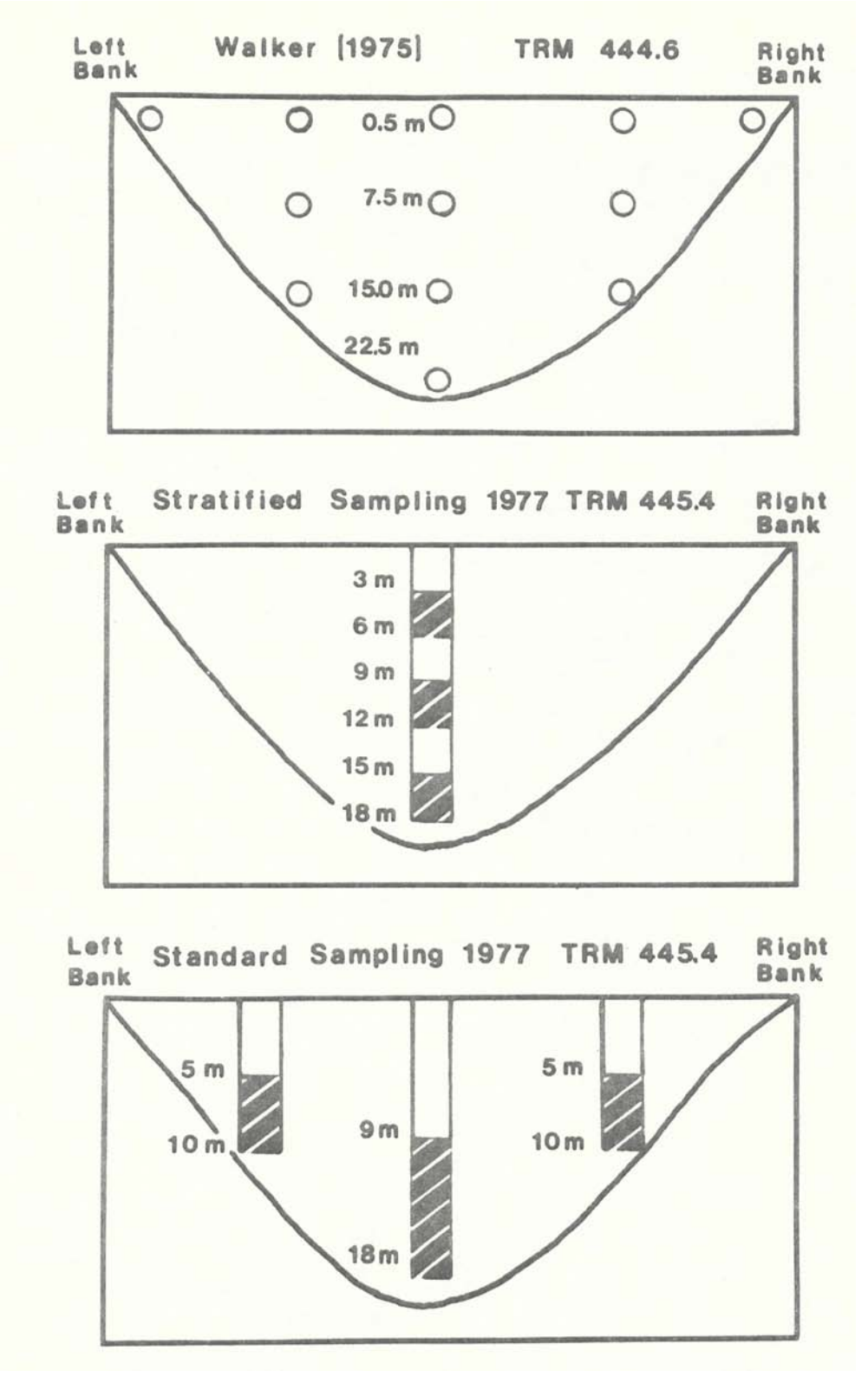

Figure 2. Sampling schemes used by Walker (1975) and for stratified and standard sampling in 1977.

stratified samples were taken. Two strata within each station were sampled. At the mid-channel station, 0 to 9 m and 9 to 18 m strata were sampled. Shoreline sampling followed the 10 m depth contour (10 to 30 percent from shore) with the 0 to 5 m and 5 to 10 m strata sampled along each shoreline.

In Walker's (1975) study, 0.5 m conical nets (0.8 mm mesh) were towed at constant depths for 5 min. Towing speed was approximately 0.6 m/s. Five stations and up to four depths were sampled weekly May 6 to July 22, 1974.

Samples were collected both day and night with nets towed in an upstream direction. Flowmeters mounted in the mouth of the nets were used to estimate volumes filtered.

The 1977 samples were preserved immediately upon collection in 10 percent Formalin and returned to the laboratory for processing. Eggs and larvae were identified to the lowest possible taxan using polarized stereomicroscopy and the key of Hogue *et al.* (1976). All fish were measured to the nearest 1 mm total length (TL). Densities were calculated as number/1,000 m^3 and were weighted by volume filtered. Only data from mid-channel stations from each of the sampling regimes were compared.

RESULTS AND DISCUSSION

Because of the short period stratified sampling was conducted, only a limited number of taxa were collected. Of these, clupeids and drum, *Aplodinotus grunniens*, larvae constituted 87.9 percent of the catch and were the only taxa used in the comparison of the various sampling methodologies.

Clupeid Larvae

Members of the family Clupeidae in Nickajack Reservoir are the skipjack herring, *Alosa chrysochloris*; gizzard shad, *Dorosoma cepedianum*; and threadfin shad, *D. petenense*. Gizzard shad is the most abundant clupeid in the reservoir while skipjack herring is the least abundant of the three.

Clupeid larvae occurred from April 18 to August 22 in 1977 and were present on all dates of stratified sampling. Larvae in stratified samples ranged from 3 to 32 mm TL.

The pattern of clupeid distribution found in stratified samples (Figure 3) was a strong surface orientation during the day tending toward a uniform distribution at night. Mean densities for all strata combined were 555 and 351 per 1,000 m^3 for day and night samples, respectively. However, abundance of larvae was higher at night for all except the 0 to 3 m stratum. The very high density of larvae in surface waters during the day thus strongly influenced diel abundance estimates. Also, larvae less than 10 mm were more abundant during day than at night while the reverse was true for all larger larvae. Since the smaller larvae were more abundant, their contribution to density estimates was greater. The greater abundance of small larvae (less than 10 mm) during the day indicated that they were more active in the water column during the day, but were not able to effectively avoid the net. The greater abundance of larger larvae (greater than 10 mm) at night could be due to reduced net avoidance and/or diel movements into and out of channel areas.

Diel differences in abundance of clupeid larvae have been reported by many authors. Netsch *et al.* (1971) reported highest densities at night

