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PROCEEDINGS OF A WORKSHOP ON

FRESHWATER LARVAL FISHES

Tennessee Valley Authority

PROCEEDINGS OF A WORKSHOP ON

FRESHWATER LARVAL FISHES

Held at
Knoxville, Tennessee
February 21-22, 1978

EDITORS:
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Tennessee Valley Authority
Division of Forestry, Fisheries, and Wildlife Development
Norris, TN 37828
1979

This document is dedicated to the memory of Doyne Richard Martin, 1945-1977. Dick was a fisheries biologist with TVA for three years.

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PREFACE

On February 21-22, 1978, the Fisheries and Waterfowl Resources Branch, Division of Forestry, Fisheries, and Wildlife Development of the Tennessee Valley Authority sponsored and hosted a freshwater larval fish workshop in Knoxville, Tennessee.

The theme of the workshop was "Current Trends in Larval Fish Taxonomy and Early Life History Studies." Objectives were to:

1. discuss current problem areas in larval fish taxonomy;

2. discuss current research in other aspects of the early life history of freshwater fishes; and

3. share ideas as well as new laboratory and field techniques and methodologies.

The meeting consisted of one day of formally presented papers and one day of informal laboratory workshop.

Fifty-five individuals representing 29 agencies attended the meeting. Universities, consulting companies, private power companies, State and Federal agencies, museums, and research institutes were represented.

Of the 12 formal presentations made at this workshop, 9 are presented herein.

MORPHOMETRY AND ALLOMETRY:

IMPLICATIONS FOR LARVAL FISH TAXONOMY

by

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ABSTRACT

Basic principles and problems of relative body sizes of fishes are discussed. Allometry was observed in five species of sucker (catostomid) larvae. This non-linear relationship of one body part to another was common to nearly all species and morphometric parameters recorded. Log-log plots of morphometric data revealed a curvilinear relationship which was satisfactorily approximated by multiple regression lines. A character was constructed using the allometry data which provided better discriminating capabilities than the conventional character of percent total length. A method for graphic identification of species is also discussed.

INTRODUCTION

Basic types of characters useful in fish taxonomy are: meristic, morphometric, pigmentary, and specialized (i.e., peculiar to a given taxon). A fifth type, applicable to larval fishes, is size or age at a given developmental state and might be termed morphological. Meristic characters are most reliable in fish taxonomy because enumeration errors are frequently small and statistical manipulations are not difficult. Unfortunately, larval fishes have few significant countable structures. Pigmentary characters vary considerably with factors such as age, sex, and substrate color and are difficult to quantify for statistical treatment. Specialized and morphological characters are of limited value for similar reasons. In taxonomic studies morphometry is typically presented as percent of some standard. This method assumes that there is a constant ratio of a part of the body to the standard (isometry). This is not a valid assumption for many dimensions of larval fishes.

This investigation is a continuation of previous studies of larval fish development. In descriptions of three species of cyprinid larvae, Fuiman and Loos (1977, 1978) found allometric trends (i.e., body proportions varied with total length through the entire larval period). Other workers (Doan, 1939; Martin, 1949) have noted allometry in fish larvae, but most studies have dealt with only the later portion of the larval period. The present study is intended to reacquaint taxonomists with the principles and problems of relative body sizes in the light of recent interest in identification of larval fishes. Specific examples of allometric growth throughout the larval period are presented with suggestions for construction of useful characters from the data.

METHODS

Materials and data used in this study are part of a descriptive investigation of northeastern catostomids (Fuiman, 1978). Larvae were reared in a laboratory at 20 C with a 14 h daylight photoperiod. Measurements were made to the nearest 0.01 mm with a dissecting microscope and ocular micrometer. Four body dimensions, standard length (SL), preanal length (PAL), head length (HL), and eye diameter (ED), were selected as examples for this study. Data were grouped according to common integer values for total length (TL), e.g. all individuals of a species between 9.00 and 9.99 mm TL were grouped together. Mean values for each group were plotted on log-log coordinates. Points of inflection, indicating a change in growth stanza, were chosen by inspection. Regression lines were calculated using Bartlett's (1949) method because values of both variables

were subject to error [Kidwell and Chase (1967) systematically compared ten methods for fitting lines to relative growth data and concluded that Bartlett's method was most adequate]. Resulting equations were used to estimate more accurately the inflection points and to model changes in body proportions.

RESULTS AND DISCUSSION

Different types of plots of the data are used in studying relative growth. These must be defined at the outset to avoid confusion. Plots may be on linear or logarithmic coordinates. The proportional plot represents the *ratio* of a body part to the standard (TL). This is not to be confused with the plot of body part against the standard. As previously stated, isometric growth is the assumption underlying the present use of morphometric characters. In a case of isometry a linear plot of a body proportion against TL would yield a horizontal line, its intercept being the mean value of that character for the taxon. This is true only when the body part-TL plot is linear and passes through the origin. A non-zero intercept yields a curve, on the proportional plot, which is asymptotic to the mean value for the taxon (Marr, 1955). In allometric growth the proportional plot is logarithmic. If growth were assumed to be isometric, taxonomic difficulties could arise. For example, Taxa A and B are routinely distinguished by the following couplet:

Preanal length less than 70% TL..... A

Preanal length greater than 70% TL..... B

This character may have been based on discrete samples representing a small size range with mean PAL values of 65 and 75 percent, respectively (Figure 1). Alternatively, these values could have been derived from specimens occupying a growth stanza which approximated isometry but followed an allometric stanza. Examination of a broader size range in taxon B may indicate that growth is allometric (line B' of Figure 1). Therefore, specimens of taxon B smaller than X mm TL would be identified incorrectly according to the proposed couplet.

Allometry is predominant in the early growth (to 25 mm TL) of the five catostomid species studied. Huxley (1932) proposed the equation, $Y = bX^k$ as a model for relative growth. This equation is linear in its logarithmic form: $\log Y = k \log X + \log b$, where k is the growth coefficient and b is a constant related to the units of measure. Isometric growth is represented by this equation

when k = 1. Log-log plots of body parts against TL (Figures 2 and 3; Table 1) show allometric growth in nearly all species and body parts. Only SL and PAL of *Carpiodes cyprinus*, the quillback, and ED of *Hypentelium nigricans*, northern hogsucker, approximate isometric growth (k = 1.01, 1.01 and 0.97, respectively). Most k values are less than unity, indicating negative allometry (i.e., the body part grows at a slower rate than TL). Cases of positive allometry (k > 1) are restricted to increases in eye diameter and head length.

Multiple growth stanzas, i.e., intervals of growth with different rates of change (k values), are found in most of these graphs. They become apparent when straight lines are fitted to log-log plots of relative growth data. There are at least two stanzas for SL, PAL and HL measurements in each species except *Erimyzon oblongus*. Data for *H. nigricans* may be resolved into three stanzas for these same dimensions and into two stanzas for ED. Eye diameters of the remaining four species are represented by single allometric lines.

Martin (1949) explained growth stanzas as being the result of physiological changes in the organism. Change from an endogenous to exogenous food source would seem to be a major physiological crisis during the larval period. Size at which yolk is typically absorbed is noted by the letter "a" on the abscissae of Figures 2 and 3. These points do not correspond with changes in growth stanzas. Discontinuities may be a result of changes in measurement criteria (e.g. head length is measured to the posterior edge of the auditory vesicles until the cleithra ossify). Formation of hypural elements may affect relative growth plots of SL. These points are noted on their respective graphs by arrows and apparently do not cause the inflections (with the possible exception of SL in *H. nigricans*).

Growth stanzas may be an artifact of the linear approximation. Laird (1965) proposed the use of a Gompertz equation in relative growth studies. The resulting sigmoid curve includes a time component not found in Huxley's equation. Laird found that the curvilinear (Gompertz) relationship adequately describes the change in growth rate with time and that the use of multiple straight lines has no biological significance.

Parr (1949) suggested a method for taxonomic treatment of morphometric data which was based on body proportion vs. body length plots. Ratio plots of this nature prohibit statistical treatment and comparisons of the data (Marr, 1955). Complexity of the Gompertz equation ($W = -ae^{-be^{-kt}}$) precludes its use in taxonomy. Multiple linear approximations of log-log graphs may

provide sufficient accuracy for this purpose. Variability in these lines can occur in two forms: differences in slope and differences in intercept. Martin (1949) experimented in this regard and concluded that only severe internal or environmental crises can alter the slope. The intercept is sensitive to less drastic environmental changes. In general, when comparing two taxa, differing slopes indicate genetically based differences and unequal intercepts reflect non-genetic differences. Two possible methods for taxonomic use of allometric growth data follow.

A suitable discriminating character was chosen by superimposing the log-log plots of each species (Figures 2 and 3). Eye diameters of *C. cyprinus* and *E. oblongus* appeared to be the most widely separated lines. A discriminant would be a line which best segregated individual data points of the two species. This line would theoretically pass through the intersection of the species' regression lines and have a slope of intermediate value. It would determine an equal percentage of misidentified individuals for each species. The equation for the discriminant line was derived by an iterative procedure using computer analysis. Further accuracy of identification was achieved by limiting the range of TL. The following character is useful for separating these two species from hatching to 17 mm TL.

log ED (1.10 log TL - 1.27) ..... *C. cyprinus*

log ED (1.10 log TL - 1.27) ..... *E. oblongus*

Two measurements are required for this character (TL and ED). Necessary log transformations are simpler now with the widespread use of multiple function calculators. If this character were presented in the standard percent TL form it, too, would require two measurements and similar algebraic manipulation. Using the above couplet, 20 individuals (13.5%) were misidentified: 11 quillbacks (14.1%) and 9 creek chubsuckers (12.8%). Best discriminating capabilities occur at smaller sizes where the regression lines diverge. Little problem with identification can occur beyond 17 mm TL since both species are well developed and resemble juveniles at that size. Morphometric data for individual quillback larvae from Gerlach (1973, Table 4) were used to further test the efficiency of the log-log couplet. Six of 110 individuals (5.5%) smaller than 17 mm TL were misclassified. No data were available for creek chubsucker larvae.

The "standard" method of morphometric presentation yields poorer discriminating capabilities. Mean values of ED as percent TL are 6.24 and 7.26 for *C. cyprinus* and *E. oblongus* (to 17 mm TL), respectively. The best discriminant is a value of 6.75%. Twenty-six individuals (17.6%)

were misidentified: 14 quillbacks (17.9%) and 12 creek chubsuckers (17.1%). In this case the difference in misclassified individuals using the two characters is four percent. Other data may give rise to similar characters with even greater efficiency over the conventional method.

A simpler approach is the direct use of logarithmic graphs and regressions. When data are presented as in Figures 2 and 3, the taxonomist can easily compare his measurements with those in the graphs. Species determinations can be based on the proximity of a data point to a regression line. Confidence intervals for the regressions may be included on the graphs and would simplify taxonomic decisions.

Examination of the relative growth patterns in different species of fishes is important if morphometric characters are to be used to characterize the species. Allometry often affects relative dimensions of body parts, particularly at early developmental stages. This demands unconventional treatment if morphometry is to be used taxonomically. On the other hand, improper analysis of morphometric variation can lead to the conclusion of allometry from purely isometric data (Marr, 1955). When analyzed properly, morphometry can be a useful tool for the larval fish taxonomist.

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Table 1—Regression constants for morphometric data for five species of catostomid larvae (X = total length, Y = body part).

$$\log Y = \log b + k \log X$$

Body Part	1st Stanza log b	k	Inflection	2nd Stanza log b	k	Inflection	3rd Stanza log b	k
				Catostomus commersoni				
SL	0.06	0.92	12.2	0.30	0.71	-	-	-
PAL	0.13	0.77	16.0	0.35	0.59	-	-	-
HL	-1.69	1.82	21.0	-1.42	1.57	-	-	-
ED	-1.29	1.08	-	-	-	-	-	-
				Hypentelium nigricans				
SL	0.06	0.92	12.5	0.45	0.57	16.4	0.03	0.91
PAL	0.23	0.68	11.7	0.43	0.50	15.4	0.05	0.81
HL	-0.83	0.95	10.5	-1.83	1.93	17.9	-0.74	1.06
ED	-1.15	0.97	19.5	-1.33	1.08	-	-	-
				Moxostoma macrolepidotum				
SL	0.04	0.94	12.6	0.45	0.57	-	-	-
PAL	-0.04	0.94	10.7	0.23	0.67	-	-	-
HL	-1.49	1.62	11.0	-2.04	2.10	-	-	-
ED	-1.78	1.50	-	-	-	-	-	-
				Carpiodes cyprinus				
SL	-0.03	1.01	10.5	0.34	0.64	-	-	-
PAL	-0.16	1.01	14.2	0.58	0.37	-	-	-
HL	-1.41	1.70	11.0	-1.00	1.31	-	-	-
ED	-1.32	1.12	-	-	-	-	-	-
				Erimyzon oblongus				
SL	0.11	0.84	-	-	-	-	-	-
PAL	0.01	0.82	-	-	-	-	-	-
HL	-1.07	1.38	-	-	-	-	-	-
ED	-1.09	0.95	-	-	-	-	-	-

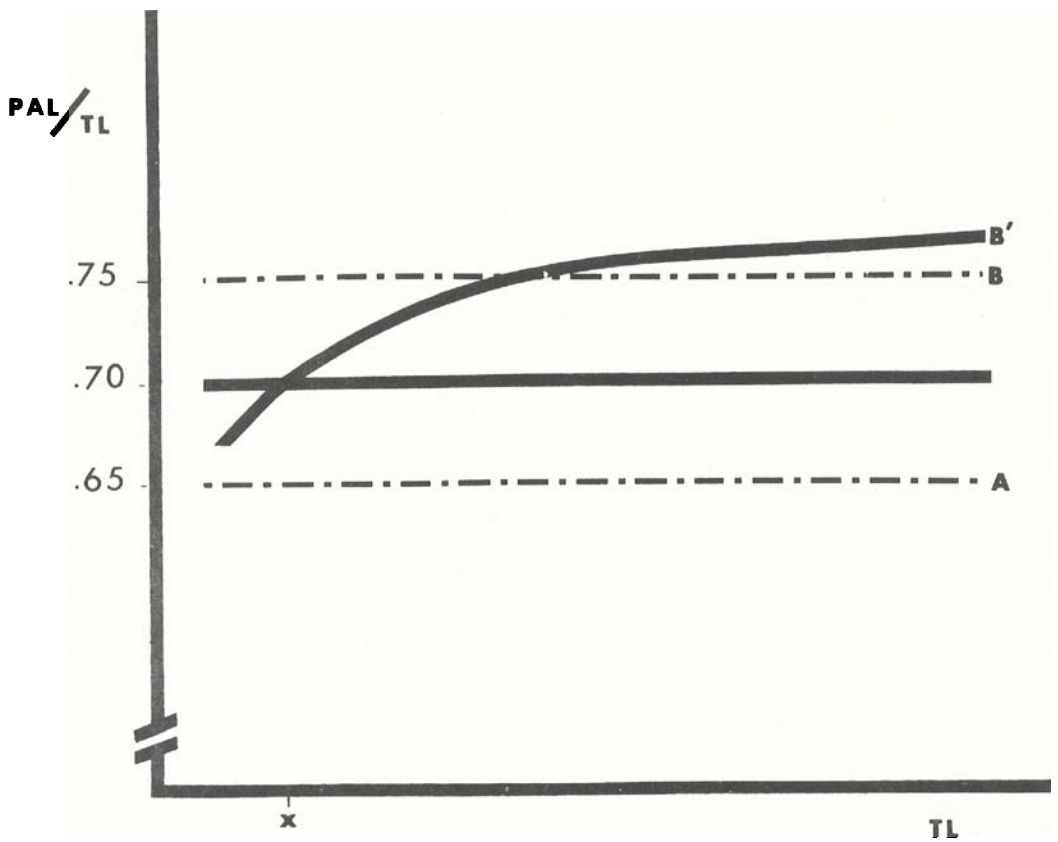

Figure 1. Proportional plot of hypothetical example where allometry may invalidate a conventional morphometric taxonomic character. See text for details.

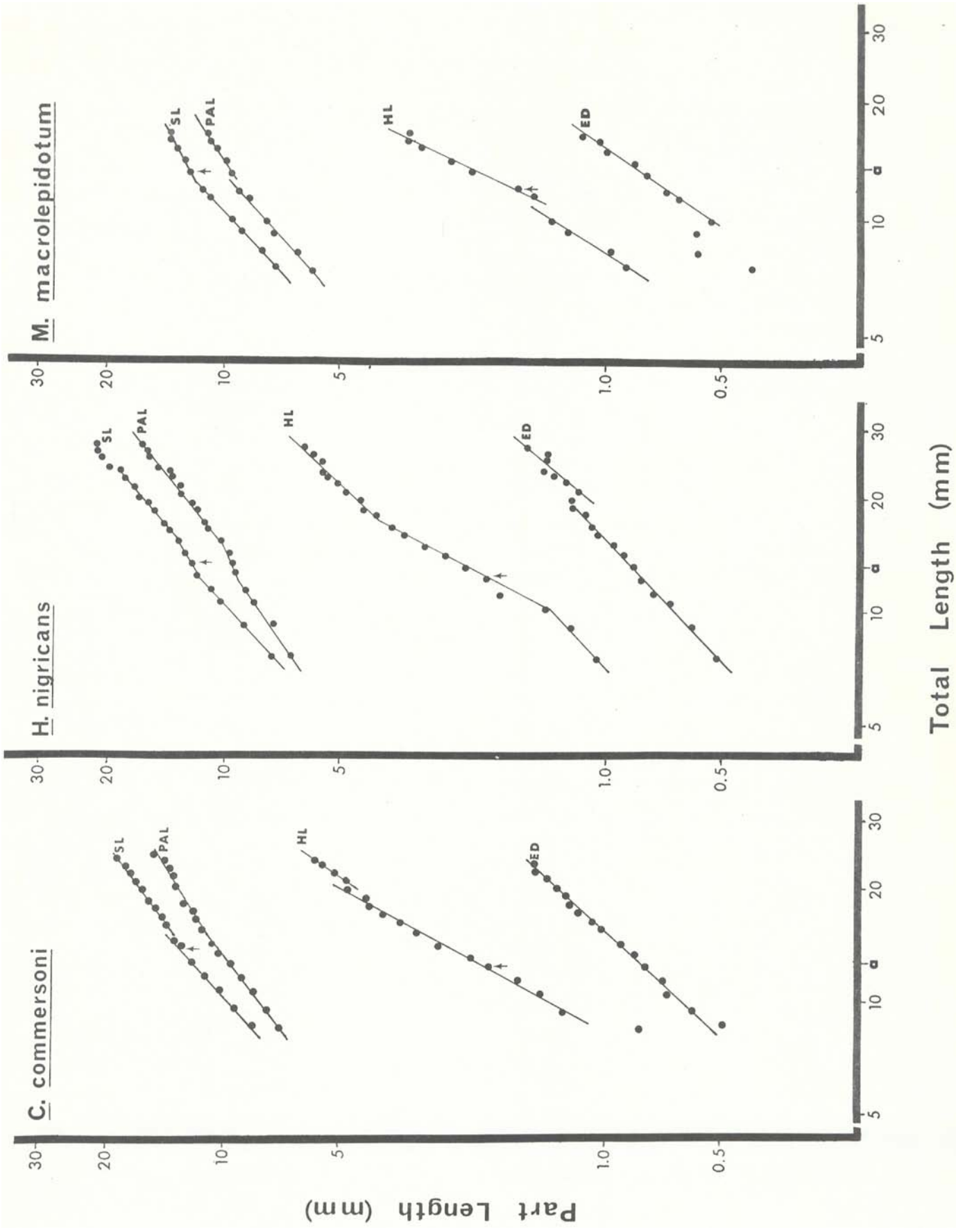

Figure 2. Log-log plots of four body dimensions among three species of catostomid larvae. Arrows indicate the points where measurement criteria are changed. Letter "a" indicates size at yolk absorption.

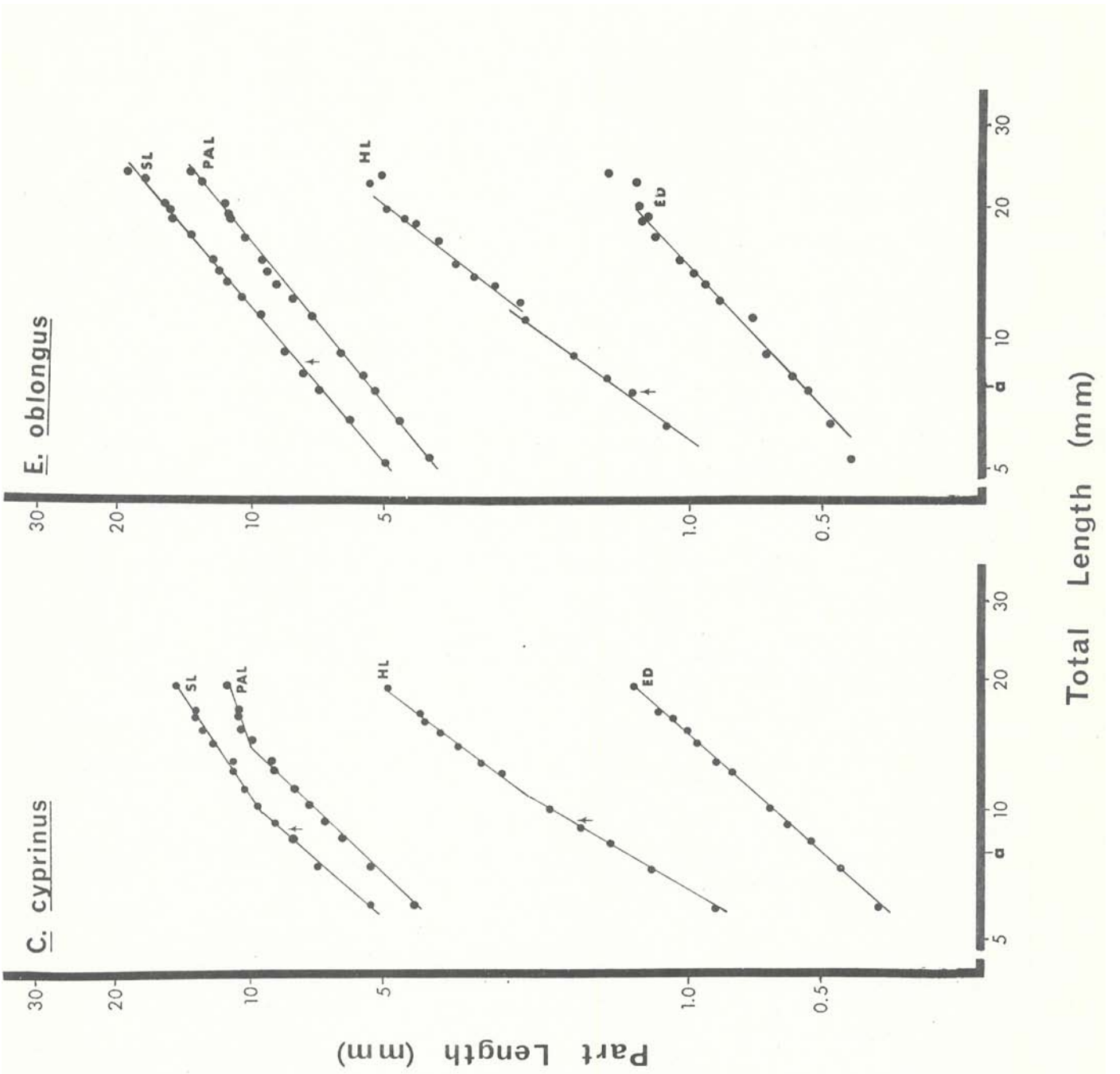

Figure 3. Log-log plots of four body dimensions among two species of catostomid larvae. Arrows indicate points where measurement criteria are changed. Letter "a" indicates size at yolk absorption.

STRIPED BASS VS. WHITE PERCH: APPLICATION OF A NEW MORPHOLOGICAL APPROACH TO ICHTHYOPLANKTON TAXONOMY

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ABSTRACT

A technique has recently been developed to stain cartilage in whole cleared specimens. This technique permits comparison of fish skeletons in their earliest stages of development (pre-ossification). Preliminary investigations employing this technique indicate that larval striped bass and white perch exhibit diagnostic differences in the position and shape of certain skeletal elements, particularly the predorsal bones, and that these differences are identifiable at the earliest appearance of these elements as cartilage. This method should reduce or eliminate the subjectivity now associated with larval striped bass-white perch identification and thus provide more rapid and potentially 100 percent accurate identification of each species from about 8 mm TL.

INTRODUCTION

The striped bass (*Morone saxatilis*) is one of the most important sport and commercial fish found along the Atlantic Coast of North America. Because of its importance, large amounts of money and effort are spent on studies of its population dynamics and life history. A large portion of the research effort is concerned with the particularly vulnerable early life history stages. Environmental perturbations adversely affecting the eggs and larvae of striped bass could have far reaching effects on the population. Accurate identification of the eggs and larvae of this species is therefore, crucial to the study of its biology.

Mansueti (1958, 1964) described the eggs and larvae of white perch (*M. americana*) and striped bass after stripping and fertilizing ripe ova from spawning fish. His studies provided the basis for the sorting methods now used. However, it has become apparent that specimens between 6.0 and 20.0 mm TL are not unequivocally distinguishable using Mansueti's criteria. Morgan (1975) used electrophoretic patterns of muscle proteins to distinguish white perch from striped bass. This method, although very accurate, requires a great deal of time and the specimens are destroyed in the process. Sidell *et al.* (1978) developed a valid method of biochemical identification using starch gel electrophoresis and stains for specific enzyme systems. They conclude, however, that routine electrophoretic analysis of samples may be logistically difficult.

A recently developed cartilage staining technique (Dingerkus and Uhler, 1977) allows examination of osteological development prior to complete ossification of the endoskeleton. Preliminary investigations with a modification of this technique indicate that larval striped bass and white perch exhibit diagnostic differences in the position and shape of certain skeletal elements. These differences are identifiable at the earliest appearance of these elements as cartilage.

METHOD

Larval-juvenile series of field collected *M. saxatilis* and *M. americana* were cleared and stained using modifications of the cartilage technique of Dingerkus and Uhler (1977). Cleared and stained specimens were then examined for possible species-specific osteological differences. We began by examining readily identifiable juveniles and then traced characters back through the size series. As a check we examined a series of striped bass reared from yolk-sac larvae obtained from the hatchery operated by the Virginia Commission of Game and Inland Fisheries at Brookneal, Virginia.

Staining Technique:

The cartilage staining technique described by Dingerkus and Uhler (1977) was simplified and modified for more rapid preparation of larval fish samples. The modified method used for fish is the following:

1. Wash preserved material in two or three changes of distilled H_20 for several hours or until no trace of preservative can be detected.
2. Place directly into a mixture of 10 mg Alcian Blue (8GN or preferably 8GS), 80 ml 95 percent ethyl alcohol, and 20 ml glacial acetic acid for 12 to 24 hours or until cartilage is well stained. For very small larvae this step may take only 12 hours.
3. Transfer through series of approximately 95 percent, 50 percent, 10 percent ethyl alcohol for about one hour each, or until specimen(s) sink. The alcohol dilutions are made by adding distilled water to the sample so they only need be approximate.
4. Transfer to distilled H_2O for one hour, or until specimen sinks.
5. Place in sodium borate buffered trypsin enzyme solution (Taylor, 1967). Change solution if it takes on bluish color. Continue until specimen(s) is cleared and flesh retains no blue color. This step usually takes one to two days.
6. Transfer specimen(s) to 50 percent glycerins (½ distilled water-½glycerine) for sorting and identification. Transfer to 100 percent glycerine for long-term storage is recommended (several crystals of thymol should be added to this solution).

By following the above simplified procedure a sample of fish larvae will be ready for sorting and identification in two to three days. This technique leaves external and internal pigmentation intact so that pigment patterns remain available for identification purposes.

OBSERVATIONS AND DISCUSSION

By following the above procedure we discovered that the shape and position of the predorsal bones were diagnostically different in each of the two species, *M. saxatilis* and *M. americana*. In addition, the compound interhaemal in *M. americana* is much larger and more robust.

The predorsal bone pattern for *M. saxatilis* is typically 0/0/0/2 + 1/1 + 1 and that for *M. americana* is 0/0/0 + 2/1 + 1 (fig. 1) (for explanation of formula used see Ahlstrom et al. 1976). From these patterns it is evident that the most striking difference is the more anterior position of the first dorsal pterygiophore in *M. americana*, i.e., between the second and third neural spines rather than posterior to the third neural spine as in *M. saxatilis*.

The shape of the predorsal bones also differs between the species. In *M. saxatilis*, the predorsal bones have a strong winglike flange developed posteriorly. In addition, the first predorsal is strongly concave anteriorly (fig. 1B). In *M. americana*, the predorsal bones are more rod-like and are not strongly bent (fig. 1A).

These differences in shape and position can be traced back to the earliest formation of these elements as cartilage. The first (anterior-most) predorsal is the first of these elements to form, at about 8.0 mm TL. In *M. saxatilis*, this first predorsal forms at approximately 45° from the vertical so that the oval-shaped element appears to be "leaning backwards" (fig. 2B). The first predorsal in *M. americana* forms as a vertical rod (fig. 2A). The remaining two predorsals first appear at about 10 mm TL.

At 9-10 mm TL, the position of the first dorsal pterygiophore relative to the neural spines is readily apparent. The development of the neural spines preceeds that of the pterygiophores and predorsal bones.

The compound interhaemal and associated second anal spines are sufficiently well developed at about 15 mm TL that they can be used together with the predorsal pattern for identification. The white perch has the larger compound interhaemal and second anal spine. Meristic characters can also be used at this time since the claring and staining process allows fast and accurate fin-ray counting. However, there is a slight overlap in the range of fin-ray counts for the two species.

From these observations we can now say that striped bass and white perch can be easily identified from the onset of predorsal bone formation (about 8 mm TL). The only stage at which these two species cannot now be separated is between about 6.0 and 8.0 mm TL. We have some indication that internal pigment patterns may be useful; however, these investigations are still preliminary and no unequivocal results have been obtained.

Specimens came from the Potomac River in Maryland and the hatchery in Brookneal, Virginia. Specimens from other areas will be examined to reveal possible geographical variation. Final results will be published in a more comprehensive study on the developmental osteology of striped bass and white perch.

Preliminary observations on the white bass, *Morone chrysops*, indicate that this fish has the same predorsal pattern as the white perch. Osteological characters may also aid in the separation of larvae of this species and the yellow bass, *M. mississippiensis*. The modification of the Dingerkus and Uhler cartilage staining technique may also result in solutions to other larval taxonomic problems, e.g., blue back herring, *Alosa aestivalis* vs. alewife, *Alosa pseudoharengus*.

ACKNOWLEDGEMENTS

We wish to thank Guido Dingerkus for providing the manuscript describing his cartilage staining technique while it was still in press. Kathy Wood, Chesapeake Biological Laboratory, supplied the field samples containing white perch and striped bass larvae. David Whitehurst, Virginia Commission of Game and Inland Fisheries, supplied the laboratory spawned striped bass larvae. Our former colleagues at the Chesapeake Biological Laboratory, Solomns, Maryland helped rear striped bass larvae and also contributed much information during discussions of larval identification problems. This work was supported by contracts #2-72-02 (77 Mod. 2), #T2-72-02 (78 Mod. 3), and #P48-78-04 with the Power Plant Siting Program, Department of Natural Resources, State of Maryland.

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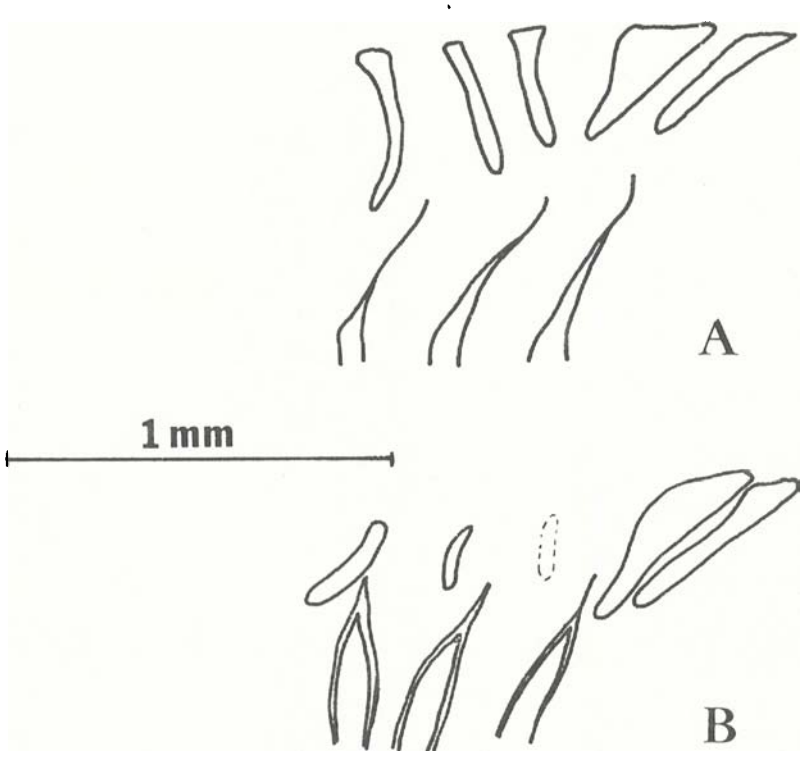

Figure 1. Relative position of developing predorsal bones and first two dorsal pterygiophores to anterior-most neural spines. A. *Morone americana,* 10.9 mm SL. B. *M. saxatilis,* 10.7 mm SL. (The predorsal bones and pterygiophores are cartilaginous at this size.) (Anterior is to the left.)

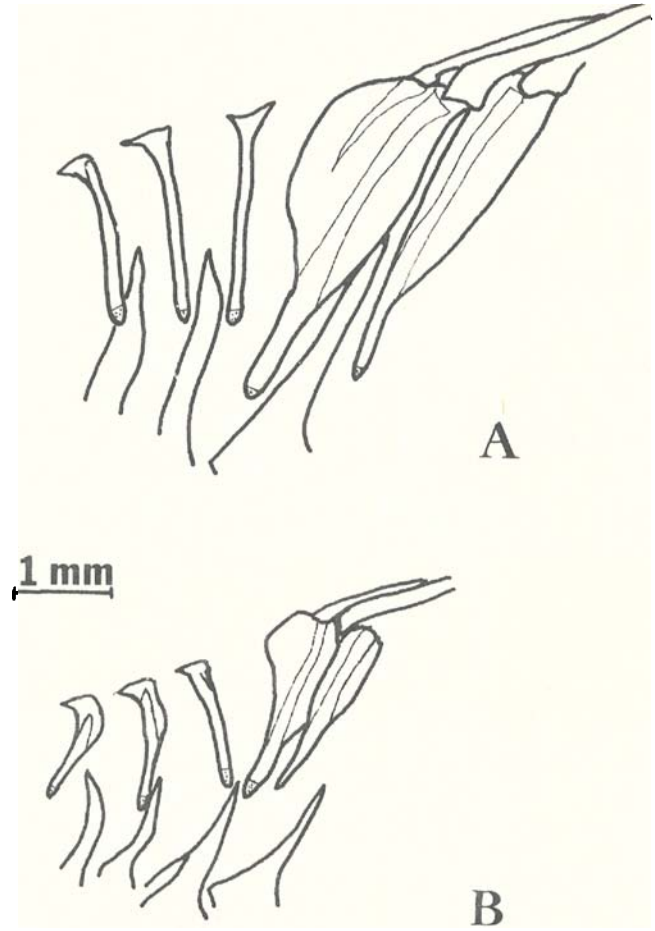

Figure 2. Relative position of predorsal bones and first two dorsal pterygiophores to anterior-most neural spines. A. *Morone americana,* 38.9 mm SL. B. *M. saxatilis,* 32.7 mm SL. (Stippled areas indicate cartilage.) (Anterior is to the left.)

CAUTION: EARLY FRESHWATER DRUM ARE PISCIVOROUS

(But there are errors in the documentation)

Two serious errors appear in a paper I published with Aaron L. Clark in 1979 (Clark, A. L. and W. D. Pearson, 1979. Early piscivory in larvae of the freshwater drum, *Aplodinotus grunniens*. Pages 31-59 in: R. Wallus and C. W. Voigtlander, Eds. Proceedings of a workshop on freshwater larval fishes. Tennessee Valley Authority, Norris, TN). The 3.4 mm SL larval fish which is photographed in Figure 3 and drawn in Figure 7 appears to have 40-45 myomeres, and was probably a percid (either a darter, or more likely a *Stizostedion*). A second error appears to have been made in measuring the standard length of this fish, and perhaps others in the data set. The larva photographed cannot be located, and may not have been part of the data set. About 75% of the fish examined are still available, and all of these have been verified as freshwater drum. The smallest of the available specimens are 4.3 mm SL. An eyepiece micrometer calibration error seems to be the most likely explanation for this discrepancy in lengths of the small specimens. The largest fish among the remaining specimens is 14.6 mm SL, not greatly different from the 14.7 mm SL maximum reported in the paper. Although the specimen photographed was misidentified and the specific lengths reported cannot be relied upon, especially for the smaller specimens, the essential conclusions of the paper remain valid. I bring these two errors to the attention of all ELHS members and ask that you make the corrections known to all students and colleagues. Photocopies of this sheet should be placed in copies of the Proceedings and reprints of the paper. I thank Darrel Snyder (Larval Fish Laboratory, Colorado State University) for notifying me of these errors and for confirming the identity of six of the smallest drum larvae.

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EARLY PISCIVORY IN LARVAE OF THE FRESHWATER DRUM, *APLODINOTUS GRUNNIENS*[1]

by

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and
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ABSTRACT

Larval freshwater drum of 3.3-8.1 mm SL from the Ohio, Cumberland, Tennessee, and Missouri Rivers consumed other larval fishes, mostly cyprinids and clupeids. This widespread piscivory in drum is accompanied by morphological characteristics which change markedly after 8-10 mm SL when the young drum cease feeding on other fishes and begin feeding almost exclusively on zooplankton. The evolutionary advantages of exploiting an abundant but ephemeral food resource and the significance of such exploitation are discussed.

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INTRODUCTION

The establishment of strong year-classes in fishes seems to depend on events taking place in the first year of life, and perhaps in the first few weeks or even days after hatching.

Hjort (1926) used the term "critical period" to refer to this early stage in the life histories of herring and cod when the subsequent strength of the year-class was set. The concept of the critical period has been reviewed by Marr (1956) and May (1974). Hjort suggested that the most important cause of morality during the critical period might be the lack of suitable food, and pointed out that the hatching period of herring in his studies corresponded with the season of maximum plankton densities. May (1974) has reviewed the available evidence bearing on the assumptions inherent in Hjort's critical period concept. He concludes that for many species of fish starvation and starvation-enhanced mortalities (especially predation) are important causes of mortality at the time of yolk sac absorption when feeding on exogenous foods is just beginning. In freshwater fishes, which are subject to greater variations in the physical environment, factors such as temperature, wave action, and turbidity may be important as catastrophic causes of direct mortality in larval fishes (Kramer and Smith 1962). Physical factors may also interact with food-related mortalities by prolonging incubation, reducing the swimming and food-gathering abilities of fish larvae relative to the escapement abilities of planktonic prey, reducing prey densities, and reducing visibility.

Hunter (1976) offered the opinion that the major causes of larval mortality in fishes are starvation and predation, and there may be interactions between them. He concluded that, although it is important to treat the problem of stock and recruitment in holistic fashion, it is unlikely that any new general models can be formulated, given the present state of knowledge.

Butler (1965) reviewed the life history of the freshwater drum (*Aplodinotus grunniens)* in the upper Mississippi River and concluded that year-class strength in this very fecund species must be set during the egg and larval stages, since no adequate source of regulating mortality could be found in subsequent stages of life. During a study of the distribution of larval fishes along a transect of the Ohio River above Louisville, Kentucky, we discovered an unusual predator-prey relation between larvae of the freshwater drum and larvae of several other fishes. This relationship has been overlooked because of its ephemeral appearance in the first week or two of life, and may be important in establishing the year-class strength of both the predatory drum and the prey species.

MATERIALS AND METHODS

A field sampling program to determine the spatial and temporal distribution of ichthyoplankton at Ohio River Mile 571 in Trimble County, Kentucky, was conducted from March through August of 1977. Four sampling stations were established along a transect and weekly surface and bottom samples were collected in midafternoon and at night at each of the stations. Each sample consisted of a five-minute, upstream tow. Sampling gear consisted of 0.5-m cone-shaped plankton nets constructed of 361μ nylon mesh. A detachable 1-liter plankton bucket was affixed to the cod end of each net and the nets were mounted on a brass ring with steel cable bridles. A flow meter was suspended in the center of each brass ring. Tow net samples were preserved in 10 percent formalin and sorted in the laboratory.

Larval drum collected with plankton nets were also obtained from the Tennessee Valley Authority and the U.S. Fish and Wildlife Service (North Central Reservoir Investigations). Tennessee Valley Authority collections were from Nickajack Reservoir on the Tennessee River (1976), Barkley Lake on the Cumberland River in southwestern Kentucky (1976), and at Ohio River Mile 946 near Paducah, Kentucky (1975). Larval drum from North Central Reservoir Investigations were collected from impoundments of the Missouri River (Ft. Peck, 1975; Sakakawea, 1976; Oahe, 1974; and Sharpe, 1975) in Montana and the Dakotas.

In the laboratory, the following measurements were made to the nearest 0.01 mm using a Bausch and Lomb dissecting microscope with calibrated ocular micrometer: standard length (SL), maxilla length, mandible length, head length (the longest distance from the most anterior portion of the maxillary to the most posterior portion of the opercular flap), and the distance from the anterior margin of the eye to the upper corner of the opercular opening. These measurements were made on 250 larval drum selected from each of the eight locations. All larvae were separated into 2 mm SL size classes for analysis of food habits.

The alimentary canal from the junction of the esophagus and the stomach to the anus was removed from 554 larval drum using a pair of finely-sharpened dissecting needles. The percentage of the yolk still to be absorbed by the larvae was estimated by comparison with newly hatched drum. All food items found in the guts were identified and counted and the percent fullness of each gut was estimated. Larval fish consumed by the larval drum were identified to the family level, condition of the specimen permitting. Ingested invertebrates were categorized as oligochaetes, eubranchiopods, cladocerans, copepods, ostracods, amphipods, chironomids, and trichopterans.

RESULTS

Larval freshwater drum first appeared in the ichthyoplankton on May 9th and constituted a significant percentage of the fauna from late May until early July. The smallest larva examined was 3.2 mm and the largest was 14.7 mm SL. There were no larvae available in the 3-5 mm size class from Lakes Sakakawea and Sharpe on the Missouri River, and some larger size classes were also absent from the samples obtained from six locations (Table 1).

Cladocerans made up the largest portion of the diet of larval drum (Figure 1). The overall mean frequency of occurrence of cladocerans in the six size classes examined ranged from 64.5 to 95.5 percent; *Daphnia* and *Leptodora* were among the largest individual prey items consumed. Copepods were the second most frequently consumed item (mean frequency range 24.2-78.3 percent) in each size class except the 3-5 mm class in which other larval fishes were the second most frequently ingested item (mean frequency range 13.8-100 percent). Other larval fishes were consumed by drum larvae in the first three size classes (3-5, 5-7, and 7-9 mm) only, and the frequency of consumption declined steadily from smallest to largest size within the three classes (from 27.3 percent to 0.7 percent; Figure 2). Larval fishes consumed by drum in this study were 35 percent clupeids (probably *Dorosoma cepedianum, D. petenense,* and *Alosa chrysochloris)*, 19 percent cyprinids (probably *Notropis atherinoides*), and 46 percent unidentifiable remains. The 3.4 mm larval drum in Figure 3 had consumed a larval shad, the eyes of which show clearly through the transparent body of the drum.