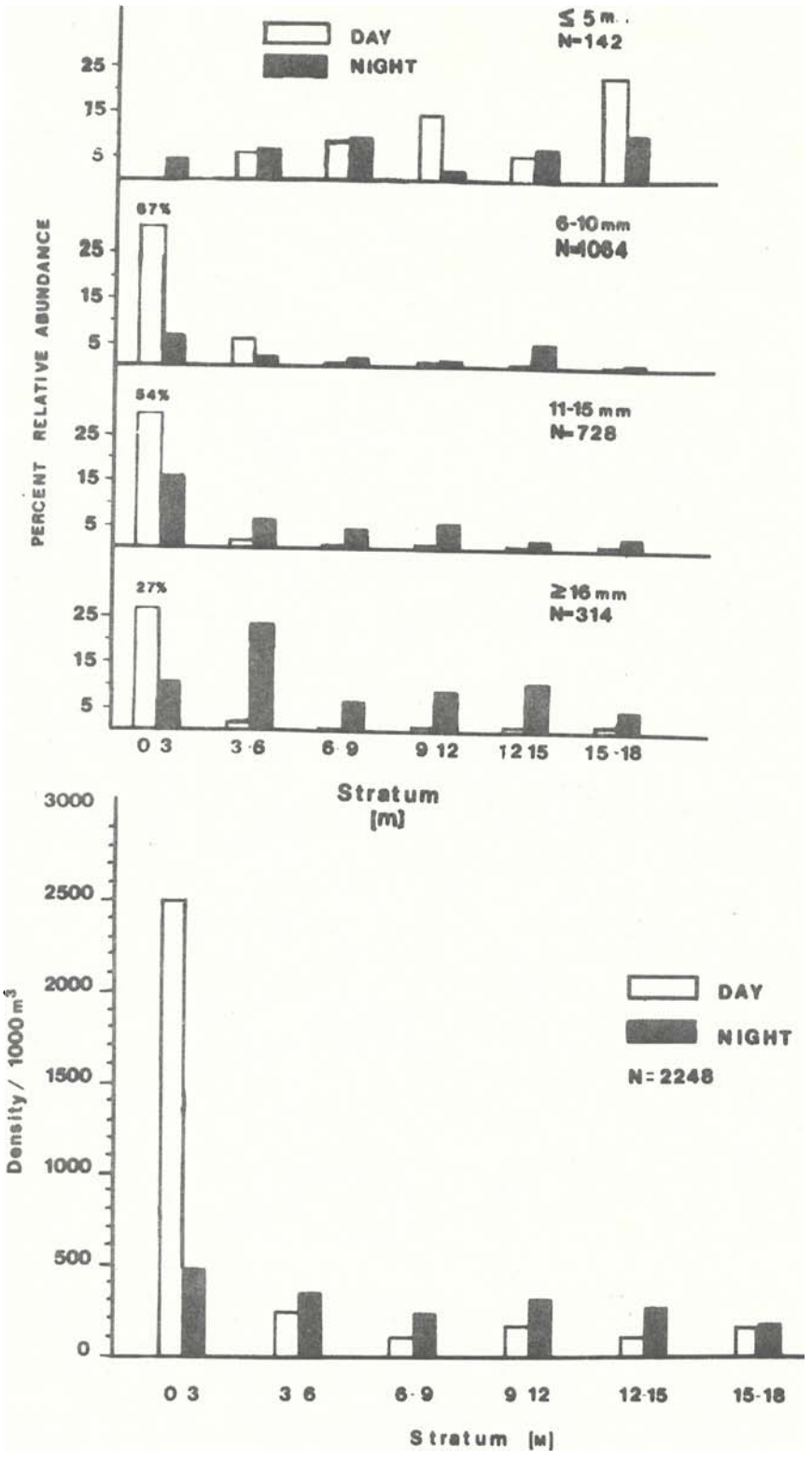

Figure 3. Relative abundance of clupeid larvae by length group and mean density by stratum for all clupeid larvae.

in Beaver Reservoir, Arkansas, and hypothesized reduced net avoidance at night as an explanation. Graser (in press) reported highest densities on the surface at mid-channel during dusk in the Cumberland River, Tennessee, and suggested "an active migration in response to the changing light stimulus." Several factors can influence density estimates (distribution, turbidity, temperature, size of larvae, gear type, and sampling technique); the nature of such influences is not well understood.

Shad less than 5 mm did not show the strong surface orientation displayed by the taxon as a group. Small larvae showed a trend toward deeper waters during day with a relatively uniform distribution at night. This is in conflict with the findings of Taber (1969) who found that small shad larvae were more abundant near the surface during day and night. However, he noted that small shad larvae were very weak swimmers. The lotic conditions in upper Nickajack Reservoir may have disrupted movements of these small larvae in Nickajack Reservoir.

The other length groups (6-10, 11-15, and greater than 16 mm TL) selected surface waters during day. Nocturnal distributions of these length groups were similar in that abundance was slightly higher toward surface. However, they differed in the relative abundance that the night catch contributed within each length group (Figure 3). The night contribution increased with increasing larval length, while the day 0 to 3 m samples decreased from 67 percent for 6 to 10 mm larvae to 27 percent for larvae greater than 16 mm TL.

Greater relative abundance in night catches among the larger larvae could be due to diurnal horizontal movements of the fish. Bodola (1966) stated that young gizzard shad moved into deeper waters as they grew

larger. Taber (1969) found that young shad were less abundant in shoreline seine samples at night than during day and hypothesized an offshore movement at night. Edwards *et al.* (1977) found that shad 20 mm and larger were most abundant in channel areas. Walker's (1975) data suggest no such horizontal movements, but length class information was not given.

Freshwater Drum

Drum larvae were present from April 18 to September 9 in 1977. Larvae collected in stratified samples ranged from 3 to 19 mm TL. Day/night drum densities were 368 and 650 per 1,000 m^3, respectively. Net avoidance during day may greatly influence abundance estimates. All sizes of larvae were collected in greater numbers in night samples than in day samples and differences were greatest for the larger larvae. Taber (1969) also found higher densities of drum at night, especially those larger than 5.0 mm TL.

Night distributions of drum larvae revealed steadily increasing density with depth (Figure 4). Day distribution showed a less precipitous increase in density with depth. The most prominent feature for day distributions was a sharp increase in density at the 3 to 6 m level. Densities within this stratum were the highest of all day samples for each sampling excursion. This pattern suggests a diurnal migration pattern whose upward movement is essentially confined to waters below the 3 m level.

Drum egg distributions tended to be highest toward the bottom at night, but were relatively uniform during day. Taber (1969) found a similar night distribution in Lake Texoma, but drum eggs were nearer the surface during

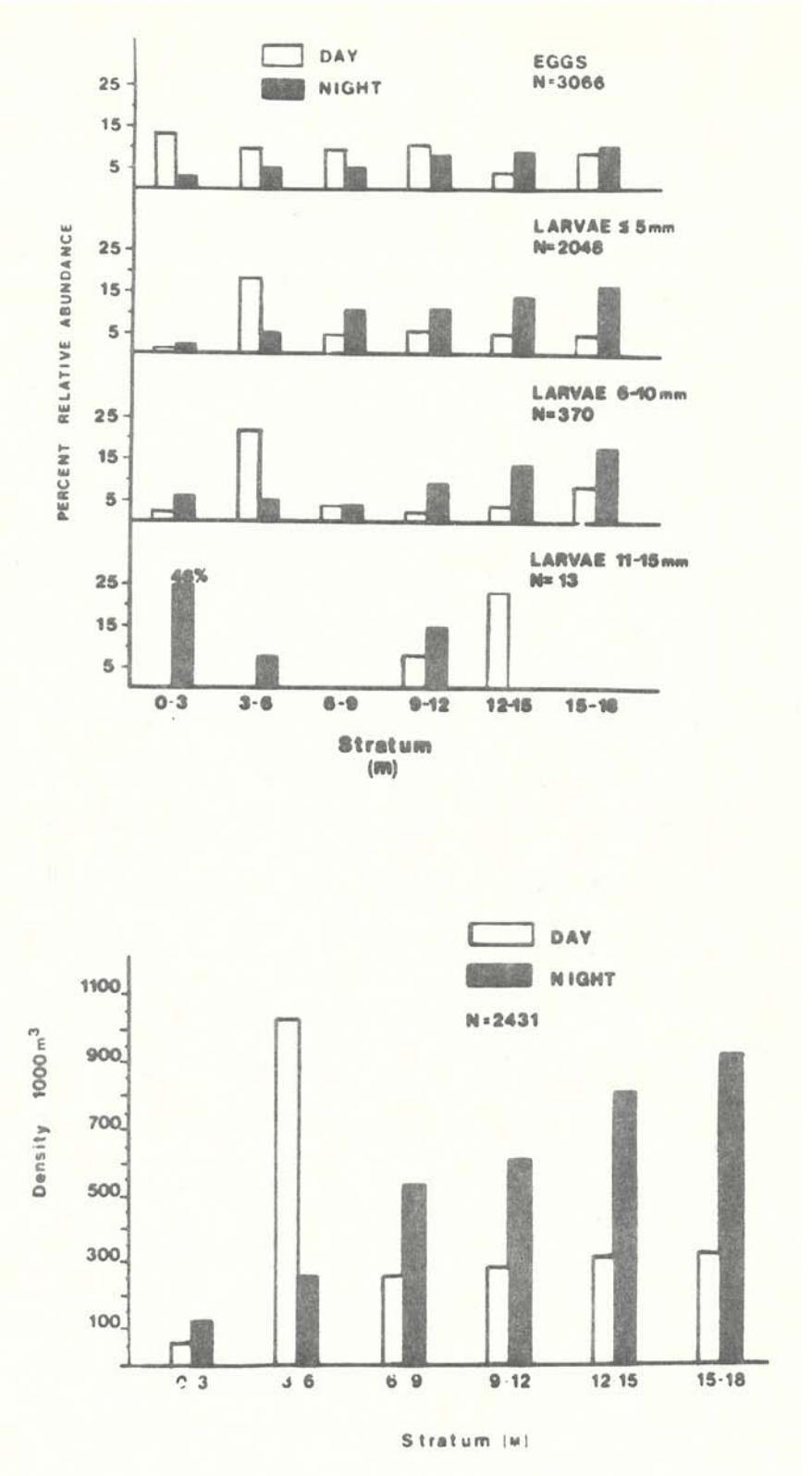

Figure 4. Relative abundance of freshwater drum, *Aplodinotus grunniens*, eggs and larvae by length group among strata and mean density by stratum for all drum larvae.

day. He proposed that drum spawning occurred at night in deep water and the semibouyant eggs ascended to shallower waters during the day. Riverine conditions in the upper reaches of Nickajack Reservoir could have disrupted stratification of semibouyant eggs. Nelson *et al.* (1967), working on Lewis and Clark Lake, collected drum eggs on the surface in calm water, but found that wave action could churn them to a depth of 15 ft.