Chironomid larvae (very early instars) were consumed in small numbers by drum at each location and in all size classes (mean frequency range 0-12.2 percent). Amphipods were consumed in still smaller numbers and only by drum in the Missouri River impoundments (mean frequency of occurrence = 0-6.5 percent). Other items which were found in three or fewer guts were trichopteran larvae, unidentified fish eggs, eubranchiopods, and oligochaetes.

The percentage of empty guts was low (<12 percent) for all size classes at all locations except at Ohio River Mile (ORM) 946 (at the intake of TVA's Shawnee power plant), where 27 percent of the guts examined were empty (Figure 4). The mean estimated fullness of guts from drum collected at ORM 946 was low (10 percent) compared to the fullness at the other seven locations (30 percent).

Larval drum begin feeding well before the yolk sac is absorbed. A substantial percentage (26 percent) of the drum examined had both food in the gut and some yolk remaining. The largest larva which still retained some yolk was 8.8 mm SL, but most larvae had absorbed all yolk before attaining a standard length of 6.0 mm.

The foods a fish eats will be determined in part by the morphology of its mouth parts. We made several measurements of the mouthparts and head size of drum in each of six larval size classes, and also of juvenile and adult drum. Regression analyses indicated that the measurements (mandible length, maxilla length, head length, and eye to opercular distance) were closely related, and each could be predicted by the other. Maxilla length was selected as the standard measure best representing the mouth size of larval drum, based upon its low variability within a size class compared to the variability of the other measurements.

In larval drum the rate of increase in maxilla length with increase in body length was very high initially, and then decreased after passing a break point at a standard length of 10-12 mm (Figure 5). A plot of the ratio of maxilla to standard length versus standard length is given in Figure 6 to illustrate the change in mouth to body proportion at a standard length of 10-12 mm. The most noticeable aspect of this plot is the large ratio of maxilla to body length in larval drum of all size classes compared with similar ratios for other fishes. A good impression of this change in proportion can also be gained by examining Figure 7, which depicts drum ranging from 3.4 to 41 mm SL.

DISCUSSION

The food habits of adult drum have been described by several authors (Daiber 1952, Moen 1955, Butler 1962, Priegel 1967, and Wrenn 1968). Most of these authors also list the food of larval or juvenile drum as zooplankton and insect larvae with fish first appearing in the diet in age class I+ individuals. Swedberg (1966, 1968) and Swedberg and Walburg (1970) found that larval drum began feeding at 5 mm on *Daphnia* and *Cyclops,* continued on this diet to a length of 20 mm, and then began eating small insect larvae. None of the larval or juvenile fish they examined had eaten fish.

Our discovery that 27.3 percent of drum larvae between 3 and 5 mm SL consumed other fishes may have resulted from our examination of smaller larvae (Swedberg 1968 and

Swedberg and Walburg 1970 examined only 38 drum between 6 and 20 mm TL), and the ephemeral appearance of piscivorous habits in drum larvae at the time of yolk sac absorption.

The drum has been reported as the third most abundant fish in both the Mississippi (Butler 1965) and Ohio (Krumholz, et al. 1962) Rivers. It has also been described as one of the most abundant fishes in the Missouri River impoundments (Swedberg and Walburg 1970) and in Lake Erie (Edsall 1967). Edsall expressed a concern which has been mentioned by many authors when he described the ascendency of the drum population in Lake Erie during a period when the populations of more desirable fishes were in decline. Swedberg (1968) found that the drum population in Lewis and Clark Lake, South Dakota, increased during the first years after impoundment while gamefish stocks declined. He attributed the success of the drum to the large prey populations of *Hexagenia* which increased dramatically during the same period, and which were a favored food of drum over 50 mm TL.

Butler (1965), described the pelagic egg and limnetic larval stages of the drum. Reasoning that one would expect that eggs and larvae of such a fecund species would be preyed upon heavily, he concluded that year-class strength in drum must be determined during the egg and larval stages. However, Butler agreed with Daiber (1952) that the most important interaction between young drum and other fishes was probably competition for zooplankton foods. We now add a predator-prey interaction with the drum cast in the predator role at a standard length of 3.3-9.0 mm SL.

Our observation of larval drum just 3.3 mm SL (3.8 mm TL) feeding on larval clupeids and cyprinids represents the earliest example of piscivory in any fish known to us.

In general discussions of the food habits of larval fishes, phyto- and zooplanktors are listed almost exclusively. A review of the literature revealed limited reports of larval and juvenile fishes less than 20 mm TL feeding on fishes. Walleye *(Stizostedion vitreum)* fed on larvae of other species at 8-10 mm TL (Bulkley, et al. 1976, Wisconsin Department of Natural Resources 1969, Houde 1967). Longnose gar *(Lepisosteus osseus)* [17-21 mm TL] consumed other fish larvae (just 5 mm TL) (Echelle 1968) and shortnose and/or spotted gar *L. platostomus* and *L. oculatus*) [50-34 mm TL] also consumed other fish (Echelle and Riggs 1972). Marak (1974) found that redfish (*Sebastes morinus*) [9-13 mm TL] fed on fish eggs but not larvae.

There are also scattered reports of cannibalism practiced by larvae of some species less than 20 mm TL (largemouth bass, *Micropterus salmoides,* 18 mm, Chew 1974; Eurasian perch, *Perca fluviatilis,* 13 mm, Spanovskaya and Grygorash 1977). Cannibalism under crowded hatchery conditions is common in some species, but data on exact lengths of the fish involved have usually not been recorded. We found no cannibalism in the larval drum examined, perhaps because the early prolarvae of drum are pelagic or seim-buoyant while the piscivorous early postlarvae are demersal.

Morphological Adaptations for Piscivory

During the larval development of most fishes the mouthparts and an oral opening form during the early prolarval stage when the yolk sac is still being absorbed; it is, therefore, possible for the fish to ingest foods before the yolk is entirely absorbed. In our study, 80 percent of the drum larvae which still retained some yolk also had food in the gut. The utilization of food by yolk-sac larvae has been reported for northern pike (*Esox lucius;* Kostomarova 1961) and sauger (*Stizostedion canadense;* Nelson 1968). In most fishes, mouth size is initially small compared to body size and increases relative to body size as the fish grows. Wong and Ward (1974) have plotted ratios of gape width to total length against total length for yellow perch (*Perca flavescens*) (a plot much like our Figure 6); at a length of 5-12 mm this ratio is very low, rises steeply to a maximum at about 17 mm TL, and then tapers off gradually to an intermediate value at 50+ mm TL. We believe that this pattern is typical for most freshwater fishes which are piscivorous in adult life (i.e. temperate basses, percids, and centrarchids). The freshwater drum, however, has an unusually large head and mouth compared to body size as a late prolarva and early postlarva. Our plot of the ratio of maxilla to SL against SL (Figure 6) indicates that mouth size of drum 3.3-5.0 mm SL is nearly as large, proportionately, as the maximum size, which will be obtained at a standard length of 10 mm, and is much larger proportionately than the mouth size of drum over 50 mm SL. It is primarily the large mouth size which permits drum larvae to consume other larval fishes.

A second adaptation which accompanies the piscivorous habits of larval drum is a unique food-handling process. The larvae which we observed in the stomachs of larval drum were always rolled into a ball. The head of the prey served as the center of the ball with the body bent laterally and wrapped tightly around the head. In this manner two 4 mm SL shad could be accommodated in the stomach of a 5 mm SL drum. The 3.4 mm SL drum drawn in Figure 7 had such a shad in its stomach. It would be interesting to know the "handling time" (Werner 1974) required to catch and ingest the prey, and to determine the mechanisms involved in rolling the prey fish. Drum

3-5 mm SL bear a series of prominent, needle-like teeth on each side of the lower jaw. These teeth, which become less prominent as the size of the larva increases beyond 10 mm SL, would appear to be useful in capturing both larval fishes and zooplankton.

Strategies for Exploiting Larval Fish

The total biomass of fish eggs and larvae produced each year must represent a significant food resource for potential predators. Although much importance is often attached to the role of predation in larval fish mortality (i.e. Ware 1975, Hunter 1976) few data are available on organisms which actually prey upon larval fishes (Theilacker and Lasker 1974), and many authors believe that food availability is more important than predation in determining larval mortality (Butler 1965, Swedberg and Walburg 1970, Blaxter and Ehrlich 1974, May 1974).

In temperate zones larval fishes are normally present for perhaps 1-3 months each year. Potential predators could employ several strategies in exploiting larval fishes including: 1) switching to alternate prey while maintaining the same general feeding mode, and 2) synchronizing life history stages with those of the prey species to achieve changes in morphology, behavior, and physiology. The latter would permit the predator to switch both mode of feeding and prey when larval fish were no longer available.

The two modes of feeding which would seem useful in exploiting larval fish are filtration, when the predator is large relative to the prey, and individual sight-hunting when the predator is nearer the size of the prey. Examples of planktivorous filter-feeders consuming larval fish in temperate regions have been reported by Hoagman (1974) for alewives (*Alosa pseudoharengus*) feeding on larval whitefish (*Coregonus clupeaformis*) in the laboratory, Heard (1965) for sockeye salmon (*Oncorhynchus nerka*) feeding on limnetic larvae of *Cottus aleuticus,* and Kimsey (1958) for threadfin shad (*Dorosoma petenense*) feeding on croaker (*Bairdiella icistius*).

Theilacker and Lasker (1974) reported sight-hunting predation by the euphausid, *Euphausia pacifica,* on anchovy larvae (*Engraulis mordax*) in the laboratory. They also pointed out that there have been many reports of other marine invertebrates (copepods, chaetognaths, ctenophores, and coelenterates) preying upon individual larvae of marine fishes. Freshwater invertebrates which consume fish larvae include coelenterates and many insects (i.e. Hemiptera, Coleoptera and Odonata; Usinger 1956). The possibly synchrony of some specialized predator instars or

developmental stages with the appearance of larval fishes should be investigated. The only recorded examples of fishes individually sight-hunting other fish larvae are those previously described, excluding examples of cannabilism.

We suspect that larval fishes are preyed upon by many organisms, and to a much greater extent than has been reported. Future studies in temperate regions should be made to examine the feeding habits of large filterfeeders (i.e. paddlefish, shad, herrings, and buffalo) during the reproductive season, keeping in mind that larval fishes are fragile and quickly digested. Studies of the morphology of mouthparts could provide clues to the existence of larvae capable of preying on other larvae. Studies in tropical regions should be directed toward finding both specialized filterfeeders and sight-hunters preying on larval fishes throughout the year.

Information from these studies would enable us to identify specific causes of egg and larval mortalities in fishes and estimate their individual impacts. This could lead to predictive and realistic models of larval fish population dynamics, and eventually to management strategies for enhancing year-class strength in desirable species.

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Table 1. Frequency of occurrence of food items in the guts of larval drum from eight locations in the U. S. Only individuals which contained some food were included in the frequency estimates (11.4% of the 554 guts examined were empty).

Location and Standard Length (mm)	Number Examined		Food Item (%)				
	With Food	Empty	Larval Fish	Cope-poda	Clado-cera	Chirono-midae	Amphi-poda
Fort Peck (Missouri River)							
3-5	17	2	23.5	29.4	76.5	0	11.7
5-7	48	3	2.1	45.8	79.2	6.3	2.1
Sakakawea (Missouri River)							
3-5	No Data Available						
5-7	7	1	0	85.7	71.4	42.9	0
7-9	15	0	0	80.0	66.7	46.7	0
9-11	4	0	0	100	100	0	0
Oahe (Missouri River)							
3-5	2	0	100	0	0	0	0
5-7	14	1	7.1	85.7	28.6	0	7.1
7-9	12	0	0	91.7	41.7	8.3	0
Sharpe (Missouri River)							
3-5	No Data Available						
5-7	19	2	15.8	68.4	57.9	0	31.6
7-9	29	1	0	75.9	75.9	0	17.2
9-11	12	0	0	66.7	75.0	0	25.0
11-13	1	0	0	100	100	0	0
Ohio River Mile 571							
3-5	21	0	75.0	12.5	25.0	12.5	0
5-7	18	0	0	71.4	57.1	28.6	0
7-9	36	3	0	94.1	91.2	8.8	0
9-11	22	0	0	77.3	90.9	18.2	0
11-13	20	0	0	80.0	65.0	10.0	0
13-15	20	1	0	75.0	95.0	0	0
Ohio River Mile 946							
3-5	6	3	16.7	16.7	50.0	16.7	0
5-7	20	27	15.0	50.0	30.0	30.0	0
7-9	41	1	2.4	56.1	73.2	7.3	0
9-11	8	0	0	25.0	87.5	0	0
11-13	2	0	0	50.0	100	0	0
13-15	2	0	0	50	100	0	0
Cumberland River							
3-5	29	11	13.8	20.7	89.7	3.4	0
5-7	24	0	0	58.3	83.3	4.2	0
7-9	6	1	0	83.3	100	0	0
Nickajack (Tennessee River)							
3-5	4	4	25.0	75.0	75.0	25.0	0
5-7	31	1	0	83.9	74.2	19.4	0
7-9	1	1	0	100	0	100	0
$\bar{X}$ values							
3-5	79	20	27.3	24.2	71.2	6.1	3.0
5-7	181	35	4.1	62.8	65.4	12.2	4.7
7-9	140	7	.7	75.7	74.3	10.7	4.3
9-11	46	0	0	67.4	86.9	8.7	6.5
11-13	23	0	0	78.3	69.6	8.7	0
13-15	22	1	0	72.7	95.5	0	0
Total	491	63					

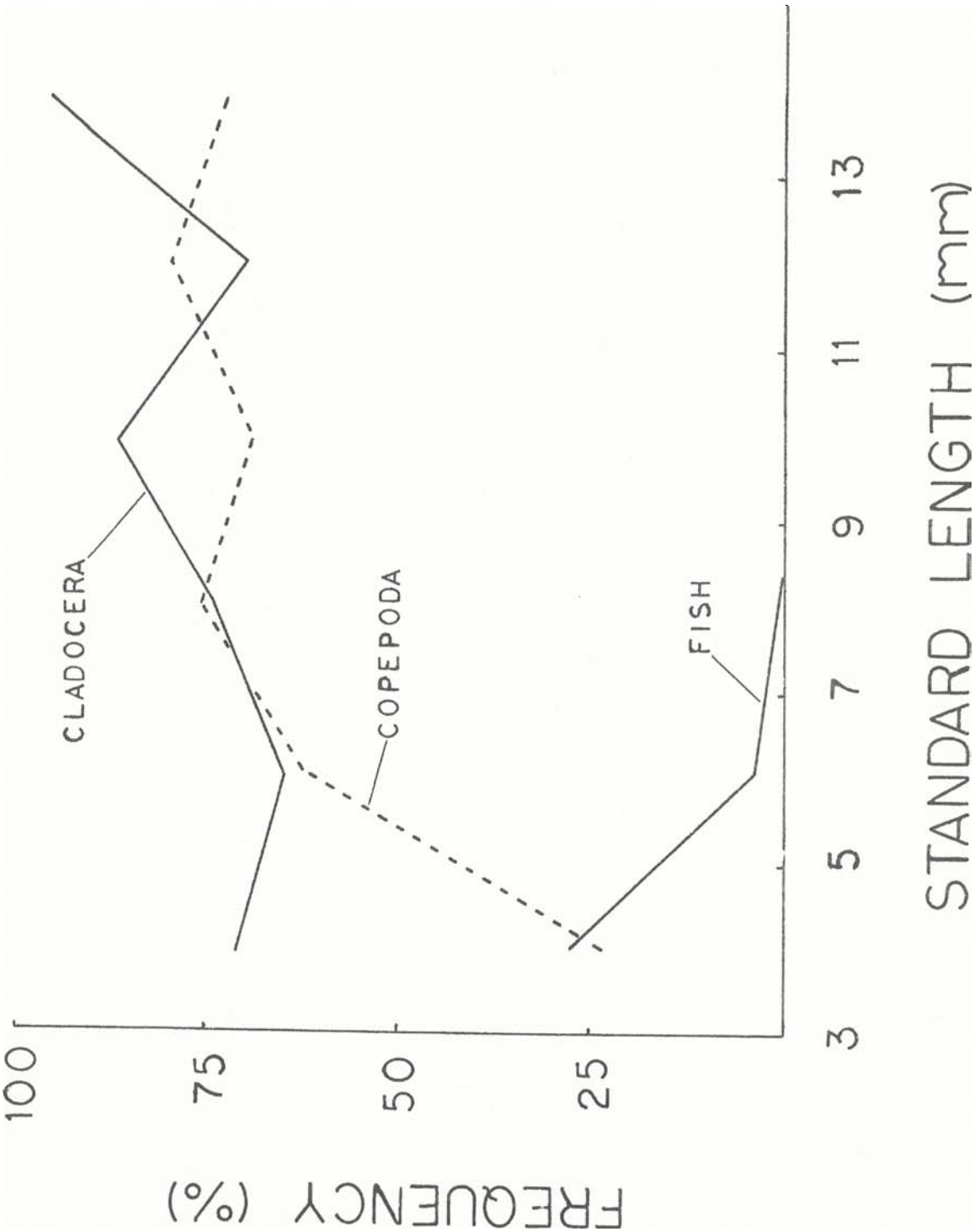

Figure 1. Percent frequency of occurrence of the three major food items of 554 larval freshwater drum (3-15 mm SL) from eight locations in the U.S.

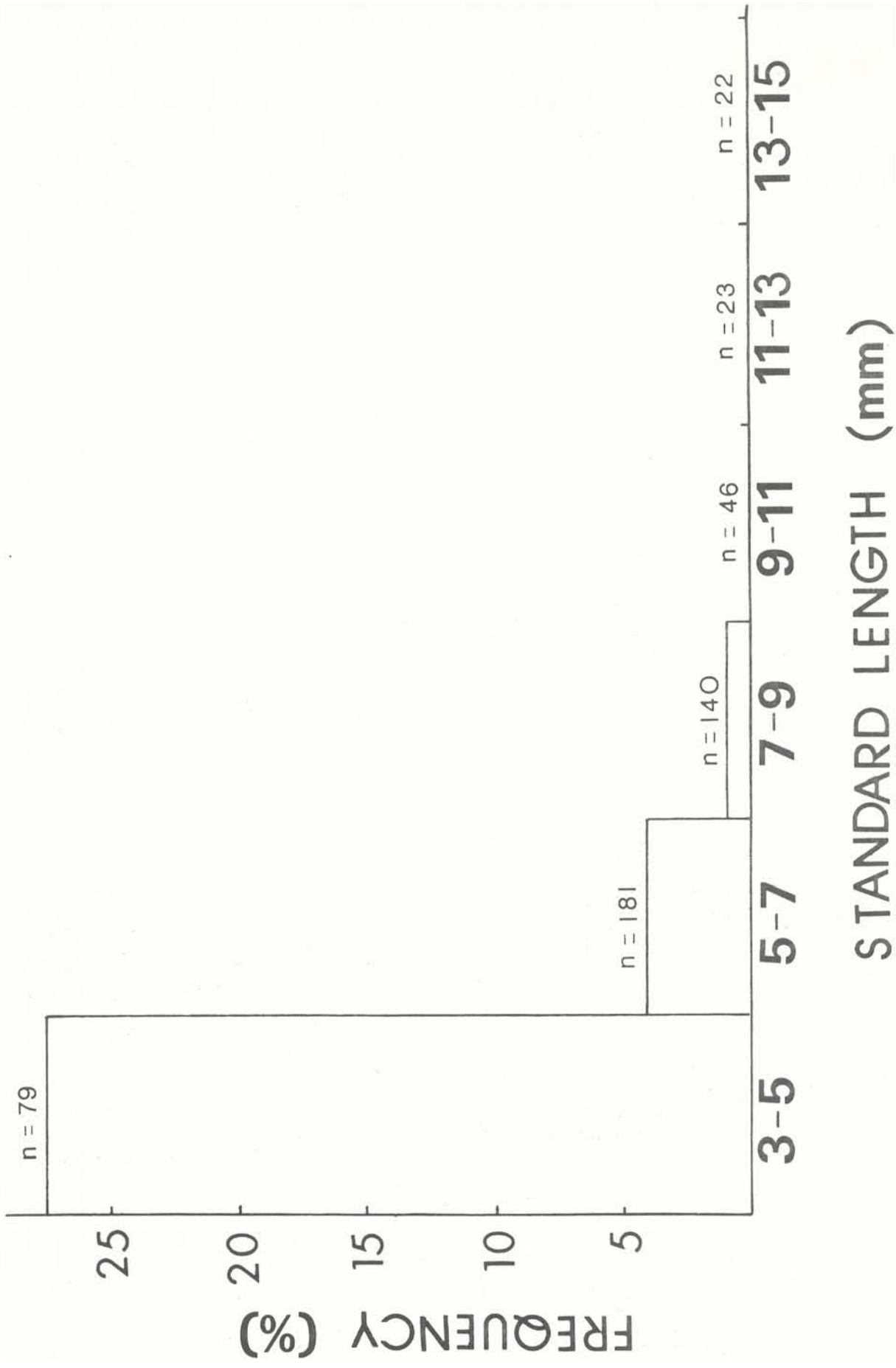

Figure 2. Percent frequency of occurrence of larval fish in the guts of 491 larval freshwater drum (n= total number of fish guts examined; only drum containing some food were included in the calculation).

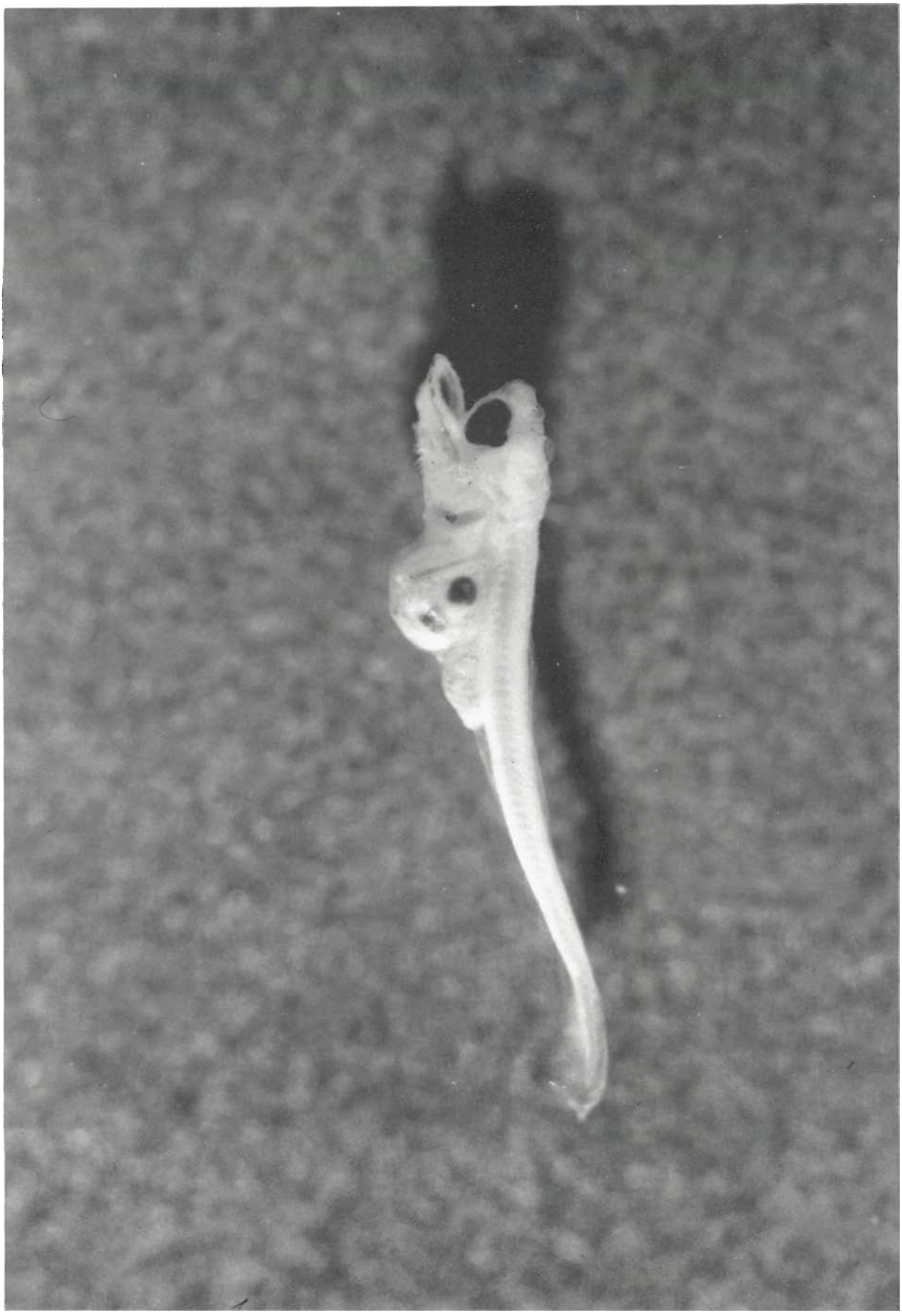

Figure 3. Piscivorous, 3.4 mm SL drum larva.

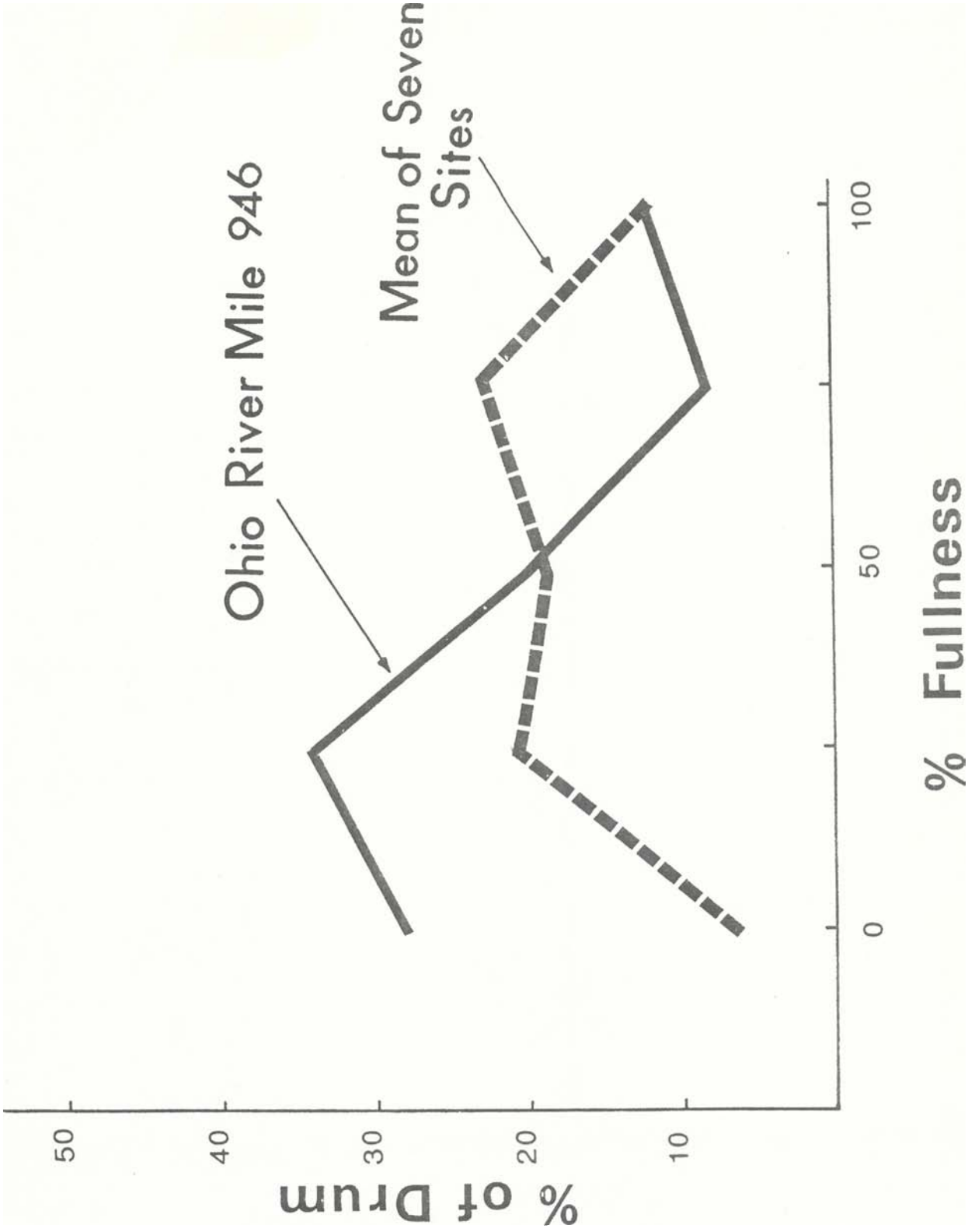

Figure 4. Comparison of mean percent fullness of the guts of larval drum (all size classes) from Ohio River Mile 946 with mean values from the remaining seven locations.

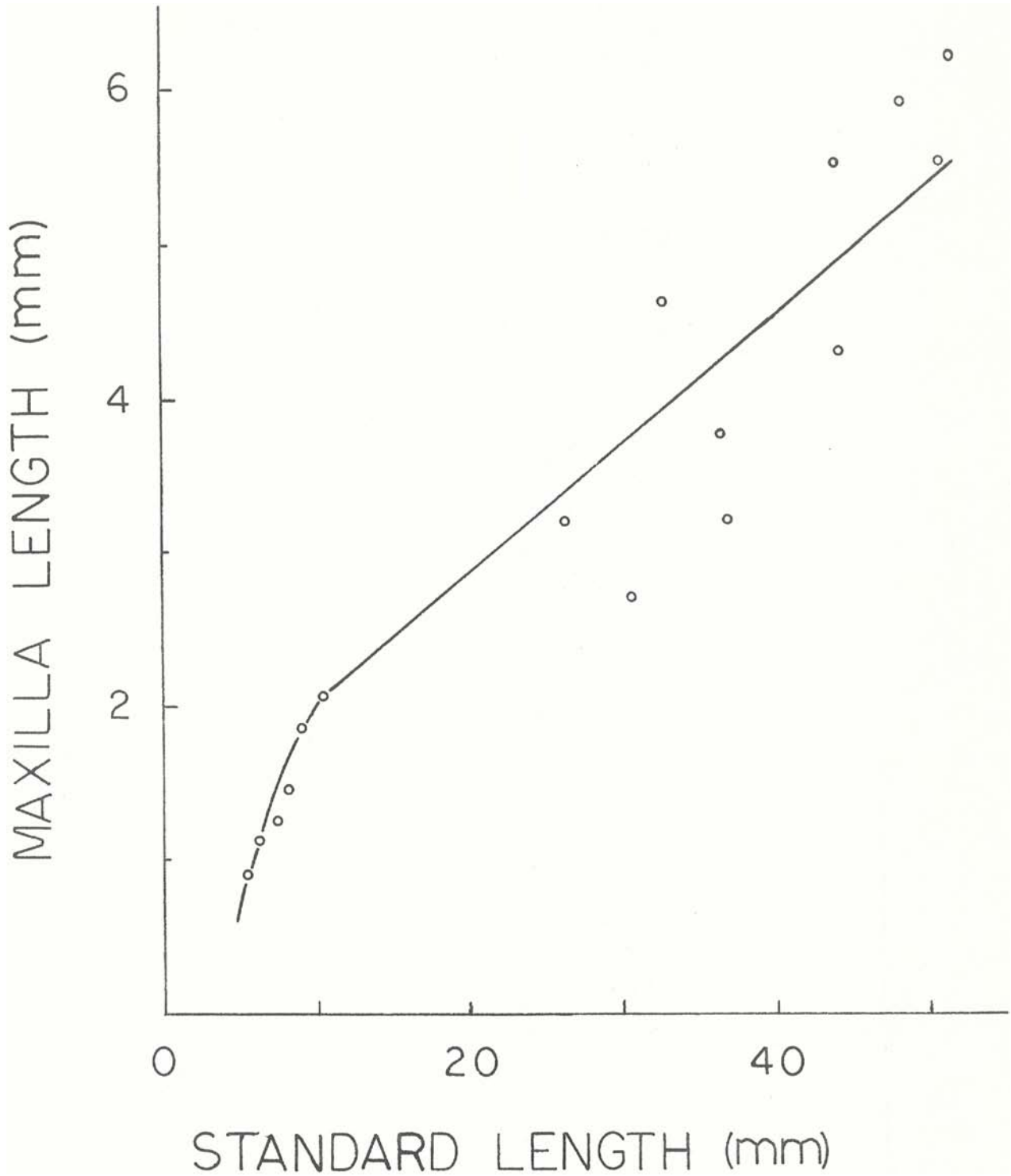

Figure 5. Relation between apparent maxilla length and standard length in larval and juvenile freshwater drum. A total of 250 larvae and 10 juveniles were measured. The larval points (< 20 mm SL) represent mean size-class values; points greater than 20 mm represent individual values.

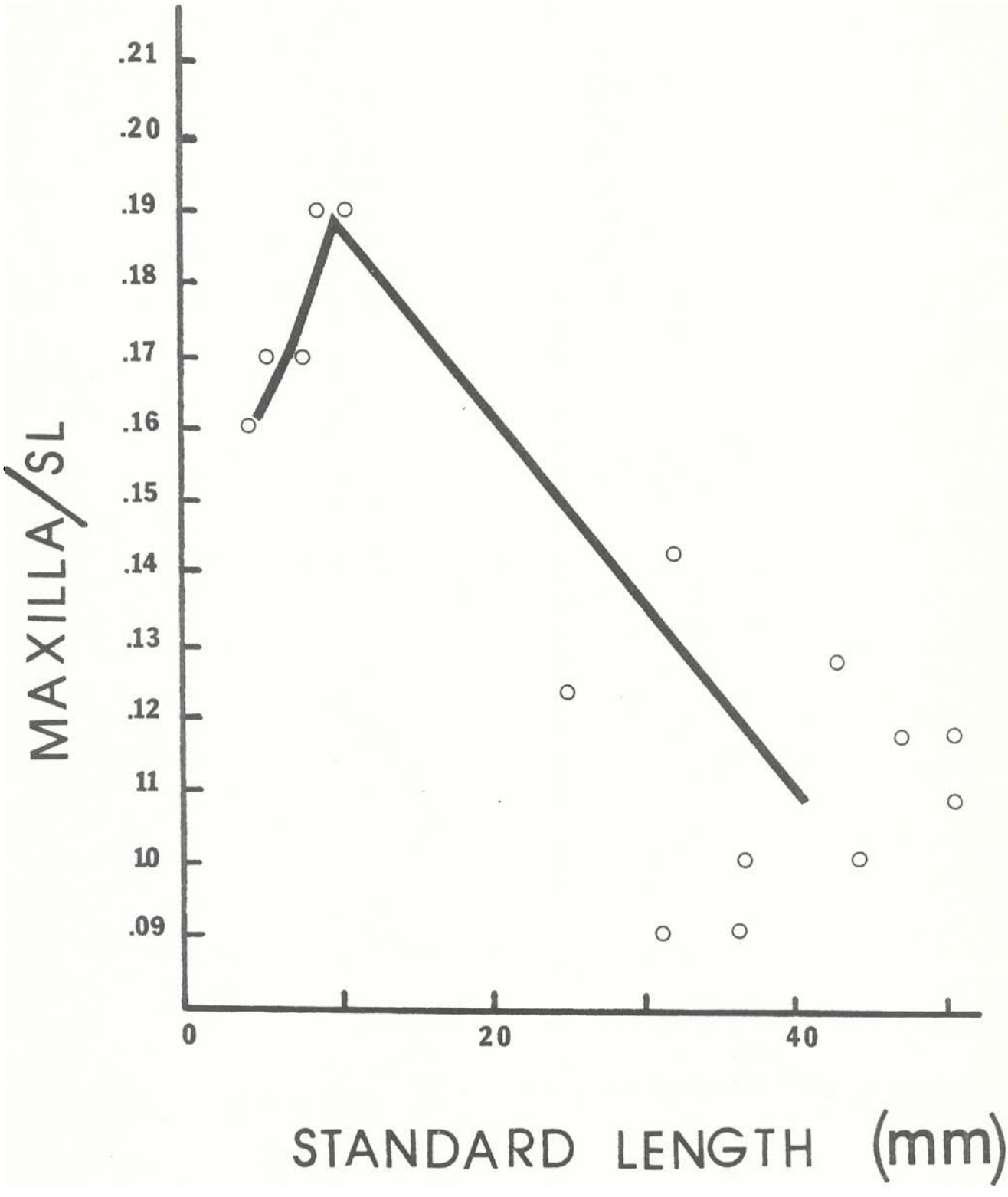

Figure 6. Relation between ratio of maxilla to standard length (SL) and standard length determined from 250 larval and 10 juvenile freshwater drum. The larval points (< 20 mm SL) represent mean size-class values; points greater than 20 mm represent individual values.

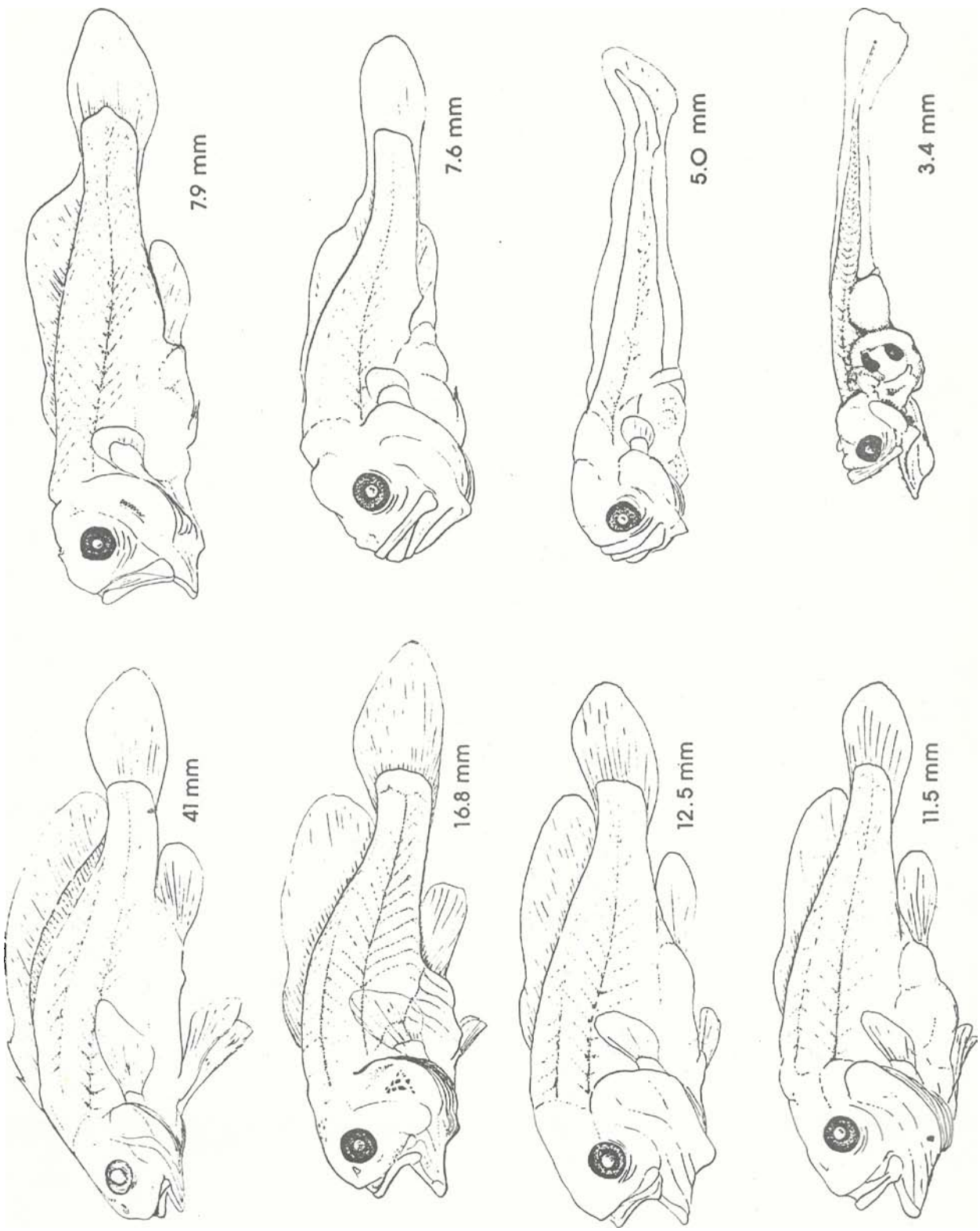

Figure 7. Relative change in mouth size with change in standard length of freshwater drum.

LARVAL AND EARLY JUVENILE DEVELOPMENT OF THE STRIPED SHINER,

NOTROPIS CHRYSOCEPHALUS (RAFINESQUE)

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ABSTRACT

Larval phases of the striped shiner, *Notropis chrysocephalus,* are described from meristic and morphometric data as well as morphological changes. Myomere counts, morphometric ratios, pigmentation, and fin ray counts are useful for identification.

Gravid striped shiners were collected from Hinds Creek, Anderson County, Tennessee. Specimens were reared from artifically fertilized eggs into the juvenile phase.

Fertilized eggs have a mean diameter of 2.2 mm and are demersal and adhesive. Larvae hatch at a mean size of 5.9 mm TL. Newly hatched larvae are unpigmented. By three days post-hatching (7.2 mm TL), larvae have a characteristic pigmentation pattern. Early larvae have 26 to 28 preanal and 12 to 14 postanal myomeres. Morphological changes associated with yolk sac absorption (7.9 mm TL) include: upward deflection of the notochord, filling of the gas bladder, and incipient median fin ray development. Successive fin ray development is: caudal, dorsal, anal, pelvics and pectorals respectively. Coiling of the gut begins at 12 mm TL and attains the characteristic adult shape at 13.5 mm TL. Squamation develops between 17 and 23 mm TL.

INTRODUCTION

The striped shiner, *Notropis chrysocephalus,* ranges throughout the east central United States from the Coosa River system of Alabama and Georgia and the lower Mississippi River drainage of Alabama, Mississippi, Tennessee, Arkansas, and Oklahoma, northward to the lower Great Lakes from Wisconsin to New York (Gilbert 1964). As juveniles and adults, striped shiners are the most commonly collected member of the *Luxilus* subgenus in eastern Tennessee streams. Striped shiner larvae are abundant in stream drift net samples. This study provides means for identification of larval and early juvenile striped shiners at various stages of development.

METHODS

On May 4, 1976, ripe adult striped shiners were collected from Hinds Creek, a tributary of the Clinch River, Melton Hill Reservoir, in Anderson County, Tennessee. Gravid females were seined from a gravel bottom riffle head in 50 cm of water. Ripe males were seined from a deep run in 80 cm of water over bedrock. Stream temperature was 13 C.

The eggs were field stripped and allowed to water-harden one hour before transport. In the laboratory, the eggs were maintained in a once-through flow incubator system utilizing spring water at 13 to 15 C. Treatment with 0.5 mg ℓ^{-1} malachite green was used on alternate days to reduce fungal infection.

Within six hours after hatching, larvae were transferred to a 114 l aquarium maintained at 13 C for three days. The temperature was then allowed to rise to room temperature and thereafter fluctuated between 18 and 22 C. A zooplankton mixture containing *Filinia, Hexarthra, Cyclops* and *Daphnia* was offered the third day after hatching. Newly hatched brine shrimp were fed to the larvae from the fifth day after hatching.

Samples of 2-10 specimens were collected in the following sequence: every 8 hours for the first 5 days, every 24 hours for the next 7 days, every 4 days for the next 24 days, and every 9 days for the last 27 days. Samples of larvae were preserved in 10 percent Formalin and later transferred to buffered 5 percent Formalin.