Larvae 11 to 15 mm TL were few, but tended to be in upper strata at night and in deep strata during day. Diurnal migration was evidently strong for this group.

Distribution Factors

The vertical distributions of clupeid and drum larvae were distinctly different both day and night. During the day, shad larvae were concentrated at the 0 to 3 m level and densities declined with depth. Drum larvae were concentrated at the 3 to 6 m level during the day, and between 6 m and 18 m densities increased with depth. Shad larvae were concentrating in shallow waters at night while drum larvae increased in abundance with depth. These distributional patterns tended to separate the two taxa in space and time.

Several factors could have incluenced the vertical distribution of drum larvae. Thermal stratification has been shown by Netsch *et al.* (1971) and Edwards *et al.* (1977) to limit vertical distribution of clupeid larvae, but thermal stratification did not occur in the study area. It was unlikely that hydraulic conditions concentrated drum larvae at the 3 to 6 m level since this was not the case at night or for drum eggs at any time.

Swedberg and Walburg (1970) suggested that movements of juvenile drum were associated with changing food habits in Lewis and Clark Lake,

Missouri River. In order to determine if feeding patterns influenced the vertical distribution of drum larvae in Nickajack Reservoir, visual inspection of stomach and gut contents was made on all undamaged drum larvae sufficiently developed to ingest food items. Individuals were simply described as "food present" or "empty". Stomach and gut contents of 2,092 drum larvae were recorded (Table 1). No clear pattern of feeding with respect to depth of capture was found, but apparent differences in diel feeding were noted. Of the larvae examined from day samples, 75.2 percent had food present while 36.6 percent of drum guts from night samples had food present. However, an apparent shift occurred on successive dates so that by the end of July, night feeding of drum had increased from 29.1 percent to 60 percent, while daytime feeding decreased from 79.3 percent to 52.9 percent during the same period.

The influence of feeding on vertical distributions is difficult to evaluate. Clark and Pearson (in press) reported piscivory for very small drum (3 to 5 mm SL). They examined the guts of 3 to 5 mm SL drum from eight locations for four river systems and found piscivory by drum at all but one location. Also, 27.3 percent of all 3 to 5 mm SL drum with food in the gut contained larval fish. Less than 12 percent of the larvae they examined had empty guts. A greater portion (48%) of empty guts was observed in the present study; however, Clark and Pearson (in press) dissected individual guts while only visual inspection of intact larvae was made in this study. Food items found in larval drum from stratified samples included cladocerans, copepods, *Leptodora* spp., and clupeid larvae (one occurrence). The distribution of young drum did not coincide with that of small shad larvae and piscivory was rare, revealing that shad

Table 1. Diurnal feeding of drum larvae from stratified sampling in upper Nickajack Reservoir, 1977.

Date		Percent With Food	Percent Without Food	Number With Food	Number Without Food
6/1/77	Day	79.3	20.7	430	112
	Night	29.1	70.9	298	726
6/28/77	Day	68.4	31.6	186	86
	Night	70.0	30.0	152	65
7/27/77	Day	52.9	47.1	9	8
	Night	60.0	40.0	12	8
Overall	Day	75.2	24.8	625	206
	Night	36.6	63.4	462	799

larvae were not an important prey item for drum during the summer of 1977.

Comparison of Sampling Methods

Clupeids: Densities from stratified samples and Walker's (1975) work were similar, generally ranging between 100 and 600 per 1,000 m^3 (Figure 5). Densities of shad larvae estimated from standard samples were higher, ranging from 500 to 1,500 per 1,000 m^3. Densities found in stratified samples were lower than those from standard samples because stratified samples were taken after most shad were spawned.

Differences between seasonal densities reported by Walker (1975) and TVA's standard sampling methodology could be due to annual differences in abundance. However, the slower sampling speed (0.6 m/s vs. 1.0 m/s) used by Walker (1975) and the bridled net with smaller mouth area (0.196 m^2 vs. 0.25 m^2) probably resulted in underestimates of larval

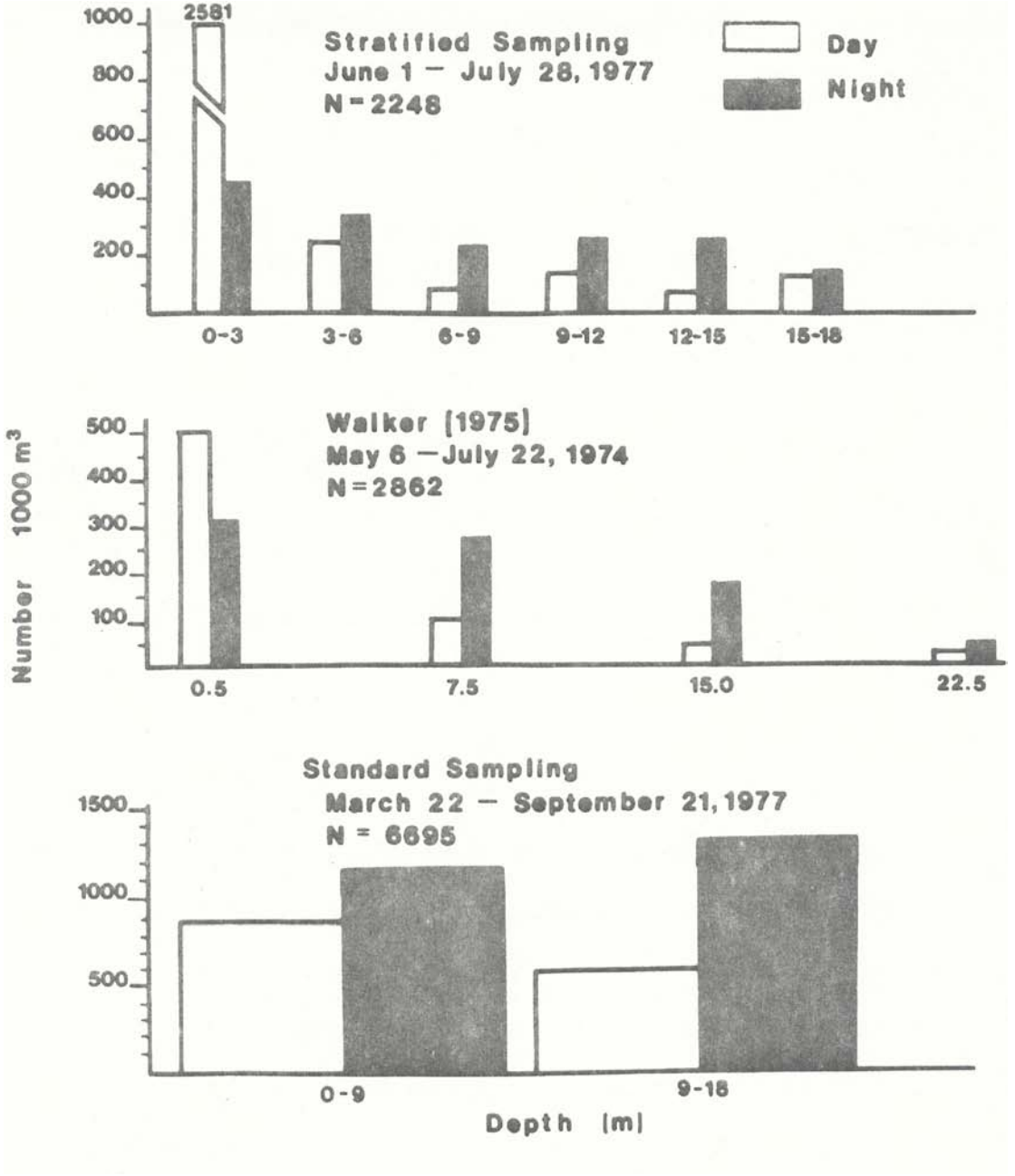

Figure 5. Diel distribution of clupeid larvae in upper Nickajack Reservoir as estimated by three sampling methodologies.

densities (Graser 1977) in his study.

Good agreement was found among distributions described by the three sampling methodologies. Exceptions were that night densities from the standard samples had slightly higher densities in the deep stratum than in the shallow stratum, while the opposite was true for the other sampling methodologies. Also, within the shallow stratum, night densities were higher than day densities for standard sampling.

Drum: Densities of drum larvae in stratified samples were higher than for other sampling methodologies (Figure 6), probably because stratified samples were taken when drum larvae were most abundant. Lowest densities were recorded by Walker (1975).