Meristic and morphometric data were obtained using a steromicroscope equipped with an ocular micrometer and polarizers. Characters examined included: total length, urostyle length, preanal length, postanal length, snout length, head length, greatest body depth, length to dorsal fin origin, length to anal fin origin, number of preanal and postanal myomeres, and numbers of fin rays.

Head length was defined as the distance from the tip of the snout to the posterior margin of the auditory vesicle or opercle (when developed). Yolk sac depth was measured at the maximum point. Other measurements were obtained following Trautman (1957). The method of counting preanal and postanal myomeres was that of Hogue et al. (1976).

Mean total lengths were tabulated by age. Meristic and morphometric information other than total length was tabulated by millimeter class size for identification. Static morphometric and meristic data are presented in tabular form, while the description of development follows the dynamic approach (Berry and Richards 1973).

Development of bone structure was studied after specimens were stained with Alizarin Red S and cleared in a KOH-glycerol solution (Granneman and Kay, MS). Scale development was observed by staining specimens in a solution of 0.2-0.3 $g\ell^{-1}$ Methylene Blue in distilled water.

Drawings were made with the aid of a camera lucida. Terminology is that of Hubbs (1943), with reference to both Balinsky (1948) and Snyder (1976).

All specimens are catalogued as TV737, DS-11 in the Larval Fish Identification and Information Center, Tennessee Valley Authority, Norris, Tennessee.

RESULTS

Meristic and morphometric data for prolarvae and postlarvae appear in Table I. Morphometric ratios appear in Table II.

Eggs and Hatching

Fertilized eggs averaged 2.2 mm in diameter (range 2.0-2.3 mm) and were demersal and adhesive. Eggs hatched between 152 and 160 hours after fertilization, yielding 752 larvae of which 260 were used for this study.

Prolarval Phase (Figures 1 and 2)

Larvae at hatching averaged 5.9 mm TL (range 5.6-6.0 mm TL).

The prolarval phase is equivalent to Balinsky's stages 25 to 32 and roughly corresponds to Snyder's protolarval phase. The notochord, however, does not deflect upwards until the postlarval phase.

At hatching the head is curved over the club-shaped yolk sac. By one day after hatching the head turns up in line with the body axis. Gills are not developed at hatching; gill arches are apparent as three or four tissue folds at two days of age. Otoliths appear as unossified refracting spheres.

Myomeres of early prolarvae range from 26 to 28 for preanal and 12 to 14 for postanal with modes of 27 and 13 respectively. The determination of completion of myoseptae on early prolarvae is difficult.

Opercular flaps are present on 7.2 mm larvae and cover the first three gill arches. At this size, larvae have a more streamlined appearance due to yolk sac absorption. The mouth has become well formed and subterminal.

Fin development on prolarvae is slow. At hatching the median finfold is present dorsally from the ninth myomere, extending around the caudal fin and ventrally to the forming anus. As the yolk sac is absorbed, the preanal median finfold becomes apparent.

Pectoral fin buds are present at hatching as opaque thickenings on the dorso-lateral area of the yolk sac. By two days after hatching, the pectoral fins extend beyond the edge of the yolk sac as viewed from the dorsal perspective. Pectoral fins are paddle-shaped on prolarvae greater than 7.2 mm TL. No ray nor hypural complex development is evident during the prolarval phase.

Except for the eyes, early prolarvae are unpigmented. Within a day after hatching, a few large melanophores are widely dispersed over the yolk sac. By three days (7.2 mm TL) several melanophores on either side of the heart area form a "V" ventrally. A double row of melanophores extends from the forming anus to the caudal fin base. The head is moderately pigmented and a double row of melanophores from the occiput to the caudal fin is present. Two or three chromatophores are present on the finfold in the peduncle area and one to three are found on the caudal fin. The opercular region, otoliths, and dorsum of the incipient air bladder are also pigmented. A midlateral row of melanophores extends from the incipient air bladder to the caudal fin. Large stellate chromatophores are present on the lateral and ventral portions of the yolk sac.

By 7.7 mm TL, the caudal pigmentation extends to the tip of the urostyle, outlining it and on some specimens making the dorsal and ventral pigment lines continuous. Snout pigmentation is moderate and the premaxilla is outlined with pigment.

On later prolarvae a diffuse caudal spot, slightly more prominent on early postlarvae, is situated on the lower caudal fin.

Five days after hatching the remaining yolk material was rapidly assimilated in a period of 16 hours. The prolarval phase was completed at about five and one-half days at an average size of 7.8 mm. Larvae larger than 7.9 mm retained no yolk material.

Postlarval Phase (Figures 3 and 4)

Postlarval stages correspond to Balinsky's stages 33 through 41, except that the median finfold has completely disappeared by the juvenile phase.

During the early postlarval phase (7.8 mm TL), corresponding to Snyder's mesolarval phase, five or six caudal rays are evident, the notochord has deflected slightly upward, the air bladder has filled, the opercle covers four gill arches, and the dorsal fin position is evident as an opaque

area along the median finfold. The apex formed by the differentiating dorsal fin is situated over the 19th and 20th myomeres. Ventrally the finfold extends forward to the fifth myomere.

Between 8.2 and 8.6 mm TL, the anal fin position becomes apparent as an opaque area on the ventral finfold. The hypural complex is present by 8.5 mm TL and five or six dorsal rays and five anal rays are apparent. The caudal fin becomes truncated and finally bilobed by 9.0 mm TL, at which size it has the adult complement of 19 rays.

By 8.8 mm the opercle extends beyond the posterior edge of the auditory vesicle and is thereafter used in determining head length measurement.

Pelvic fin buds become apparent between 11.3 and 12.2 mm TL. This stage roughly precedes the beginning of Snyder's metalarval phase, which begins between 12.2 and 13.6 mm TL when the adult complement of dorsal and anal rays is attained. Pectoral and pelvic ray development is complete by 17.2 mm.

Successive fin ray development is caudal, dorsal, anal, pelvics, and pectorals. The last vestige of the median finfold between the anus and the pelvic fins is absorbed by 19 mm TL.

The midgut begins to bend at 12-13 mm TL and as the gut lengthens a large loop forms ventrally. The gut shape then remains unchanged into the juvenile phase (to 30 mm TL). The mouth remains somewhat subterminal throughout postlarval development, gradually moving to a terminal position by the juvenile phase.

Ventro-lateral squamation appears on the caudal peduncle at 17 mm TL. Scale development proceeds anteriorly, most rapidly below the mid-lateral line. The last areas to form scales are the predorsal fin area and the ventral foregut. Squamation was complete by 23 mm TL.

Postlarvae have from 26 to 27 preanal myomeres, the mode being 26 and 12 to 14 postanal myomeres, the mode being 12. Myomeres were obscured by melanophores on larvae greater than 19.0 mm TL.

Early postlarval (8 mm TL) pigmentation resembles late prolarval pigmentation. A double row of melanophores extends from the head to the caudal fin. The head is heavily pigmented and the premaxilla is outlined by melanophores.

On older postlarvae the dorsal edge of the gut is pigmented from the heavily pigmented dorsum of the air bladder to the anus. An internal row of melanophores extends forward from the dorsum of the air bladder to the base of the skull. The midlateral line, arching slightly anteriorly, extends from the back of the eye to the caudal fin base. The heaviest portion of the midlateral line is over the region extending from the air bladder to the peduncle. The urostyle is still outlined and lower caudal fin pigmentation has increased over that seen in the prolarvae.

Some specimens have one to three large chromatophores on the forming opercle. The nares are outlined by 8.1 mm TL. The sides of the air bladder are pigmented, the upper and lower rims of the mouth are well pigmented, and the dorsal fin has a few chromatophores by 8.9 mm TL.

A definite "V" pattern of pigmentation is evident in the branchiostegal region. The foregut has a characteristic trident-shaped pigment pattern with the outside lines of melanophores extending dorsally and posteriorly to fuse with the pigmentation on the dorsum of the air bladder and gut.

The middle fork fades immediately below the air bladder. By 12 mm TL this ventral midline may extend the length of the gut.

Late postlarvae still have a double row of melanophores dorsally with increased pigmentation within the rows. Internally, the gill arches become pigmented by 12.2 mm. The midlateral line is now heaviest in the peduncle area. The head and opercle are heavily pigmented. The caudal fin rays are moderately pigmented and the dorsal rays are pigmented in the proximal half.

Juvenile Phase (Figure 5)

Specimens having the full adult complement of fin rays were considered juveniles.

Virtually all transitions occurred between 17 and 19 mm TL; the smallest size at which a specimen became a juvenile was 14 mm TL. Attainment of the juvenile phase was a function of size rather than age. A 17.2 mm TL specimen 27 days old was juvenile; a 15 mm TL specimen 35 days old was not.

On juveniles (19 mm TL) the ventral postanal double row of melanophores is present only from the anus along both sides of the anal fin. Thereafter it fuses to form a single diffuse line to the caudal fin base. The visceral area is characterized by increasing pigmentation.

REMARKS

Descriptions of larval cyprinids are scarce and often cursory. Specimens collected in areas other than the Tennessee River Valley often exhibit geographical variation which limits their utility as practical taxonomic aids in identifying specimens from this area.

Larval cyprinid descriptions in the literature include Fish (1932), Battle (1940), Taber (1969), Fuiman and Loos (1977), Snyder et al. (1977), and Granneman and Kay (MS). Moore (1944), Harrington (1947), and Reed (1958) present some descriptive material on larval notropids.

Fish (1932) presents a cursory description of *N. cornutus chrysocephalus* from Lake Erie collections. However, the preanal myomere count given (21) is much too low, probably due to inability to detect myomeres. Her line drawing of a 13.2 mm specimen does closely resemble *N. chrysocephalus* and the proportional relationships of body parts is consistent with those found in the present study for specimens of similar size.

The larval development of the majority of cyprinid species in the Tennessee Valley has not been described. Differentiation of *N. chrysocephalus* from notropid larvae other than *N. spilopterus* and *N. atherinoides* is thus impractical at this time.

The best characters for separating *N. chrysocephalus* from either of these species are the preanal myomere counts and pigmentation. *N. chrysocephalus* has 26 to 27 preanal myomeres whereas *N. spilopterus* has 22 to 24 and *N. atherinoides* 23 to 24. As a postlarva, *N. chrysocephalus* also has the characteristic trident-shaped melanophore pattern ventrally on the foregut, a pattern lacking in both of the other species.

Morphometric data are presented in Table I. Morphometric ratios (Table II) chosen to best represent visual cues are presented by size interval. For all size classes an average ratio of two body parts possibly would be misleading for use in separating similar notropid species showing differential growth.

The relationships of preanal length, postanal length, and head length to total length are essentially linear (Figure 6). The inflection point associated with greatest body depth is due to absorption of yolk sac material between 5.9 and 7.9 mm TL and subsequent general body growth.

Larval growth, reflected by increase in total length (Figure 7) is rapid. During the prolarval phase total length increases 33 percent in five days. Larvae more than double in size during the postlarval phase of about 35 days. Rapid growth continues into the early juvenile phase.

The development of *Notropis chrysocephalus* may be summarized as follows:

5.6-5.9 mm (hatching) Pectoral fin buds are present; the club-shaped yolk sac extends the length of gut; the larvae are unpigmented except for the eyes.

7.2 mm The head is moderately pigmented and a double row of melanophores extends from the occiput to the caudal fin. Ventrally there is a "V" for melanophores in the isthmus region and a double row of melanophores from the anal position to the caudal fin.

7.7 mm The urostyle is outlined to the tip.

7.8 mm The remaining yolk sac is rapidly absorbed.

7.9 mm Five or six hypural rays are evident, the notochord has deflected upwards, the air bladder has filled, and the incipient dorsal fin is present.

8.2 mm The anal fin position is evident.

8.5 mm The hypural complex is present.

9.0 mm The caudal fin has become bilobed and the adult complement of caudal rays is present.

11.3 mm The pelvic fin buds are apparent.

13.0 mm The characteristic trident-shaped pigmentation pattern is present ventrally.

17.2 mm Pectoral and pelvic fin ray development is complete; squamation begins.

19.0 mm The last vestige of the median finfold is absorbed.

23.0 mm Squamation is completed.

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Table 1. Morphometric Data (mm.) For Striped Shiner Larvae.

Size Interval	Number of Specimens	Statistic	Total Length	Urostyle Length	Preanal Length	Postanal Length	Snout Length	Head Length	Head Depth	Eye Length	Greatest Body Depth	Body Width	Yolksac Length	Yolksac Depth	Length to Dorsal Fin Origin	Length to Anal Fin Origin
5.6-5.9	7															
		Mean	5.89	5.71	4.15	1.74	.10	.95	.80	.48	1.24	1.18	3.51	.96	-	-
		S.D.	.08	.08	.07	.04	.02	.02	.02	.01	.07	.06	.07	.10		
		S.E.	.03	.03	.03	.02	*	*	*	*	.03	.02	.03	.04		
6.0-6.9	22															
		Mean	6.55	6.34	4.32	2.23	.12	1.05	.54	.54	1.10	.93	3.37	.74	-	-
		S.D.	.29	.27	.11	.21	.02	.07	.03	.03	.13	.15	.18	.16		
		S.E.	.06	.06	.02	.05	*	.01	*	*	.03	.03	.04	.03		
7.0-7.9 Prolarva	30															
		Mean	7.41	7.07	4.69	2.72	.15	1.22	.91	.56	.95	.70	2.58	.37	-	-
		S.D.	.22	.24	.16	.16	.03	.09	.06	.02	.04	.05	.83	.25		
		S.E.	.05	.04	.03	.03	*	.02	.01	*	*	*	.15	.05		
7.0-7.9 Postlarva	13															
		Mean	7.86	7.47	4.93	2.93	.16	1.39	.98	.58	1.00	.63	-	-	-	-
		S.D.	.09	.08	.06	.09	.03	.03	.03	.02	.04	.03				
		S.E.	.02	.02	.02	.03	*	*	*	*	.01	*				
8.0-8.9	65															
		Mean	8.60	8.02	5.38	3.22	.19	1.63	1.07	.68	1.09	.69	-	-	-	-
		S.D.	.28	.20	.19	.12	.03	.14	.06	.07	.08	.05				
		S.E.	.03	.02	.02	.02	*	.02	*	*	*	*				
9.0-9.9	35															
		Mean	9.41	8.52	5.84	3.57	.23	1.82	1.18	.76	1.27	.79	-	-	-	-
		S.D.	.25	.23	.24	.15	.05	.11	.10	.06	.18	.11				
		S.E.	.06	.04	.04	.03	*	.02	.02	*	.03	.02				
10.0-10.9	8															
		Mean	10.44	9.21	6.48	3.96	.38	2.16	1.51	.88	1.72	1.11	-	-	4.65	6.47
		S.D.	.33	.27	.25	.15	.04	.15	.19	.05	.19	.21			.14	.20
		S.E.	.12	.09	.09	.05	.01	.05	.07	.02	.07	.07			.05	.07
11.0-11.9 .	13															
		Mean	11.31	9.70	6.80	4.51	.42	2.33	1.64	.96	1.79	1.16	-	-	4.94	6.75
		S.D.	.25	.22	.16	.26	.03	.12	.08	.03	.16	.09			.10	.11
		S.E.	.07	.01	.04	.07	*	.03	.02	*	.04	.03			.03	.03
12.0-12.9	7															
		Mean	12.44	10.68	7.31	5.13	.45	2.72	1.89	1.05	2.20	1.46	-	-	5.34	7.20
		S.D.	.31	.12	.24	.46	.08	.15	.03	.07	.26	.16			.12	.30
		S.E.	.12	.08	.09	.17	.03	.06	.01	.03	.10	.06			.05	.11
13.0-13.9	8															
		Mean	13.46	11.51	7.88	5.58	.61	2.94	2.03	1.10	2.40	1.63	-	-	5.79	7.85
		S.D.	.33	.23	.17	.29	.04	.18	.09	.05	.29	.19			.17	.22
		S.E.	.12	.08	.06	.10	.02	.06	.03	.02	.10	.07			.06	.08
14.0-14.9	5															
		Mean	14.51	12.30	8.23	6.28	.66	3.20	2.22	1.19	2.46	1.73	-	-	6.06	8.25
		S.D.	.31	.48	.26	.28	.05	.15	.09	.06	.27	.19			.26	.32
		S.E.	.14	.22	.12	.13	.02	.07	.04	.03	.12	.08			.12	.14

Table 1. CONTINUED

Size Interval	Number of Specimens	Statistic	Total Length	Urostyle Length	Preanal Length	Postanal Length	Snout Length	Head Length	Head Depth	Eye Length	Greatest Body Depth	Body Width	Yolksac Length	Yolksac Depth	Length to Dorsal Fin Origin	Length to Anal Fin Origin
15.0-15.9	8															
		Mean	15.43	12.74	8.46	6.97	.68	3.40	2.38	1.25	2.78	1.98	-	-	6.53	8.47
		S.D.	.31	.25	.19	.41	.08	.09	.07	.06	.23	.13			.18	.17
		S.E.	.11	.09	.07	.14	.03	.03	.03	.02	.08	.04			.06	.06
16.0-16.9	5															
		Mean	16.37	13.59	9.15	7.22	.77	3.68	2.61	1.28	2.89	2.13	-	-	6.75	9.23
		S.D.	.17	.37	.12	.20	.04	.16	.07	.03	.17	.11			.15	.14
		S.E.	.08	.06	.06	.09	.02	.07	.03	.02	.08	.05			.07	.06
17.0-17.9	6															
		Mean	17.65	14.40	9.66	7.99	.76	3.87	2.73	1.45	3.45	2.41	-	-	7.54	9.69
		S.D.	.26	.27	.20	.15	.19	.13	.11	.07	.20	.13			.24	.17
		S.E.	.14	.22	.12	.13	.02	.07	.04	.03	.12	.08			.10	.07
18.0-18.9	6															
		Mean	18.54	15.56	10.48	8.06	.80	4.15	2.94	1.49	3.62	2.67	-	-	7.87	10.33
		S.D.	.32	.58	.91	.77	.04	.16	.14	.04	.08	.20			.33	.54
		S.E.	.13	.24	.37	.31	.02	.07	.06	.02	.03	.08			.13	.22
19.0-19.9	2															
		Mean	19.51	16.06	10.67	8.84	.83	4.34	2.99	1.54	3.84	2.75	-	-	8.31	10.76
		S.D.	.62	.68	.74	.12	.03	.43	.06	.06	.34	.40			.62	.62
		S.E.	.44	.48	.53	.09	.02	.30	.04	.04	.24	.28			.44	.44
20.0-20.9	3															
		Mean	20.70	17.10	11.37	9.33	.93	4.75	3.38	1.66	3.77	2.92	-	-	8.73	11.47
		S.D.	.17	.10	.32	.15	.08	.12	.14	.04	.06	.06			.21	.40
		S.E.	.10	.06	.19	.09	.05	.07	.08	.02	.04	.04			.12	.23
21.0-21.9	7															
		Mean	21.44	17.76	11.87	9.57	1.01	4.63	3.37	1.65	3.88	3.12	-	-	8.98	11.94
		S.D.	.37	.42	.36	.24	.09	.17	.11	.05	.11	.07			.18	.31
		S.E.	.14	.16	.13	.09	.04	.07	.04	.02	.04	.03			.07	.12
22.0-22.9	2															
		Mean	22.09	18.15	12.20	9.85	.95	5.07	3.56	1.72	4.40	3.37	-	-	9.15	12.30
		S.D.	.07	.21	.14	.07	.09	.14	0.00	.03	.51	.37			.21	0.00
		S.E.	.05	.15	.10	.05	.06	.10	*	.02	.36	.26			.15	*
23.0-23.9	3															
		Mean	23.40	19.20	12.53	10.87	1.02	5.08	3.60	1.80	4.91	3.51	-	-	9.63	12.60
		S.D.	.40	.20	.45	.45	.09	.15	.04	.02	.25	.12			.23	.40
		S.E.	.23	.12	.26	.26	.05	.09	.02	.01	.10	.07			.13	.23
24.0-24.9	5															
		Mean	24.38	20.12	13.23	11.15	1.09	5.28	3.89	1.81	4.59	3.51	-	-	9.92	13.36
		S.D.	.30	.26	.17	.36	.14	.16	.05	.02	.09	.06			.24	.26
		S.E.	.13	.12	.08	.16	.06	.07	.02	*	.04	.03			.11	.12

*Denotes Standard Error (S.E.) of less than .01.

Table 2. Morphometric Ratios For Striped Shiner Larvae

Size Interval (mm)	Preanal Length / Total Length	Snout Length / Head Length	Head Length / Total Length	Greatest Body Depth / Total Length	Yolk Sac Depth / Greatest Body Depth	Yolk Sac Length / Total Length	Head Depth / Head Length	Eye Length / Head Length	Body Width / Preanal Length	Length to Dorsal Fin / Length to Anal Fin
5.6-5.99	.704	.105	.162	.211	.777	.596	.836	.509	.285	-
6.0-6.99	.661	.115	.160	.167	.674	.514	.771	.514	.215	-
7.00-7.99	.633	.122	.165	.129	.392	.348	.740	.461	.149	-
7.00-7.99	.627	.112	.177	.128	-	-	.706	.419	.128	-
8.00-8.99	.626	.115	.189	.127	-	-	.659	.419	.128	-
9.00-9.99	.620	.128	.194	.135	-	-	.650	.418	.136	-
10.00-10.99	.621	.174	.207	.165	-	-	.699	.407	.171	.719
11.00-11.99	.601	.181	.206	.163	-	-	.703	.412	.171	.732
12.00-12.99	.587	.164	.219	.177	-	-	.693	.387	.200	.742
13.00-13.99	.586	.208	.219	.179	-	-	.690	.374	.206	.738
14.00-14.99	.507	.206	.220	.169	-	-	.693	.372	.211	.733
15.00-15.99	.548	.198	.220	.180	-	-	.699	.367	.234	.771
16.00-16.99	.599	.210	.225	.177	-	-	.710	.348	.233	.731
17.00-17.99	.547	.196	.219	.195	-	-	.707	.374	.250	.778
18.00-18.99	.566	.193	.224	.195	-	-	.707	.358	.254	.762
19.00-19.99	.547	.191	.223	.197	-	-	.688	.353	.257	.772
20.00-20.99	.549	.195	.229	.182	-	-	.711	.348	.257	.761
21.00-21.99	.555	.218	.216	.181	-	-	.727	.356	.264	.752
22.00-22.99	.553	.187	.230	.200	-	-	.701	.339	.277	.744
23.00-23.99	.536	.202	.217	.210	-	-	.708	.355	.280	.764
24.00-24.99	.543	.207	.216	.188	-	-	.738	.343	.265	.743

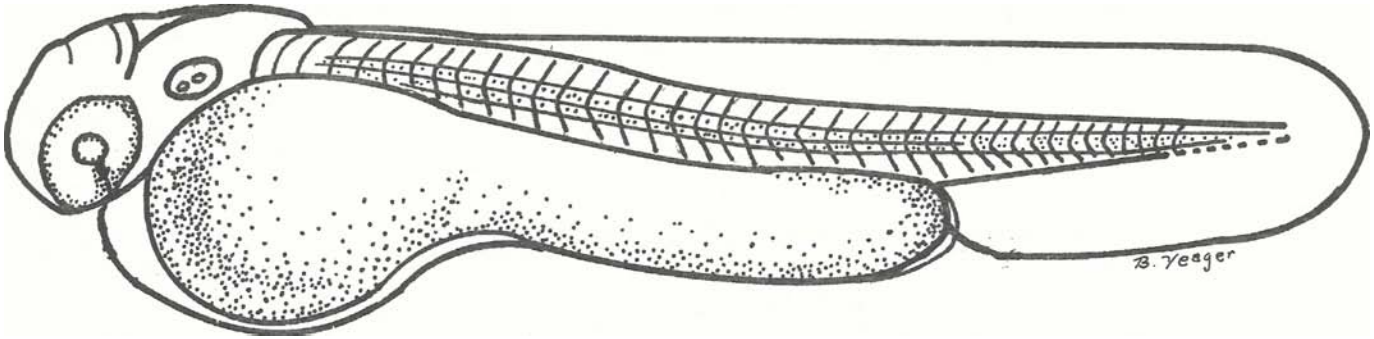

Figure 1. Prolarva at hatching 5.6 mm TL

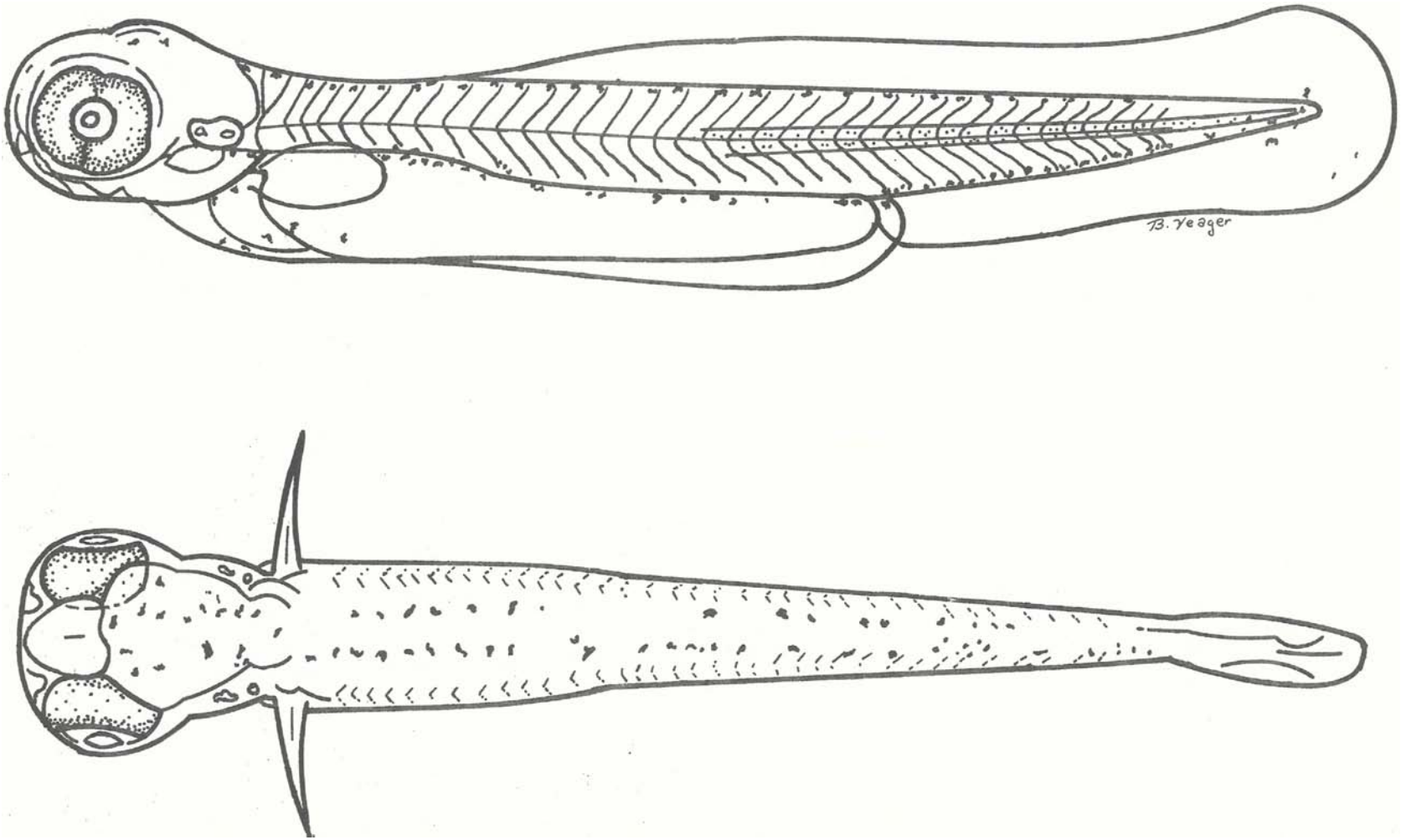

Figure 2. Prolarva 7.3 mm TL

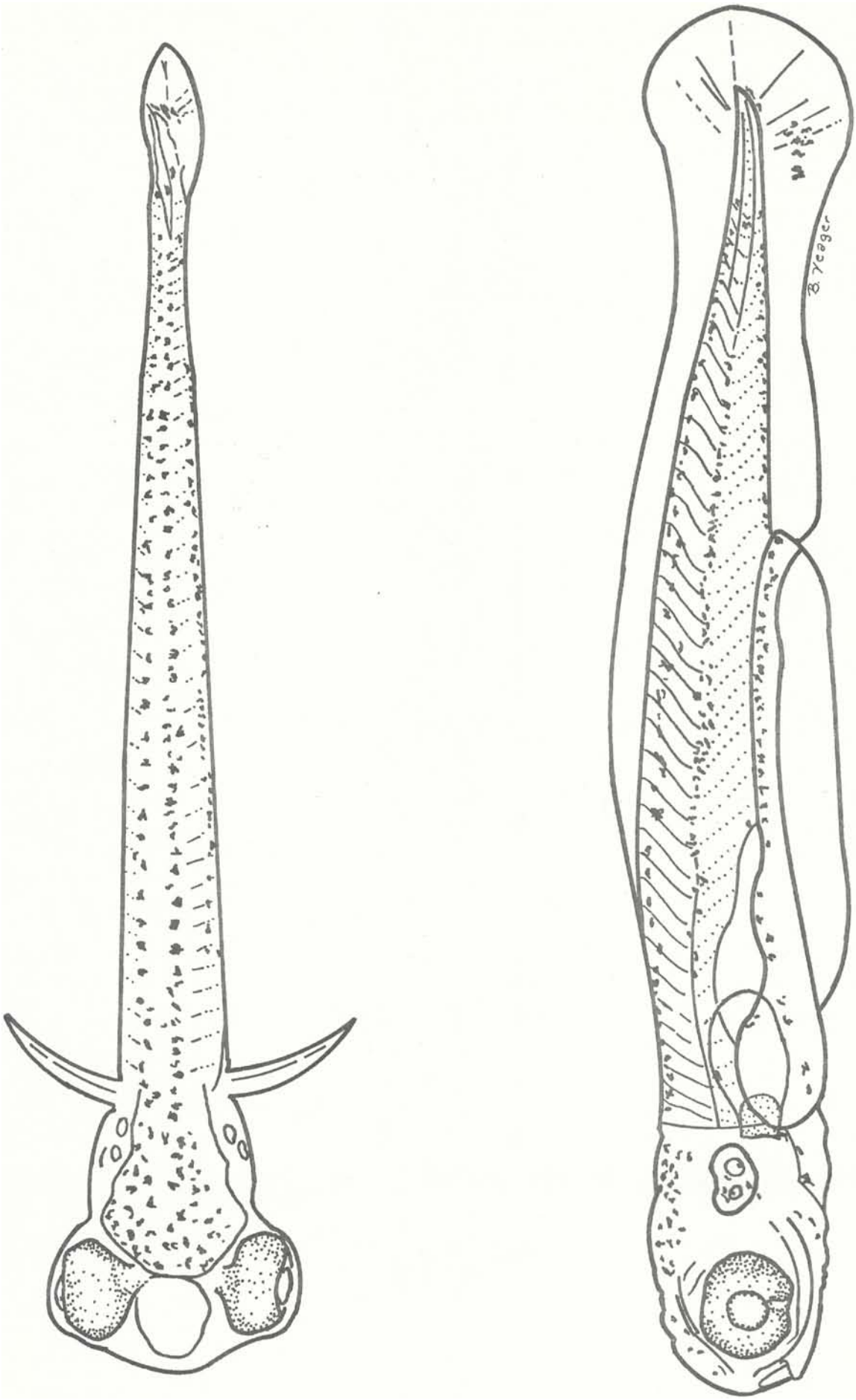

Figure 3. Postlarva 7.8 mm TL

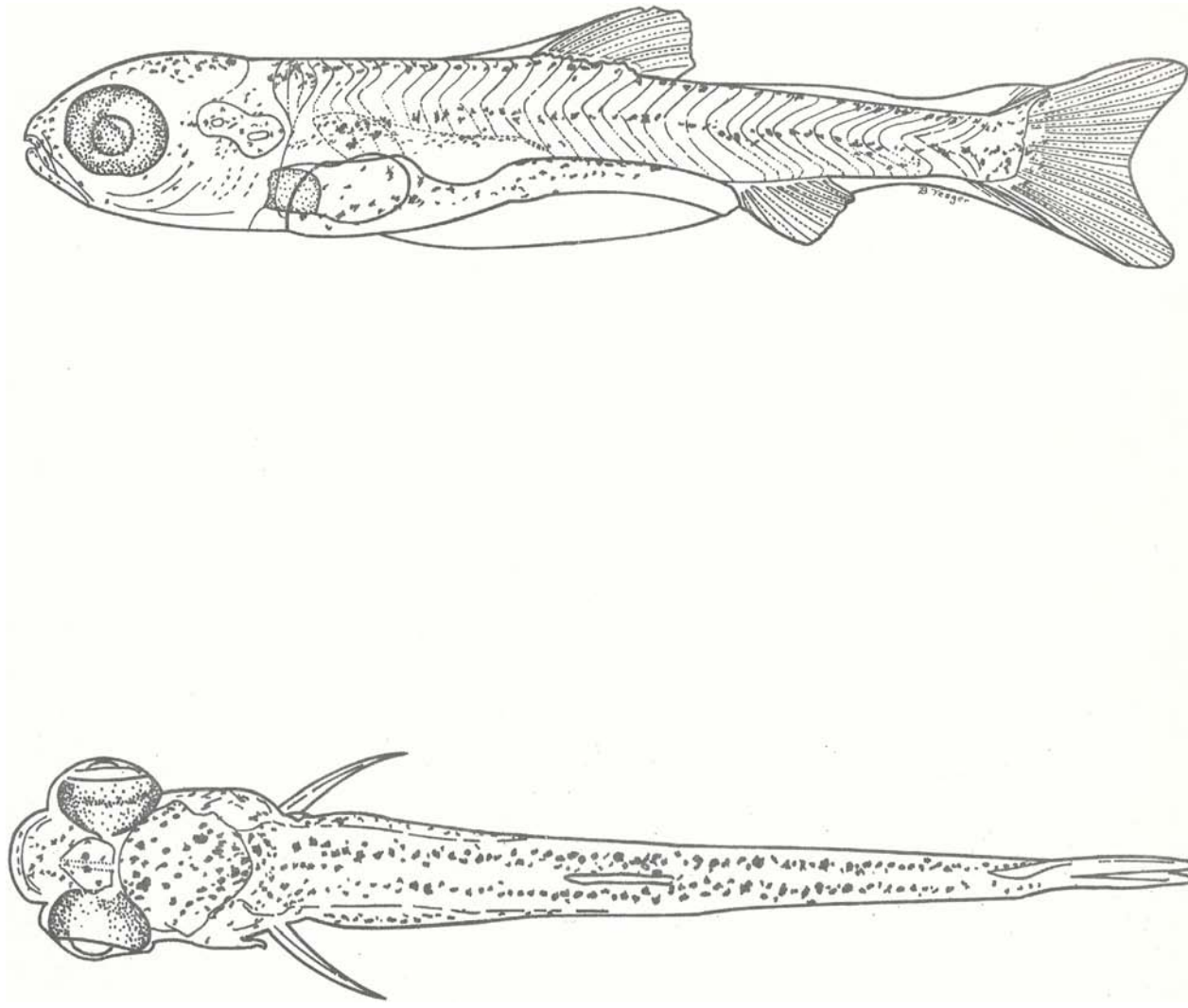

Figure 4. Postlarva 13.0 mm TL

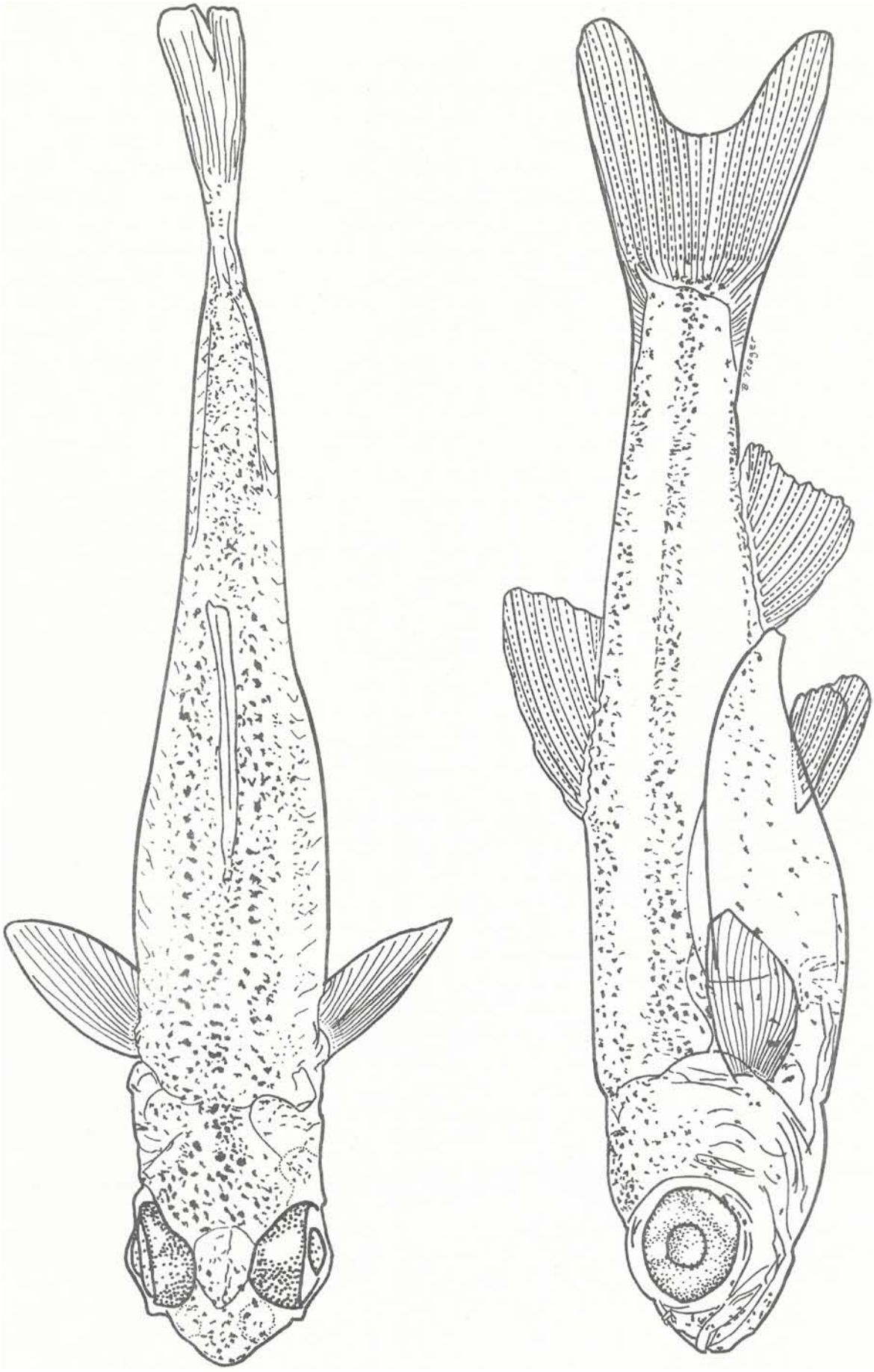

Figure 5. Juvenile 18.2 mm TL

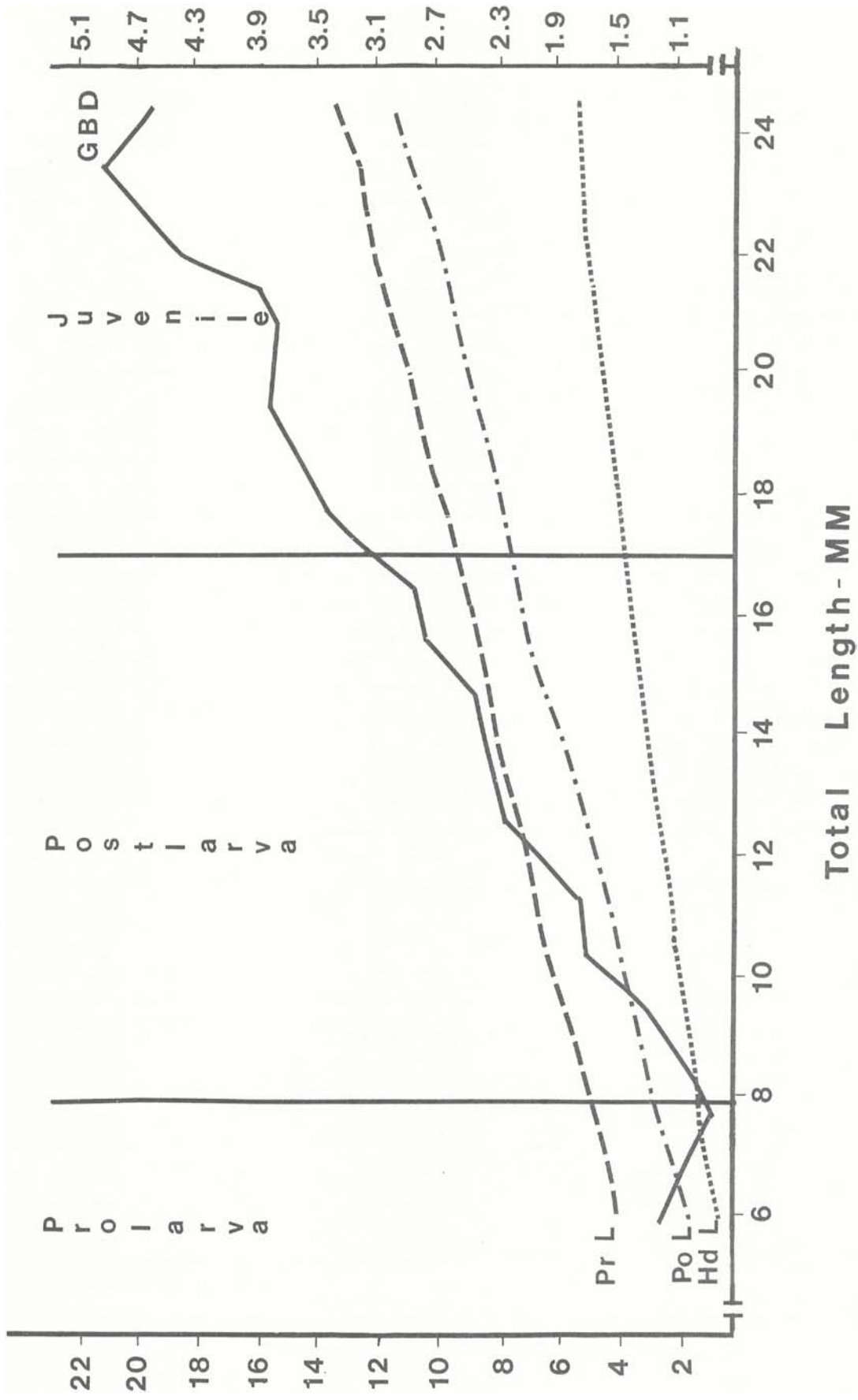

Figure 6. Head Length, Preanal Length, Postanal Length, and Greatest Body Depth vs Total Length

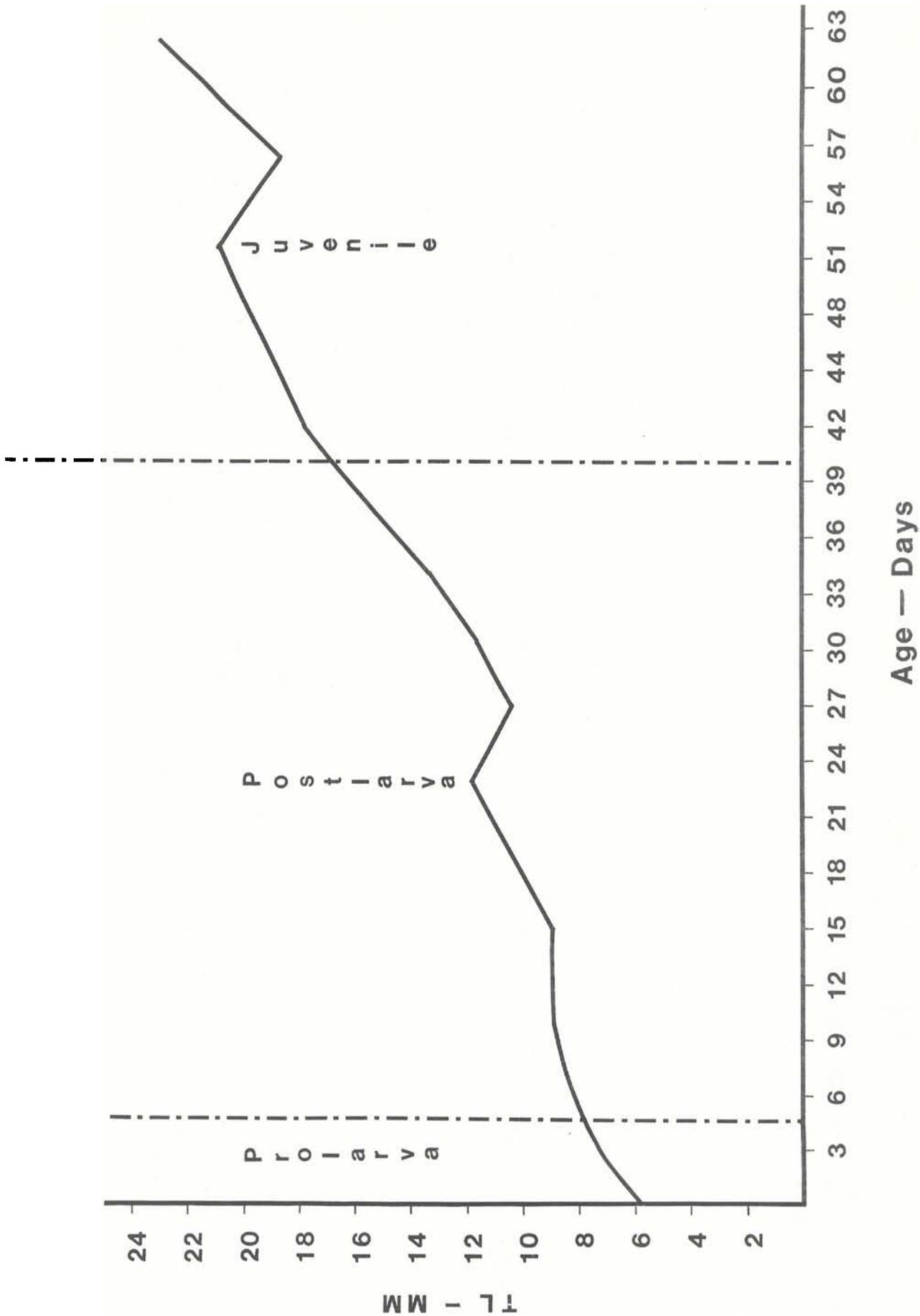

Figure 7. Mean total length (TL) in millimeters by age.

NOTES ON

EARLY LIFE HISTORIES OF CYPRINOID FISHES

OF THE UPPER POTOMAC RIVER

by

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ABSTRACT

Eggs of cyprinoid fishes in the upper Potomac River were collected from natural spawning sites, then reared through the larval period to identifiable size. It was found (as expected) that groups of species that utilize similar spawning sites had in common certain early developmental characteristics. Rearing is usually necessary to ensure correct identifications within such groups.

While collecting and identifying eggs, the authors discovered or verified several reproductive associations: spawning of *Notropis procne* in the nests of *Lepomis auritus,* spawning of *Notropis amoenus* over completed nests of *Nocomis micropogon,* and a strong tendency for *Rhinichthys cataractae* to use spawning areas of *Catostomus commersoni.*

INTRODUCTION

The study of the early life history of fishes is of both academic interest and practical importance for fisheries management and evaluation of man's environmental impacts. While much data is at hand for North American game and commercial species, little information is available concerning numerous smaller fishes, especially in the suborder cyprinoidei (Scott and Crossman 1973). This taxon exhibits an extraordinary range of reproductive habits (Breeder and Rosen 1966) and detailed studies have elucidated many points of biological interest (Balon 1975, Kryzhanovsky 1948, Nakamura 1969).

The purpose of this paper is to present notes on the early life history of cyprinoid species collected from Frederick and Montgomery Counties, Maryland during environmental studies in the vicinity of the Dickerson Generating Station located on the Potomac River. Twenty-six of the 37 cyprinoids reported from the Potomac River drainage by Jenkins *et al.* (1972) and Davis and Enamait (1977) are considered in this study, with emphasis placed on the relationship of spawning site to egg and larval traits. Additional information was derived from collections made at other locations in Pennsylvania, Maryland, and Virginia. Although breeding behavior and spawning seasonality are summarized elsewhere (Breeder and Rosen 1966 and Carlander 1969), eggs and larvae of many cyprinoids collected were not previously described.

METHODS

The Academy of Natural Sciences of Philadelphia (ANSP) conducted twelve surveys of juvenile and adult fish fauna (in conjunction with comprehensive surveys of other aquatic life) in the Potomac River, Frederick and Montgomery Counties, Maryland, from 1956 to 1974 at stations circled in Fig. 1. Fishes were collected with rotenone and/or a 20-foot bag seine as described by Cairns and Kaesler (1971). In addition, a list of the cyprinoid fishes (Table 1) was compiled from specimens deposited in the Ichthyology Department of ANSP.

Reproductive studies were carried out primarily between 2 May and 14 July 1973. Observations and collections were made at 15 Potomac River areas indicated by triangles in Fig. 1. Similar supplementary collections and observations were made in local Potomac tributaries at the following sites now shown in Fig. 1:

Catoctin Cr. at the crossing of Maryland Route 464, Frederick County, Maryland

Monacacy R. at Lily Pons, Frederick County, Maryland

Unnamed tributary approximately 4 km south of the confluence of the Monacacy and Potomac Rivers, just above junction with Chesapeake and Ohio Canal, Montgomery County, Maryland

Identification of larvae was facilitated by rearing eggs or larvae of questionable identity to a stage where identification was possible or by comparison with developmental reference series. Much of the reference series material was reared from eggs collected at other locations. In most cases naturally fertilized eggs or larvae were collected and taken back to a field laboratory or to ANSP. Eggs or larvae were placed in shallow plastic containers (89 x 152 x 304 mm) in aerated stream water between 16 to 20 C. Newly fertilized eggs generally hatched within a week. Larvae were fed daily with *Artemia* nauplii and finely ground commercial fish food. All material, preserved in five percent Formalin buffered with borax, is deposited in the collection of the Ichthyology Department of ANSP.

We use the reproductive guild terminology of Balon (1975) and the developmental terminology of Snyder (1976). Hatching is used as the boundary between the embryonic and larval periods rather than complete yolk absorption and feeding.

Myomeres were counted with the aid of polaroid filters placed above and below the larvae and used with a microscope equipped with a substage lamp. Myomeres between the most anterior myoseptum and a vertical line at the posterior margin of the anus were termed preanal myomeres. We follow Siefert (1969) in including all myomeres transected by this line in the preanal count. Myomeres in metalarvae were difficult to count due to opacity. Consequently, counts are given only for protolarvae and mesolarvae.

Internal melanophores, useful in identification of cyprinoid fishes (Balinsky 1948), were made visible by clearing larvae in glycerine for a few minutes. Larvae which became dehydrated by this procedure were completely reconstituted when replaced in dilute Formalin.

The presence of cement glands was another character useful in identification. The ability of a larva to adhere to the walls of the rearing chamber was considered evidence of the presence of cement glands. Illustrations of *Notropis* species are not included because these are being published in an earlier workshop in this series (Loos and Fuiman 1978).

Campostoma anomalum (Stoneroller, Fig. 2 A-C). Stoneroller eggs, adhesive during water hardening, are reported to be 2.4 mm in diameter (Reed 1958). They are found in irregular pit-like nests constructed by the breeding male or in nests of other species such as creek chubs (Miller 1962) or river chubs (Reighard 1943).

Newly hatched larvae have a large yolk mass that is bulbous anteriorly and tubular posteriorly. Hatching length is approximately 5.7 mm TL (Reed 1958), but absence of the tubular posterior portion of the yolk in his illustration suggests that his specimens were not developing normally. The retina is unpigmented or light tan at this stage. The head is deflected over the yolk and pectorals are not prominent. These characteristics suggest early hatching larvae. Balon (1975) indicates that protolarval characteristics of brood hiding lithophils may facilitate respiration.

Hogue, *et al.* (1976) report 27 to 28 preanal myomeres and a mesolarval pigment pattern similar to that we have observed for other nest-building minnows as well as *Rhinichthys* in the same phase. In metalarvae, the distinct caudal spot separated from the lateral body stripe and the subterminal mouth readily distinguishes stonerollers from fallfish and creek chubs. The intestine does not become greatly elongated until the juvenile period (Kraatz 1924).

Chrosomus oreas (Mountain Redbelly Dace, Fig. 4 D-F)—This dace, while not found in the study area, occurs in the Potomac drainage. It is a common breeding associate of *Nocomis leptocephalus.* Mesolarvae are characterized by diagonal rows of external body melanophores aligned along the myosepta.

Clinostomus funduloides (Redside Dace, (Fig. 89 D-F)—This breeding associate of *Semotilus atromaculatus* is found in the Potomac drainage but not the study area. Its eggs are smaller than those of *S. atromaculatus* (1.8 to 2 mm in diameter) and distinctly more yellow; newly hatched larvae have the characteristics of other lithophils at the same stage. Hogue *et al.* (1976) indicate 22-25 preanal myomeres and a pigment pattern different than that expressed by our specimens. Theirs from the Tennessee drainage had a single midventral row of melanophores extending to the anus; our specimens from the Delaware drainage had a dark patch of melanophores on the breast and a poorly developed midventral row.

Cyrpinus carpio and *Carassius auratus* (Carp and Goldfish, Fig. 2 D-F)—Eggs are attached to aquatic plants or flooded vegetation (Richardson 1913). Along the Potomac River exposed roots of trees are common spawning sites.

Eggs of both species were reared; eggs of the carp were slightly larger than those of goldfish (1.8 mm versus 1.5 mm). Hatching size for carp is also slightly greater (5.2 mm versus 4.7 mm TL).

At hatching, the eyes of both are pigmented and the head is not deflected over the yolk. These traits indicate that larvae are relatively advanced at hatching. This and the presence of cement glands, which allow the larvae to adhere to a substrate, are characters Balon (1975) considers typical of the open substrate phytophilous reproductive guild. In the mesolarval phase the carp develops a prominent dark spot at the base of the caudal fin; the goldfish, which lacks this spot, develops a line of melanophores along the horizontal myoseptum.

A dense band of melanophores on the ventral aspect of preanal and postanal myomeres and a proportionately larger preanal length are useful for differentiating protolarval and mesolarval carp and goldfish from native minnows. Both species lack a lateral band or line of body melanophores common to mesolarvae and metalarvae of other minnows. Metalarval carp and goldfish have ten or more incipient dorsal rays; other minnows of the area have fewer.

Ericymba buccata (Silverjaw Minnow)—The presence of silverjaw minnows in the area was confirmed by rearing one larval specimen collected just above area three in early May (exact date and temperature data lost) and two others from Catoctin Creek in July (24 C). Reproductive life history information is presented by Hoyt (1971) and Wallace (1973).

Exoglossum maxillingua (Cutlips Minnow, Fig. 3 A-C)—Adults are rare in the study area and no larvae were collected. Fuiman and Loos (in press) describe larval development and note that eggs may be laid in nests of *Nocomis micropogon*. Van Duzer (1939) gave a detailed account of its reproductive habits including nest building, spawning association with common shiners, and a brief description of its eggs.

Hybognathus regius (Silvery Minnow)—The silvery minnow was rarely collected in the study area. No larvae were identified, but their apparent similarity to larvae of the spottail shiner

may have caused misidentifications. Raney (1939) described breeding behavior and illustrated larval specimens of *H. regius*. These and additional illustrations and descriptions were presented by Mansueti and Hardy (1967).

Nocomis micropogon (River Chub, Fig. 3 D-F)—Its nests (often used by other species) were described by Cope (1868), Greely (1929), Raney (1940b), Reighard (1943), Lachner (1952) and others.

Eggs, adhesive during water hardening, are approximately two mm in diameter (Fish 1932). They are relatively clear, with yellowish yolk, and can be distinguished from those of *Rhinichthys cataractae,* which sometimes uses *Nocomis* nests, because the latter are more opaque. They are similar to eggs of breeding associates, *Notropis rubellus, N. cornutus, Exoglossum maxilligua* and *Campostoma anomalum*. When only *Nocomis* and *N. rubellus* eggs are present, they can be distinguished by the smaller size of the shiner eggs. If eggs of the others are present, accurate identification is not feasible with available data.

Newly hatched, unpigmented protolarvae of all nest builders and their associates are similar. They do differ in size, but overlapping measurements usually make identification impractical without rearing. Larvae are robust and approximately 7 mm TL at hatching. They develop two dorsal body rows of melanophores that are strongly divergent just posterior to the head in the mesolarval phase. They are similar to *Nocomis leptocephalus* (Fig. 4 A-C) larvae reported from the drainage system (Jenkins *et al.,* 1972) but not from the study area.

Notemigonus crysoleucas (Golden Shiner, Fig. 4 A-E)—Eggs were found attached to small pebbles in a tributary of Piscataway Cr. (Potomac drainage) and were hatched and larvae were reared to confirm identification.

Golden shiners reportedly spawn over vegetation and centrarchid nests (Kramer and Smith 1960, Johnson C. S. Wang, personal communication). Snyder *et al.* (1977) present a detailed description of egg and larval characteristics of this species. No other cyprinoid from the study area had this combination of developmental characters. Larvae which we reared conform to their descriptions except that our specimens hatched at approximately 4.2 mm TL with darkly pigmented eyes. An earlier statement by Loos (1974) that mesolarval *N. crysoleucas* may lack the midventral abdominal stripe was apparently incorrect.

Larvae apparently possess cement glands for they adhered to the walls of the rearing chamber. These glands, found on the head, are characteristic of species assigned by Balon (1975) to the open substrate phytophilous reproductive guild.

Notropis amoenus (Comely Shiner)—Specimens of this *Notropis* species are illustrated by Loos and Fuiman (1978)—No eggs or larvae were identified from the study area; however, we reared eggs from the Susquehanna drainage of south central Pennsylvania. These were similar to *Notropis rubellus* and closely corresponded to descriptions and illustrations of *Notropis atherinoides,* the emerald shiner (Flittner 1964).

The delicate nonadhesive egg capsule of these species is not unlike that of striped bass. The colorless egg is approximately 2.7 to 3 mm in diameter. The perivitelline space width, larger than for any other Potomac River cyprinoid, is nearly equal to the diameter of the yolk.

The newly hatched larvae (approximately 5.5 mm TL) are also similar to *N. atherinoides* specimens illustrated by Flittner (1964), except that they are more advanced, i.e., eyes are darkly pigmented; the head is not deflected over the yolk, and the pectorals are developed. A midventral row of abdominal melanophores is present; *N. atherinoides* is not pigmented at this stage.

Mesolarvae and metalarvae are similar to *Notropis rubellus* in the same phases, in that both have a single midventral row of abdominal melanophores and melanophores on the tip of a projecting lower jaw. Both lack the concentration of melanophores on the dorsal urostyle found in *Notemigonus crysoleucas* at the same phase of development.

Notropis cornutus (Common Shiner)—Eggs are found in hollows cleared by breeding males or in nests of river chubs, fallfish, cutlips, minnows, creek chubs or stonerollers (Kendall and Goldsborough 1908, Raney 1940a).

Eggs, approximately 1.7 to 1.8 mm in diameter (Raney 1940a), are intermediate between those of the rosyface shiner and river chub. Egg capsules are adhesive during water hardening and relatively clear. Newly hatched larvae are approximately 5 mm TL. Mesolarvae are characterized by two rows of dorsal body melanophores, a concentration of melanophores on the dorsal urostyle, and generally by variously developed midventral and ventro-lateral rows of abdominal melanophores.

Notropis hudsonius (Spottail Shiner)—This species dominated larval collections in late May and early June. Midsummer spawning, as reported by Griswold (1963), does not occur in the study area.

In the Potomac River and elsewhere their eggs were found in shallow riffles attached to the upper surface of fine gravel or sand (Wright and Allen 1913, Greely 1930). Eggs were also found in patches of *Cladophora* (Wells and House 1974).

Balon (1975) tentatively placed *N. hudsonius* in the open substrate psammophilous reproductive guild. Our observations support his classification, i.e., eggs are small (approximately 1.3 mm in diameter); protolarvae lack cement glands; and they are phototropic after the swim bladder fills.

Newly hatched protolarvae (approximately 4.3 mm TL) have poorly pigmented eyes and dense ventral pigmentation similar to that of *Notropis bifrenatus* (Harrington 1947, Mansueti and Hardy 1967). In this stage, the former can be distinguished by the absence of cement glands. In the mesolarval phase (Lippson and Moran 1974), *N. hudsonius* is characterized by two dorsal rows of body melanophores and scattered melanophores on ventrum (sometimes arranged in three vague rows—Darrel Snyder, personal communication). The caudal spot is sometimes well developed in the metalarval phase.

Notropis procne (Swallowtail Shiner)—We have found swallowtail shiner eggs attached to pebbles in the nests of *Lepomis auritus* (redbreast sunfish). They also spawn in riffle areas over fine gravel and sand (Raney 1947b). No larvae were identified from our collections in the study reach.

Notropis rubellus (Rosyface Shiner)—Eggs are found in nests of other cyprinids (Pfeiffer 1955, Hankinson 1932b, Lachner 1952, Pflieger 1975); river chub nests are used in the study area.

Eggs and larvae are most similar to those of *Notropis ardens,* which are found in the Potomac River drainage, but not in the study area. Raney (1947a) considers *N. ardens* a southern ecological replacement of *N. rubellus.* The eggs and newly hatched larvae of these two species are similar in size. The exact sizes are unknown because eggs were mixed with those of other

species, but they are among the smallest eggs in the nest (1.5 to 1.7 mm in diameter). Newly hatched larvae are approximately 5 mm TL. Reed (1958) reported that *N. rubellus* eggs were 1.5 mm in diameter and newly hatched larvae were 5.1 mm TL.

Mesolarvae of the two species are similar in pigmentation, morphology, and behavior (Loos and Fuiman 1978). Compared with other minnow larvae from the study area, rosyface shiner larvae were similar to those of the golden and common shiners. The mesolarva of the common shiner has a concentration of melanophores dorsally on the urostyle. This concentration is absent in the rosyface shiner. *N. rubellus* also lacks ventro-lateral abdominal rows of melanophores often found in common shiner mesolarvae. The golden shiner protolarvae have cement glands; the rosyface shiner protolarvae do not. (See *Notropis amoneus* for comparisons with that specis.)

Notropis spilopterus (Spotfin Shiner)—Adhesive eggs (1.2 to 1.5 mm in diameter, Snyder *et al.* 1977) are generally attached to wood in moderate current. Clumps of eggs are frequently found in cracks in branches or boards or under bark (Hankinson 1930, Stone 1940, Pflieger 1965). No other minnow in the study area has clumped eggs laid in this manner.

Larvae (approximately 4 mm TL at hatching) have been described in detail by Snyder *et al.* (1977). They can be identified in the mesolarval phase on the bases of dorso-ventral compression of the head, absence of a midventral abdominal stripe, and pale dorsal pigmentation. Eggs and larvae of this species are similar to those of the satinfin shiner *(Notropis analostanus)* (Loos and Fuiman 1978), another species of the *Cyprinella* subgenus found in the Potomac River near Washington, D.C. (Lippson and Moran, 1974).

Mesolarval satinfin shiners often lack the "V"-shaped pattern of melanophores on top of the head and the elongate breast melanophores described by Loos (1974). Protolarvae and mesolarvae are indistinguishable from those of the spotfin shiner. Metalarvae can readily be distinguished because the satinfin shiner typically has nine anal rays while the spotfin shiner typically has eight.

Pimephales notatus (Bluntnose Minnow, Fig. 6 A-D)—Adhesive eggs (1.6 mm in diameter, Hubbs and Cooper 1936) are laid on the underside of flat objects (Westman 1938). Embryonic and protolarval development has been described (Fish 1932) and a complete developmental series of our specimens is available at ANSP.

Mesolarvae and metalarvae are superficially similar to spottail shiners in the same stage of development. The metalarvae of both generally have an intensification of pigment in the caudal area. The bluntnose minnow is characterized by chevron-shaped markings along the notochord that become visible when the specimen is cleared in glycerin.

Rhinichthys atratulus (Blacknose Dace, Fig. 6 C-F)—Adhesive eggs are approximately 2.3 mm in diameter. We have found eggs in gravel riffles and in pockets of gravel in streams over bedrock, often near those of the longnose dace and white sucker. Bartnik (1970) reports spawning sites of the daces, though sometimes nearly adjacent, are separate; the western blacknose dace (*R. a. melegris)* spawn in slower water over finer substrata than the longnose dace. Elsewhere, *R. atratulus* spawns over nests of *Semotilus corporalis* (Reed, 1971) and *Nocomis biguttatus* (Hankinson, 1932a). We have not found eggs of the Potomac or Susquehanna populations in *Nocomis micropogon* nests, although *Rhinichthys cataractae* often spawns there.

Fuiman and Loos (1977) described the larvae that hatch at 6 mm TL. A subterminal mouth, numerous scattered dorsal body melanophores, and a mode of 24 preanal myomeres are characteristics developed by the mesolarval phase. The mouth of the mesolarva is more terminal than that of *R. cataractae* in the same phase. Mesolarvae are difficult to distinguish from those of *Campostoma anomalum* and *Exoglossum maxillingua.* The subterminal mouth and frenum and position of dorsal-fin origin posterior to base of pelvic fin buds are the only characters needed to distinguish the metalarvae of this species from those of other minnows in the area.

Rhinichthys cataractae (Longnose Dace, Fig. 7 A-D)—The adhesive, relatively opaque eggs are 2.5 mm in diameter. Fuiman and Loos (1977) report that larvae hatch at approximately 5.5 mm TL and lack pigment and that mesolarvae have a pigment pattern similar to *R. atratulus,* modally 25 preanal myomeres, and an inferior mouth. Their long noses are unmistakable in the metalarval phase.

Semotilus atromaculatus (Creek Chub, Fig. 8 A-C)—This species' nest and breeding habits were described by Reighard (1910). Eggs are 2.0 to 2.1 in diameter, and newly hatched larvae are 5.3 mm TL.

Mesolarvae are similar to those of the fallfish, but have a concentrated area of pigment on the pectoral fin near its base which is not present in mesolarval fallfish. Both species

have more preanal myomeres (usually 28-29) than other minnows in the area. A metalarval specimen was described and illustrated by Fish (1932). She indicated fewer preanal myomeres, but her counting techniques differed from ours.

Semotilus corporalis (Fallfish, Fig. 9 A-C)—Reed reported that the adhesive eggs are 2.7 mm in diameter and that the larvae are approximately 6.5 mm TL at hatching; thus being larger than eggs and newly hatched larvae of other minnows in the area. Reed's descriptions and illustrations (1971) as well as our observations indicate that fallfish larvae are generally larger than those of the blacknose and longnose dace at any given stage of development.

Carpiodes cyprinus (Quillback Carpsucker, Fig. 9 D-F)—Juveniles have been collected in tributaries of the Potomac River below Washington, D.C., but none have been collected in the study area. We have found eggs attached to the upper surface of gravel and organic matter in shallow water. These eggs are approximately 2.1 mm in diameter.

Development of *C. cyprinus* larvae was described by Gerlack (1973). Newly hatched larvae have darkly pigmented eyes. In white suckers, northern hogsuckers, and shorthead and golden redhorses the larvae are larger at any given stage and the snout-to-vent length is about 0.8 times the TL, while in quillback carpsucker this proportion is much less. *C. cyprinus* lacks the pale dorsal head stripe of the creek chubsucker.

Erimyzon oblongus (Creek Chubsucker, Fig. 10 A-C)—Adhesive eggs are found in gravel. They are approximately 1.8 mm in diameter and the newly hatched larvae are approximately 6.5 mm TL. Both eggs and larvae are considerably smaller than those of white suckers, hogsuckers, and redhorses. Larvae illustrated by Carnes (1958) and reprinted by Mansueti and Hardy (1967) appear deformed. Mesolarvae and metalarvae are characterized by a pale stripe on top of the head extending posterior to the eye.

Moxostoma macrolepidotum (Shorthead Redhorse) and *M. erythrurum* (Golden Redhorse)—Descriptions of larval series of the shorthead redhorse are available (Furiman 1978) while those of the golden redhorse are forthcoming (Fuiman and Witman, ms.).

Hypentelium nigricans (Hogsucker, Fig. 10 D-E)—This sucker spawns in rapids (Carlander 1969). Raney and Lachner (1946) reported that nonadhesive eggs were dislodged from spawning sites.

The development of the larvae of this species has been described by Fuiman (1978), and Fish (1932) described and illustrated a young juvenile.

Catostomus commersoni (White Sucker, Fig. 11 A-D)—Adhesive eggs are deposited in gravel riffles where protolarvae remain after hatching for an undetermined period. Detailed embryological descriptions of the stages and rates of development at several temperatures were made by Long and Ballard (1976). Eggs and larvae (Steward 1927, Mansueti and Hardy 1967) are least superficially similar to those of the redhorses and hogsucker. Their presence in the study area was documented by collecting larvae and rearing them to an identifiable size.

COMPARISONS AMONG CYPRINOID GROUPS THAT UTILIZE DIFFERENT SPAWNING SITES

At the present time, it is often impossible to identify eggs based on morphological characters without hatching and culturing them at least through the protolarval phase. However, one can usually determine immediately if a specimen belongs to a group of species with similar reproductive habits, thereby at least narrowing the range of choices. In some cases there is only one representative in a given mode. The following list summarizes information on reproductive modes of species from the study area. Some species will appear in more than one group; the primary mode of a given species is indicated by an asterisk.[1]

Group:

1 Eggs laid over abandoned redds (or nests) built by other species; nonadhesive eggs are not buried but sift into chinks between pebbles: *Notropis amoenus.**

2 Eggs attached to aquatic plants or roots: *Carassius auratus,** *Cyprinus carpio,** *Notemigonus crysoleucas** (Copper, 1935) and *Notropis hudsonius* (Wells and House, 1974).[2]

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[1]These groupings are not proposed as a substitute for Balon's system but are used as a convenient way to summarize our data and to serve as an interim system until the species can be placed with certainty into Balon's scheme based on morphological and ecological characteristics.

[2]A report of *Rhinichthys atratulus* spawning on aquatic plants (Wright and Allen, 1913) needs verification.

3 Eggs laid on the upper surface of gravel or small pebbles or in sand: *Notemigonus crysoleucas, Notropis hudsonius,* Notropis procne* (Raney, 1947b) and *Erimyzon oblongus.** Occasionally, carp eggs have been found on this substrate.)

4 Eggs laid in centrarchid nests: *Notropis cornutus* (Latta, 1963), *Notropis procne,* Notemigonus crysoleucas* Kramer and Smith, 1960; Pflieger, 1975).

5 Eggs laid in nests built by male principally by picking up pebbles in mouth; nests of the following types described by Raney (1940b):

pit-and-ridge: *Semotilus atromaculatus**
pit-mound: *Nocomis micropogon*; Exoglossum maxillingua**
pit: *Campostoma anomalum**
mound: *Semotilus corporalis**

6 Eggs buried in nests constructed by one of more species in group 5: *Notropis cornutus,* Notropis rubellus,* Rhinichthys cataractae,* and *Rhinichthys atratulus* (Reed, 1971).

7 Constructs spawning site in nests of other species in group 5: *Campostoma anomalum* (Reighard, 1943) and *Exoglossum maxillingua.*

8 Eggs laid in depressions cleared out by sweeping action of body and fins sometimes by a group of males (Raney, 1940a): *Notropis cornutus.*

9 Eggs, buried in gravel by vibrations during spawning: *Rhinichthys cataractae,* Rhinichthys atratulus,* Catostomus commersoni,* Hypentelium nigricans,* Moxostoma macrolepidotum** (Jenkins, 1970); *Rhinichthys* species often lay eggs in spawning areas of *Catostomus.*[3]

10 Eggs hidden in crevices: *Notropis spilopterus.**

11 Eggs laid on underside of flat objects that form roofs over excavated hollows: *Pimephales notatus.**

Eggs and newly hatched larvae of species in each group are united by certain developmental characters summarized in Table 2. The adaptive significance of such traits in

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[1]Reed (1971) considered eggs of *C. commersoni* from *S. corporalis* nests a "drift" product.

cyprinoids and other fishes is discussed by Balon (1975), Kryzhanovski (1949, as translated 1974), Nakamura (1963, English summary) and Norman (1963).

Egg size is related to adult body size and spawning substrate. Species that spawn primarily over vegetation (group 2) and fine gravel (group 3) have smaller ratios of egg diameter to adult total length than those that spawn over coarse gravel (group 9) or those whose eggs are buried in cyprinid nests (groups 5-8) (Fig. 12). Also, larvae in groups 2 and 3 are usually comparatively more advanced at hatching than those in groups 5-9 (Table 2).

Besides Potomac River species in group 4, several other cyprinoids have been found with centrachid breeding associations: *Notgropis umbratilis* with *Lempomis cyanellus* (Hunter and Hasler, 1965; Snelson and Pflieger, 1975); *Notropis lutrensis* with *Lepomis humilis* and *L. cyanellus* (Pflieger, 1975); *Notropis maculatus* and *Erimyzon sucetta* with *Micropterus salmoides* (Chew, 1974; Carr, 1942, respectively).

Group 5 consists of species considered closely related by Jenkins and Lachner (1971). Eggs and newly hatched larvae in this group are similar. Species identity of the male which has constructed the nest can be determined in many cases using nest characteristics described by Raney (1904b).

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Table 1. Cyprinoid fishes (juvenile/adult and egg/larva) collected in the study reach as compared to those reported from the Potomac River drainage (Jenkins et al. 1972).

Species in Potomac drainage (Jenkins et al. 1972)	ANSP Surveys		Eggs reared by us (other localities included)
	Juv./Adult	Egg/larva	
Campostoma anomalum (Stoneroller)	x	x	x
Carassius auratus (Goldfish)	x	x	x
Chrosomus oreas (Mountain Redbelly Dace)	-	-	x
Clinostomus funduloides (Rosyside Dace)	-	-	x
Cyprinus carpio (Carp)	x	x	x
Ericymba buccata (Silverjaw Minnow)	x	x	-
Exoglossum maxillingua (Cutlips Minnow)	x	-	x
Hybognathus regius (Silvery Minnow)	x	-	-
Leuciscus idus (Ide)	-	-	-
Nocomis leptocephalus (Bluehead Chub)	-	-	x
N. micropogon (River Chub)	x	x	x
Notemigonus crysoleucas (Golden Shiner)	x	x	x
Notropis amoenus (Comely Shiner)	x	-	x
N. analostanus (Satinfin Shiner)	-	-	x
N. ardens (Rosefin Shiner)	-	-	x
N. bifrenatus (Bridle Shiner)	-	-	-
N. chalybaeus (Ironcolor Shiner)	-	-	-
N. cornutus (Common Shiner)	x	x	x
N. hudsonius (Spottail Shiner)	x	x	x
N. procne (Swallowtail Shiner)	x	-	x
N. rubellus (Rosyface Shiner)	x	x	x
N. spilopterus (Spotfin Shiner)[1]	x	x	x
Pimephales notatus (Bluntnose Minnow)	x	x	x
P. promelas (Fathead Minnow)	-	-	-
Rhinichthys atratulus (Blacknose Dace)	x	x	x
R. cataractae (Longnose Dace)	x	x	x
Semotilus atromaculatus (Creek Chub)	x	-	x
S. corporalis (Fallfish)	x	x	-
S. margarita (Pearl Dace)	-	-	-
Tinca tinca (Tench)	-	-	-
Carpiodes cyprinus (Quillback)	-	-	x
Catostomus commersoni (White Sucker)	x	x	x
Erimyzon oblongus (Creek Chubsucker)	x	x	x
Hypentelium nigricans (Northern Hog Sucker)	x	x	x
Moxostoma macrolepidotum (Shorthead Redhorse)[2]	x	-	x
M. rhothoecum (Torrent Sucker)	-	-	-

[1]Ecological Analysts (1974) reported the two species in the subgenus Cyprinella from the area: Notropis spilopterus and N. analostanus (Satinfin Shiner), however, we have not found the latter species in our collections.

[2]Some specimens included in materials examined by Jenkins (1972): ANSP 81184(2); ANSP 95591(1); ANSP 93700(1); ANSP 95961(1). Moxostoma erythrurum is also common in the study area (Davis and Enamait 1977) and has apparently been misidentified in ANSP surveys. Eggs of both Moxostoma spp were reared.

Table 2. Developmental characteristic of study cyprinoids[1] grouped by spawning-site preference.[2]

Group	Family or Subfamily	Egg			Newly Hatched Protolarva		
		Egg Clumping	Modal Diameter	Pervitelline Space Width/ Egg Diameter	Eye Pigmentation	Pectorals	Cement Glands
1	Leuciscinae	No	Ca. 3.0	1/3	Dark	Prominent	Absent
2	Cyprininae	No	1.4-1.8	1/4 or less	Dark	Prominent	Present
	Abramidinae	No	1.2-1.4	1/4 or less	Absent or dark	Prominent	Present
3	Leuciscinae	No	Ca. 1.4	1/4 or less	Pale to dark	Prominent	Absent
	Catostomidae	No	Ca. 1.9	1/4 or less	Dark	Not prominent	Absent
4	Leuciscinae	No	Ca. 1.2	1/4 or less	Dark	Prominent	Absent
5 to 8	Leuciscinae	Sometimes	1.5-2.7	1/4 or less	Absent to pale	Not prominent	Absent
9	Leuciscinae	No	2.3-2.5	1/4 or less	Absent to pale	Not prominent	Absent
	Catostomidae	No	2.8-3.0	1/4 or less	Absent to pale	Not prominent	Absent
10	Leuciscinae	Yes, clump fills crevice	Ca. 1.3	1/4 or less	Dark	Prominent	Absent
11	Leuciscinae	Yes, in single plane	Ca. 1.6	1/4 or less	Dark	Prominent	Absent

[1] *Hybognathus nuchalis* and *Ericymba buccata* are not included.

[2] Sources for data used in this table are given in Annotated List of Species. These data are for species whose spawning site preferences are listed in text.

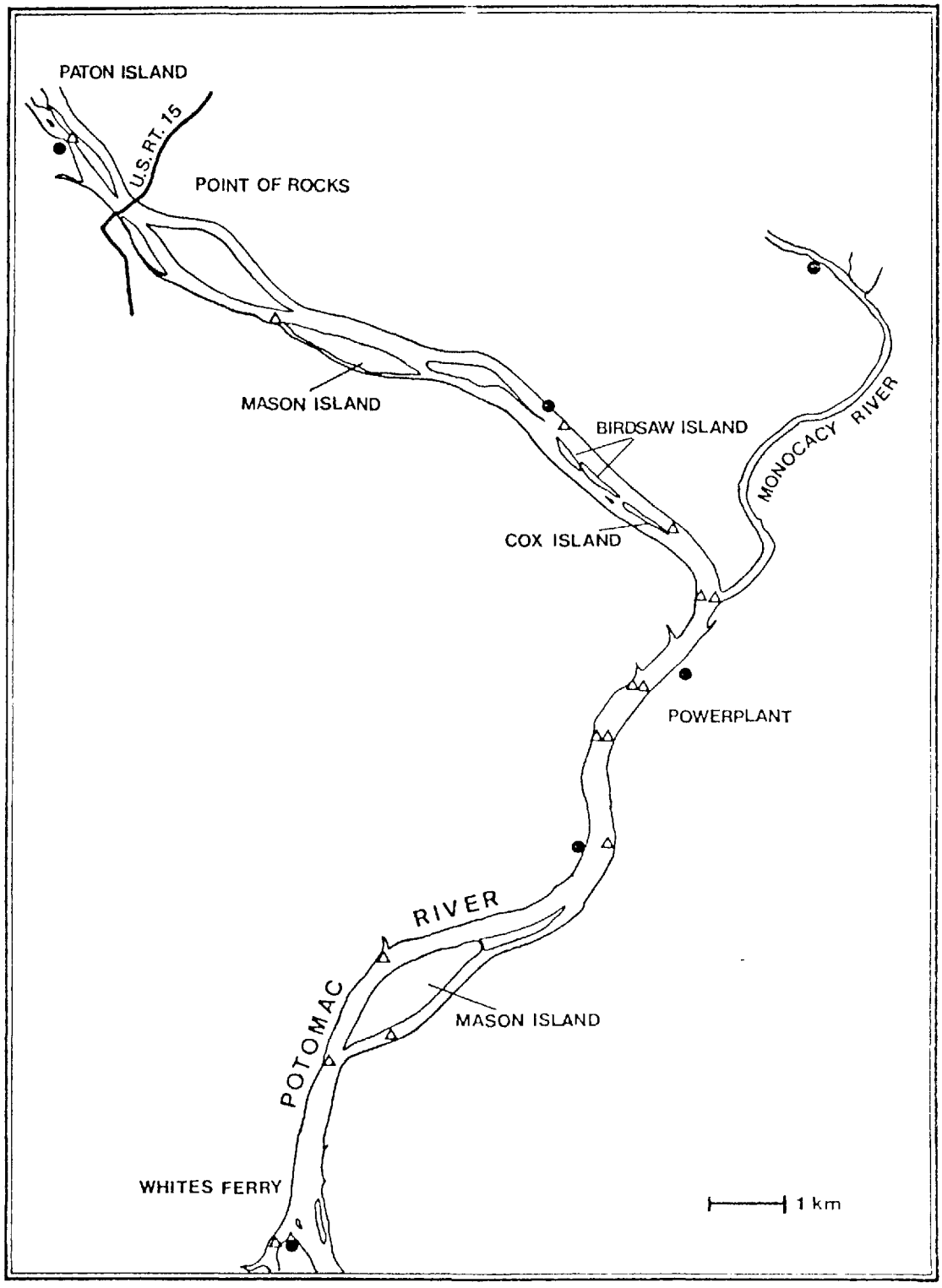


Figure 1. Map of study area.

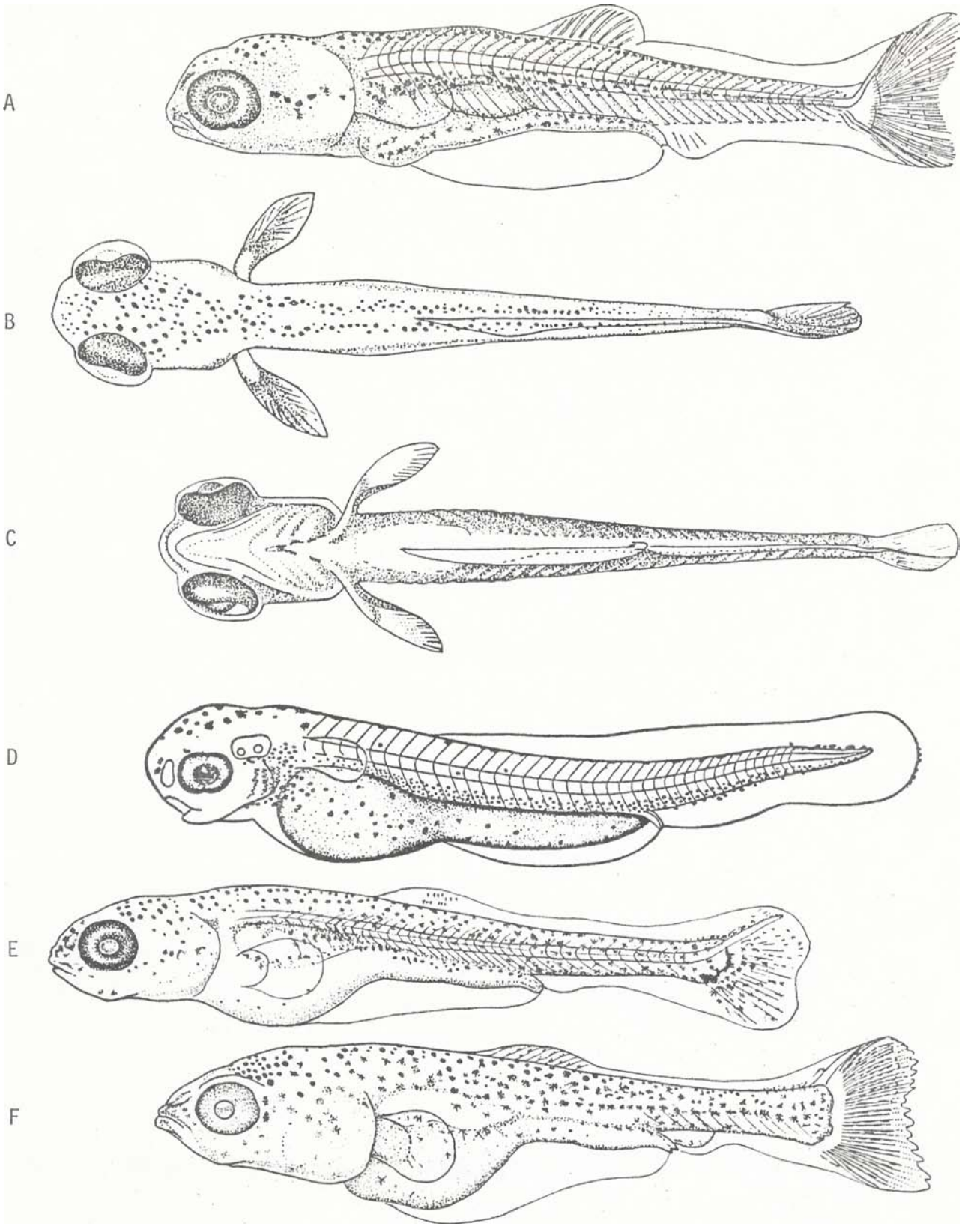


Figure 2. A-C. *Campostoma anomalum*, mesolarva, 9.8 mmTL: A. lateral view; B. dorsal; C. ventral. D. *Cyprinus carpio*, recently hatched, 5.5 mmTL, from Bragensky, 1960: Fig. 1, reprinted by Mansueti and Hardy, 1967. E. *Cyprinus carpio*, mesolarva, 8.6 mmTL. F. *Carassius auratus*, mesolarva, 9.1 mmTL.