Night distributions found in 1977 by both stratified and standard sampling followed a similar pattern of increasing density with depth. Walker (1975) showed a more uniform vertical distribution. While he may have underestimated abundance because of limitations of gear type and sampling technique, the good agreement found for the shad data reveals that these limitations did not mask distributional patterns. It therefore seems likely that the night distribution of drum larvae reported by Walker (1975) was likely near the true distribution; *i.e.*, night drum distributions in 1974 probably differed from those in 1977.

Day distribution of drum larvae as described by the three sampling methods initially appeared to be different. Close inspection of the data revealed that they were actually consistent. Stratified samples and Walker's (1975) data show a gradual increase in density with depth. However, the abrupt increase in abundance at the 3 to 6 m level, if present in 1974, was not identified by the constant-depth sampling conducted that

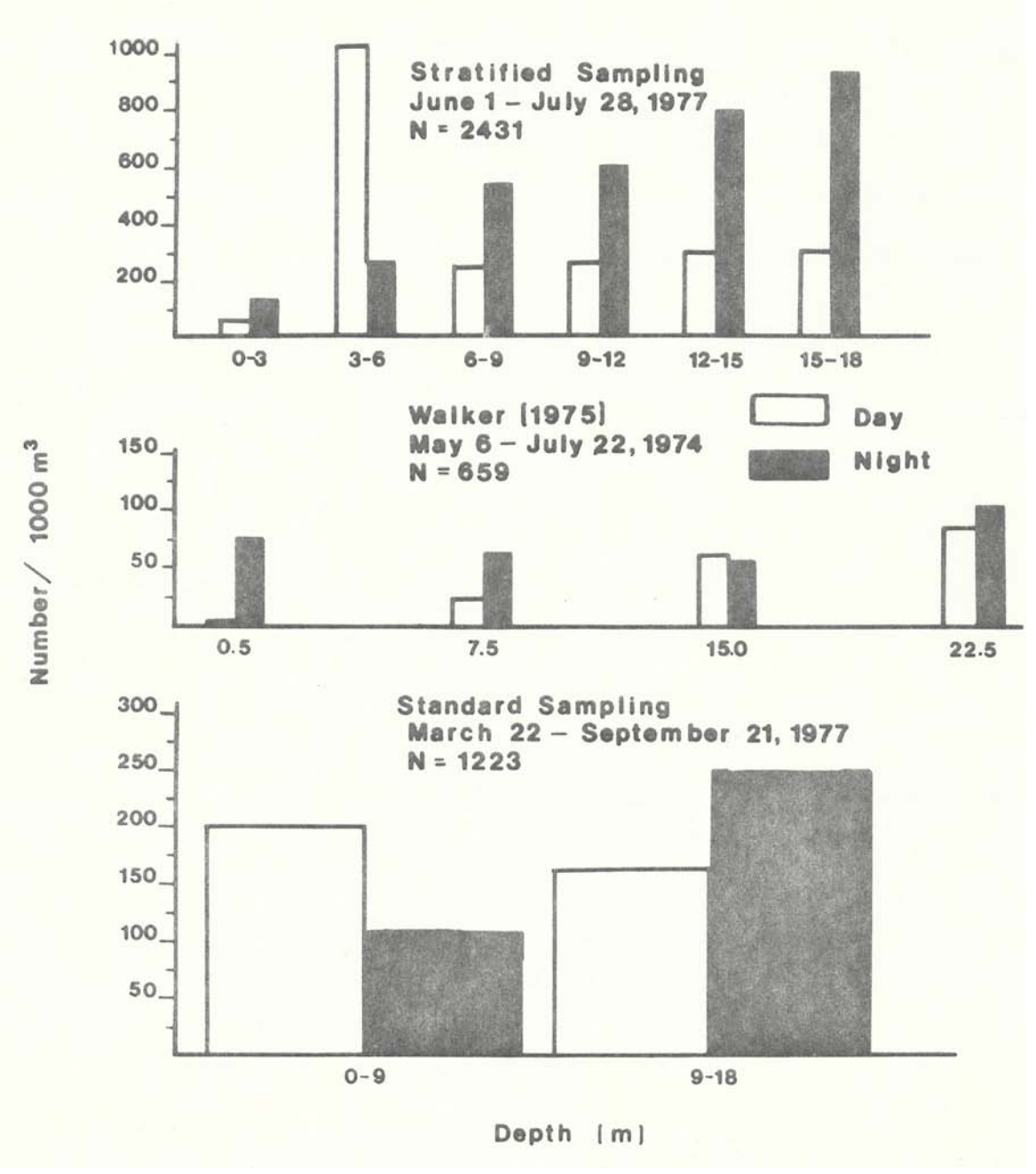

Figure 6. Diel distribution of freshwater drum, *Aplodinotus grunniens*, larvae in upper Nickajack Reservoir as estimated by three sampling methodologies.

year. Data from standard samples in 1977 appear to be the opposite of those found by Walker (1975), *i.e.*, highest densities in shallower waters versus highest densities in deeper water. However, these standard samples, taken in the shallow (0 to 9 m) stratum, were apparently strongly influenced by the abundance of larvae at the 3 to 6 m level. Walker's (1975) samples did not include any portion of that stratum.

Evaluation of Sampling Schemes

The discrete depth sampling method used by Walker (1975) and others (Netsch *et al.* 1971, Edwards *et al.* 1977, Taber 1969) provides a maximum of information for the depth the net is towed since the entire sample comes from the selected stratum. If ichthyoplankton distribution is a continuum from lowest to highest density, a few discrete depth samples may yield a reasonable estimate of that distribution. The weakness of discrete-depth sampling is the loss of vertical integration. Such sampling may miss strata with high concentrations of larvae and thus result in poor estimates of abundance and misinterpretations of distributional patterns.

The standard sampling conducted on Nickajack Reservoir in 1977 utilized a vertically integrated sampling design with few strata. This technique is useful for estimating abundance and requires a minimal number of samples. Although the full water column is sampled, strata of greatest abundance may not be identified.

A highly stratified design employing oblique sampling is the best method of obtaining precise vertical distribution data while retaining the advantages of full integration of the water column. Unfortunately, the

highly stratified design requires more effort. Workers will have to weigh the advantages against the cost for individual studies, but oblique samples will almost always be preferable to an equal number of discrete-depth samples.

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BURBOT - LARVAL EVIDENCE FOR MORE THAN ONE NORTH AMERICAN SPECIES

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ABSTRACT

Historically, the burbot of North America had been described as more than one species, but by the latter part of the 19th century all, including the Eurasian burbot, were generally recognized as one circumpolar holarctic species. During the last few decades, the burbot has been considered by some authorities to exist as three subspecies: Lota lota lota in Eurasia, L. l. leptura in eastern Siberia and northwestern North America, and L. l. lacustris (= maculosa) in central and northeastern North America. However, the more recent literature suggests that recognition of these subspecies may be unwarranted. Most systematic work to date has been restricted to adult forms, but we have dramatic evidence based on burbot larvae that, with further study, might lead to the recognition of more than one species, or subspecies, but not corresponding to the aforementioned subspecific designations. There appear to be two distinct larval forms. One is well pigmented with melanophores even as a late embryo and appears to be common to both Europe and North America. The other is without any melanophore pigmentation during the protolarval phase, except for the eyes and dorsal surface of the air bladder, and appears to be restricted to the lower Great Lakes and their tributaries.

INTRODUCTION

Lota lota, commonly known as the burbot, ling, lush, lake lawyer, metling, dogfish, eelpout, mother-of-eels, *etc.*, is the only freshwater member of the Gadidae or cod family (Figure 1). It is a circumpolar holarctic species typically inhabiting the depths of lakes and cooler rivers and streams. In North America it is found as far south as the

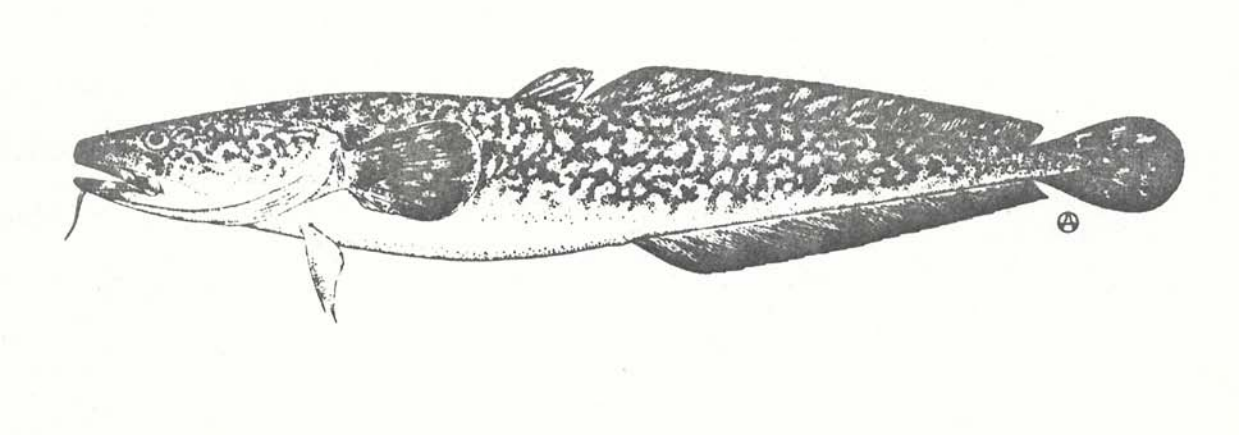

Figure 1. *Lota lota* adult, 510 mm TL from Lake Opeonge, Ontario. Reproduced from Scott and Crossman 1973, page 641.