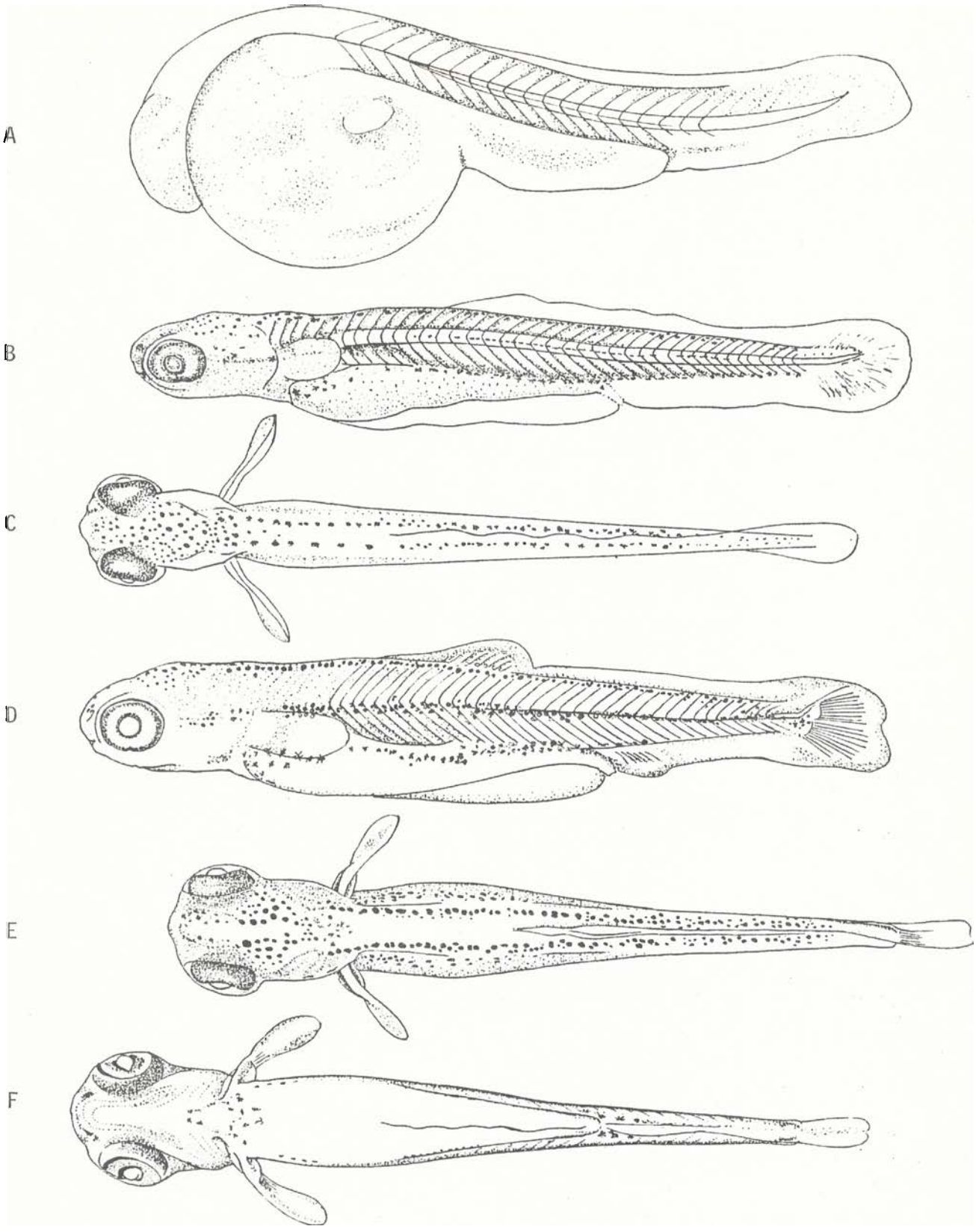


Figure 3. A. *Exoglossum maxillingua,* newly hatched, 5.4 mmTL. B-C *Exoglossum maxillingua,* protolarva, 7.8 mmTL; lateral and dorsa views. D-F. *Nocomis micropogon,* mesolarva, 9.1 mmTL: D. lateral view; E. dorsal; F. ventral.

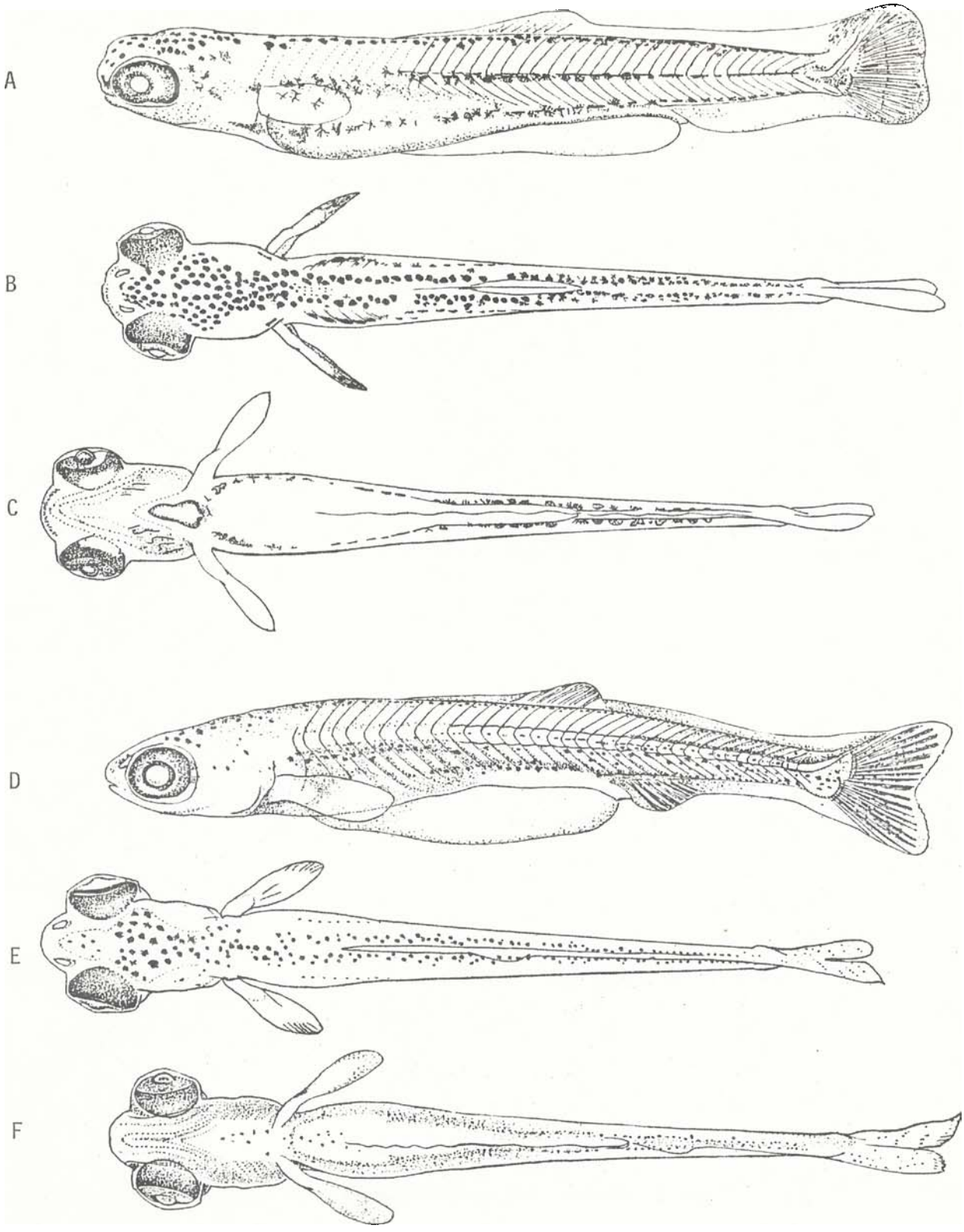


Figure 4. A-C. *Nocomis leptocephalus*, mesolarva, 9.1 mmTL: A. lateral view; B. dorsal; C. ventral. D-F. *Chrosomus oreas*, mesolarva, 10.3 mmTL: D. lateral view; E. dorsal; F. ventral.

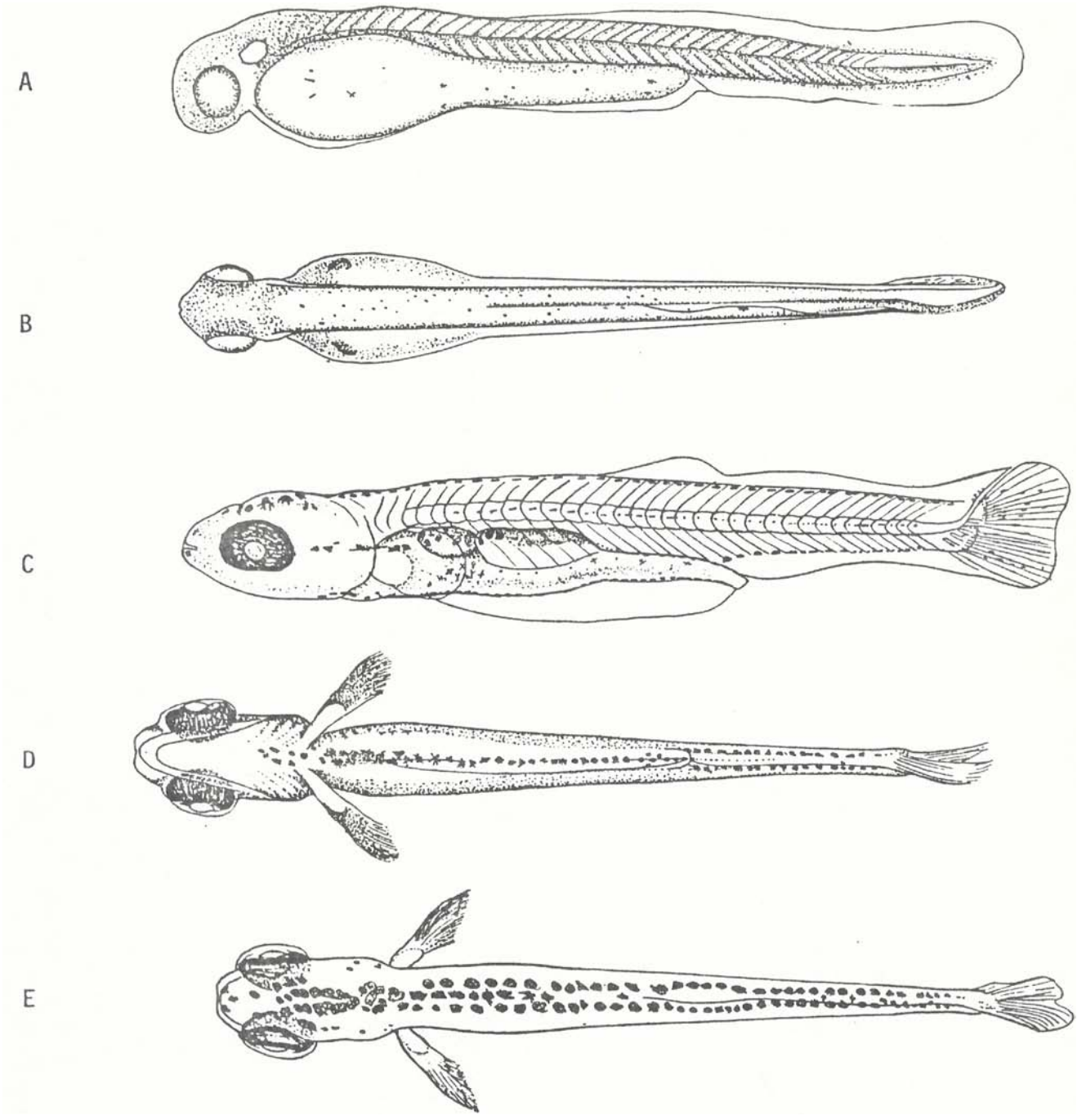


Figure 5. *Notemigonus crysoleucas*: A-B. newly hatched, 4.2 mmTL; C-E, mesolarva, 9.9 mmTL: C. lateral view; D. ventral view; E. dorsal view.

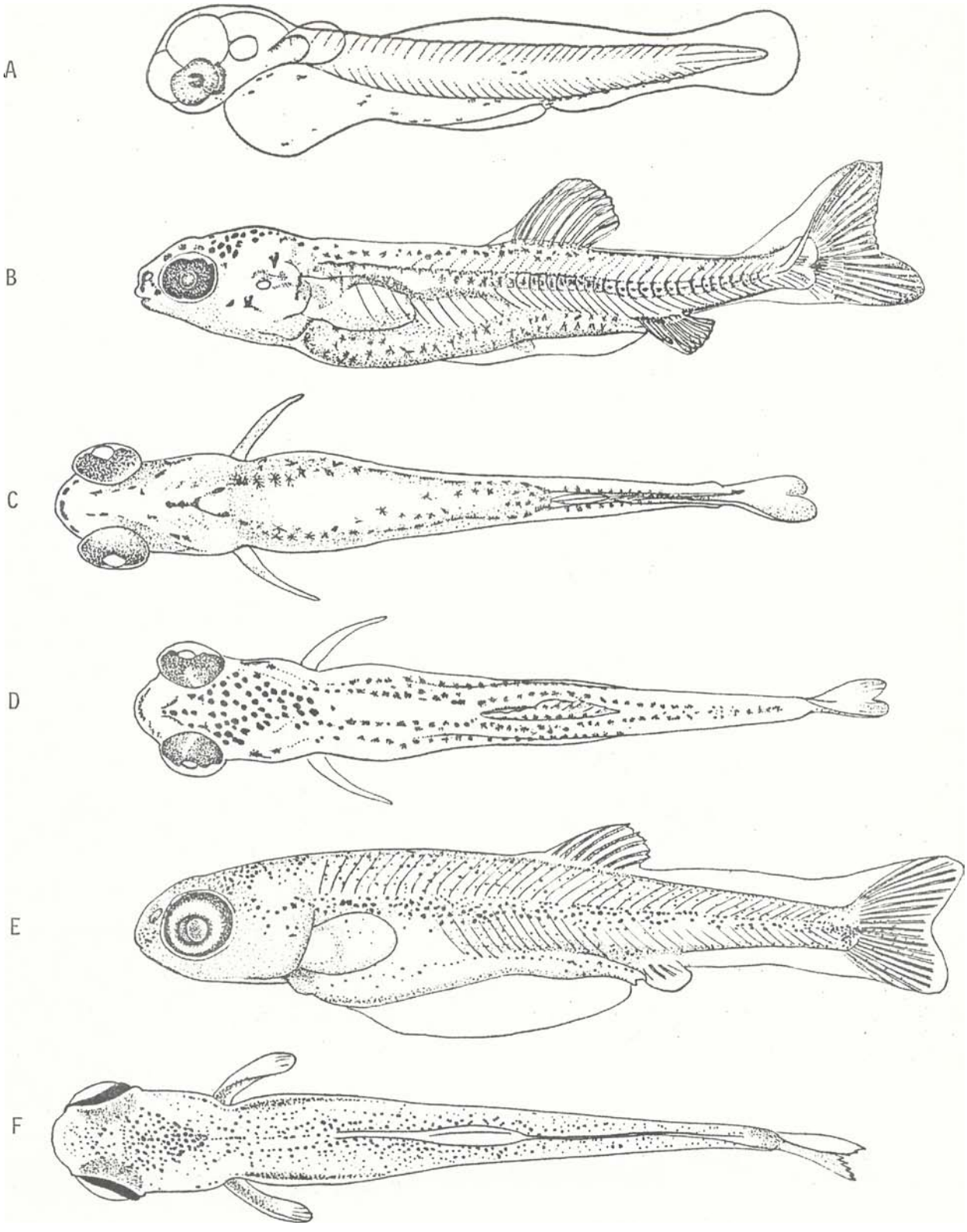


Figure 6. A. *Pimephales notatus*, one day after hatching, 5.0 mmTL from Fish, 1932: Fig. 56. B-D. *Pimephales notatus,* mesolarva, 9.3 mmTL: B. lateral view; C. ventral; D. dorsal; E-F. *Rhinichthys atratulus,* mesolarva, 9.9 mmTL: E. lateral view; F. dorsal.

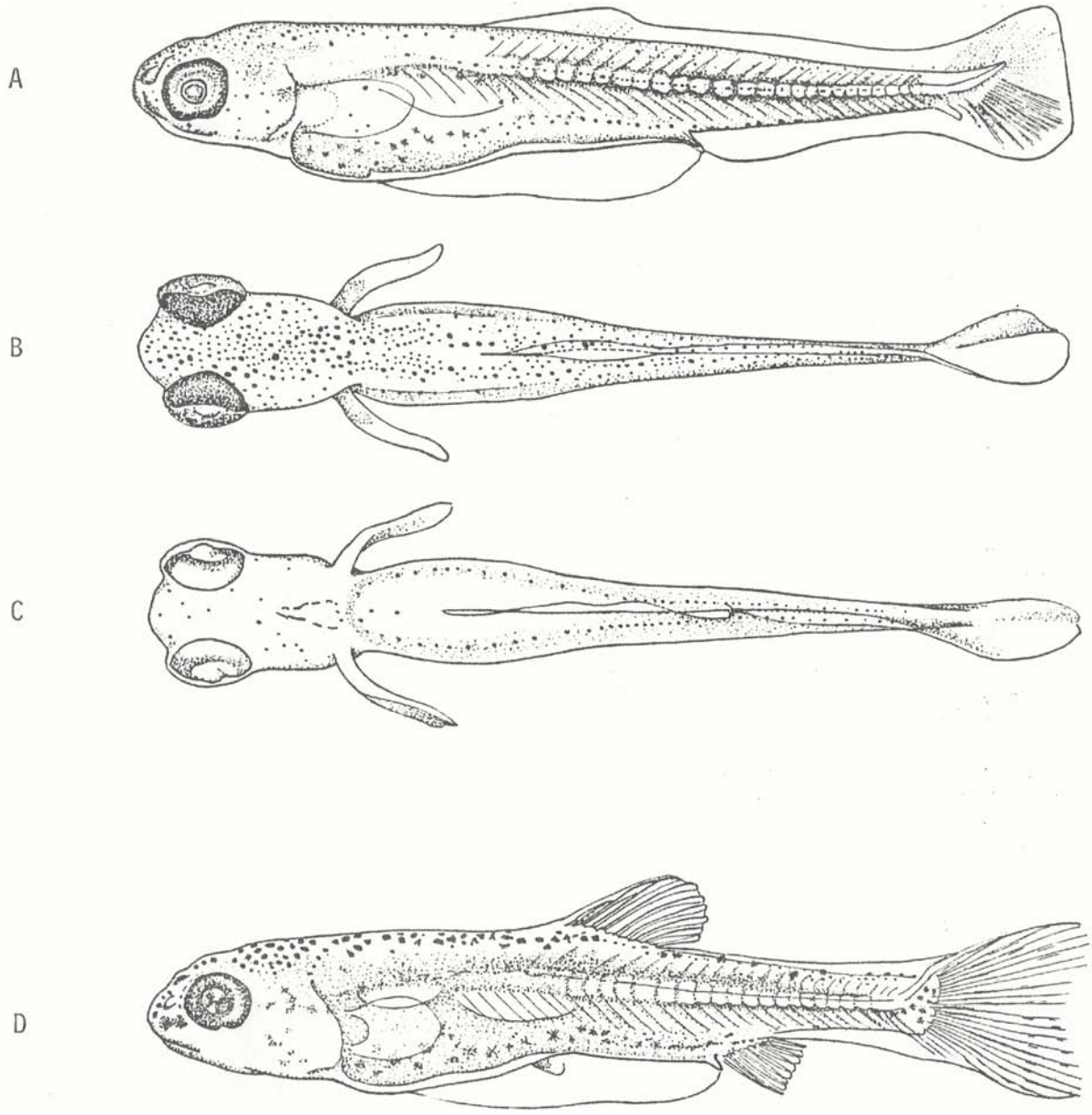


Figure 7. *Rhinichthys cataractae:* A-C. mesolarva, ca. 8.5 mmTL: A. lateral view; B. dorsal; C. ventral; D. metalarva, ca. 11 mmTL.

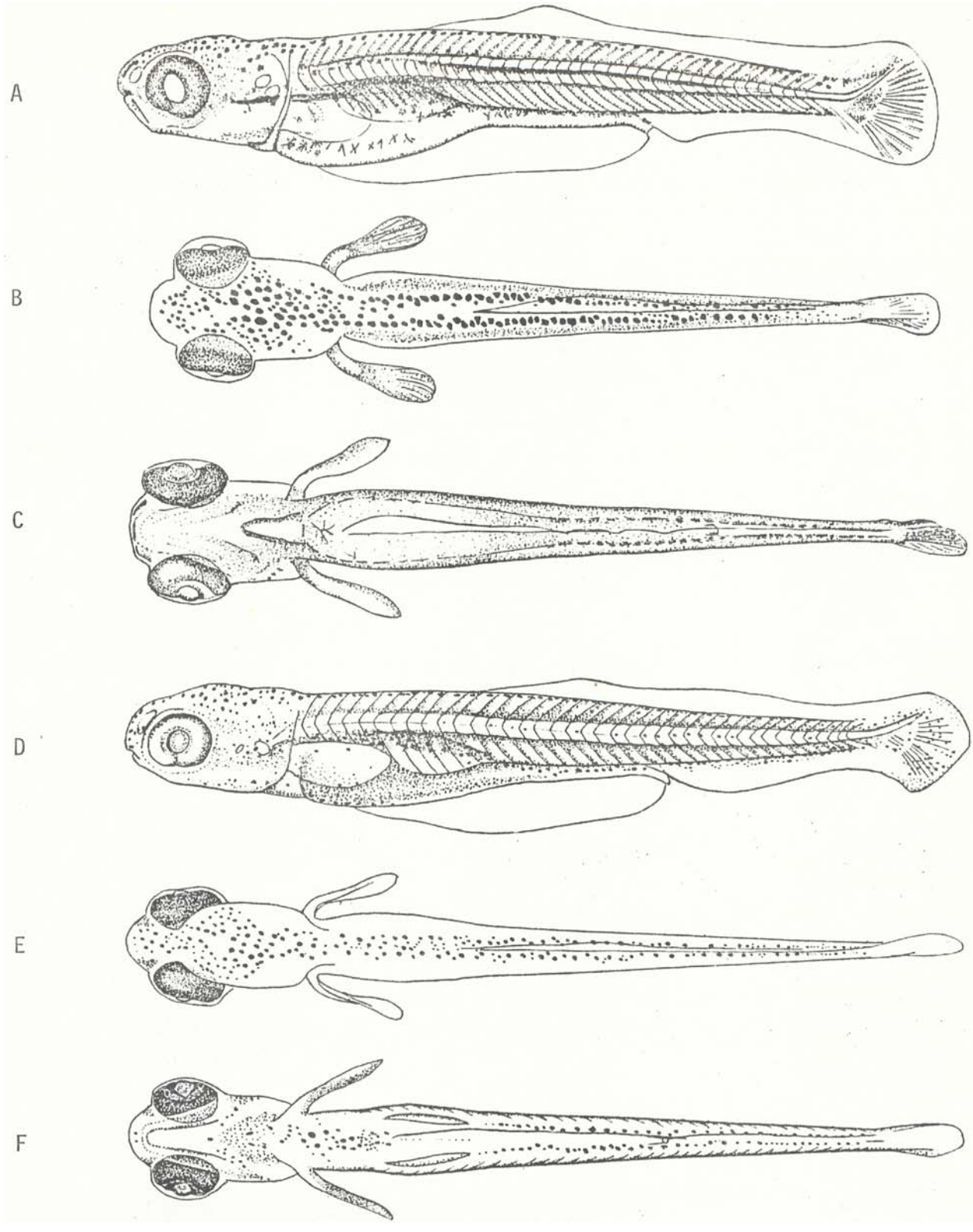


Figure 8. A-C. *Semotilus atromaculatus,* mesolarva, 9.2 mmTL: A. lateral view; B. dorsal; C. ventral. D-F. *Clinostomus funduloides,* mesolarva, 9.2 mmTL: D. lateral view; E. dorsal; F. ventral.

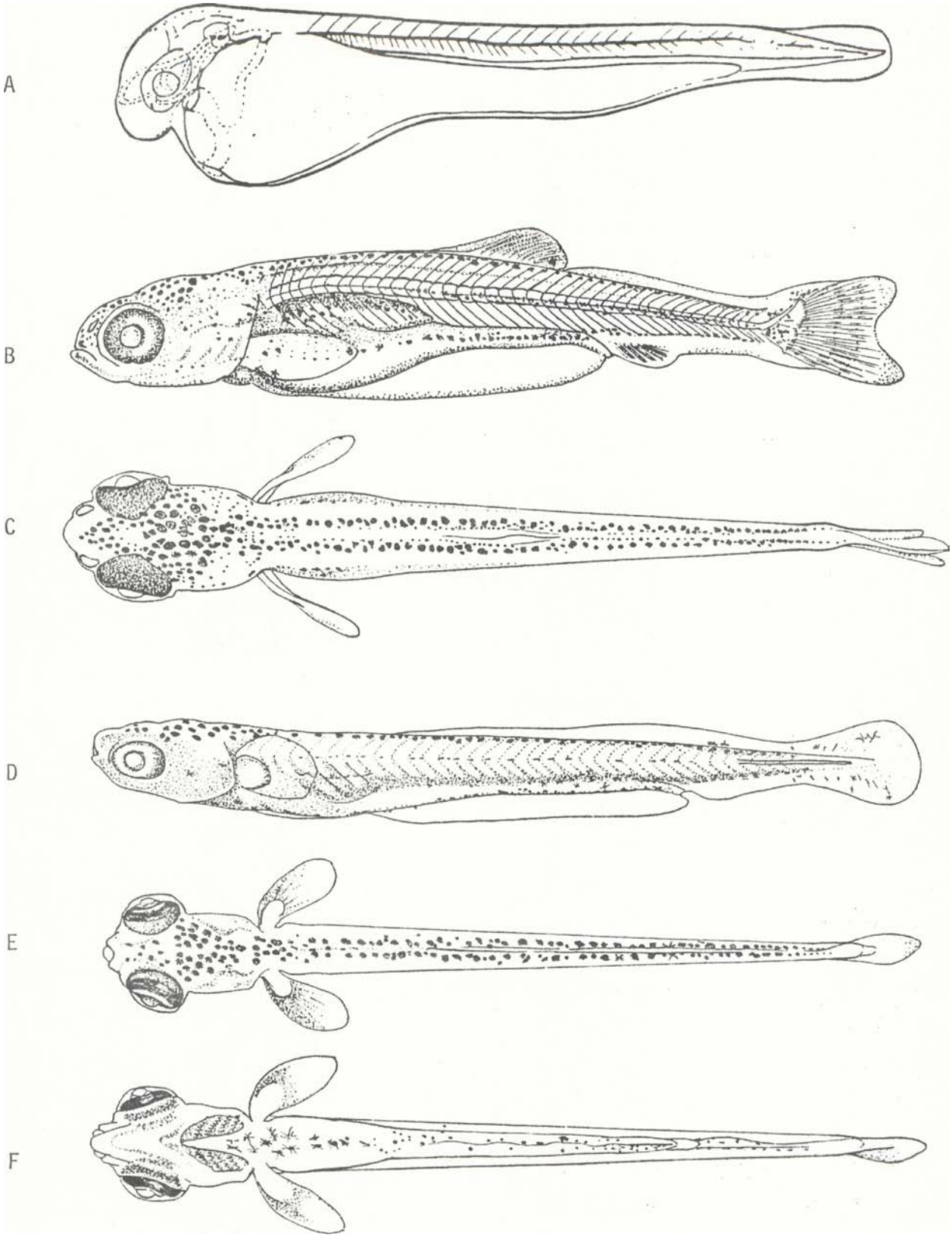


Figure 9. A. *Semotilus corporalis,* newly hatched, 6.8 mmTL, from Reed, 1971: Fig. 2A. B-C. mesolarva, 9.2 mmTL, lateral and dorsal views. D-F. *Carpiodes cyprinus,* protolarva, 9.2 mmTL: D. lateral view; E. dorsal; F. ventral.

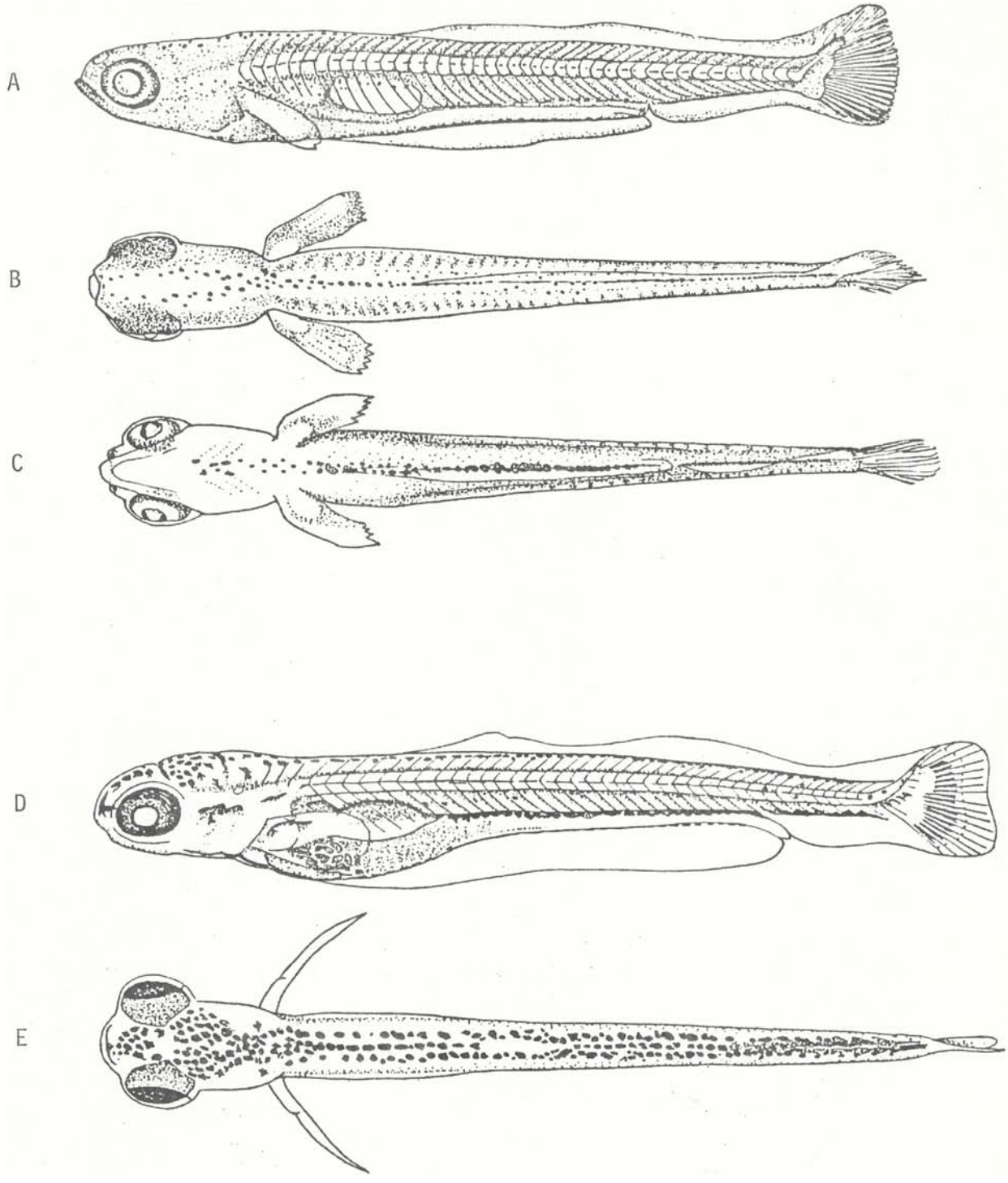


Figure 10. A-C. *Erimyzon oblongus,* mesolarva, 10.3 mmTL: A. lateral view; B. dorsal; C. ventral. D-E. *Hypentelium nigricans*, mesolarva, 13.1 mmTL, lateral and dorsal views.

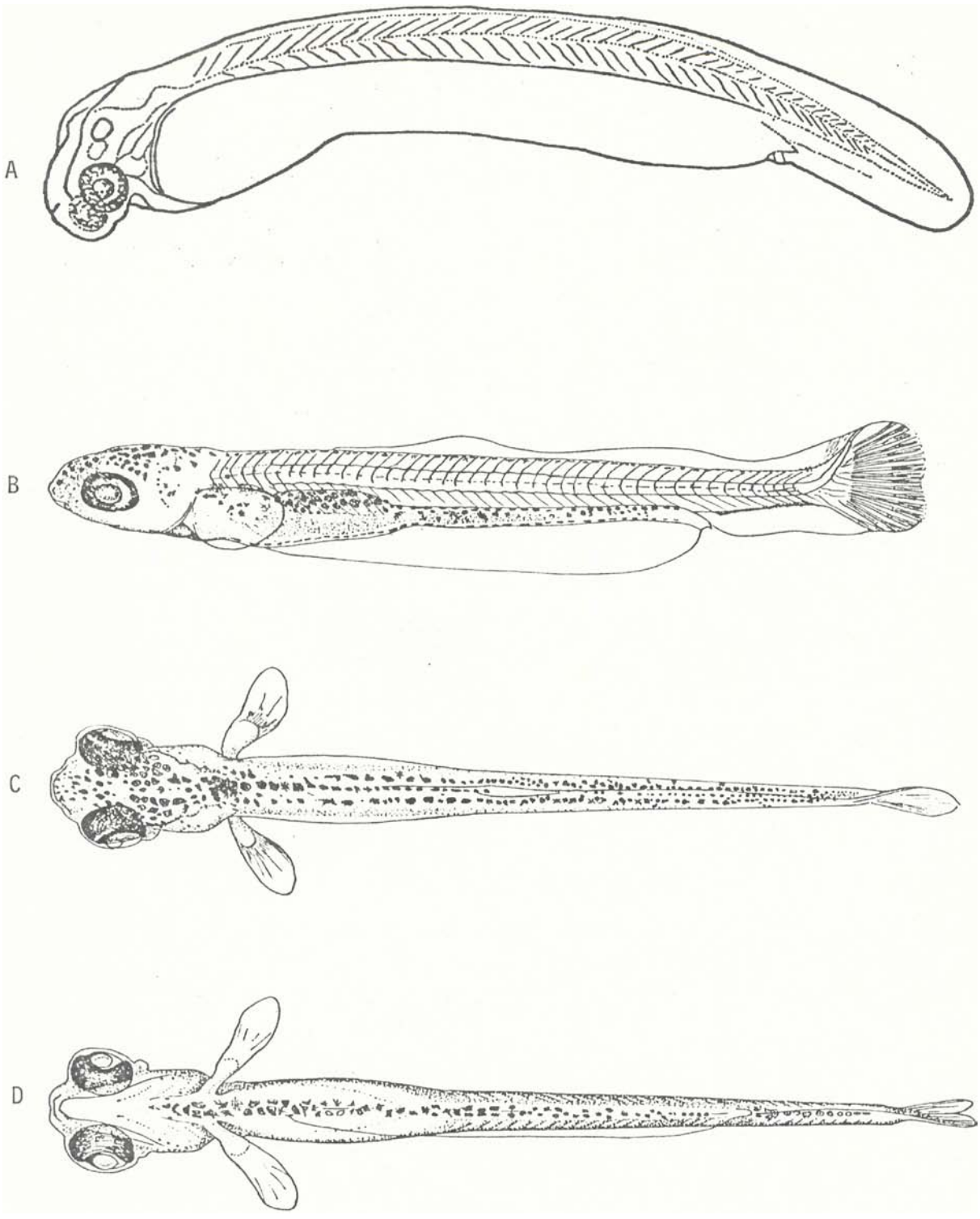
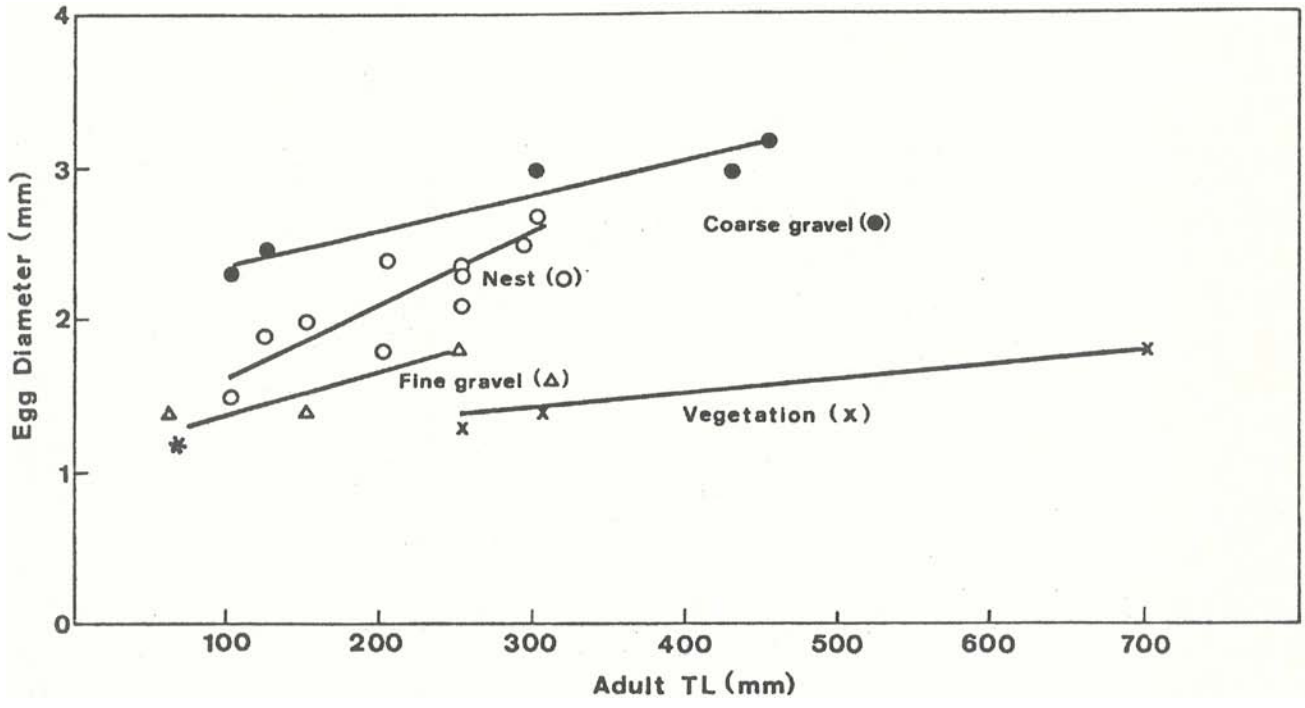


Figure 11. A. *Catostomus commersoni*, newly hatched, 8.0 mmTL, from Steward, 1926, Fig. 20 reprinted by Mansueti and Hardy, 1967. B-D. *Catostomus commersoni*, mesolarva, 14.3 mmTL: B. lateral view; C. Dorsal; D. ventral.



*This triangle represents data for *Notropis procne*; principle sqawning sites for other species listed in text.

Figure 12. The relationship between preferred spawning site and the ratio of egg diameter to adult total length among study cyprinoids.

IDENTIFICATION OF NINE LARVAL CYPRINIDS INHABITING SMALL NORTHERN RIVERS*

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ABSTRACT

Taxonomic descriptions are given for larvae of nine species of cyprinids: *Campostoma anomalum, Hybognathus hankinsoni, Notropis cornutus, N. dorsalis, N. lutrensis, N. stramineus, Pimephales notatus, P. promelas, and Semotilus atromaculatus.* Study material was collected in the upper Skunk River, Story County, Iowa. Identification criteria emphasize characters that are useful for distinguishing between morphologically similar species.

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INTRODUCTION

Species identification of North American cyprinid larvae presently is hindered by a paucity of published descriptions and keys and by the general morphological, ecological, and reproductive similarities of many species. Identification of undescribed larvae may be accomplished by comparison with series of reference specimens produced from controlled matings; however, few such reference collections are available. Alternatively, identification may be made by field collection of sequential size series of conspecific larvae. Characters of greatest diagonostic utility are initially determined through examination of a life stage that can be positively identified. Recognition of progressively smaller-sized conspecifics then proceeds according to the presence of shared characteristics. For distinguishing between morphologically similar forms, characters must be selected that are species specific and relatively invariable during larval development. Complete developmental series of larvae of all species occurring in the study area should be available for comparative purposes.

In this study, extensive field collection of larvae resulted in identification of nine species of the genera *Campostoma, Hybognathus, Notropis, Pimephales,* and *Semotilus.* Larvae of several of these species are described here for the first time. All of the taxa discussed range widely through the north-central United States and the fish are common inhabitants of streams and small rivers.

METHODS

Specimens were obtained from the upper Skunk River between Story City and Cambridge, Story County, central Iowa. Collections were made with stationary drift nets and dip nets from April 25 to July 11, 1977. Identification of each species was based upon a combination of characters including melanophore distribution, lengths at selected developmental stages, myomere and fin ray counts, and several morphometric measurements. Available literature descriptions were utilized where applicable. The presence of identifiable juveniles in the collections and knowledge of the local adult populations also aided in species determinations. All specimens were field preserved in 5-10 percent Formalin. Observations and measurements were made with a stereoscopic microscope equipped with an ocular micrometer. The characters of greatest diagnostic value were determined empirically with the aid of guidelines in Berry and Richards (1973) and Lippson (1976a). Total length (TL), standard length (SL), and snout-vent length measurements were made according

to the methods of Mansueti and Hardy (1967). The predorsal length measurement was made from the tip of the snout to the origin of the dorsal finfold (when present) or to the dorsal fin origin. The method of Siefert (1969) was utilized to distinguish preanal and postanal myomeres. Principal anal rays were counted in standard fashion (Hubbs and Lagler 1964). Photography was accomplished with a Leitz macro-dia utilizing a circular reflected-light system and Kodak Plus-X 35-mm film. Common and scientific names of fishes follow Bailey *et al.* (1970).

The use of the descriptive terms larva, protolarva, mesolarva, metalarva, and juvenile are in accordance with the definitions of Snyder (1976). The term stage is defined as "a just observed, immediate moment of development" (Balon 1975). Interspecific differences were apparent in the relative length at which comparable developmental stages were reached. Accordingly, the lengths (TL mm) of each species of initial caudal fin ray formation (i.e., beginning of mesolarval phase of development) and initial pelvic fin bud appearance were recorded for comparative purposes.

RESULTS AND DISCUSSION

The features that are useful for identifying cyprinid larvae are summarized in Lippson and Moran (1974) and Lippson (1976b) as follows. The vent (anus) position generally is posterior to the midpoint of the body. The yolk sac is typically spherical anteriorly and more cylindrical near the vent. Although pigmentation is variable, several series of melanophores are usually evident: dorsally on the head and body, laterally along the horizontal septum, on the ventral surface anterior to the vent, and ventrally on the myomeres behind the vent. The latter series is also continuous internally above the body cavity. As development progresses, a single dorsal fin and a two-chambered gas bladder appear. The anal fin origin is usually below or just behind the insertion of the dorsal fin, and the pelvic fins develop below or slightly in advance of the dorsal fin origin.

The descriptions of key characters given immediately below, plus data presented in Table 1 and Fig. 1, allow for initial separation of the nine species into four groups on the basis of morphological similarities. Each group is subsequently treated in more detail for species identification. The descriptions follow a "dynamic" approach (Berry and Richards 1973) and are comparative; i.e., the distinguishing features of each species are described as they develop. Although there is frequent reference to melanophore distributions, newly hatched individuals may lack pigment entirely. As a result, caution should be exercised when using these descriptions for identifying early protolarvae.

Group Descriptions:

Group I. Preanal Myomeres usually 27-28. Midventral surface between origin of preanal finfold and vent unpigmented or only a few scattered melanophores present.

Semotilus atromaculatus—creek chub
Campostoma anomalum—stoneroller

Group II. Preanal myomeres usually 25-26. A prominent midventral series of melanophores present between heart region and vent.

Notropis cornutus—common shiner
Hybognathus hankinsoni—brassy minnow

Group III. Preanal myomeres usually 24-25. Yolk usually persists in size range 5.0—6.5 mm TL. Distinct linear series or aggregation of melanophores on each side of midline immediately behind heart region. Midventral surface from behind heart region to origin of preanal finfold usually unpigmented. Scattered melanophores ventrally below intestine.

Pimephales promelas—fathead minnow
Pimephales notatus—bluntnose minnow

Group IV. Preanal myomeres usually 21-22. Yolk completely assimilated by 5.0 mm TL. Entire midventral surface between heart region and vent with scattered melanophores or unpigmented.

Notropis dorsalis—bigmouth shiner
Notropis stramineus—sand shiner
Notropis lutrensis—red shiner

Species Descriptions:

Group I. *Semotilus atromaculatus*—creek chub (Plates 1-4)
Campostoma anomalum—stoneroller (Plates 5-8)

The only published description of the larval creek chub is that of a 14 mm TL specimen by Fish (1932). Creek chub larvae are characterized by a high number of preanal myomeres, usually 28 (Table 1). Protolarvae are large, ranging 7.0-8.5 mm TL. A substantial amount of yolk may persist early in the mesolarval phase. Various stages in the larval development of the stoneroller are described in Fish (1932) and Hogue et al. (1976), and are included in the key of May and Gasaway (1967). Length at hatching has been recorded as 6.3-6.9 mm (Hogue et al. 1976). The usual preanal myomere count for this species is 27 (Table 1).

Although larvae of the creek chub and stoneroller are morphologically sinilar, several characters serve to separate them. Stoneroller larvae develop more precociously, usually acquiring caudal fin rays and pelvic fin buds at a smaller size (Fig. 1). In creek chub larvae, the "ventro-visceral" pigmentation (Balinsky 1948) branches anterior to the gas bladder and extends anteriorly under each auditory vesicle. A dense, continuous line of internal pigment is thus evident above the body cavity from immediately behind the eye to the vent (Plate 1). On stoneroller larvae, the internal melanophores above the intestine and anterior to the gas bladder are sparse and scattered, and the ventro-visceral pigment line appears discontinuous and less dense than that of creek chub larvae. Protolarval creek chubs have scattered melanophores on the ventral surface of the yolk sac immediately behind the heart region. As the yolk is absorbed, midventral pigment is confined to the region anterior to the preanal finfold. The midventral surface between the origin of the preanal finfold and the vent remains unpigmented throughout larval development (Plates 2,4). Protolarval stonerollers have scattered melanophores on the ventral surface below the intestine. The midventral surface anterior to the preanal finfold usually remains unpigmented, although a few melanophores may occur in this region (Plates 6,8).

Early in the mesolarval phase, creek chubs acquire a concentration of melanophores on the ventral surface of the operculum (Plate 4). The ventral opercular surface remains unpigmented on mesolarval stonerollers (Plate 8). As metalarvae, the ratio of predorsal length to TL is greater in creek chubs relative to stonerollers (Table 1). Juvenile creek chubs have a large, terminal mouth. The tip of the upper jaw is on a level with the lower margin of the pupil, and the maxillary extends posteriorly to a point below the eye. A small, subterminal mouth is characteristic of juvenile stonerollers. The upper jaw is entirely below the eye, and the maxillary is short, its posterior margin not extending under the eye.

Group II. *Notropis cornutus*—common shiner (Plates 9-12)
Hybognathus hankinsoni—brassy minnow (Plates 13-16)

The description of newly hatched and 2-day old larvae of *Notropis cornutus chrysocephalus* by Fish (1932) includes several features that are inconsistent with the distinguishing characteristics of cyprinid larvae as given by Lippson and Moran (1974) and Lippson (1976b). Specifically, an apparent midbody location of the vent and the presence of an oil globule in the yolk sac are not typical features of the family. The preanal and postanal myomere counts (14 and 19, respectively) additionally conflict with the findings of the present study. Accordingly, certain portions of that description are unreliable for identification. There is no other published description of common shiner larvae. It is uncertain whether the *chrysocephalus* form of the common shiner group represents a distinct species or a subspecies of *Notropis cornutus* (Gilbert 1961, Miller 1968, Menzel 1976). Our study material represents *Notropis cornutus cornutus* in the nomenclatural arrangement recommended by Menzel (1976). The larval development of the brassy minnow has not been described previously.

Common shiner larvae are characterized by the presence of three diverging, ventral lines of melanophores which emanate from a common origin immediately behind the heart region. One line extends along the midventral surface to the vent. The others extend obliquely across the body cavity (Plates 10, 12). In contrast, brassy minnow larvae possess only a single line of melanophores anterior to the vent (Plates 14, 16). An additional feature of this species is the acquisition of a prominent melanophore on the pectoral fin base early in the mesolarval phase (Plate 16). The pectoral fin base of the common shiner remains unpigmented during larval development.

Late in the metalarval phase, common shiners acquire a longitudinal band of melanophores on the midlateral body surface. In brassy minnow metalarvae, surface melanophores on the epaxial myomeres are evenly distributed so that no lateral pigment band is evident. The relatively smaller sizes at which brassy minnow larvae acquire caudal fin rays and pelvic fin buds also are diagnostic for distinguishing between these two species (Fig. 1).

Group III. *Pimephales promelas*—fathead minnow (Plates 17-20)
Pimephales notatus—bluntnose minnow (Plates 21-24)

Characters useful for identifying fathead minnow larvae are given in Fish (1932), Hogue et al. (1976), and Snyder et al. (1977). Hatching length has been recorded as 4 mm TL (Hogue et al. 1976, Snyder et al. 1977). Fish (1932) described the larval development of the bluntnose minnow from hatching (4.6 mm TL) to the "young adult" stage (17.75 mm TL). Hogue et al.

(1976) provided a photograph of a 6 mm TL specimen, which they indicated may be a larval *Pimephales*. Separating species of *Pimephales* as protolarvae is difficult, but two features were useful for distinguishing bluntnose and fathead minnows among our collections. Fathead minnow protolarvae of 5.0-5.5 mm TL acquire heavy pigmentation dorsally on the head and body (Plate 18), while pigment on the dorsal surface of bluntnose minnow protolarvae is restricted to a few late-developing melanophores in the occipital region and nape (Plate 22). The eye of bluntnose minnow protolarvae is distinctly flattened dorso-ventrally, whereas that of the protolarval fathead minnow is rounder (Plates 17, 21).

As the yolk is absorbed and the position of the mouth becomes established, bluntnose minnow larvae can be distinguished by the conspicuously decurved snout and subterminal mouth, the upper jaw placed well below the center of the eye (Plates 21, 23). In contrast, the snout of the fathead minnow larvae is not noticeably decurved, the mouth is terminal, and the tip of the upper jaw is level with the center of the eye (Plates 17, 19). Late in the metalarval phase, bluntnose minnows acquire a concentration of melanophores at the base of the dorsal fin and a dark spot at the base of the caudal fin. These characters are not evident on fathead minnow metalarvae.

Group IV. *Notropis dorsalis*—bigmouth shiner (Plates 25-28)
Notropis stramineus—sand shiner (Plates 29-32)
Notropis lutrensis—red shiner (Plates 33-36)

Larval features of the bigmouth shiner have not been recorded previously. Fish (1932) described the larval development of *Notropis deliciosus stramineus* (Cope) from 5 mm TL to 28.6 mm TL. Descriptions and illustrations of red shiner larvae are provided in Saksena (1962) and Taber (1969). Hatching lengths for the bigmouth shiner and sand shiner evidently are less than 3.5 mm TL, as indicated by the frequent occurrence of protolarvae in our collections ranging from 3.5-4.0 mm TL. The eye and entire body of early protolarvae of these species may lack pigment, thus making their separation tentative at this stage (see Plate 29, specimen A). The smallest red shiner observed (4.3 mm TL) had a small cylindrical yolk sac, pigmented eye, and a series of melanophores on the lateral surface of the yolk (Plate 33). Larvae of all three species usually complete assimilation of yolk material by 5.0 mm TL.

Bigmouth shiner protolarvae (greater than ca. 3.8 mm TL) have melanophores scattered on the dorsal surface of the head and body. After yolk absorption, the entire dorsal surface is

densely pigmented, and scattered melanophores are present ventrally between the heart region and vent (Plate 26). On sand shiner protolarvae (less than ca. 5.0 mm TL), dorsal pigmentation is restricted to the occipital region. After yolk absorption, two irregular rows of melanophores appear on the dorsal surface of the body (Plate 30). This dorsal pigment remains less dense than that of the bigmouth shiner; however, the melanophores are consistently smaller and more widely spaced along the body axis. Pigment on the ventral surface of sand shiner larvae is essentially similar to that of the bigmouth shiner.

Early in the mesolarval phase, bigmouth shiners acquire a prominent melanophore in the nasal pit. The nasal pits of sand shiner larvae remain unpigmented until the late metalarval phase. As metalarvae, sand shiners acquire a concentration of melanophores along the base of the dorsal fin, and a dusky lateral band becomes evident during the juvenile period. Both characters are lacking on bigmouth shiners of comparable development.

Red shiner protolarvae have pigment in the occipital region, and a few melanophores appear dorsally on the body late in the phase. A short, linear series of melanophores is present on each side of the midline immediately behind the heart region. A prominent series also is present on the lateral surface of the intestine from immediately behind the gas bladder to the vent. The midventral surface between the heart region and the vent usually remains unpigmented during larval development (Plates 34, 36). In contrast, melanophores are scattered over the entire ventral region of bigmouth and sand shiner larvae (Plates 26, 28, 30, 32).

ACKNOWLEDGMENTS

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Table 1. Selected morphometric and meristic characters of larvae of nine species of cyprinids. Means (of length measurements) and modes (of myomere and anal ray counts) are given with ranges below. Data based on five specimens in each developmental phase.

Developmental Phase	TL(mm)	Lengths (%TL) SL	Snout-vent	Pre-dorsal	Myomeres Pre-anal	Post-anal	Principal anal rays
			Semotilus atromaculatus				
protolarvae	7.7	95	65	42	29	12	
	7.0-8.1	94-96	64-67	40-45	28-29	12-13	-
mesolarvae	9.1	94	64	43	28	12	
	8.0-10.7	91-95	62-66	41-48	28-29	12-13	-
metalarvae	13.6	88	63	47	28	12	8
	12.3-14.7	88-90	61-64	46-48	27-29	12-13	
			Campostoma anomalum				
protolarvae	6.5	94	66	42	27	12	
	5.7-7.0	91-95	64-68	39-44	27-28	11-12	-
mesolarvae	9.1	93	65	42	28	12	
	8.0-10.7	88-95	64-66	40-44	27-28	11-12	-
metalarvae	12.7	88	63	44	27	12	7
	12.2-13.2	87-89	61-64	43-45	26-28	11-12	
			Notropis cornutus				
protolarvae	6.3	96	63	36	26	13	
	5.6-6.8	95-96	61-65	34-38	25-26	12-14	-
mesolarvae	9.2	93	63	38	26	14	
	7.6-10.9	90-95	63-64	36-40	26-27	12-15	-
metalarvae	13.7	87	60	42	26	13	9
	12.6-14.7	85-87	58-61	40-43	25-27	12-14	
			Hybognathus hankinsoni				
protolarvae	5.7	95	65	38	25	11	
	5.1-6.6	95	63-66	36-40	24-25	9-13	-
mesolarvae	8.0	93	65	39	26	12	
	7.0-9.4	87-96	64-66	37-40	25-26	11-13	-
metalarvae	10.8	87	62	43	25	12	8
	9.8-12.2	84-88	59-64	41-44	24-26	11-13	
			Pimephales promelas				
protolarvae	5.5	95	61	39	24	14	
	5.0-6.3	95-96	59-63	37-41	24	13-15	-
mesolarvae	8.3	94	61	41	24	13	
	7.4-8.9	94-95	53-63	40-42	24-25	12-15	-
metalarvae	11.4	86	60	44	25	12	7
	9.1-14.0	84-88	59-62	41-47	24-25	11-12	
			Pimephales notatus				
protolarvae	5.6	95	61	40	24	15	
	5.4-6.1	95-96	58-62	39-41	24-25	14-15	-
mesolarvae	7.1	94	63	42	25	14	
	6.5-7.5	91-95	62-64	40-44	24-25	14-15	-
metalarvae	9.2	88	61	45	25	13	7
	8.6-10.6	85-91	60-61	44-46	25	12-14	
			Notropis dorsalis				
protolarvae	4.1	95	61	41	21	13	
	3.7-4.5	95-96	59-63	38-44	20-21	13-14	-
mesolarvae	8.2	92	61	41	22	13	
	7.0-9.4	89-95	59-62	40-44	21-22	12-14	-
metalarvae	11.9	87	58	44	21	13	8
	10.2-13.2	86-89	56-59	43-44	20-21	12-14	
			Notropis stramineus				
protolarvae	4.6	95	62	38	22	13	
	3.9-5.5	93-96	59-64	36-41	22-23	13-14	-
mesolarvae	7.7	93	63	41	23	13	
	6.7-9.8	90-96	62-65	39-44	22-23	12-13	-
metalarvae	10.9	87	60	44	22	12	7
	9.9-13.0	85-88	56-63	42-46	21-23	11-13	
			Notropis lutrensis				
protolarvae	4.9	95	60	38	21	14	
	4.3-5.5	94-97	59-62	37-39	20-22	13-15	-
mesolarvae	7.0	92	60	40	21	14	
	6.3-7.8	89-95	58-63	39-41	21-22	13-15	-
metalarvae	10.0	86	57	44	22	13	9
	9.4-10.7	85-88	56-58	41-44	21-22	12-14	

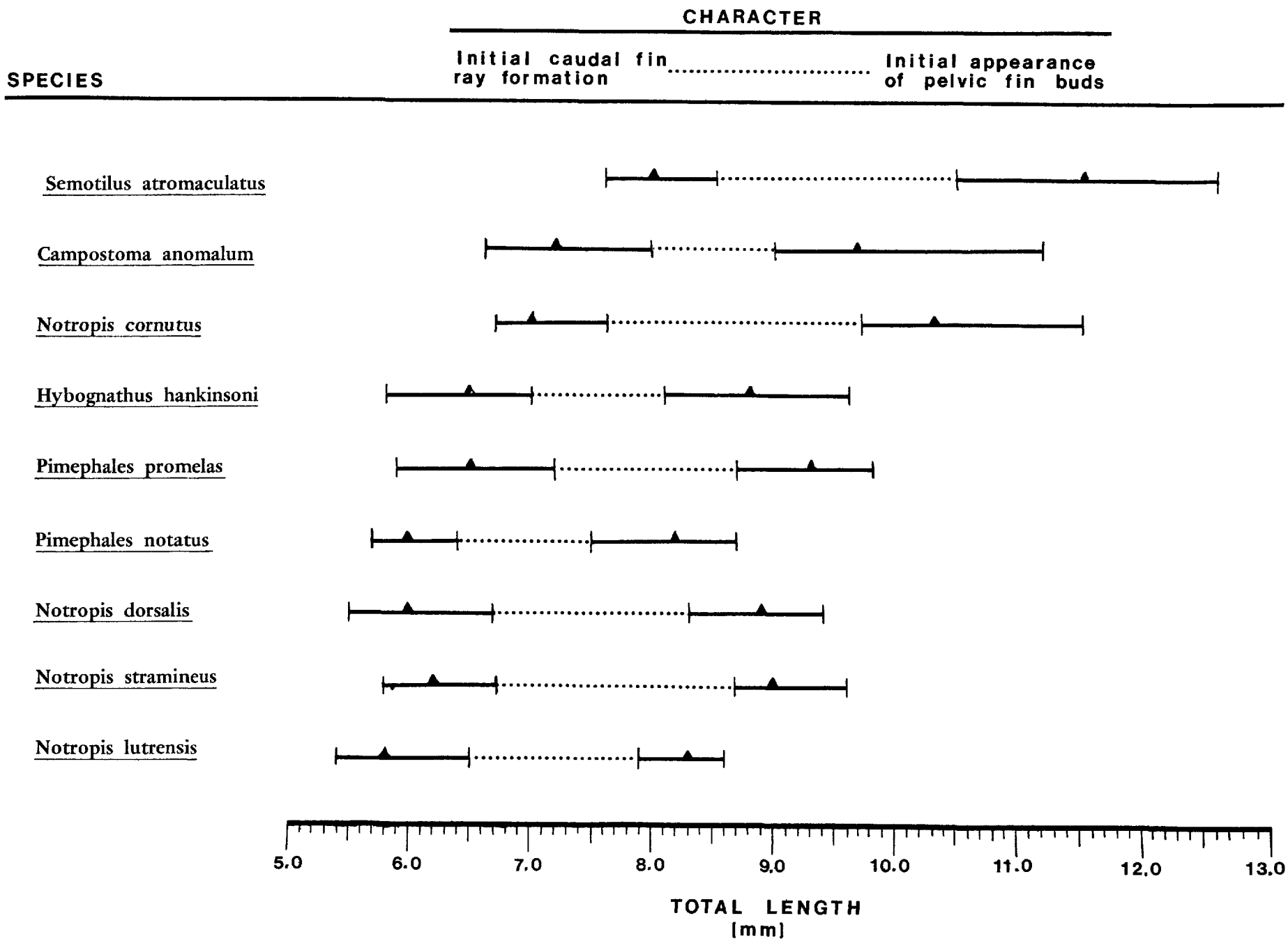

Figure 1. Total lengths (mm) at which caudal fin rays and pelvic fin buds are acquired in nine species of cyprinids. Means (▲) and ranges (⊢——⊣) are based upon 10 specimens in each stage of development.