Missouri and Ohio River systems. The species can be characterized as a relatively large, negatively phototropic, piscivorous carnivore. It is valued by many, when caught during the winter or in cold waters, for its firm, white, delicately flavored flesh (similar to lobster when boiled), and for the exceptionally rich Vitamin A and D content of its liver oil. (Baxter and Simon 1970, Clay 1975, Eddy and Underhill 1974, Hubbs and Lagler 1958), Lindsey 1956, Lo-Chai 1969, McPhail and Lindsey 1970, Moore 1917, Pflieger 1975, and Scott and Crossman 1973).

The burbot is most frequently reported to spawn at twilight or during the night from January to mid-April in the shallows of lakes, usually under ice, and to a lesser extent in streams. It is also suspected to spawn in the depths of lakes. The fish have been observed to spawn as individual pairs but more frequently in large, relatively dense, spawning aggregations, and occasionally in a very compact "withering ball" of about a dozen fish. During the spawning season large females may, based on fecundity studies, scatter more than a million eggs over gravel or sand substrates. The eggs are semibuoyant, clear with a large oil globule, and, when water hardened, typically measure 0.9 to 1.3 mm in diameter, with a with a reported range of 0.8 to 1.9 mm or more. Incubation requires about four to six weeks at 6 to 2 C (Bailey 1972, Baxter and Simon 1970, Bjorn 1939, Breder and Rosen 1966, Cahn 1936, Fabricius 1954, Hewson 1955, Lo-Chai 1969, McCrimmon 1959, McPhail and Lindsey 1970, Miller 1970, Prince and Halkett 1906, and Scott and Crossman 1973).

The young hatch as protolarvae (Snyder 1976) at about 3 to 4 mm total length (TL) and transform to the mesolarval phase at about 8 to 9 mm TL. Protolarvae and early mesolarvae are most readily identified by a large myomere count of about 55 to 65, 14 to 21 of which are preanal, and

a ventral finfold that continues unbroken below the vent region (Figures 2, 3, and 5). The earlier stages typically carry a large oil globule with the yolk, while later stages exhibit pelvic buds below or anterior to the pectoral fins and a bulky coil in the gut. Later mesolarvae, metalarvae and juveniles can be easily distinguished by a single medium chin barbel, a short first dorsal fin, long second dorsal and anal fins (over 60 rays each) which extend onto the caudal peduncle, and a proterocercal (diphycercal) caudal fin (Figure 4).

Historically, the burbot has been described as more than one species. LeSueur in 1817 described what he believed to be two species of burbot from the Connecticut River in Massachusetts. These were similar to but considered distinct from the European species. Additional descriptions and species designations followed but in 1862 Gunther concluded that all, including Old and New World forms, were indeed but one universal species. Thereafter it was generally accepted that only one species inhabited North America. But, since the American burbot differs in vertebra counts and predorsal lengths, not all ichthyologists agreed that the burbot should be considered one holarctic species. This difference of opinion was sustained well into the 20th century (Fish 1930). In 1941, Hubbs and Schultz, though recognizing one species, described and designated three subspecies: *Lota lota lota* of Eurasia, *L. l. leptura* of northwestern North America and eastern Siberia, and *L. l. maculosa* (*L. l. lacustris*, Speirs 1952) of central and eastern North America. Lo-Chai (1969) agreed with the designations. Differentiation was based on the shape of the caudal peduncle, predorsal length, and various meristic values. However, since these characters appear to be clinal with relatively broad areas of integradation,

Berg (1949) and Pivnicka (1970) considered *L. l. leptura* as a form of *L. l. lota* and Lindsey (1956), Lawler (1963), McPhail and Lindsey (1970), and Scott and Crossman (1973) considered recognition of any subspecies unwarranted without more intensive taxonomic study.

LARVAL EVIDENCE

Most systematic work to date has been restricted to the adult forms. But we have dramatic evidence based on burbot eggs and larvae that, with further study, might lead again to the recognition of more than one species, or at least subspecies, but not corresponding to the aforementioned subspecific designations. Fish (1930) recognized and pointed out the potential significance of this larval evidence, but the evidence seems to have been ignored. She found that the melanophore pigmentation of the eggs and larvae of the European burbot, as described by Sundevall (1855) and Ehrenbaum (1911), differed markedly from that of the American form. The late embryos and recently hatched protolarvae of the European burbot were described and illustrated as having considerable pigmentation along the dorsal surface of the head and body, over the dorsal surface of the gut, and on the lateral and ventral surfaces in the stomach or yolk region (Figure 2). Subsequent descriptions and illustrations of European protolarvae and mesolarvae by Nordqvist (1915) and Kasansky (1928) were similar but included additional pigmentation along the mid-ventral surface posterior to the vent. In contrast to the European larvae, Fish (1929, 1930 and 1932) found burbot protolarvae from Lake Erie to be totally without melanophore pigmentation except in the eyes and, in later protolarvae, over the air bladder (Figure 3). The only additional melanophores on a

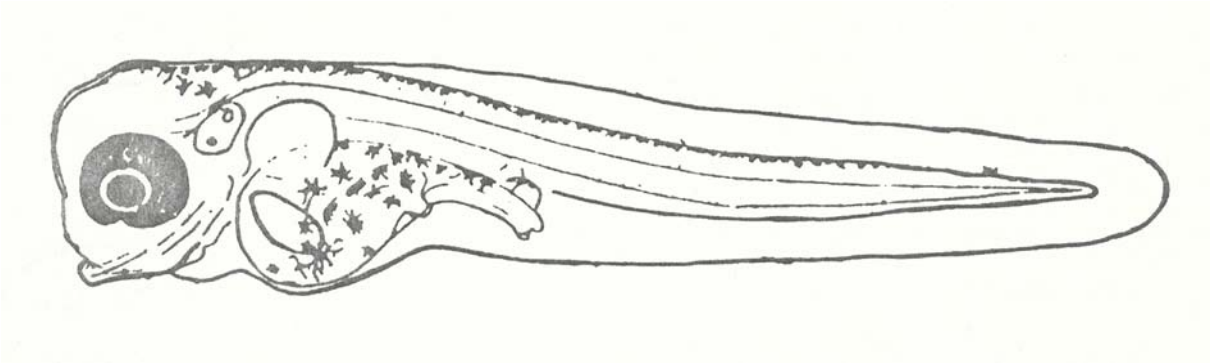

Figure 2. *Lota lota* protolarva, 5 mm TL from Europe. Reproduced from Ehrenbaum 1909, Figure 98, page 274.