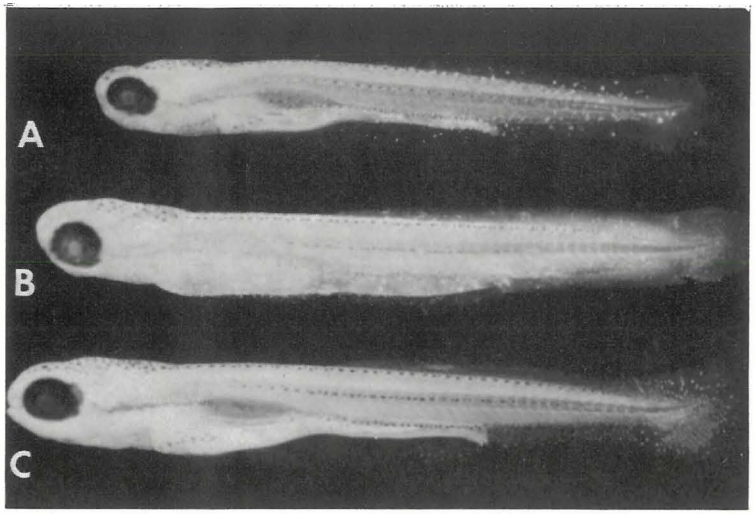

Plate 1. A) protolarva 7.0 mm TL
B) protolarva 7.8 mm TL
C) mesolarva 8.2 mm TL

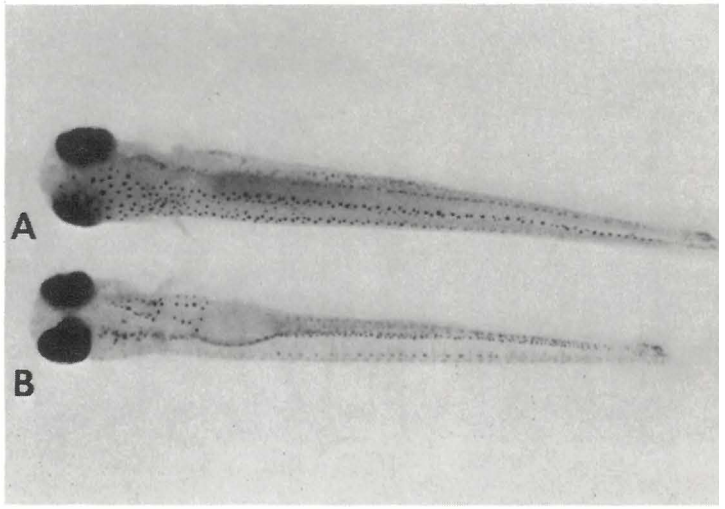

Plate 2. A) protolarva 7.7 mm TL
B) protolarva 7.4 mm TL

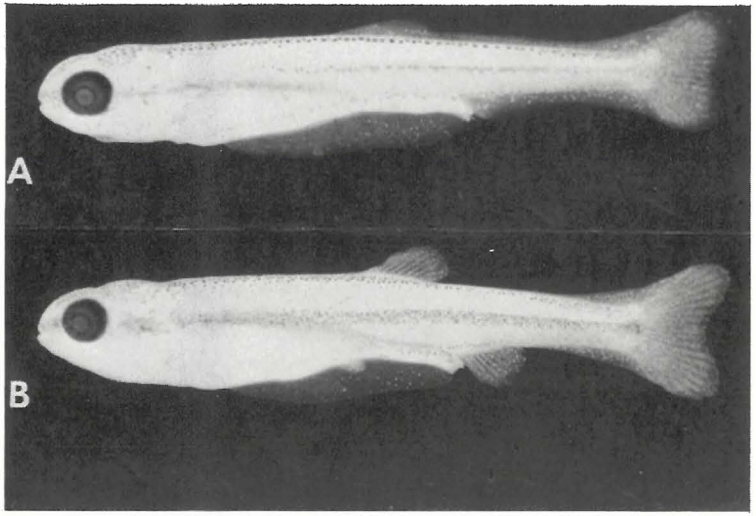

Plate 3. A) mesolarva 10.6 mm TL
B) metalarva 14.2 mm TL

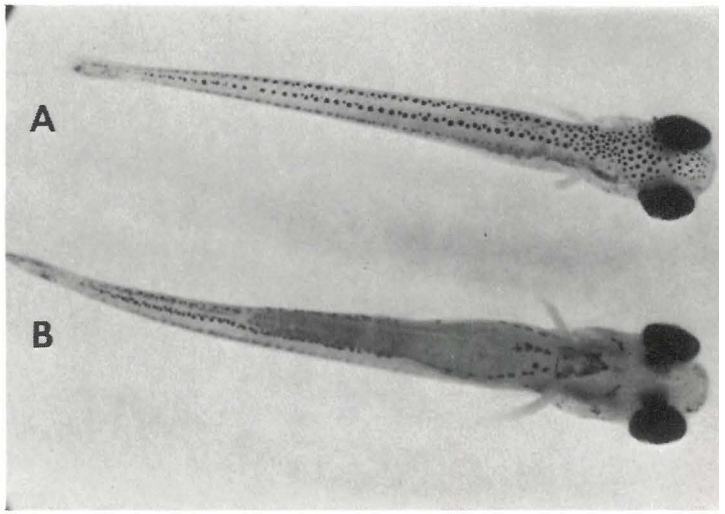

Plate 4. A) mesolarva 8.6 mm TL
B) mesolarva 9.3 mm TL

SEMOTILUS ATROMACULATUS

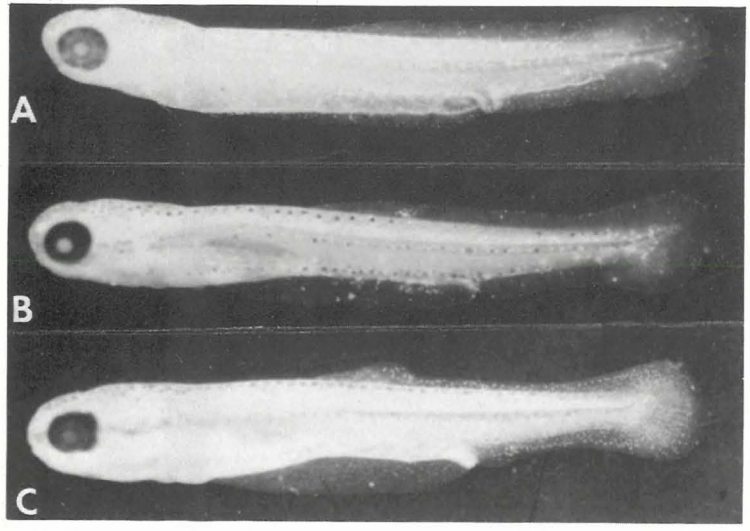

Plate 5. A) protolarva 6.8 mm TL
B) mesolarva 7.5 mm TL
C) mesolarva 10.4 mm TL

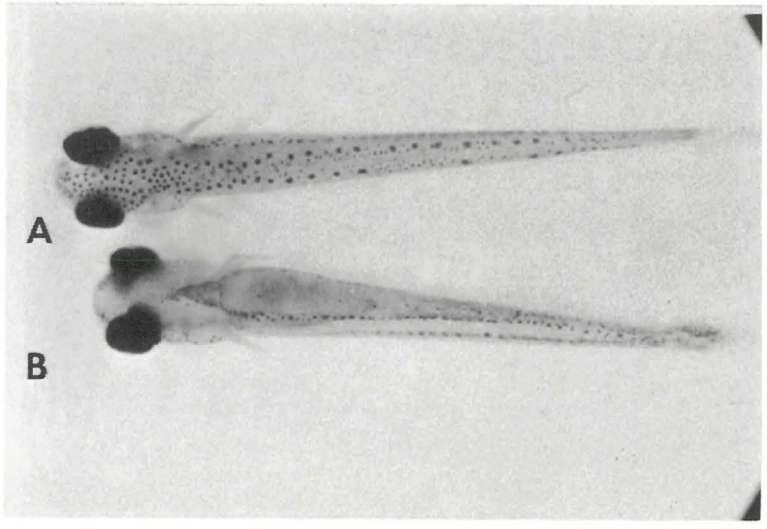

Plate 6. A) protolarva 6.5 mm TL
B) protolarva 6.6 mm TL

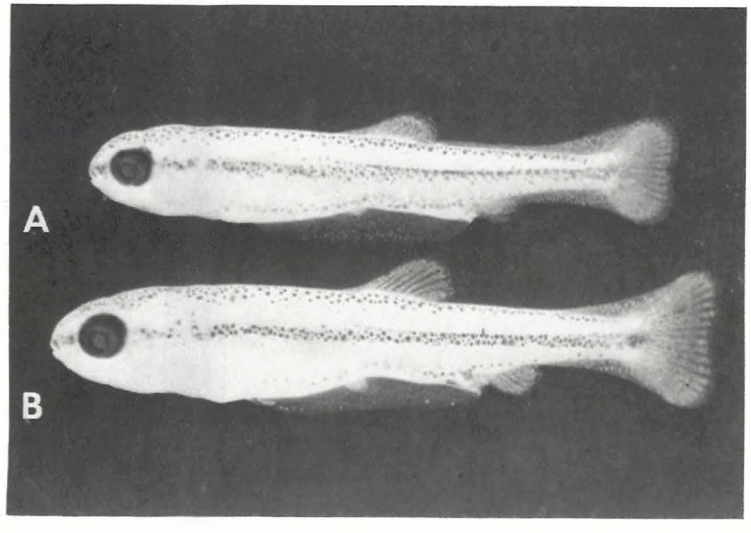

Plate 7. A) mesolarva 10.5 mm TL
B) metalarva 11.8 mm TL

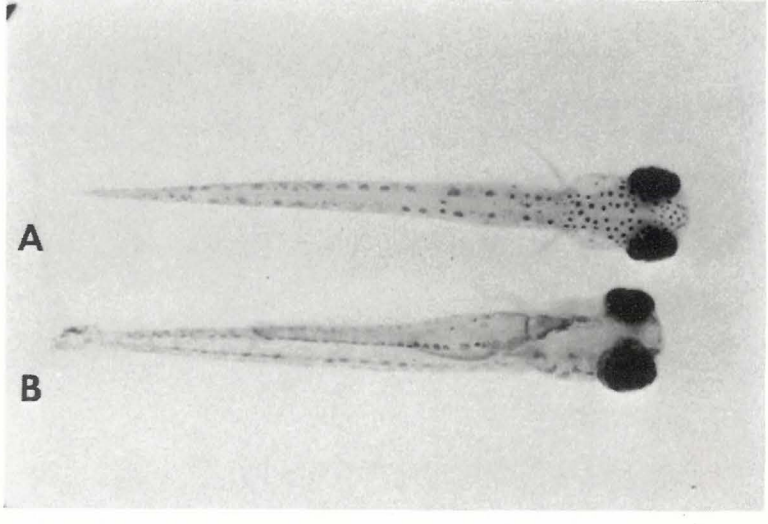

Plate 8. A) mesolarva 8.7 mm TL
B) mesolarva 8.4 mm TL

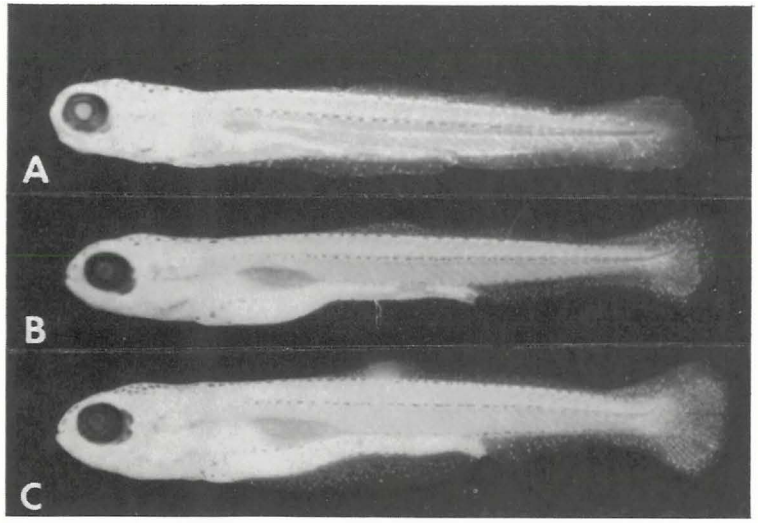

Plate 9. A) protolarva 6.4 mm TL
B) mesolarva 7.8 mm TL
C) mesolarva 9.8 mm TL

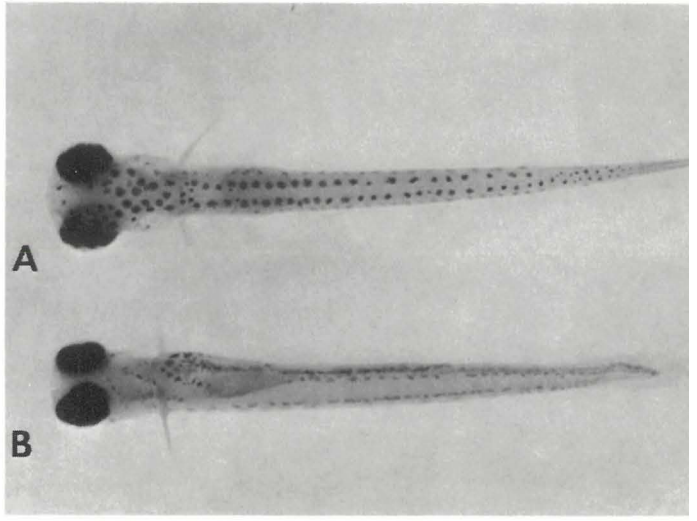

Plate 10. A) protolarva 6.4 mm TL
B) protolarva 6.0 mm TL

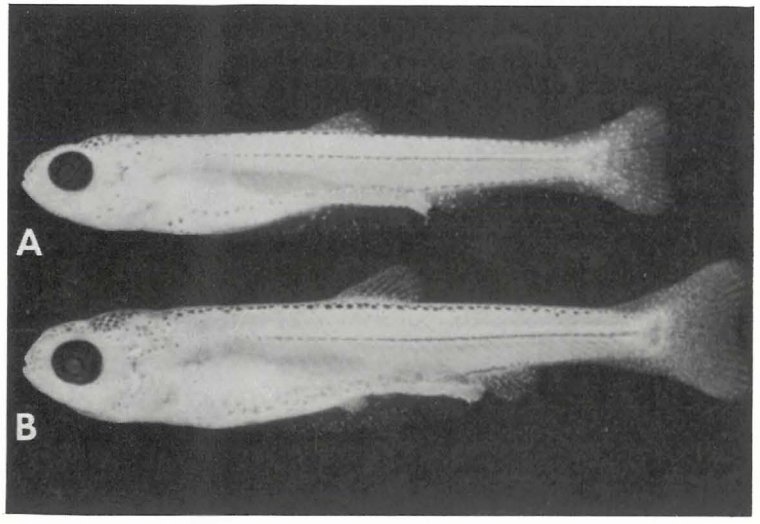

Plate 11. A) mesolarva 11.3 mm TL
B) metalarva 12.7 mm TL

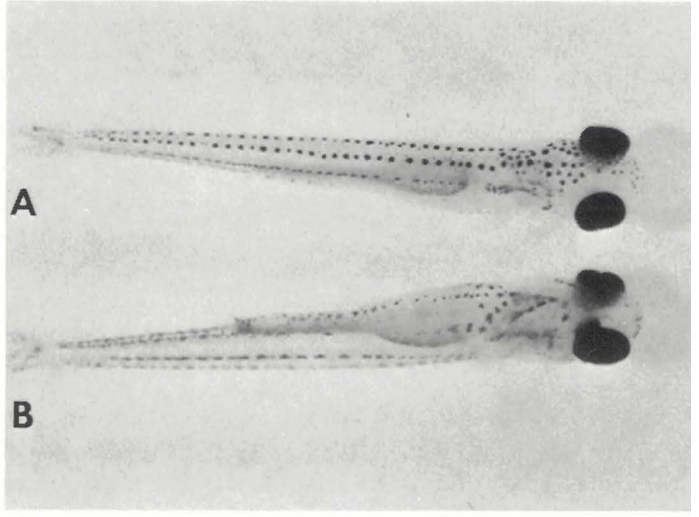

Plate 12. A) mesolarva 8.8 mm TL
B) mesolarva 8.4 mm TL

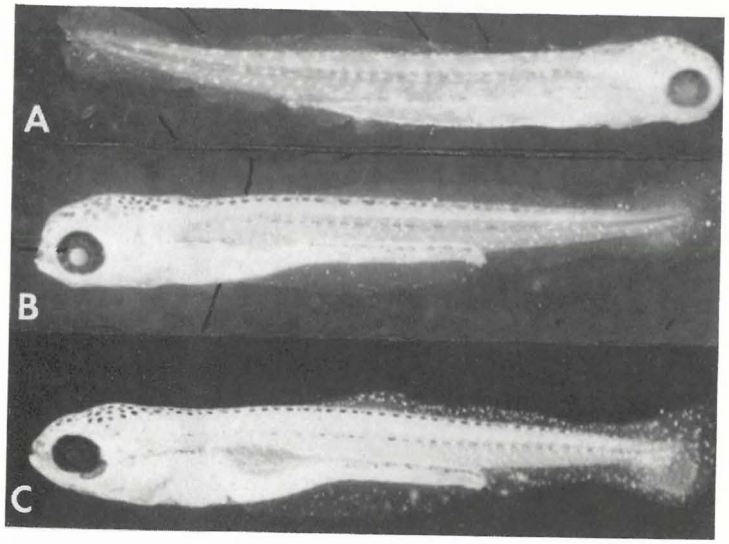

Plate 13. A) protolarva 5.0 mm TL
B) protolarva 5.2 mm TL
C) mesolarva 7.6 mm TL

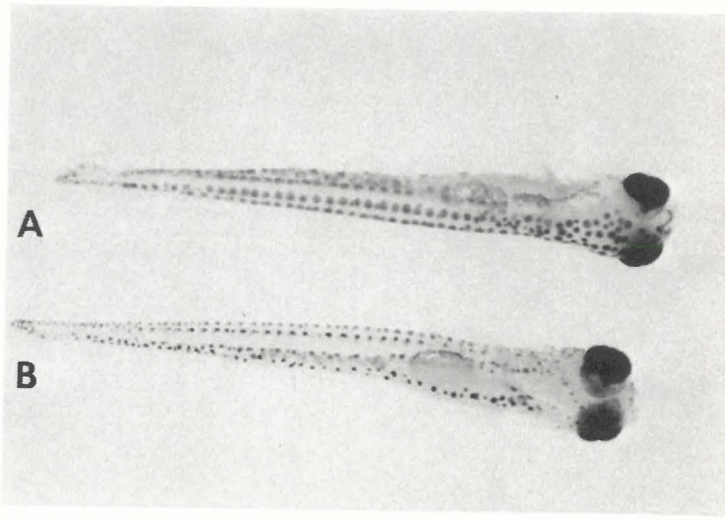

Plate 14. A) protolarva 5.0 mm TL
B) protolarva 5.2 mm TL

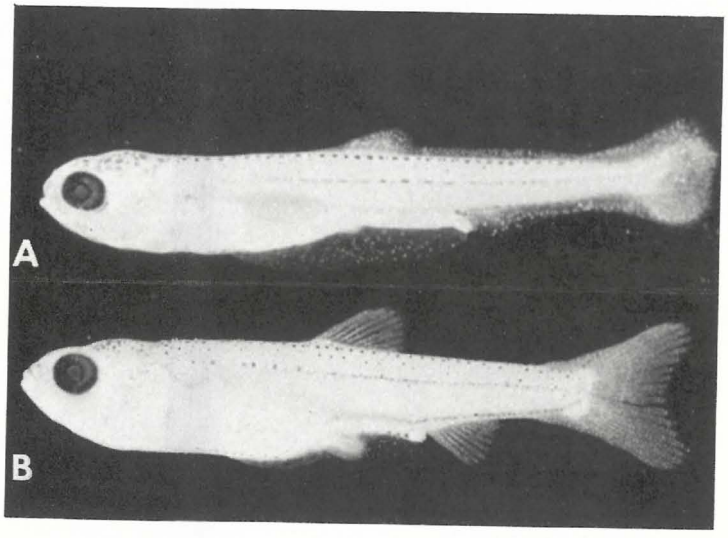

Plate 15. A) mesolarva 9.6 mm TL
B) metalarva 13.9 mm TL

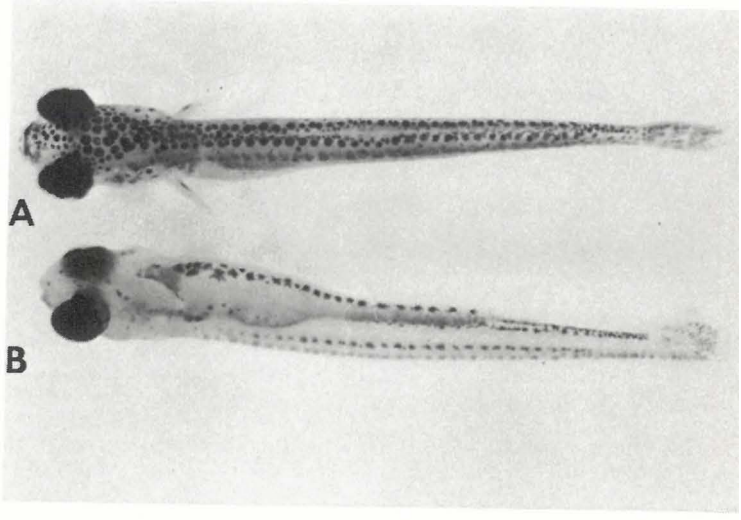

Plate 16. A) mesolarva 7.7 mm TL
B) mesolarva 7.6 mm TL

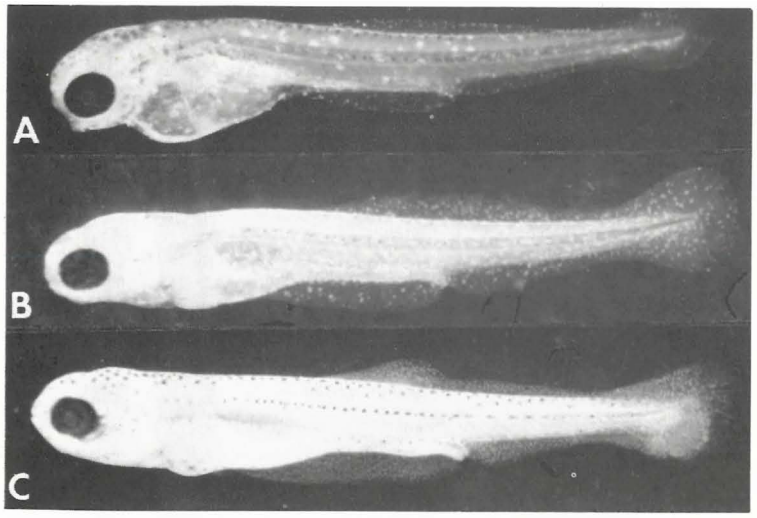

Plate 17. A) protolarva 5.3 mm TL
B) protolarva 5.7 mm TL
C) mesolarva 9.0 mm TL

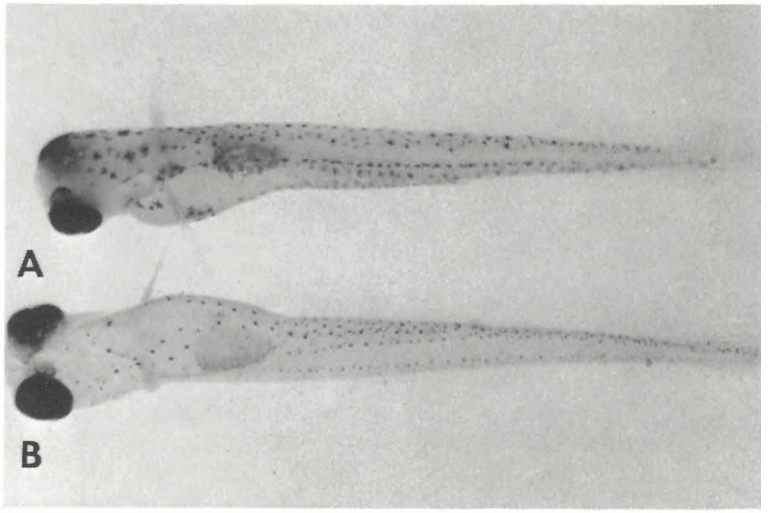

Plate 18. A) protolarva 5.3 mm TL
B) protolarva 5.6 mm TL

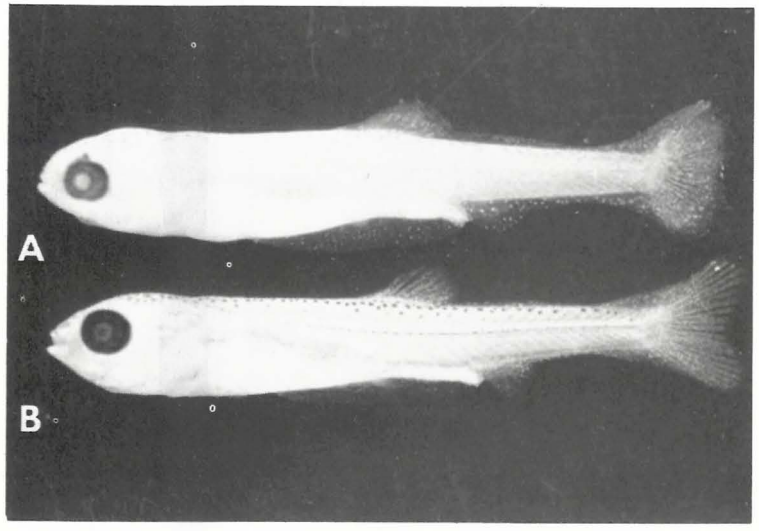

Plate 19. A) mesolarva 9.9 mm TL
B) metalarva 10.2 mm TL

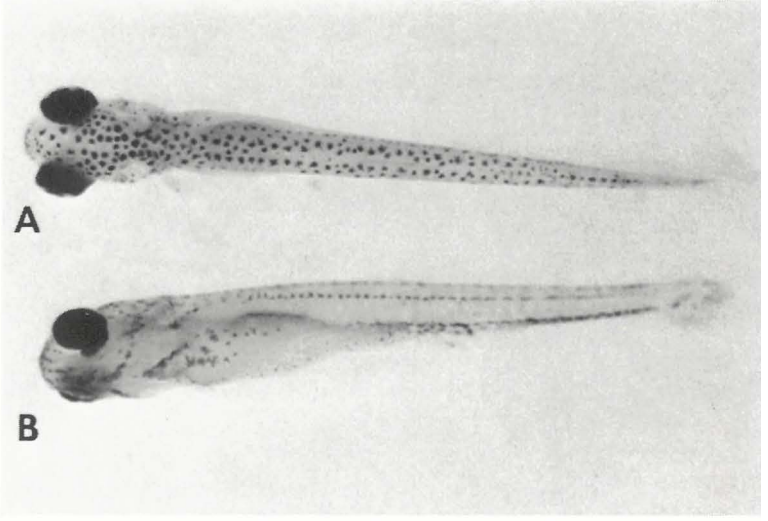

Plate 20. A) mesolarva 9.0 mm TL
B) mesolarva 9.0 mm TL

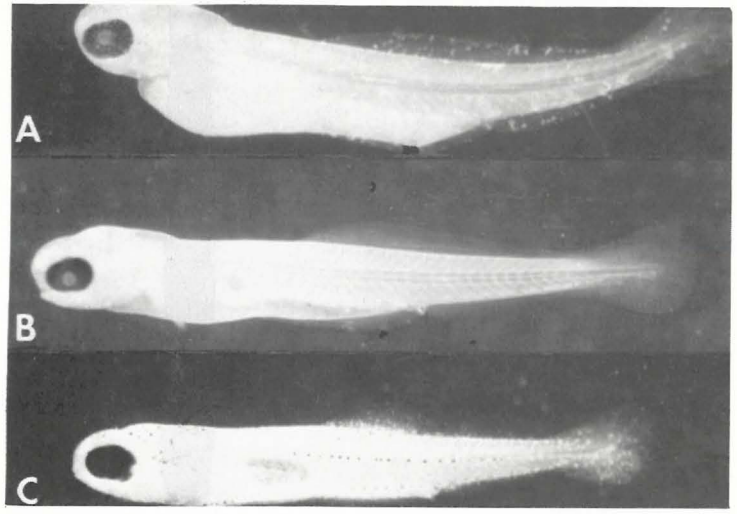

Plate 21. A) protolarva 5.9 mm TL
B) protolarva 6.0 mm TL
C) mesolarva 6.9 mm TL

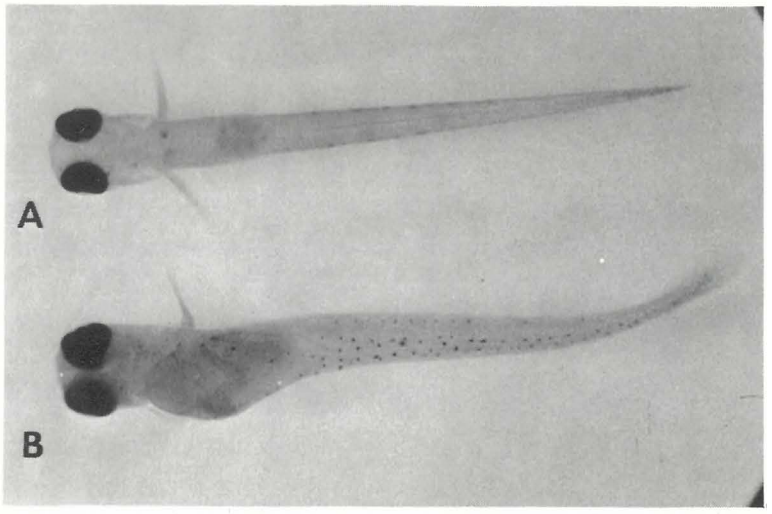

Plate 22. A) protolarva 5.9 mm TL
B) protolarva 6.2 mm TL

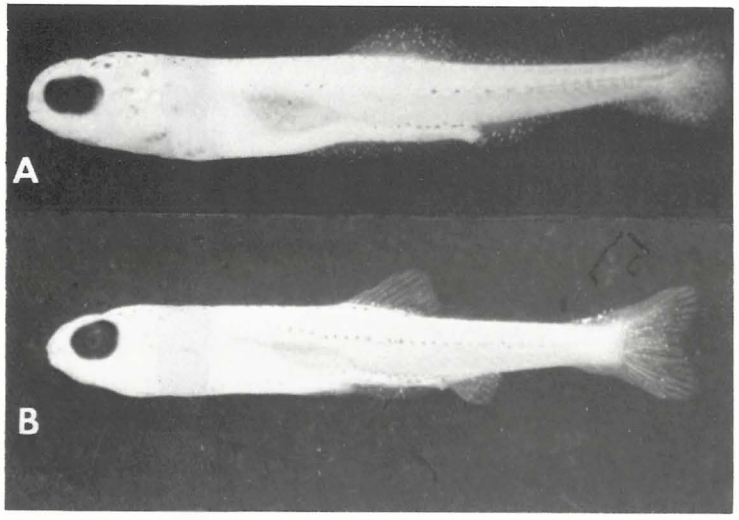

Plate 23. A) mesolarva 8.0 mm TL
B) metalarva 9.8 mm TL

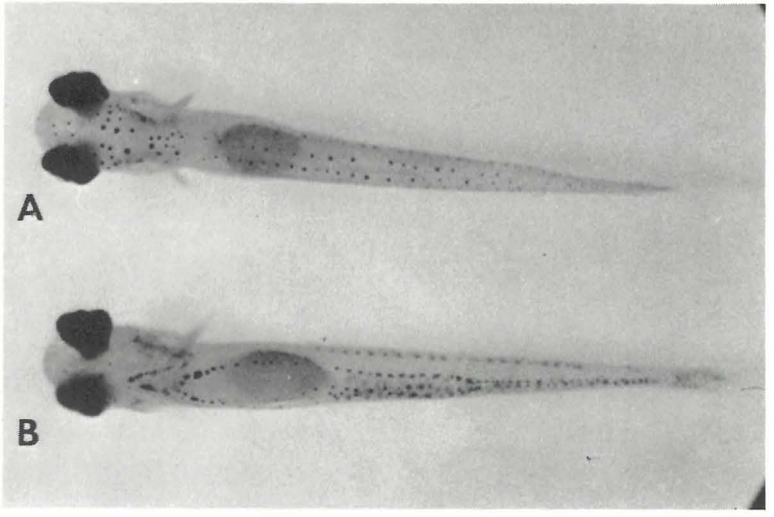

Plate 24. A) mesolarva 6.9 mm TL
B) mesolarva 7.2 mm TL

PIMEPHALES NOTATUS

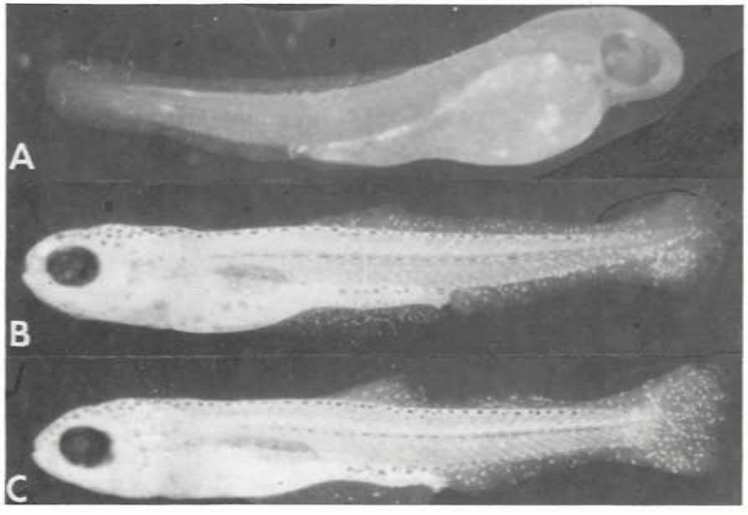

Plate 25. A) protolarva 3.8 mm TL
B) mesolarva 5.7 mm TL
C) mesolarva 7.8 mm TL

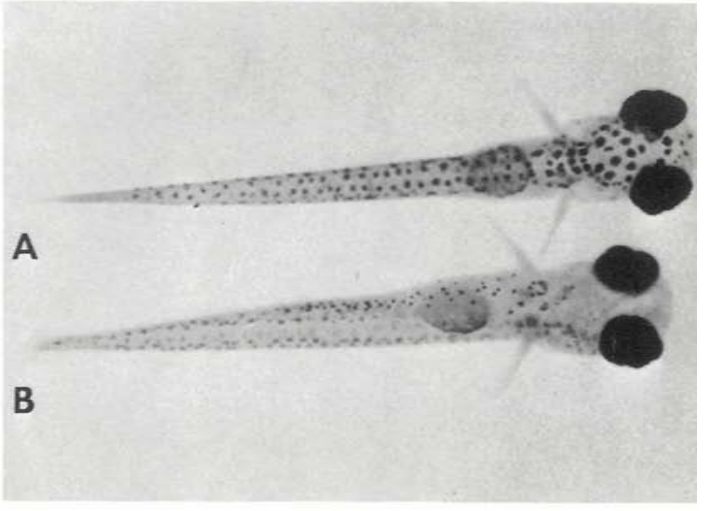

Plate 26. A) protolarva 4.3 mm TL
B) protolarva 4.3 mm TL

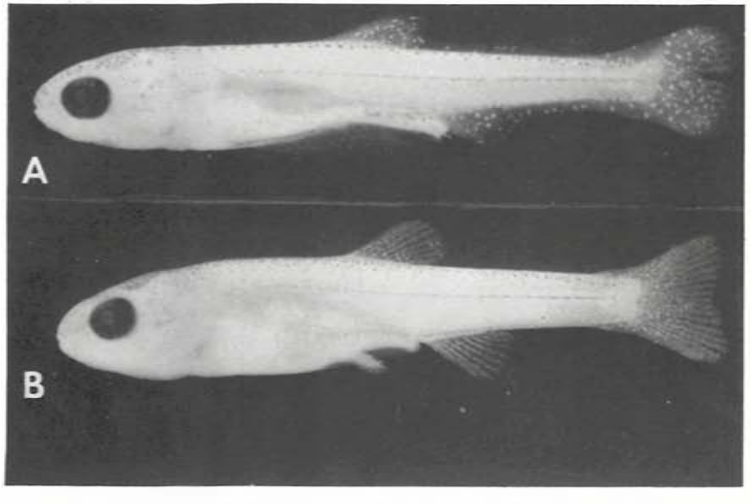

Plate 27. A) mesolarva 10.1 mm TL
B) metalarva 14.0 mm TL

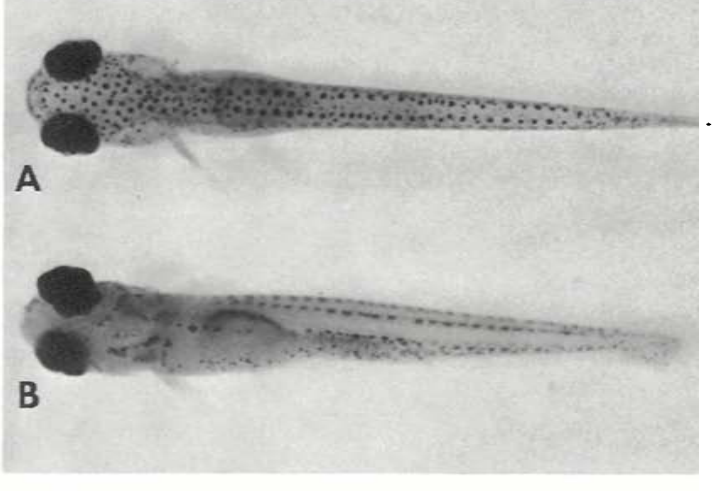

Plate 28. A) mesolarva 6.9 mm TL
B) mesolarva 6.6 mm TL

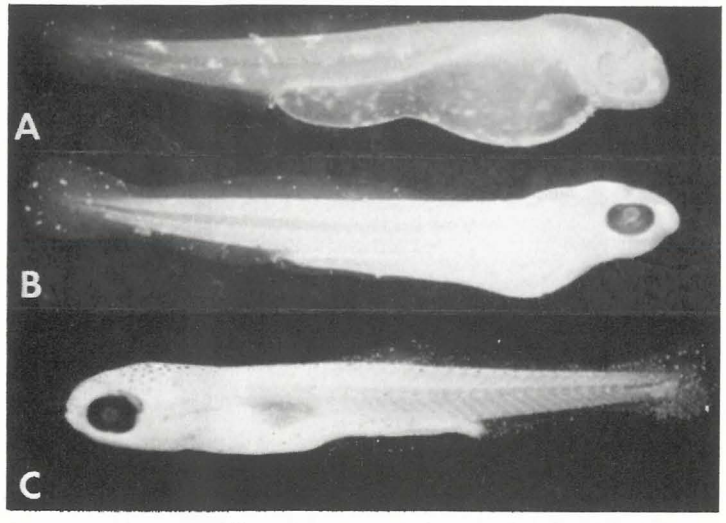

Plate 29. A) protolarva 3.6 mm TL*
B) protolarva 4.2 mm TL
C) mesolarva 7.0 mm TL

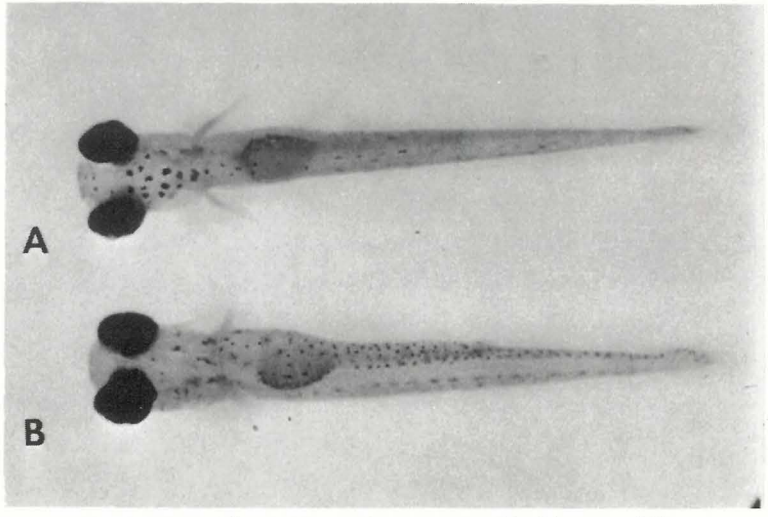

Plate 30. A) protolarva 5.3 mm TL
B) protolarva 5.3 mm TL

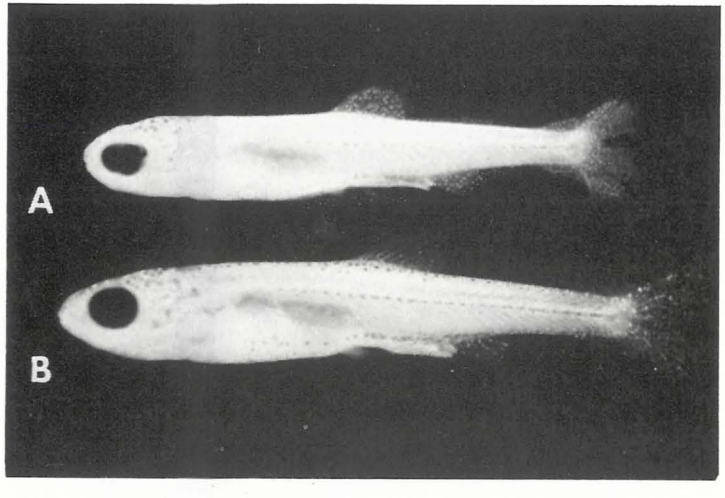

Plate 31. A) mesolarva 9.1 mm TL
B) metalarva 10.8 mm TL

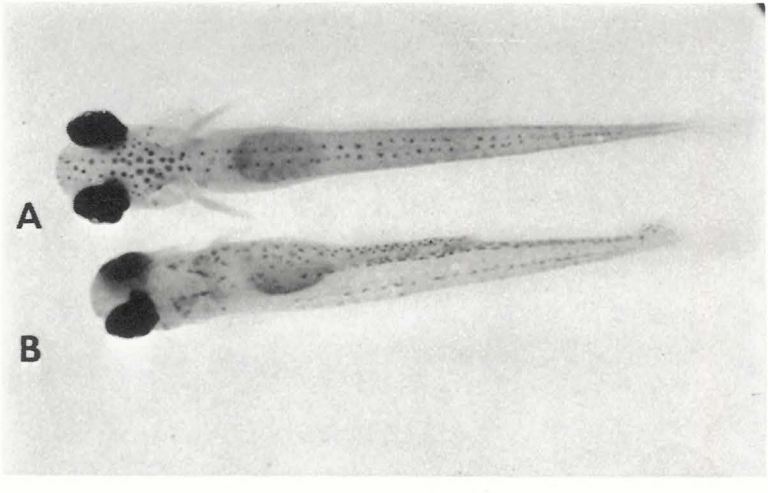

Plate 32. A) mesolarva 7.0 mm TL
B) mesolarva 6.6 mm TL

*N. stramineus or
N. dorsalis

NOTROPIS STRAMINEUS

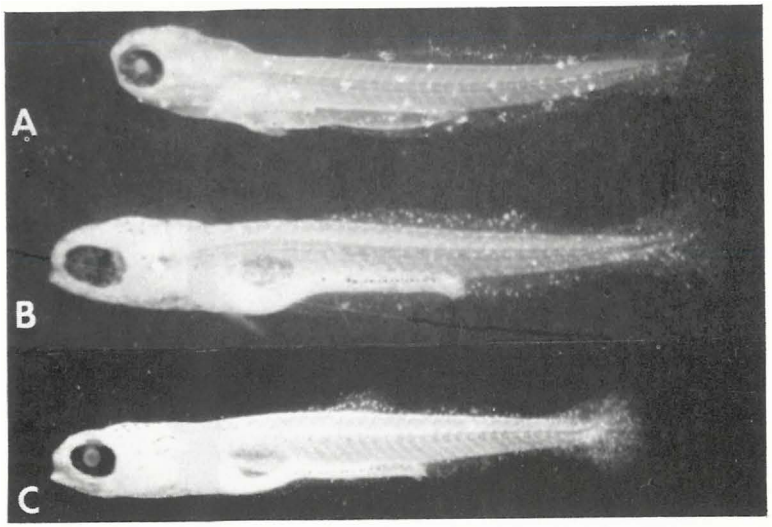

Plate 33. A) protolarva 4.3 mm TL
B) protolarva 4.7 mm TL
C) mesolarva 6.6 mm TL

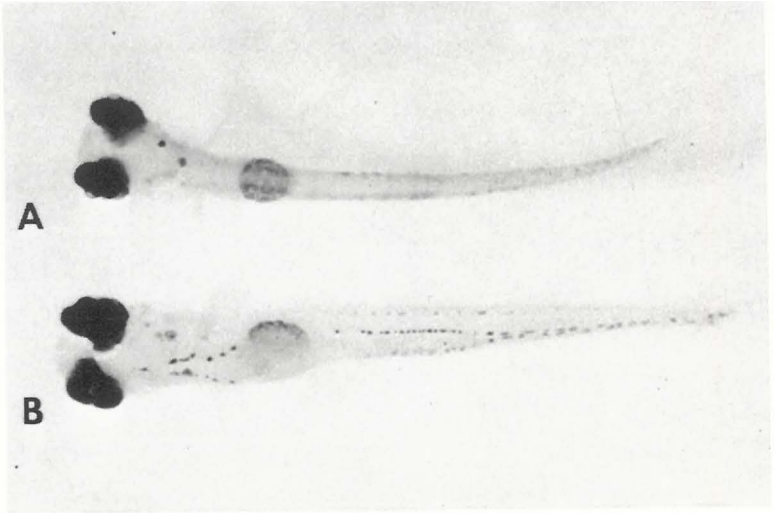

Plate 34. A) protolarva 4.3 mm TL
B) protolarva 4.7 mm TL

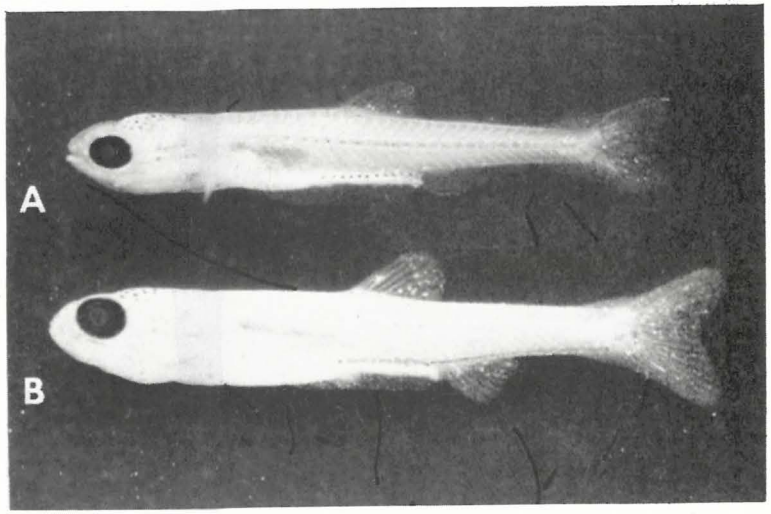

Plate 35. A) mesolarva 8.1 mm TL
B) metalarva 9.2 mm TL

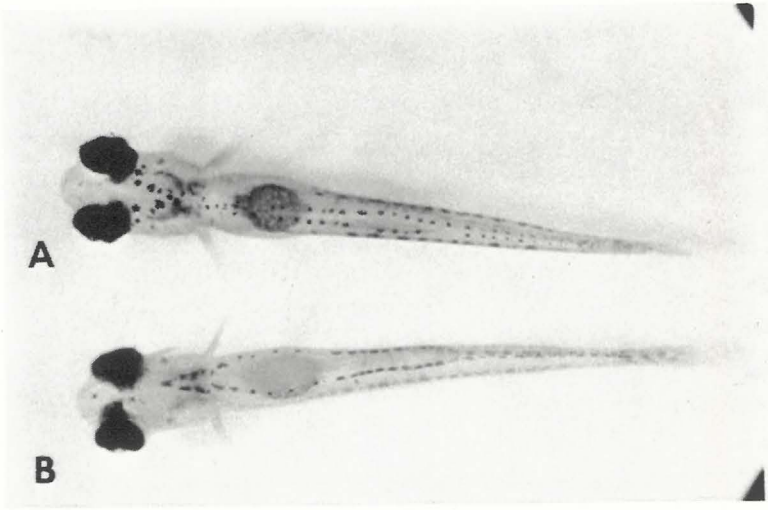

Plate 36. A) mesolarva 7.0 mm TL
B) mesolarva 7.0 mm TL

IDENTIFICATION OF CATFISH ALEVINS OF THE PIEDMONT CAROLINAS

by

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ABSTRACT

A key to the alevins of catfishes (excluding madtoms) of the Piedmont Province of North and South Carolina is provided. Characters most useful for identification include anal ray counts, pelvic ray counts, caudal fin morphology, pectoral spine morphology, and pigmentation.

INTRODUCTION

Eleven species of catfishes are known to occur in the Piedmont Province of North and South Carolina. Six of these species are native: snail bullhead, *Ictalurus brunneus* (Jordan); white catfish, *I. catus* (Linnaeus); yellow bullhead, *I. natalis* (LeSueur); brown bullhead, *I. nebulosus* (LeSueur); flat bullhead, *I. platycephalus* (Girard); orangefin madtom, *Noturus gilberti* (Jordan and Evermann); and margined madtom, *N. insignis* (Richardson). Four species are introduced: blue catfish, *I. furcatus* (LeSueur); black bullhead, *I. melas* (Rafinesque); channel catfish, *I. punctatus* (Rafinesque); and flathead catfish, *Pylodictis olivaris* (Rafinesque). The native species are generally common except for the yellow bullhead, which is characteristically a Coastal Plain inhabitant, and the orangefin madtom, which is rare and localized in the upper Dan River drainage. Most of the introduced species are rare, except for the channel catfish, which is common in several rivers and reservoirs.

Larval development in many fishes is commonly divisible into prolarval (sac fry) and postlarval stages. However, in ictalurids there is no true postlarval stage because the fish resemble adults when the yolk sac disappears. Early juveniles just after the prolarval stage, are called alevins (Lagler et al. 1977). Even though alevins have some adult features, certain problems in identification have been encountered. Morphology and pigmentation may differ between alevins and adults. Pigmentation may be affected by water or light conditions and is also masked by stains such as rose bengal, which are used to facilitate picking and sorting of fish eggs and larvae from samples. Consequently, reliable diagnostic characters need to be established for identification of alevins.

The purpose of this paper is to describe characters which can be used to identify catfish alevins from the Piedmont Carolinas. Most specimens used in this study were from the Piedmont Province of North and South Carolina, but other specimens were also used to obtain supplementary data or to fill information gaps. It is hoped that the characters presented here will also be useful in other regions. A key is provided to facilitate identifications.

Madtoms are excluded from this paper because of lack of material. They cannot be separated from bullheads unless development of the adipose fin is complete.

MATERIALS AND METHODS

Materials Examined

Number of specimens examined followed by range of total lengths (mm) are given in parentheses.

Ictalurus brunneus: Broad R., Cherokee Co., S.C. (30, 14-54); Dan R., Rockingham Co., N.C. (16, 31-105).

Ictalurus catus: Broad R., Cherokee Co., S.C. (38, 12-67); Lake Wylie, Catawba R. dr., Gaston Co., N.C. (3, 16-24); Lake Norman, Catawba R. dr., Lincoln Co., N.C. (21, 16-29); Yadkin R., Davie-Davidson Co. border, N.C. (2, 15-16).

Ictalurus furcatus: Tennessee R., Tennessee-Mississippi-Alabama border (4, 16-18).

Ictalurus melas: Trib. of Long Crk., Yadkin R. dr., Stanley Co., N.C. (15, 36-40); Belews Lake, Dan R. dr., Forsyth Co., N.C. (128, 30-57); Little Bear Reservoir, Bear Crk. dr., Franklin Co., Ala. (50, 32-41); Cow Crk., Arkansas R. dr., Crawford Co., KS. (2, 49-55).

Ictalurus natalis: Back Crk., Pee Dee R. dr., Cabarrus Co., N.C. (1, 57); Lynches R., Chesterfield Co., S.C. (2, 56-61); Lake Robinson, Pee Dee R. dr., Chesterfield Co., S.C. (1, 17); Gapeway Swamp Canal, Pee Dee R. dr., Columbus Co., N.C. (7, 29-45); Dan R., Rockingham Co., N.C. (1, 74); Holston R., Hawkins Co., Tenn. (29, 14-30).

Ictalurus nebulosus: Broad R., Cherokee Co., S.C. (158, 12-17); Lake Norman, Catawba R. dr., Lincoln Co., N.C. (40, 16-58).

Ictalurus platycephalus: Broad R., Cherokee Co., S.C. (4, 17-19); Lake Norman, Catawba R. dr., Lincoln Co., N.C. (12, 18-38); Lynches R., Chesterfield Co., S.C. (3, 36-50).

Ictalurus punctatus: Broad R., Cherokee Co., S.C. (10, 14-17); Lake Wylie, Catawba R. dr., Gaston Co., N.C. (108, 13-31); Yadkin River, Davie-Davidson Co. border, N.C. (34, 13-19); Dan R., Rockingham Co., N.C. (1, 29).

Pylodictis olivaris: Yadkin R., Davie-Davidson Co. border, N.C. (1, 15); Kentucky Lake, Hardin Co., TN (3,15-21).

Methods

The total length of each specimen was measured to the nearest millimeter. The anal and pelvic rays were counted, including the smallest anterior rudiments; the last two rays (double rays with a single base) were counted as one. Pectoral spines were excised from the fish, and the flesh covering each spine was removed by soaking in enzyme detergent. Ray counts and observations of pectoral spine morphology were made with a dissecting microscope using polarized light. Drawings of pectoral spines were made with the aid of a camera lucida or microprojector.

RESULTS AND DISCUSSION

The most useful characters for identification of alevins 15 mm or longer include anal ray counts, pelvic ray counts, caudal fin morphology, pectoral spine morphology, and pigmentation (Table 1, Fig. 1). With smaller specimens, identification may be difficult or impossible because fins and spines may not be sufficiently developed to be useful (e.g., a channel catfish 14 mm or less in length may have a rounded rather than a forked tail and the anal rays may not have developed enough for an accurate count). Fortunately, most specimens taken by conventional trawls are 15 mm or larger. Data on distribution, habitat requirements, and reproductive habits of adults from the collection area may also provide insight for identification of alevins.

Further descriptions and identification aids can be found in Armstrong (1962), Fish (1932), Hogue et al. (1976), Lippson and Moran (1974), and Mansueti and Hardy (1967).

Key to Species of Catfish Alevins

1. a. Anal fin rays usually 32-34 (30-36); Caudal fin deeply forked ..... *Ictalurus furcatus*

   b. Anal fin rays less than 30; Caudal fin may or may not be forked 2

2. a. Distal barb of pectoral spine hook-shaped (Fig. 1 F, G); Caudal fin forked to emarginate 3

   b. Pectoral spine barbs not distinctly hooked; Caudal fin rounded, truncate, or emarginate 4

3. a. Anal rays usually 21-24 (18-26); Caudal fin emarginate to moderately forked; Body dusky gray and moderately robust; Maxillary barbels dark gray or black, chin barbels white ..... *Ictalurus catus*

   b. Anal rays usually 26-29 (24-30); Caudal fin deeply forked; Body and barbels light; Body slender ..... *Ictalurus punctatus*

4. a. Pelvic rays normally 8; No diffuse patch of pigment in middle of caudal fin 5

   b. Pelvic rays normally 9 or 10; Diffuse patch of pigment in middle of caudal fin ..... *Pylodictis solivaris*

5. a. Pectoral spine barbs relatively short (width greater than length) (Fig. 1 C, E) 6

   b. Barbs longer (length equal to or greater than width) (Fig. 1 A, B, D) 7

6. a. Anal rays usually 17-21 (16-24); Chin barbels dark ..... *Ictalurus melas*

   b. Anal rays usually 25-27 (23-28); Chin barbels light ..... *Ictalurus natalis*

7. a. Distal barbs on pectoral spine long (length greater than width) and slightly curved (Fig. 1 D); Body and barbels dark..... *Ictalurus nebulosus*

   b. Distal barb on pectoral spine shorter (length approximately equal to width) and triangular in shape (Fig. 1 A, B); Body dusky brownish gray; Barbels light dusky or cream color 8

8. a. Anal rays usually 17-20 (16-22) ..... *Ictalurus brunneus*

   b. Anal rays usually 21-24 (19-24)..... *Ictalurus platycephalus*

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I wish to thank E. F. Menhinick, University of North Carolina at Charlotte; Bill Tarplee, Carolina Power and Light Company, New Hill, North Carolina; Bob Wallus, Tennessee Valley Authority, Norris, Tennessee; and T. L. Wenke, Fort Hays, Kansas State University, Hays, Kansas, for loaning specimens used in this study.

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Table 1

Key characters for identification of catfish alevins in the Piedmont Carolinas

Species	Anal Rays	Pelvic Rays	Pectoral Spine Morphology	Caudal Fin Morphology	Pigmentation
I. brunneus	Usually 17-20 (16-22)	8	Distal barb triangular in shape	Posterior margin emarginate	Body dusky brownish-gray; Barbels light dusky or cream color
I. catus	Usually 21-24 (18-26)	8	Distal barb hook-shaped; serrations cover about 2/3 of leading edge	Posterior margin emarginate to moderately forked; small individuals do not differ significantly from bullheads	Body dusky gray; maxillary barbels dark gray or black, chin barbels white.
I. furcatus	Usually 32-34 (30-36)	8	Specimens too small for complete analysis	Forked	Body and barbels light
I. melas	Usually 17-21 (16-24)	8	Barbs relatively short (width usually greater than length). Serrations cover less than 1/2 of leading edge.	Posterior margin truncate or emarginate	Body dark brownish gray to black; maxillary barbels dark gray to black; chin barbels dusky gray to black.
I. natalis	Usually 24-27 (23-28)	8	Barbs sharp but not as long as in I. nebulosus, sometimes relatively short.	Posterior margin rounded or truncate	Body light yellowish brown to brown; maxillary barbels brown to dark brown; chin barbels light.
I. nebulosus	Usually 21-24 (20-25)	8	Distal barb long and slightly curved but not distinctly hooked as in I. catus or I. punctatus; serrations cover less than 1/2 of leading edge	Posterior margin truncate or emarginate	Body dark brownish gray to black; maxillary barbels dark gray to black; chin barbels dusky gray to black.
I. platycephalus	Usually 21-24 (19-24)	8	Distal barb triangular in shape as in I. brunneus	Posterior margin emarginate	Body dusky brownish-gray; barbels light dusky or cream color.
I. punctatus	Usually 26-29 (24-30)	8	Distal barb hook-shaped as in I. catus	Forked	Body and barbels light
P. olivaris	Usually 14-17 (13-18)	9 or 10	Specimens too small for complete analysis	Truncate or emarginate	Body and barbels light in small specimens becoming darker with increased size; diffuse patch of pigment in middle of caudal fin.

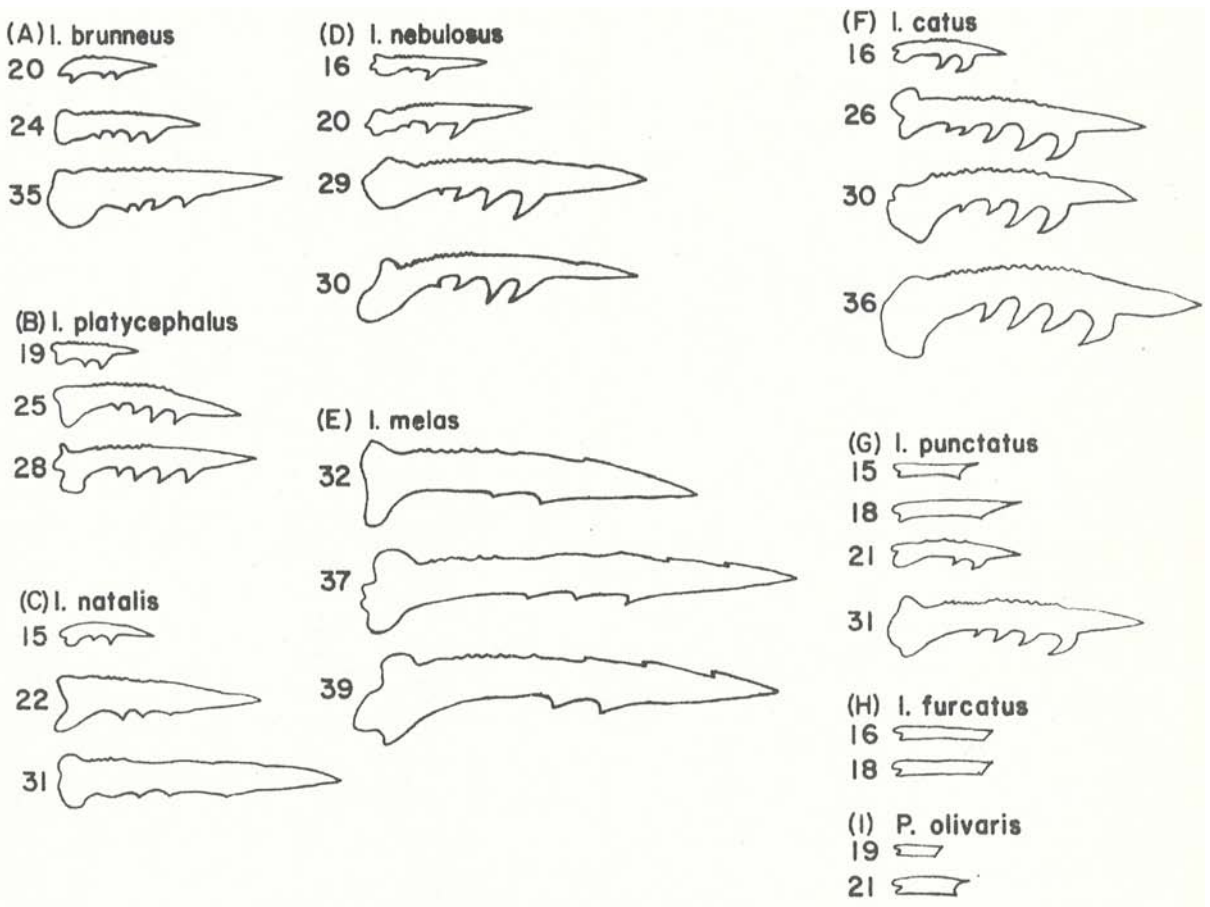

Figure 1. Pectoral spine morphology of ictalurids from the Piedmont Carolinas. Numbers to the left of each spine are the total length (mm) of the fish from which the spine was taken.

LARVAE AND JUVENILES OF THE BROOK SILVERSIDE,

Labidesthes sicculus[1]

by

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ABSTRACT

Protolarvae have 6 to 7 preanal and 29 to 31 postanal myomeres. Migration of the anus and pelvic buds during the metalarval phase results in 14 to 15 preanal and 24 to 25 postanal myomeres and causes a relative increase in prepelvic body length. Pectoral fins in protolarvae appear before finfold differentiation. Median fin ray development in mesolarvae appears sequentially in the caudal, anal, and soft dorsal fins. The spinous dorsal and pelvic fins differentiate in metalarvae. Protolarval pigmentation consists of numerous large melanophores on the dorsal surface of the head and on the ventral surface of the breast, and a single row of melanophores midventrally and midlaterally. Juvenile fish lack the fully formed beak-like snout of adults.

1. The information contained in this article was developed during the course of work under Contract No. AT(07-2)-1 with the U.S. Department of Energy.

INTRODUCTION

Larval fish keys (May and Gasaway 1967, Hogue et al. 1976) provide descriptions of larval brook silverside, *Labidesthes sicculus,* which adequately distinguish atherinid larvae from those of other families. A more detailed characterization of silverside larvae is necessary to distinguish sympatric atherinids. This study describes larvae and juveniles of the brook silverside and provides a basis for separating this species from other atherinid larvae and juveniles.

METHODS

Brook silverside larvae were obtained from a cooling water intake canal at the U.S. Department of Energy's Savannah River Plant on the Savannah River in South Carolina. Larvae were collected by hand nets and 0.5 m dia, 760 μ mesh plankton nets during July and August when water temperatures ranged from 22 to 26 C, averaging 24 C. Juveniles were collected by electrofishing in September and October. Specimens were preserved in 4% formaldehyde. Meristic and morphometric characteristics were determined with a polarized stereomicroscope equipped with an ocular micrometer.

Myomere and fin ray counts were the meristic characters studied. Preanal myomeres are those bisected by, or anterior to, an imaginary vertical line at the posterior margin of the anus; postanal myomeres are posterior to this line. Total length, snout length, eye diameter, prepelvic length, and snout-to-vent length were the morphometric characters studied. Larval terminology and criteria for determining developmental intervals follow the guidelines proposed by Snyder et al. (1977).

RESULTS

Protolarvae

Protolarval descriptions were based upon six larvae, 5.5 to 6.0 mm total length (TL). Yolk sac absorption was already complete in this size interval. The mean snout-vent length of the protolarvae was 1.7 mm, equivalent to 29% of their mean total length. Six to eight preanal myomeres, 29-32 postanal myomeres, and 36-39 total myomeres were characteristic of this stage (Table I).

The median finfold originated dorsally at the seventh or eighth myomere and extended to the posterior margin of the anus. The pectoral fins were paddle-shaped but exhibited no fin ray development. Gill rakers and filaments were present and the opercular flap covered the gill arches. The eyes were well developed, pigmented, and elliptical in shape, and the auditory vesicles were visible posterior to the eyes (Figure 1b).

Dorsal pigmentation consisted of numerous large melanophores in the tissue overlying the midbrain and hindbrain, with smaller melanophores extending onto the anterior one-quarter of the body along the middorsal line (Figure 1a). Melanophores were present at the base of the median finfold on the caudal peduncle. Two small melanophores were present at the nares.

Ventral pigmentation consisted of 4 to 6 large melanophores in the tissue covering the breast and abdomen. Melanophores formed a single line of pigment from the anus to the caudal fin. Three to four small melanophores were present on the anterior portion of the mandible and the dorsal surface of the swim bladder was heavily pigmented (Figure 1c).

Lateral pigmentation consisted of scattered melanophores midlaterally, small melanophores surrounding the caudal end of the notochord, and melanophores ventral to the auditory vesicle between the eye and pectoral fin (Figure 1b).

Mesolarvae

Caudal fin differentiation was initiated in mesolarvae of 6.2 mm TL. Dorsal flexion of the notochord occurred on mesolarvae at 8.1 mm TL. Fin rays appeared in the anal and soft dorsal fins of mesolarvae at 8.3 and 8.6 mm TL, respectively (Figure 1d). Myomere counts remained as they were in the protolarvae.

The small melanophores surrounding the notochord moved with it as it flexed. Three parallel rows of melanophores appeared ventrally: one row on each side of the midventral line from the anus to the caudal fin, and one row at the base of the anal fin and the remaining finfold (Figure 1e). Other regions of pigmentation remained basically as they were in protolarvae.

Metalarvae

Metalarval development was characterized by anal and pelvic bud migration between 11-15 mm TL. This migration altered the proportional relationship of preanal myomeres (13 to 15)

to postanal myomeres (24 to 25) while the total number of myomeres remained constant (37 to 39). Simultaneously, the mean snout-vent length of the 18 metalarvae studied increased to 36% of their total length (Table 1).

By 9.4 mm TL 11-12 rays were present in the pectoral fin, 4-5 spines had appeared in the spinous dorsal, and pelvic buds were present. Subsequently, 5 to 6 fin rays developed in the pelvic fins during migration. Metalarvae 15 mm TL had the characteristic sickle-shaped anal fin and 22 to 25 anal rays and one spine (Figure 1f). The last remnant of the finfold, between the anus and anal fin, persisted until the metalarvae reached a total length of 16.5 mm. Ten to 11 soft dorsal fin rays developed.

The large melanophores on the dorsal surface of the head and ventral surface of the breast fused during the metalarval phase. Scattered dorsal melanophores formed a double row of pigment from the soft dorsal fin to the caudal fin. Pigmentation increased on the lips and adjacent tissues. Melanophores occurred on the branchiostegal membranes, and midlaterally a solid black line developed.

Juveniles

Development of the beak-like snout increased the ratio of snout length to eye diameter from 0.6 to 1.0 in juveniles. The eye assumed a round shape and a silvery choroid coat.

The development of small melanophores increased the pigmentation of the head, dorsum, and ventrum. Increased pigmentation along the midlateral line produced a silvery lateral stripe of adult proportions.

DISCUSSION

Larval development of the brook silverside resembles the larval descriptions of estuarine atherinids provided by Kuntz (1916), Kuntz and Radcliffe (1917), and Lippson and Moran (1974). The overlapping geographical ranges of the tidewater silverside, *Menidia beryllina,* and the brook silverside provide the potential for the larvae of the two species to occur sympatrically in tidal fresh waters. Larval separation can be based on size differences at hatching; the tidewater silverside hatches at 3.0 mm, (Hildebrand 1922) and the brook silverside hatches at 4.0 mm (Nelson 1968).

The tidewater silverside has fewer anal rays (15 to 18) than does the brook silverside (22 to 25). In addition, the origin of the spinous dorsal fin is anterior to the origin of the anal fin on the tidewater silverside but directly above the anal fin origin on the brook silverside.

The Mississippi silverside, *Menidia audens,* and the brook silverside occur sympatrically in the Mississippi River drainage. The Mississippi silverside has fewer anal rays (15-20) than does the brook silverside and the origin of the spinous dorsal fin is anterior to the anal fin origin. Brook silverside larvae and juveniles lack the fully formed, beak-like snout characteristic of the adults and they have a snout length less than their eye diameter (Table I) as do the Mississippi silversides. The beak-like snout of adult brook silversides distinguishes them from Mississippi silversides; however, the larvae and juveniles of these two species cannot be separated by this late-developing character.