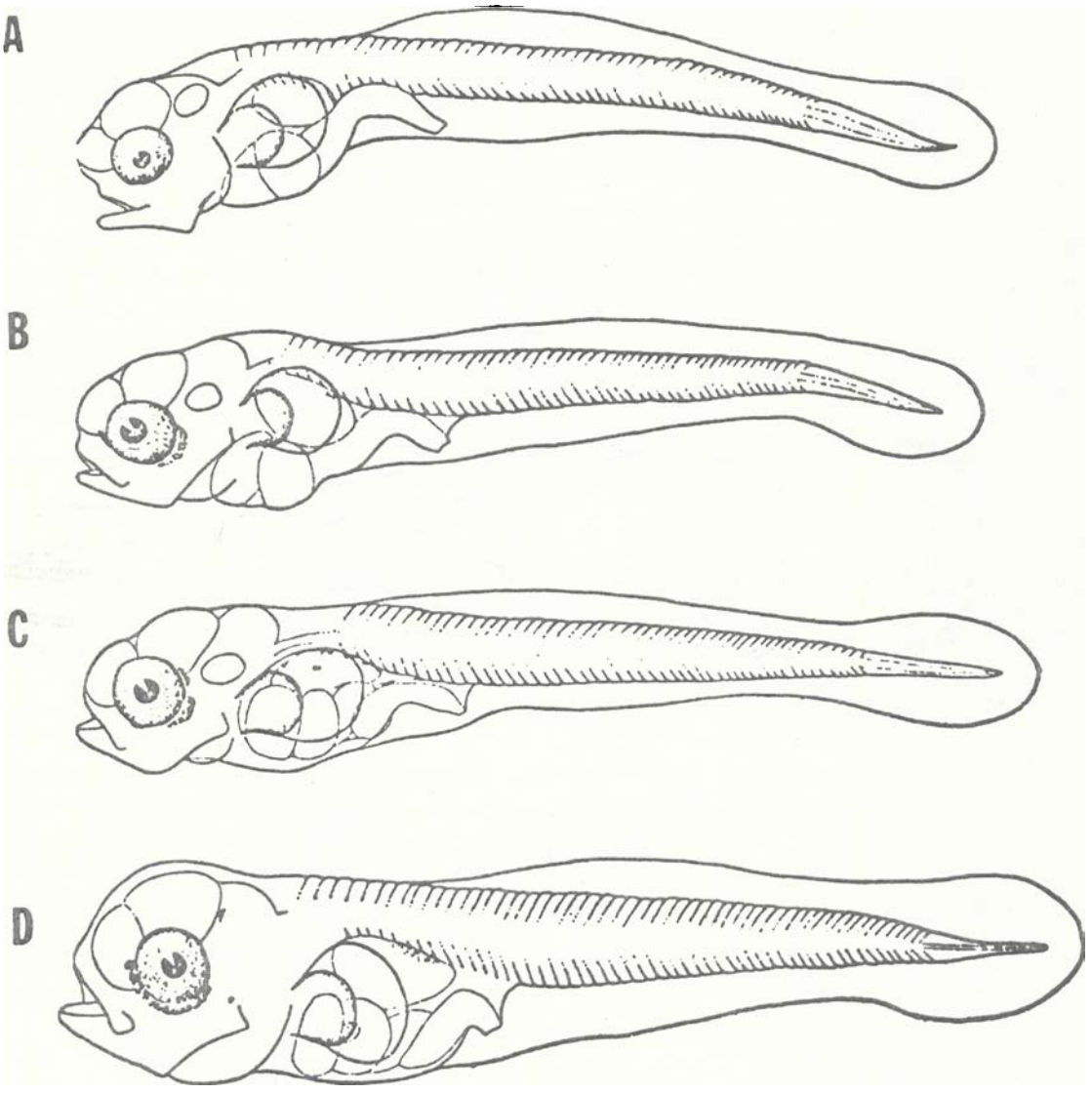

Figure 3. *Lota lota* protolarva, 3.5 (A), 4.5 (B), 6.0 (C), and 6.8 mm TL (D) from Lake Erie. Reproduced from Fish 1932, Figures 138-141, pages 393 and 394.

10.9 mm total length (TL) mesolarva were found on top of the head, followed by barely discernable subsurface pigmentation over the anterior portion of the notochord, and possibly continuing for its entire length (Figure 4). Melanophore pigmentation was considerable over the dorsal and lateral surfaces of 14- and 19-mm TL specimens, but Fish neither described nor illustrated pigmentation on the ventro-lateral and ventral surfaces. The ventral surface of a 30.5-mm TL specimen remained "unmarked except for a double series of about 20 chromatophores along the base of the anal fin." Fish apparently assumed that the numerous Lake Erie specimens she examined were representative of the early developmental stages of all American burbot. This is not the case.

Other biologists working with larvae of the American burbot have either ignored pigmentation or failed to note it in published form. Faber (1967 and 1970) and Clady (1976) published on the distribution of burbot larvae in Wisconsin Lakes, Lake Huron and Oneida Lake, respectively, but neither described the larvae or mentioned pigmentation. Miller (1970) noted that burbot larvae he collected in Wyoming were comparable to those described by Fish from Lake Erie, but in a personal communication to me, he related that he failed to mention pigmentation and that melanophore distribution was similar to that illustrated in Figure 5. Grant Hagen provided several photographs of burbot eggs and larvae in 1952 in an unpublished report to the Wyoming Game and Fish Commission, "Ling hatching experiment, Cokeville." All were pigmented in a manner similar to that illustrated in Figure 5.

During the past few years, I have had an opportunity to examine cultered burbot embryos and protolarvae from Wyoming and collected protolarvae and

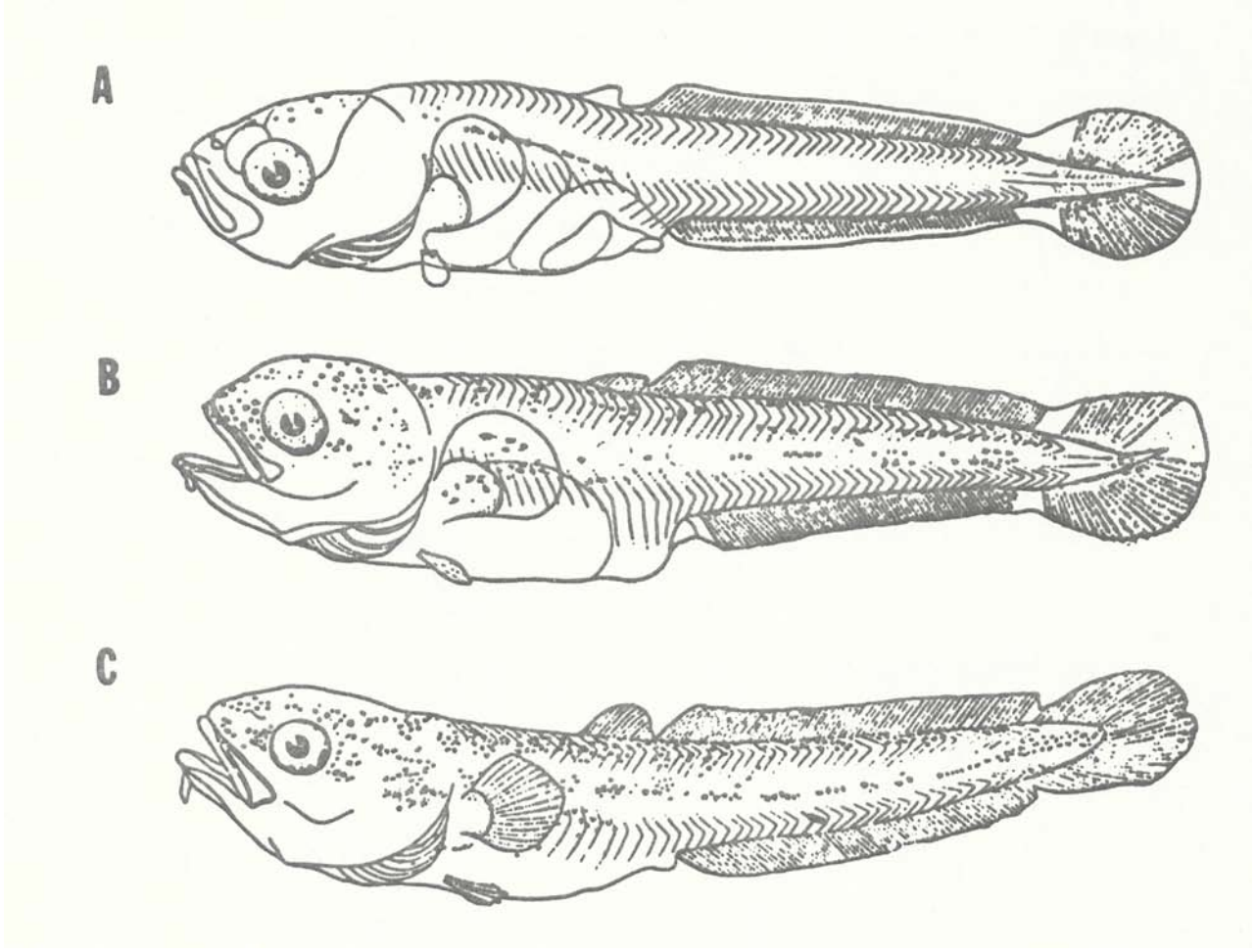

Figure 4. *Lota lota* mesolarvae, 10.9 (A) and 14 mm TL (B), and metalarva (?), 19 mm TL (C) from Lake Erie. Reproduced from Fish 1932, Figures 142-144, pages 395 and 396.

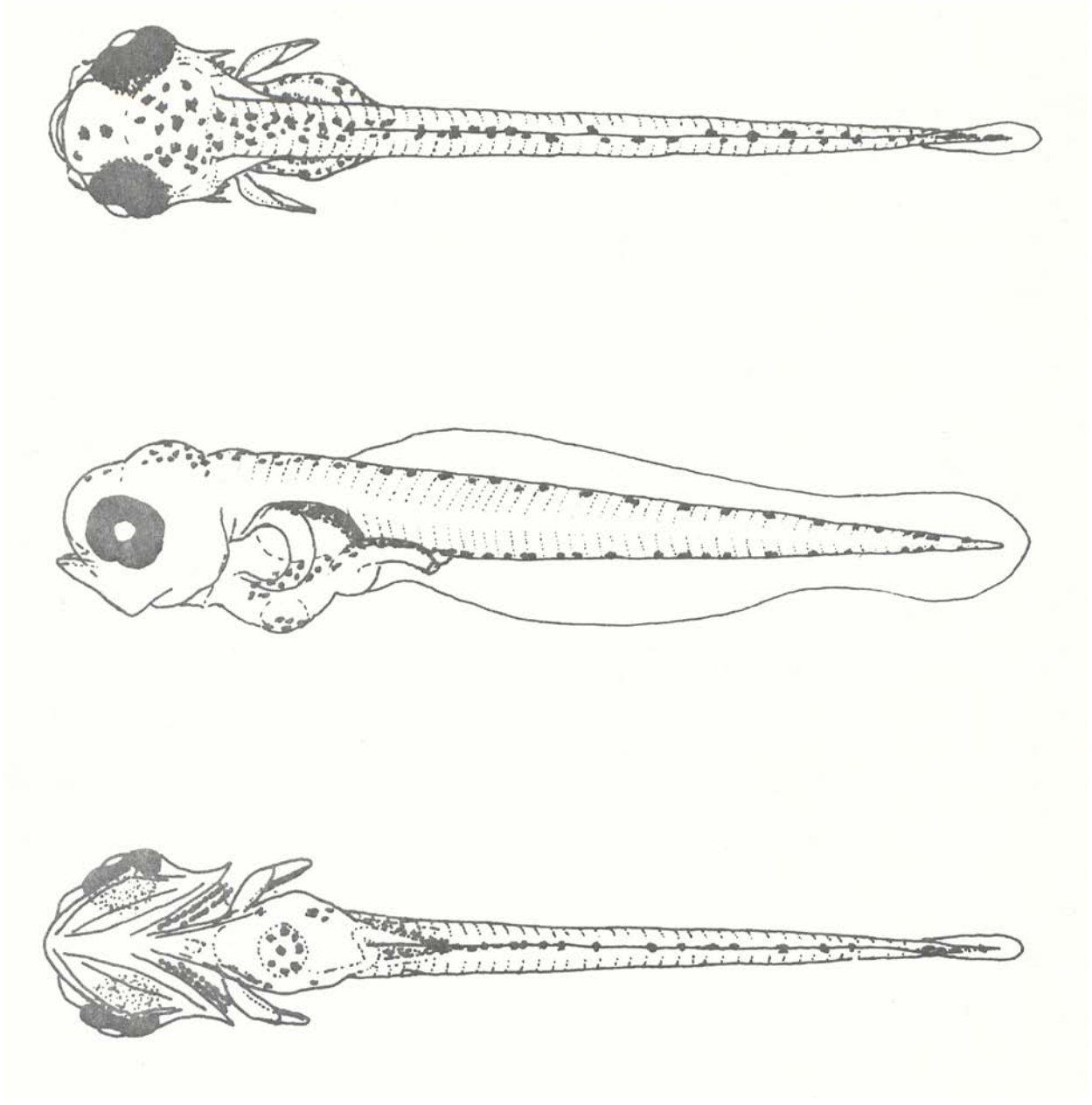

Figure 5. *Lota lota* protolarva, 4.7 mm TL from Mississippi River, Minnesota.

mesolarvae from the Missouri River in North Dakota, Mississippi River in Minnesota, Chippewa River in Wisconsin, Genessee River and Oneida Lake in New York, and Lakes Superior, Michigan, Erie, and Ontario. Of these, only a protolarva from the Lake Ontario tributary, the Genessee River, was of the unpigmented form described by Fish. All others were pigmented with most approximating the form of the upper Mississippi River protolarva illustrated in Figure 5 and described for the European burbot by Nordqvist (1915) and Kasansky (1928). Some exhibited reduced pigmentation on the ventral surface posterior to the vent, approaching the condition described and illustrated by Ehrenbaum (1905) (Figure 2). Pigmentation on recently collected specimens from Lake Erie was generally reduced to a state somewhat intermediate to the typical pigmented and unpigmented forms.

CONCLUSIONS

It appears that there are at least two distinct larval forms of burbot. One form is well pigmented, even as a late embryo, and appears to be common in Europe and North America (I have not yet seen larvae or descriptions of burbot from northwestern North America or the Soviet Union). The other form remains essentially unpigmented until well into the mesolarval phase and has been observed thus far only in Lake Erie and the Genessee River (tributary to Lake Ontario). Specimens recently collected in Lake Erie are somewhat intermediate.

Do the two extreme forms represent distinct species or subspecies? Are the recently collected "intermediate" specimens from Lake Erie a variation of the unpigmented form described for the Lake Erie burbot by Fish (1930)? Or do they represent hybridization between the two forms

and/or the near loss of the unpigmented form? Is the unpigmented form, apparently common throughout Lake Erie half a century ago, approaching extinction due to man's activities, as is (or was) the case for the blue pike (*Stizostedion vitreum glaucum*)?

Or do we simply have one species which exhibits unprecendented variation in embryonic and larval pigmentation? The larvae of the burbot's many marine relatives are often distinguished by relatively subtle differences in pigmentation (Hardy 1978).

To answer the above questions, and others, it will be necessary to examine many more larvae from throughout North America, Europe, and northern Asia, to study in detail other larval characters, and to try to correlate differences in the larvae with differences in the adults. Emphasis on the systematics of the burbot should focus immediately on both the adults and larvae in the Great Lakes region of North America. If there are two distinct genetic forms and one is restricted to the lower Great Lakes, we may lose the latter form to man-caused extinction before we know it exists.

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I also thank Dr. Robert Behnke, Dr. Clarence Carlson, Edmund Wick and Maryann Snyder, all of Colorado State University, for critically reviewing the manuscript.

ADDENDUM

At the end of this paper is a special form entitled "*Lota lota*, burbot. Contributed notes on early developmental stages." I am maintaining a file of these "notes" on larvae from all locations. Individuals who have collected burbot larvae and wish to contribute their observations should make photocopies of the blank form and supply as much of the requested information as possible. The sources of all information used in publications will of course be duly acknowledged.

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Lota lota, Burbot
Contributed notes on
early developmental stages

Please print clearly and use a separate photocopy of this form for each developmental phase (Snyder 1976) and/or general location.

Specimen Data

Developmental Phase:_____
Number:_____ Size Range:_____mm TL

If time permits, any of the following information for one or more specimens would be appreciated.

Lengths (mm)

Total	___	___	___
Standard	___	___	___
Snout (Sn)* to Eye*	___	___	___
Sn* to Pectoral bud or fin*	___	___	___
Sn* to Pelvic bud or fin*	___	___	___
Sn* to Dorsal finfold*	___	___	___
Sn* to Dorsal fin*	___	___	___
Sn* to Preanal finfold*	___	___	___
Sn* to Air bladder*	___	___	___
Sn* to Vent'	___	___	___
Eye	___	___	___
Yolk	___	___	___
Oil Globule	___	___	___
Pectoral bud or fin	___	___	___
Pelvic bud or fin	___	___	___

Body Depths (mm)

Posterior margin of eye"	___	___	___
Posterior margin of vent"	___	___	___

Myomeres

Preanal (as per Siefert '69)	___	___	___
Postanal	___	___	___

*origin or anterior margin.
'posterior margin.
"just posterior to, excluding finfold or fin.

(Place any additional notes on reverse side.)

Illust. typical pigmentation by completing the generalized drawings regardless of developmental stage. Atypical pigmentation should be illustrated on separate forms.

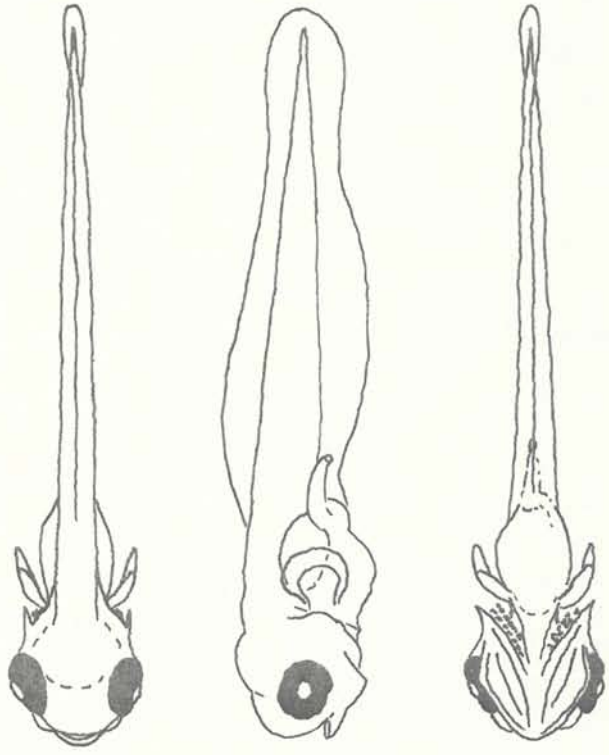
Collection Data

State:_____ County:_____
Body of water:_____

Specific location:_____

Distribution within study area:_____

Dates:_____
Water temperatures:_____



Contributor (Name, affiliation, address and phone):_____

Specimens available for study via loan (___) or donation (___).
Mail form(s) to above address c/o Darrel E. Snyder. Sources of data or specimens used for publication will be duly acknowledged.

LARVAL FISH WORKSHOP AGENDA

Western Kentucky University
Bowling Green, Kentucky
February 20-21, 1979

Tuesday, February 20, 1979

8:30 a.m.

Schneider Hall -- Welcome Robert D. Hoyt
Western Kentucky University

Observations on the Larval Ecology of the Smallmouth Buffalo.

Robert D. Hoyt, Gary J. Overmann, and Greg A. Kindschi
Department of Biology
Western Kentucky University
Bowling Green, Kentucky 42101

Identification of Larval Sunfishes (Centrarchidae:Elassomidae) from Southern Louisiana.

John V. Conner
School of Forestry and Wildlife Management
Louisiana State University
Baton Rouge, Louisiana 70803

Myomere and Vertebra Counts of the North American Cyprinids and Catostomids.

Darrel E. Snyder
Larval Fish Laboratory
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

10:00 a.m. Coffee Break

10:30 a.m.

Larval Development of the Greenside Darter, Etheostoma blennioides newmanii.

James M. Baker
Tennessee Valley Authority
F. F. & W. D.
Norris, Tennessee 37828

Materials for a Description of Lake Chubsucker, (Erimyzon sucetta), Larvae.

Lee A. Fuiman
Department of Biology
University of Mississippi
University, Mississippi 38677

Development of the Young of the Creek Chub, Semotilus atromaculatus.

Vincent R. Kranz
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North Central Operations
236 South Main Street
Stillwater, Minnesota 55082

Kenneth N. Mueller
Northern States Power Co.
Prairie Island Environmental Laboratory
Welch, Minnesota 55089

Susan C. Douglas
215 Charles Street
Pittsburgh, Pennsylvania 15210

12:00 Lunch

1:15 p.m.

Spatio-Temporal Distributions of Clupeid Larvae in Barkley Reservoir.

Lee F. Graser
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F. F. & W. D.
Norris, Tennessee 37828

Notes on the Larval Life History of Fishes in a Small Flood Control Lake in Kentucky.

Greg A. Kindschi, Robert D. Hoyt, and Gary J. Overmann
Department of Biology
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Bowling Green, Kentucky 42101

Temporal and Spatial Variations in Abundance and Species Composition of Larval Fishes in Center Hill Reservoir, Tennessee.

Richard A. Krause and Mike J. Van Den Avyle
Tennessee Cooperative Fishery Research Unit
Tennessee Technological University
Cookeville, Tennessee 38501

3:00 p.m. Break

3:30 p.m.

Vertical Distribution of Ichthyoplankton in Upper Nickajack Reservoir, Tennessee.

Jack D. Tuberville
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Burbot - Larval Evidence for More Than One North American Species.

Darrel E. Snyder
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(FOLLOWING PRESENTATIONS NOT INCLUDED IN PROCEEDINGS)!!!

Evaluation of Gear Used by Duke Power Company to Collect Ichthyoplankton.

Donald Cloutman
Duke Power Company
Environmental Laboratories
Huntersville, North Carolina 28078

5:00 Evening Meal

7:30 p.m.

Ichthyoplankton Investigations in the Chesapeake Bay Region.

Joe Mihursky
Center for Environmental and Estuarine Studies
Chesapeake Biological Laboratory
Solomons, Maryland 20688

8:30 p.m.

Open Discussion.

Wednesday, February 21, 1979

Schneider Hall

8:30 a.m.

Update on First Year's Activities of TVA's Regional Larval Fish Identification and Information Center.

Bob Wallus
Tennessee Valley Authority
F. F. & W. D.
Norris, Tennessee 37828

The Establishment of the Laboratory for the Identification and Study of North America's Freshwater Larval Fishes, Colorado State University.

Darrel E. Snyder
Larval Fish Laboratory
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

Fish Larvae Studies at the Great Lakes Research Division, University of Michigan, 1973 through 1978 and the Current Status of the Great Lakes Regional Larvae Collection (GLRFLC).

John Dorr and David Jude
Great Lakes Research Division
University of Michigan
Institute of Science and Technology Building
Ann Arbor, Michigan 48105

10:00 a.m. Coffee Break

10:30 a.m.

Snell Hall

Laboratory Specimen Examination

12:00 Lunch

1:15 p.m.

Laboratory Specimen Examination

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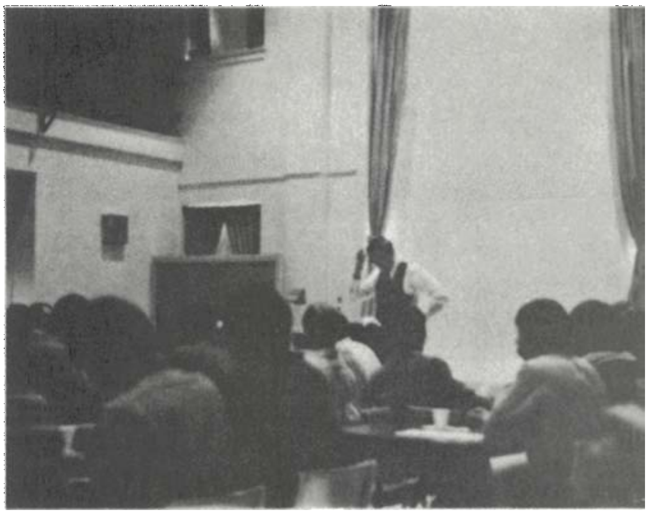
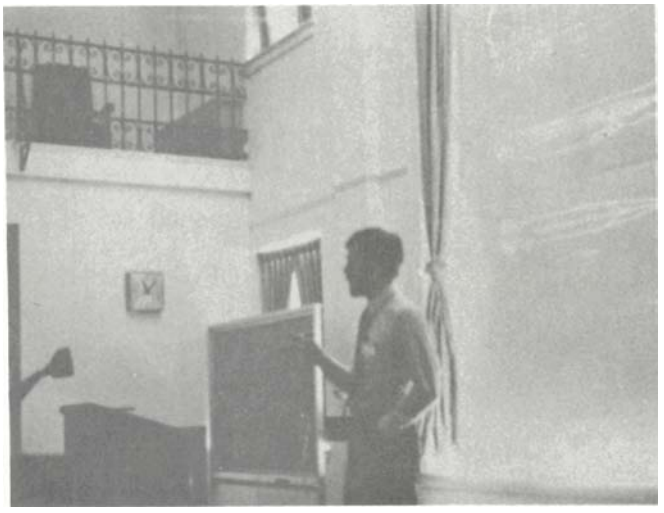


Ben Hoyt

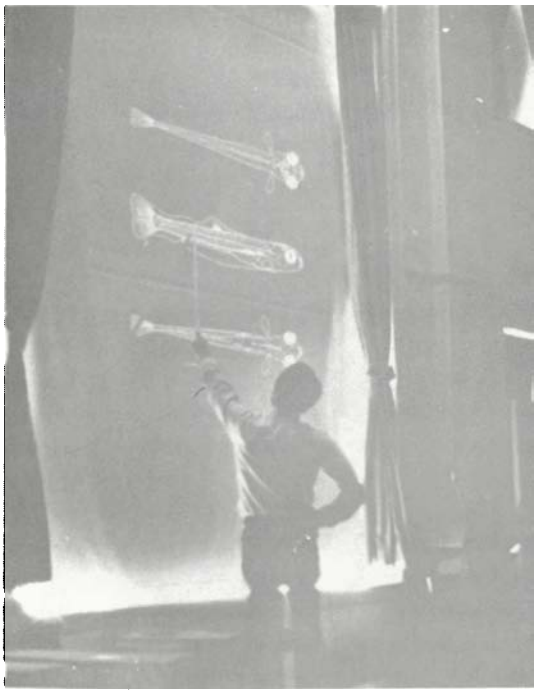
Jim Baker



Ken Mueller

Pan Chattanooga

Robert D Hoyt



John Van Connor