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TABLE I

Comparative Morphometric and Meristic Data
for Developmental Intervals of *Labidesthes sicculus*

	Protolarvae	Mesolarvae	Metalarvae	Juvenile
Number Examined	6	21	18	8
Total Length (mm)	5.5-6.0	6.2-8.8	9.4-16.5	17.4-42.9
Preanal Myomeres	6-8	6-9	7-15	14-15
Postanal Myomeres	29-32	29-32	24-31	24-25
Total Myomeres	36-39	37-39	36-39	36-39
Snout Length (mm)	0.15	0.24	0.54	1.67
Eye Diameter (mm)	0.28	0.61	1.06	2.03
Snout-Vent Length (mm)	1.69	2.26	4.60	12.01
Snout Length/Eye Diameter	0.28	0.38	0.50	0.77
Snout-Vent Length/Total Length	0.29	0.31	0.36	0.41

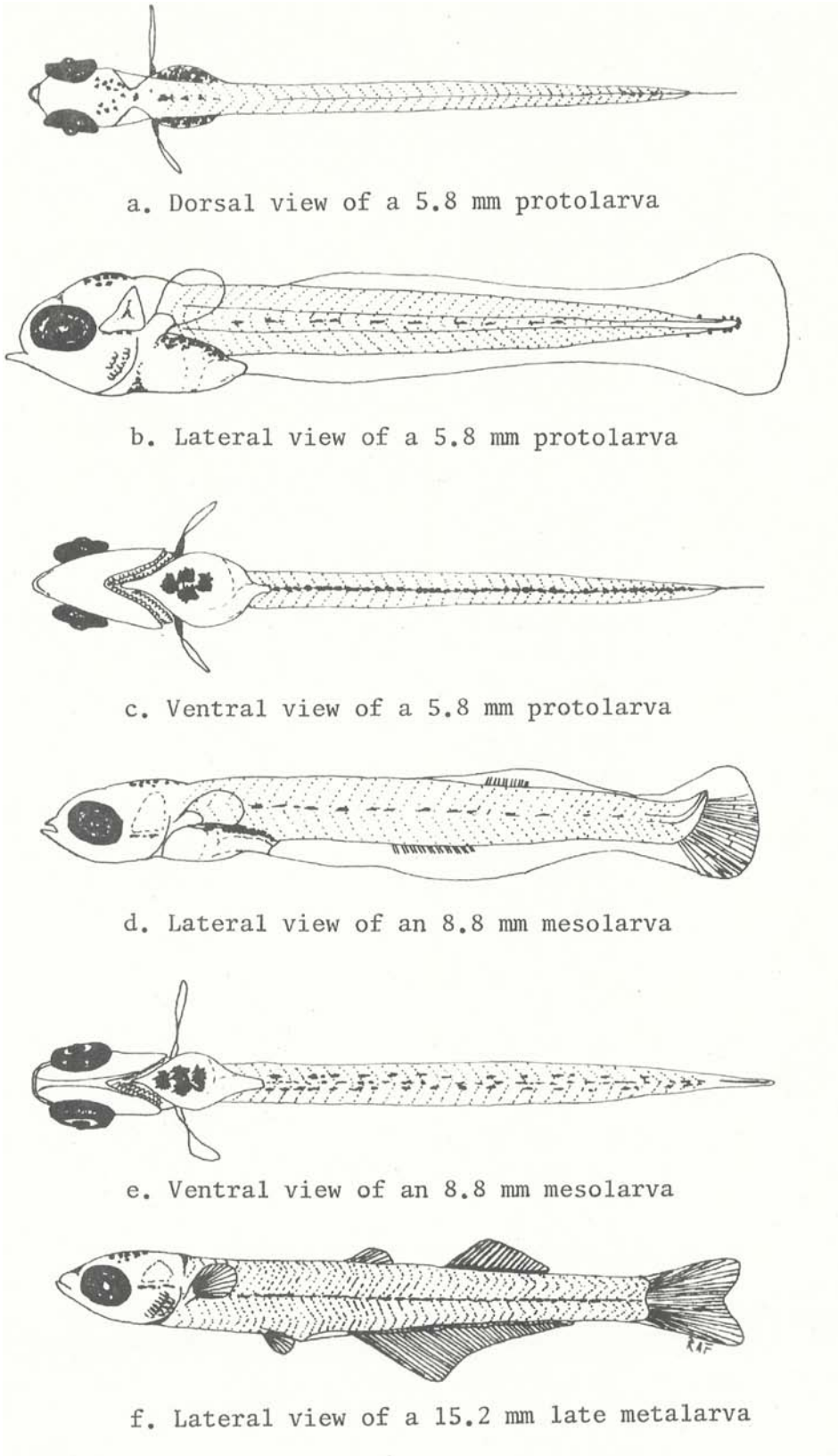

Figure 1. Developmental stages of *Labidesthes sicculus.*

SPAWNING BEHAVIOR AND EARLY DEVELOPMENT OF THE BANDED SCULPIN, *COTTUS CAROLINAE* (GILL)

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ABSTRACT

Observations were made on the spawning behavior, incubation period, and larval and juvenile development of a north Alabama population of banded sculpins, *Cottus carolinae* (Gill). Eggs incubated in the laboratory at 16-19 C hatched between 15 and 19 days after fertilization; the majority hatched between 16 and 18 days. Newly hatched larvae averaged 6.86 mm total length and began larval development in Snyder's (1976) mesolarval phase. The mesolarval phase was complete by 132 hours after hatching (between 8.5 and 9 mm total length). Metalarval development was completed for a few specimens as early as 252 hours after hatching. All specimens examined were juveniles by 348 hours after hatching. Little growth occurred in total length during metalarval development, with most specimens attaining juvenile characteristics by 9.5 to 10 mm. The end of the yolk-sac stage of development corresponded very closely to the end of larval development. Juvenile development was marked by an obvious increase in head size and completion of ossification. Early life history characteristics of *Cottus carolinae* seem to be very similar to those of *Cottus bairdi* as described in the literature.

INTRODUCTION

The banded sculpin, *Cottus carolinae* (Gill), is widely distributed in the southeastern United States. It occurs in upland spring-fed streams from eastern Kansas and Oklahoma to West Virginia; north to Indiana and Illinois; and south to Mississippi, Alabama, and Georgia (Moore 1968).

Spawning habits and early ecological aspects of the life histories of the cottids have been well documented (Bailey 1952, Craddock 1965, Craig and Wells 1976, Foltz 1976, Goto 1975, Heard 1965, Ikusemiju 1975, Jones 1972, Ludwig and Lange 1975, Northcote 1954, Petrosky and Waters 1975, Savage 1963, Sheldon 1968, Simon and Brown 1943, Smith 1922, and Zarbock 1952). The systematics of adult cottids have also been well documented (Abe 1976, Bailey and Bond 1963, McAllister and Aniskowicz 1976, Robins 1961, Robins and Miller 1957, Williams 1968, and Williams and Robins 1970), and larval development of several species in the genus *Myoxocephalus* has been described (Khan and Faber 1973). There is, however, little descriptive detail in the literature concerning post-hatching development of species of the genus *Cottus*.

This study was initiated to document aspects of the spawning behavior and early life history of the banded sculpin, *Cottus carolinae,* and to describe in detail its larval development.

METHODS

During January and February 1975-1976, observations were made on the spawning activities of a population of banded sculpin in Buffler Spring on Cypress Creek, a tributary of the Tennessee River (Pickwick Reservoir, Lauderdale County, Alabama). During the two years of study, several clusters of fertilized eggs were collected and returned to TVA's laboratory in Muscle Shoals, Alabama, where notes were made on egg development and larval behavior.

Eggs were removed from nests and immediately transported to the laboratory for incubation in MacDonald hatching jars. During incubation, a continuous flow of filtered, dechlorinated, aerated water ranging in temperature from 16 to 19 C was provided. On hatching, larvae were transferred to flow-through aquaria (30 x 50 x 15 cm). Water temperatures in the aquaria ranged from 15 to 19 C.

Larvae were fed brine shrimp three times daily for a week after the onset of feeding. From that time forward they were fed mixed zooplankton, primarily *Daphnia* spp.

Larvae, from hatching through juvenile stages, were preserved for descriptive purposes. Specimens were initially preserved in 10 percent Formalin and were later transferred to a solution of 5 percent Formalin buffered to approximately pH 7.5. A minimum of five specimens was preserved daily for description of larval development. A total of 225 larval and juvenile specimens was examined in the study.

Specimens were examined with a stereo-microscope equipped with an ocular micrometer and polarizers. Terminology used for developmental phases follows Snyder (1976). Morphometric and meristic characters examined (Figure 1) include: total, standard, preanal, postanal, and head length; orbit diameter; greatest body depth; and numbers of preanal myomeres, postanal myomeres, vertebrae, and fin rays. Standard length measurements were made to the posterior tip of the notochord until complete development of the hypural complex. Head length was the distance from the tip of the snout to the posterior margin of the auditory vesicle, initially, then to the posterior margin of the operculum when it formed. Some specimens were stained with Alizarin Red S and cleared in a KOH-glycerol solution to facilitate vertebral counts. Fin rays were counted using techniques described by Robins and Miller (1957) and adult complements were based on Moore (1968).

Illustrations for each developmental phase were drawn with the aid of a camera lucida. Each drawing is a composite, blending characteristics from several specimens of the size indicated in an effort to portray an idealized specimen.

The dynamic approach is utilized for the presentation of descriptive data. Meristic and morphometric data are tabulated by age and size intervals.

RESULTS

Spawning Behavior

The spawning habits of this population of *Cottus carolinae* are similar to those of its relatives *C. meridionalis* (Smith 1922), *C. bairdi* (Adams and Hankinson 1928, Hann 1927), *C.*

bairdi punctulatus (Bailey 1952), *C. bairdi semiscaber* (Zarbock 1952), *C. beldingi* (Jones 1972), and *C. semiscaber* (Simon and Brown 1943). Spawning took place in a small spring-fed stream (Buffler Spring) 1 to 2 meters wide and less than 0.3 meter deep. Simon and Brown (1943) found that the velocity of water seemed to make no difference in the choice of "nest rocks" for *Cottus semiscaber.* Water velocity was likewise not a determining factor for selection of nest sites for this population of *Cottus carolinae,* as nests were also observed in both slow and rapid currents of Cox Creek, a somewhat larger stream in the Cypress Creek system. Bottom substrate in both streams was primarily sand, gravel, and rubble. Clusters of eggs were found in crevices on the undersurfaces of rocks and logs.

Spawning males were larger and more darkly pigmented than females. The adults were often captured in nesting crevices on overturning rocks or logs. Single males, spawning pairs lying side by side, and males apparently guarding or attending the eggs were captured, but single females were not found in the crevices. Apparently the male establishes a territory beneath a rock or log, the female enters the nest, spawning occurs, a cluster of adhesive eggs is deposited on the underside of the rock or log, the female departs, and the male remains to guard eggs until hatching occurs.

A paternal brooding habit is commonplace in the cottids. Simon and Brown (1943) observed that rarely were developing eggs of *Cottus semiscaber* found unaccompanied by a male fish, and that females, when found in nests during the spawning season, were usually accompanied by the male. Hann (1927) stated that the male *Cottus bairdi* guards the nest while the eggs were incubating. Bailey (1952) preferred to call the male *Cottus bairdi punctulatus* an attendant rather than a guardian; Smith (1922) also observed a paternal brooding habit with *Cottus meridionalis.*

Occasionally, males were found guarding more than one cluster of eggs. This phenomenon was observed by Bailey (1952) for *Cottus bairdi punctulatus* and by Simon and Brown (1943) for *Cottus semiscaber.* Generally, however, male *Cottus carolinae* in this investigation were observed guarding only one cluster of eggs.

Eggs and Hatching

Eggs were laid in round or oval clusters and were so adhesive that a complete cluster could be dislodged from a rock without separating the eggs from each other. No actual counts were made, but it is estimated that each cluster contained from 100 to 300 eggs.

On January 27, 1975, one cluster of eggs was found on the underside of a railroad tie lying in about 0.2 meter of water (14 C). The eggs were removed from the nest and transported to the laboratory for incubation. When the eggs were first discovered they were dull yellow in color, but as development progressed, they turned salmon and became continuously darker as they approached hatching. Eggs were "eyed" and embryos could be seen occasionally moving within the chorion, beginning on the eighth day after spawning. Hatching occurred from 15 to 19 days after spawning with the majority hatching between 16 and 18 days after spawning.

Larvae used for the descriptions in this paper were reared from eggs collected in Buffler Spring on February 12, 1976. Thirty-four eggs from this collection ranged from 2.6-3.3 mm in diameter, with a mean diameter of 3.05 mm. Several clusters were hatched. The resulting larvae used for description were the progeny of a single population but not of a single breeding pair.

DEVELOPMENT

Morphometric data obtained from larvae and juveniles are presented by post-hatching age and by size intervals in Tables 1 and 2. Meristic data are presented by post-hatching age and by size intervals in Tables 3 and 4.

Mesolarval Development

Banded sculpins are precocious at hatching and exhibit characteristics that exclude Snyder's (1976) protolarval phase from the description of their development. At hatching the caudal fin had six to nine hypochordal rays and the urostyle had already begun its upward turn. These characteristics result in the larval period of development beginning in Snyder's mesolarval phase. Dorsal and lateral line drawings of recently hatched and 2.5-day-old *Cottus carolinae* are shown in Figures 2 and 3. Average size at hatching was 6.86 mm total length. The mesolarval phase was completed on some specimens by 132 hours after hatching between 8.5 and 9.0 mm total length.

By the time hatching occurred, banded sculpin larvae were well developed. The eyes were large with heavy pigmentation and nares were present. Auditory vesicles were well developed although the otoliths were not yet visible. Mouth parts were formed or nearly so. Gill arches with bud-like filaments were present.

At hatching, a large, round, yellowish-orange yolk sac was present with an oil globule located anteriorly. A patch of off-colored tissue was observed dorso-laterally on the left side slightly anterior to the middle of the yolk sac (Figure 2). This tissue, probably generative in nature, was visible throughout the mesolarval phase and into the metalarval phase until obscured by heavy dorso-lateral pigmentation. We did not determine the developmental function or significance, if any, of the tissue. A fairly rapid decrease in yolk mass occurred during the first 36 hours as evidenced by a reduction in greatest depth measurements (Table 1). Little change in the mass occurred, however, during the remainder of the mesolarval phase (Figure 4).

The opercular flap had begun to form at hatching and nearly covered the gill arches. By 36 hours the opercular flap extended to the pectoral fin base and branchiostegals appeared in the opercular membranes.

Myosepta were well developed at hatching with mesolarvae having from 15-17 preanal and from 14-17 postanal myomeres (Table 3). By 36 hours, myomeres had developed a piscine shape ("w" configuration).

Fin development was well advanced at hatching. Pectoral fins were large and well formed with 11-12 incipient rays. Fourteen to 16 pectoral rays were visible by the end of the mesolarval phase. The median finfold was continuous from the first or second myomere from the occiput to the posterior margin of the anus, and median fin differentiation had begun at hatching. The caudal fin was slightly bilobed and possessed six to nine incipient rays in its lower lobe. Incipient soft dorsal and anal fin rays were visible on close examination of some specimens at hatching. By 36 hours the caudal fin had lost its bilobed appearance and was rounded. Mesolarval development of median fins was rapid, with adult complements of soft dorsal, anal, and caudal rays having developed by 132 hours. Pelvic buds first appeared between 8.5 and 9.0 mm TL and were present on all specimens by 108 hours.

The urostyle showed a slight dorsal deflection at hatching (Figure 1), but by 36 hours was well upturned and hypural development was visible. The hypural complex was very nearly developed by the end of the mesolarval phase.

Although the eyes were darkly pigmented at hatching, very little body pigmentation was present. That present was limited to one or more stellate erythrophores on the yolk sac near the

anus. By 36 hours a few stellate erythrophores were present between the eyes and scattered over the forebrain and midbrain. By 60 hours, in addition to this dorsal pigment, varying degrees of pigmentation were present (Figure 3) as: a band of pigment at the anterior base of the pectoral fin extending ventrally to the gular region from either side; concentrations of stellate erythrophores dorsolaterally on the torso in the region of the occiput extending ventrally onto the yolk and proceeding posteriorly on the yolk to the anal region; a few stellate erythrophores present laterally on the caudal peduncle; and little or no ventral pigmentation. By the end of the mesolarval phase, more advanced specimens showed nares outlined with pigment, as well as more profuse pigmentation on the head and yolk and laterally on the body. A patch of stellate erythrophores was present ventrally in the gular region and bars of such pigment were beginning to form behind the eyes. No ventral pigment was present on the yolk sac at the end of mesolarval phase.

Larval activity during the first few days after hatching was limited. Larvae clustered in aquaria corners and in crevices until three or four days after hatching when they began to scatter randomly across the bottoms.

Metalarval Development

The metalarval phase of development for *Cottus carolinae* began between 8.5 and 9.0 mm TL. Figure 5 shows dorsal and lateral views of a typical metalarva. Figure 6 shows a specimen at completion of metalarval development.

Yolk material diminished gradually during metalarval development as evidenced by a gradual reduction in greatest depth (Figure 4). In many specimens the yolk material was absorbed more rapidly anteriorly with the shape of the yolk mass becoming oval by 132 to 156 hours after hatching. The end of the yolk-sac phase of development corresponded closely to the end of metalarval development. Yolk material was almost gone on several specimens by 252 hours after hatching and by 348 hours (14.5 days) specimens lacked yolk material.

Metalarvae had 15-16 preanal and 15-17 postanal myomeres. Myomeres were obscured by pigmentation by 252 hours after hatching. No counts were taken from specimens greater than 10 mm TL.

Fin development was rapid during the metalarval phase. The adult complement of spinous dorsal rays and pectoral rays was present on most specimens soon after the onset of metalar-

val development. The full complement of pelvic rays was present (marking the end of metalarval development) as early as 252 hours after hatching. The smallest specimen seen with an adult complement of fin rays in all fins was 9.3 mm TL. Most specimens, however, achieved this state of development at total lengths beween 9.5 and 10.0 mm. By two weeks post-hatching, all specimens were juveniles.

By the beginning of the metalarval phase, pigmentation had increased to the degree that the first indication of adult banding could be seen. By 132 hours concentrations of pigment appeared as bands at the posterior margin of the yolk sac and near the middle of the caudal peduncle. Dorso-lateral pigmentation continued to intensify on the yolk, converging to the spinous dorsal fin, until the most anterior band was visible. By this time (156 hours), two dorso-lateral concentrations of postanal pigment as well as an aggregation of pigment in the hypural region were obvious. This pattern of pigment development continued until, by approximately 9.0 mm TL, four dorso-lateral bands of pigment were present. By 180 hours, at approximately 9.4 mm TL, the posterior bars behind the eyes ran through the eyes onto the snout, the head was heavily pigmented dorsally and laterally, and specimens exhibited the adult pigment pattern of four to five dorso-lateral bands.

Ossification first became evident in metalarvae 228 hours after hatching. Initial calcification was observed in the cleithrum, pharyngeal arch, branchiostegals, operculum, and mouth parts (premaxilla, maxilla, and dentary). At 276 hours post-hatching, considerable braincase ossification had occurred; the anterior attachment for the branchiostegals, the ceratohyal, had begun to ossify; and teeth were visible on the premaxilla and dentary. The vertebral column had begun to ossify with the neural and hemal spines heavily stained. At this time preopercular armament was obvious with three prominent spines visible. At 300 hours vertebral ossification was complete enough to facilitate counts on stained specimens (Table 3) and four preopercular spines were obvious. The ossification process seemed to slow for the remainder of the metalarval phase.

Metalarval activity in the aquaria was limited to short quick dashes associated with feeding. This suggests that larvae of *Cottus carolinae,* like several other larval cottids (Heard 1965, Sheldon 1968, and Goto 1975), are benthic in nature. The larvae began feeding on freshly hatched brine shrimp soon after becoming metalarvae (five to seven days after hatching) and well before their yolk material was used up. Attempts to feed frozen brine shrimp, tubificid worms, and commercial fish food were unsuccessful. Observations indicated that larvae fed by sight and would only ingest moving organisms. Nutrition appeared to be good throughout the metalarval phase.

Juvenile Development

Figure 7 is a line drawing of the lateral view of a 20.0 mm TL juvenile *Cottus carolinae.*

Few significant changes were noted in the external morphology of the banded sculpin during juvenile development. One rather obvious change, however, was an increase in head size. This was expressed to some degree by head length (Table 2); however, length did not adequately show the overall growth that occurred.

Pigmentation patterns continued to develop toward that of the adult with further concentration of pigment in the areas of the band and the appearance of another bar of pigment near the eye which extended from the eye posterio-ventrally across the operculum. Adult pigment patterns seemed to be completed by about 420 hours (17.5 days) after hatching.

Prickles were not apparent until approximately 11 mm TL. By approximately 20 mm TL they appeared as two parallel patches that began below the origin of the spinous dorsal fin (the lower patch at a level with the dorsal-most three or four pectoral rays) and extended its length. A few scattered prickles were also present posteriorly along the base of the soft dorsal fin.

Preopercular armament continued to develop during the juvenile phase with the dorsal-most spine becoming prominent and pointing posteriorly with a slight hook to the dorsum. The second spine was pointed posterioventrally, and the third was pointed ventrally and was considerably smaller than the dorsal two. The fourth spine, mentioned earlier, was not noticeable by 20 mm TL.

Poor staining techniques or a reduction in the rate of ossification process precluded detailed descriptions of bone development during the juvenile phase. This could be related to poor nutrition, which became apparent by about 2.5 weeks. At this time (396 hours), growth rate as expressed by mean TL (Table 1) began a steady decline. This trend continued until, by about three weeks, larvae became emaciated. However, vertebral ossification was complete enough to obtain counts for some juveniles ranging in age from 14.5 days (348 hours) to 7 weeks (Table 3).

Table 5 provides mean meristic data obtained from juvenile *Cottus carolinae*. Mean spinous dorsal, soft dorsal, and anal fin ray counts were all lower than those recorded by Craddock (1965) on specimens from Kentucky, Indiana, and Illinois. This is possibly the result of higher incubation temperatures in this investigation. Mean pectoral ray counts, however, were very close to his observations and mean vertebrae counts (32.34) were approximately one higher in this study than his recordings for populations in Doe Run, Kentucky.

DISCUSSION

Hann (1927) stated that fry of *Cottus bairdi* did not thrive well in the lab and that growth was slow. This was also the case for *Cottus carolinae* with mean total length increasing from 6.86 mm at hatching to only 10.66 mm by 396 hours (16.5 days). From this point their nutritional needs were apparently not met (Table 1).

Mean values of body morphometric measurements for *Cottus carolinae* are shown in Figures 4, 8, and 9. Larval growth as expressed by TL was characterized by an initial spurt (36 hours) and then a gradual increase for the remainder of the larval period. The sharp initial increase in TL was accompanied by a rapid use of yolk material as witnessed by a corresponding reduction in greatest depth (Figure 4). The inverse relationship between TL and greatest depth was characteristic throughout larval development.

There was little difference in preanal and postanal lengths during mesolarval development (Figure 8). However, near the transition from mesolarval to metalarval phase (108-132 hours) the ratio of postanal length over preanal length began to increase. This, of course, marked the beginning of advanced development and growth of the caudal fin. Increases in head length and orbit diameter seemed to be simply the function of age as gradual growth was evident throughout the larval period (Figure 9).

Hann (1927) reported that the hatching time for *Cottus bairdi* eggs was 20 days at 55-59 F (13-15 C); the "eyed" stage was reached in 12 days. Bailey (1952) observed an incubation period for *Cottus bairdi punctulatus* of 21-28 days in streams with maximum water temperatures ranging from 46-63 F (8-17 C) and 30-40 days in the laboratory at constant temperatures of 48-50 F (9-10 C). In this study *C. carolinae* hatched 15 to 19 days after spawning; most hatched between 16 to 18 days. Eggs were "eyed" eight days after fertilization. Since laboratory incubation temperatures were

higher (16-19 C) than those reported by either Hann or Bailey, it is reasonable to assume that the rate of egg development is probably similar for *C. carolinae* and *C. bairdi* in natural conditions, especially since Craddock (1965) indicated developmental rates similar to those of *C. Bairdi* for banded sculpins studied in Kentucky.

Hann (1927) gives the hatching size of *C. bairdi* as about 6.4 mm in length. Mean hatching size for *C. carolinae* was 6.86 mm TL. Bailey (1952) reported that it took 14 days for *C. bairdi punctulatus* to completely absorb their yolk-sacs at 51-56 F (11-13 C). These specimens had attained total lengths of 9.0-9.9 mm ($\bar{x}$ = 9.5). At 14.5 days (348 hours) mean total length was 10.05 mm for *C. carolinae* with a range of 9.5-10.3. Complete yolk absorption was first apparent on specimens at approximately 9.5 mm TL and had occurred on all specimens by 14.5 days (348 hours). These observations suggest that taxonomic differentiation of these two species may be as difficult with larval forms as it sometimes is for the adults.

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Table 1. Selected morphometrics (mm) by age of larval and juvenile Cottus carolinae expressed as means (number of specimens measured in parenthesis) with range beneath.

Age	Lengths					Orbit Diameter	Greatest Depth
	Total	Standard	Preanal	Postanal	Head		
Hatching	$\bar{X}$ 6.86 (10) R 6.66-6.99	6.46 (10) 6.16-6.66	3.33 (10) 3.17-3.50	3.53 (10) 3.17-3.66	1.41 (10) 1.25-1.58	.63 (10) .50-.67	3.03 (10) 2.92-3.08
36 hours	$\bar{X}$ 8.23 (5) R 8.00-8.50	7.15 (5) 6.91-7.33	4.17 (5) 4.00-4.33	4.07 (5) 3.83-4.33	1.65 (5) 1.58-1.67	.70 (5) .67-.75	2.45 (5) 2.33-2.67
60 hours	$\bar{X}$ 8.26 (9) R 7.83-8.50	7.11 (9) 6.83-7.33	4.15 (9) 3.99-4.165	4.11 (9) 3.66-4.165	1.69 (9) 1.50-1.83	.69 (9) .67-.75	2.47 (9) 2.17-2.83
84 hours	$\bar{X}$ 8.08 (10) R 7.16-9.00	6.92 (10) 6.25-7.58	3.95 (10) 3.49-4.17	4.13 (10) 3.49-4.83	1.68 (10) 1.50-1.75	.73 (10) .67-.75	2.58 (10) 2.17-2.92
108 hours	$\bar{X}$ 8.66 (8) R 8.16-9.00	7.32 (8) 7.00-7.58	4.21 (8) 3.99-4.33	4.46 (8) 4.17-4.75	1.79 (8) 1.75-1.96	.74 (8) .71-.75	2.49 (8) 2.17-2.75
132 hours	$\bar{X}$ 8.78 (7) R 8.16-9.16	7.27 (7) 7.00-7.50	4.02 (7) 3.83-4.17	4.76 (7) 4.33-4.99	1.90 (7) 1.75-2.00	.78 (7) .75-.83	2.44 (6) 2.00-2.58
156 hours	$\bar{X}$ 8.86 (12) R 8.16-9.58	7.34 (12) 6.91-7.83	4.17 (12) 3.99-4.33	4.698 (12) 4.17-5.25	1.91 (12) 1.67-2.08	.78 (12) .67-.83	2.24 (12) 2.08-2.50
180 hours	$\bar{X}$ 9.35 (8) R 8.50-9.83	7.60 (8) 7.00-8.00	4.29 (8) 4.00-4.50	5.06 (8) 4.50-5.33	2.01 (8) 1.75-2.08	.82 (8) .75-.83	2.18 (8) 2.00-2.33
204 hours	$\bar{X}$ 9.44 (9) R 9.00-9.66	7.61 (9) 7.33-7.83	4.17 (9) 4.00-4.33	5.27 (9) 5.00-5.49	2.08 (9) 1.92-2.17	.85 (9) .75-.92	2.17 (9) 1.75-2.42
228 hours	$\bar{X}$ 9.09 (7) R 8.33-10.00	7.40 (7) 6.83-8.00	4.17 (7) 4.00-4.33	4.92 (7) 4.33-5.83	2.07 (7) 1.75-2.41	.82 (7) .75-.92	1.98 (7) 1.83-2.17
252 hours	$\bar{X}$ 9.89 (10) R 9.33-10.33	7.94 (10) 7.50-8.33	4.33 (10) 4.17-4.66	5.56 (10) 5.16-5.83	2.32 (10) 2.17-2.50	.88 (10) .83-.92	1.87 (10) 1.67-2.08
276 hours	$\bar{X}$ 10.06 (11) R 9.33-10.83	8.07 (11) 7.66-8.66	4.32 (11) 7.66-8.66	5.75 (11) 5.00-6.33	2.39 (11) 1.92-2.58	.84 (11) .79-.92	1.89 (11) 1.75-2.00
300 hours	$\bar{X}$ 9.85 (8) R 9.33-10.50	7.87 (8) 7.50-8.50	4.27 (8) 4.17-4.50	5.58 (8) 5.16-6.00	2.25 (8) 1.92-2.50	.87 (8) .83-1.00	1.75 (8) 1.66-1.92
324 hours	$\bar{X}$ 10.25 (8) R 9.83-10.66	8.08 (8) 7.66-8.66	4.21 (8) 4.00-4.50	6.04 (8) 5.66-6.49	2.34 (8) 2.08-2.50	.896 (8) .83-1.00	1.80 (8) 1.66-1.92
348 hours	$\bar{X}$ 10.05 (6) R 9.50-10.33	7.91 (6) 7.50-8.16	4.28 (6) 4.17-4.50	5.78 (6) 5.33-6.16	2.42 (6) 2.08-2.67	.92 (5) .92	1.696 (5) 1.58-1.92
372 hours	$\bar{X}$ 10.19 (6) R 9.66-10.66	8.07 (6) 7.66-8.50	4.33 (6) 4.17-4.50	5.86 (6) 5.49-6.16	2.38 (6) 2.17-2.50	.93 (6) .92-1.00	1.62 (6) 1.50-1.66
396 hours	$\bar{X}$ 10.66 (8) R 10.16-11.00	8.46 (8) 8.00-8.83	4.5 (8) 4.33-4.67	6.16 (8) 5.83-6.33	2.54 (8) 2.42-2.67	.98 (8) .92-1.00	1.62 (8) 1.50-1.66
420 hours	$\bar{X}$ 10.45 (10) R 9.66-11.16	8.35 (10) 7.66-9.33	4.42 (10) 4.17-4.83	6.03 (10) 5.49-6.50	2.48 (10) 2.25-2.67	.96 (9) .92-1.00	
444 hours	$\bar{X}$ 10.39 (12) R 10.00-10.83	8.23 (12) 7.83-8.66	4.36 (12) 4.17-4.67	6.02 (12) 5.67-6.33	2.50 (12) 2.42-2.75	.97 (12) .92-1.00	
468 hours	$\bar{X}$ 10.12 (12) R 10.00-10.83	8.05 (12) 7.83-8.50	4.21 (12) 4.17-4.34	5.91 (12) 5.67-6.50	2.49 (12) 2.33-2.67	.92 (12) .92-1.00	
492 hours	$\bar{X}$ 10.10 (8) R 9.50-10.50	8.03 (8) 7.50-8.33	4.27 (8) 4.17-4.33	5.83 (8) 5.33-6.17	2.43 (8) 2.33-2.58	.96 (8) .92-1.00	
516 hours	$\bar{X}$ 10.33 (7) R 10.00-10.50	8.16 (7) 8.00-8.33	4.36 (7) 4.17-4.50	5.97 (7) 5.67-6.16	2.46 (7) 2.33-2.58	.95 (7) .92-1.00	
540 hours	$\bar{X}$ 10.37 (9) R 9.66-10.83	8.22 (9) 7.66-8.66	4.28 (9) 4.17-4.50	6.09 (9) 5.49-6.50	2.46 (9) 2.33-2.58	.96 (9) .92-1.00	
564 hours	$\bar{X}$ 10.00 (5) R 9.66-10.33	7.96 (5) 7.66-8.33	4.20 (5) 4.17-4.33	5.79 (5) 5.49-6.00	2.45 (5) 2.42-2.50	.95 (5) .92-1.00	
588 hours	$\bar{X}$ 10.25 (6) R 9.50-10.66	8.14 (6) 7.50-8.50	4.31 (6) 4.00-4.50	5.94 (6) 5.50-6.16	2.46 (6) 2.33-2.50	.96 (6) .92-1.00	
6 weeks	10.83 (1)	8.50 (1)	4.50 (1)	6.33 (1)	2.58 (1)	1.00 1	
7 weeks	$\bar{X}$ 13.17 (2) R 11.50-14.83	10.33 (2) 9.00-11.66	5.67 (2) 4.83-6.50	7.50 (2) 6.67-8.33	3.46 (2) 2.92-4.00	1.38 (2) 1.33-1.42	

Table 2. Selected morphometrics (mm) by size intervals of larval and juvenile *Cottus carolinae* expressed as means (number of specimens measured in parenthesis) with range beneath.

Size Interval		Lengths						
		Total	Standard	Preanal	Postanal	Head	Orbit Diameter	Greatest Depth
6.00- 6.99	$\bar{X}$	6.86 (10)	6.46 (10)	3.33 (10)	3.53 (10)	1.41 (10)	.63 (10)	3.03 (10)
	R	6.66- 6.99	6.16-6.66	3.17-3.50	3.17-3.66	1.25-1.58	.50- .67	2.92-3.17
7.00- 7.99	$\bar{X}$	7.49 (4)	6.52 (4)	3.83 (4)	3.66 (4)	1.61 (4)	.69 (4)	2.36 (4)
	R	7.16- 7.83	6.25- 6.83	3.49-4.17	3.49-3.83	1.50-1.67	.67- .75	2.17-2.50
8.00- 8.99	$\bar{X}$	8.44 (41)	7.14 (71)	4.10 (41)	4.34 (41)	1.76 (41)	.73 (41)	2.44 (39)
	R	8.00- 8.91	6.83- 7.58	3.75-4.33	3.83-4.83	1.50-2.08	.67- .83	1.83-2.92
9.00- 9.99	$\bar{X}$	9.48 (58)	7.63 (58)	4.20 (58)	5.29 (58)	2.17 (58)	.86 (56)	2.04 (45)
	R	9.00- 9.83	7.33- 8.00	4.00-4.50	4.75-5.83	1.75-2.50	.75-1.00	1.66-2.58
10.00-10.99	$\bar{X}$	10.32 (102)	8.18 (102)	4.33 (102)	5.98 (102)	2.46 (102)	.95 (102)	1.77 (40)
	R	10.00-10.83	7.83- 8.66	4.00-4.67	5.50-6.50	2.17-2.75	.83-1.00	1.50-2.08
11.00-11.99	$\bar{X}$	11.17 (4)	8.87 (4)	4.70 (4)	6.46 (4)	2.61 (4)	1.07 (4)	
	R	11.00-11.50	8.66- 9.00	4.50-4.83	6.33-6.67	2.42-2.92	.96-1.33	
14.00-14.99		14.83 (1)	11.66 (1)	6.50 (1)	8.33 (1)	4.00 (1)	1.42 (1)	
22.00-22.99		22.00 (1)	18.00 (1)	10.00 (1)	12.00 (1)	5.25 (1)	1.75 (1)	
24.00-24.99		24.00 (1)	20.00 (1)	11.00 (1)	13.00 (1)	6.66 (1)	2.33 (1)	
26.00-26.99	$\bar{X}$	26.00 (3)	20.50 (3)	11.33 (3)	14.67 (3)	6.83 (3)	2.28 (3)	
	R	26.00	20.00-21.00	11.00-12.00	14.00-15.00	6.66-6.91	2.08-2.50	

Table 3. Selected meristics (mm) by age of larval and juvenile Cottus carolinae expressed as means (number of specimens counted in parenthesis) with range beneath.

Age		Myomeres		Vertebrae	Fin Ray Counts					
		Preanal	Postanal		D_1	D_2	A	C	P_1	P_2
Hatching	$\bar{X}$	16.00 (5)	15.60 (5)							
	R	15-17	15-16							
36 hours	$\bar{X}$	16.00 (5)	15.20 (5)							
	R	16	15-16							
60 hours	$\bar{X}$	15.78 (9)	15.89 (9)			14.20 (5)	11.20 (5)	11.00 (5)		
	R	15-17	15-17			12-16	10-12	11		
84 hours	$\bar{X}$	15.80 (5)	15.60 (5)			15.10 (10)	11.40 (10)	11.00 (10)	14.80 (5)	
	R	15-16	14-17			11-17	10-12	9-12	14-16	
108 hours	$\bar{X}$	16.00 (4)	15.75 (4)		5.00 (6)	15.88 (8)	12.00 (8)	11.75 (8)	15.80 (5)	Buds
	R	16	15-16		4-6	15-16	11-13	11-12	15-17	
132 hours	$\bar{X}$	15.75 (4)	16.00 (4)		5.83 (7)	16.14 (7)	12.14 (7)	11.85 (7)	15.50 (4)	
	R	15-16	16		5-6	16-17	12-13	11-12	15-16	
156 hours	$\bar{X}$	16.00 (6)	16.50 (6)		6.17 (12)	16.08 (12)	11.92 (12)	11.92 (12)	16.00 (6)	
	R	16	15-17		4-7	15-17	11-12	11-12	16	
180 hours	$\bar{X}$	16.00 (3)	16.33 (3)		7.00 (8)	15.86 (8)	11.75 (8)	12.00 (8)	16.25 (4)	IR*
	R	16	16-17		7	15-17	11-13	12	15-17	
204 hours	$\bar{X}$				7.11 (9)	15.25 (9)	11.00 (8)	11.50 (8)	16.60 (5)	IR
	R				7-8	15-16	11	11-12	16-17	
228 hours	$\bar{X}$	15.33 (3)	16.67 (3)		6.57 (7)	16.00 (7)	11.57 (7)	11.86 (7)	16.00 (4)	IR
	R	15-16	16-17		6-7	15-17	11-13	11-12	15-17	
252 hours	$\bar{X}$				6.90 (10)	15.33 (10)	11.80 (10)	11.90 (10)	16.40 (5)	4.00 (2)
	R				6-7	13-16	11-12	11-12	16-17	4
276 hours	$\bar{X}$				7.09 (11)	15.50 (11)	11.64 (11)	11.81 (11)	16.71 (7)	4.00 (4)
	R				7-8	15-16	11-13	11-12	16-17	4
300 hours	$\bar{X}$			32.25 (4)	7.13 (8)	16.00 (8)	11.63 (8)	12.00 (8)	16.75 (4)	4.00 (2)
	R			32-33	6-8	15-17	11-12	12	16-17	4
324 hours	$\bar{X}$				6.88 (8)	16.13 (8)	12.13 (8)	12.00 (8)	16.75 (4)	4.00 (4)
	R				6-8	15-17	12-13	12	16-17	4
348 hours	$\bar{X}$			32.75 (4)	7.00 (6)	16.17 (6)	12.00 (6)	12.00 (6)	16.50	4.00 (4)
	R			32-33	6-8	16-17	11-13	12	16-17	4
372 hours	$\bar{X}$			32.50 (2)	7.83 (6)	16.17 (6)	12.00 (5)	12.00 (6)	17.00 (4)	4.00 (3)
	R			32-33	7-8	15-17	12	12	17	4
396 hours	$\bar{X}$			32.75 (4)	7.50 (6)	16.00 (6)	12.00 (6)	12.00 (6)	17.00 (4)	4.00 (4)
	R			32-33	7-8	16	12	12	17	4
420 hours	$\bar{X}$			32.20 (5)	7.33 (9)	15.33 (9)	12.20 (10)	12.00 (10)	16.75 (8)	4.00 (5)
	R			32-33	7-8	15-16	12-13	12	16-17	4
444 hours	$\bar{X}$			32.50 (6)	7.33 (12)	15.56 (12)	11.92 (12)	12.00 (12)	16.33 (12)	4.00 (12)
	R			32-33	7-8	15-16	11-13	12	15-17	4
468 hours	$\bar{X}$			32.00 (6)	7.30 (11)	15.64 (11)	11.83 (12)	12.00 (12)	16.17 (12)	4.00 (6)
	R			31-33	6-8	15-16	11-13	12	16-17	4
492 hours	$\bar{X}$			32.00 (4)	7.38 (8)	16.00 (8)	12.25 (8)	11.86 (7)	16.83 (6)	4.00 (4)
	R			32	7-8	15-17	11-13	11-12	16-17	4
516 hours	$\bar{X}$			32.00 (4)	7.17 (6)	15.67 (6)	11.83 (6)	12.00 (6)	16.50 (6)	4.00 (4)
	R			32	7-8	15-17	11-12	12	16-17	4
540 hours	$\bar{X}$			33.00 (2)	7.00 (8)	15.70 (8)	12.29 (7)	11.88 (8)	16.29 (7)	4.00 (4)
	R			33	7	15-16	12-13	11-12	16-17	4
564 hours	$\bar{X}$				7.33 (3)	15.33 (3)	11.66 (3)	12.00 (3)	16.33 (3)	4.00 (2)
	R				7-8	15-16	11-12	12	16-17	4
588 hours	$\bar{X}$				7.00 (3)	15.67 (3)	12.33 (3)	12.00 (4)	16 (1)	4.00 (2)
	R				7	15-17	12-13	12	16	4
6 weeks	$\bar{X}$					15 (1)	11 (1)	11 (1)	16 (1)	
	R									
7 weeks	$\bar{X}$			32.00 (1)	8.00 (2)	15.50 (2)	12.00 (2)	12.00 (2)	16.50 (2)	4.00 (2)
	R				8	15-16	12	12	16-17	4

* IR - Incipient Rays

Table 4. Selected meristics by size interval of larval and juvenile Cottus carolinae expressed as means (number of specimens counted in parenthesis) with range beneath.

Size Interval		Myomeres		Vertebrae	Fin Ray Counts					
		Preanal	Postanal		D_1	D_2	A	C	P_1	P_2
6.00- 6.99	$\bar{X}$	16.00 (5)	15.60 (5)							
	R	15-17	15-16							
7.00- 7.99	$\bar{X}$	15.50 (2)	16.50 (2)			12.50 (4)	10.75 (4)	10.25 (5)	15 (1)	
	R	15-16	16-17			11-15	10-12	9-11		
8.00- 8.99	$\bar{X}$	15.89 (28)	15.71 (28)		5.65 (20)	15.89 (36)	11.68 (37)	11.41 (37)	15.33 (18)	*
	R	15-17	14-17		4-6	14-17	10-13	9-12	14-16	
9.00- 9.99	$\bar{X}$	15.89 (9)	15.56 (9)	32.33 (6)	6.98 (56)	16.02 (54)	11.68 (56)	11.86 (56)	16.53 (36)	**
	R	15-16	15-17	32-33	5-8	13-17	11-13	11-12	15-17	
10.00-10.99	$\bar{X}$			32.34 (35)	7.16 (92)	15.75 (88)	11.98 (91)	11.97 (94)	16.49 (70)	4.00 (52)
	R			31-33	6-8	15-17	11-13	11-12	15-17	4
11.00-11.99	$\bar{X}$				7.75 (4)	15.75 (4)	12.00 (4)	12.00 (4)	17.00 (3)	
	R				7-8	15-16	12	12	17	
14.00-14.99				32 (1)	8 (1)	15 (1)	12 (1)	12 (1)	16 (1)	4 (1)
22.00-22.99					7 (1)	15 (1)	12 (1)	12 (1)	17 (1)	4 (1)
24.00-24.99					8 (1)	17 (1)	13 (1)	12 (1)	17 (1)	4 (1)
26.00-26.99	$\bar{X}$				7.33 (3)	15.67 (3)	11.67 (3)	12.00 (3)	16.00 (2)	4.00 (3)
	R				7-8	15-16	11-12	12	16	4

*Pelvic buds appear in this size range.

**Development of the pelvic fin in this size interval varies from flaps with barely visible incipient rays to adult ray counts of 4.

Table 5. Selected mean meristic data from juvenile Cottus carolinae with number of specimens counted in parenthesis and range of counts below.

Spinous Dorsal Rays	Soft Dorsal Rays	Anal Rays	Pectoral Rays	Vertebrae
7.23 (81)	15.74 (78)	11.99 (81)	16.49 (70)	32.34 (38)
6-8	15-17	11-13	15-17	31-33

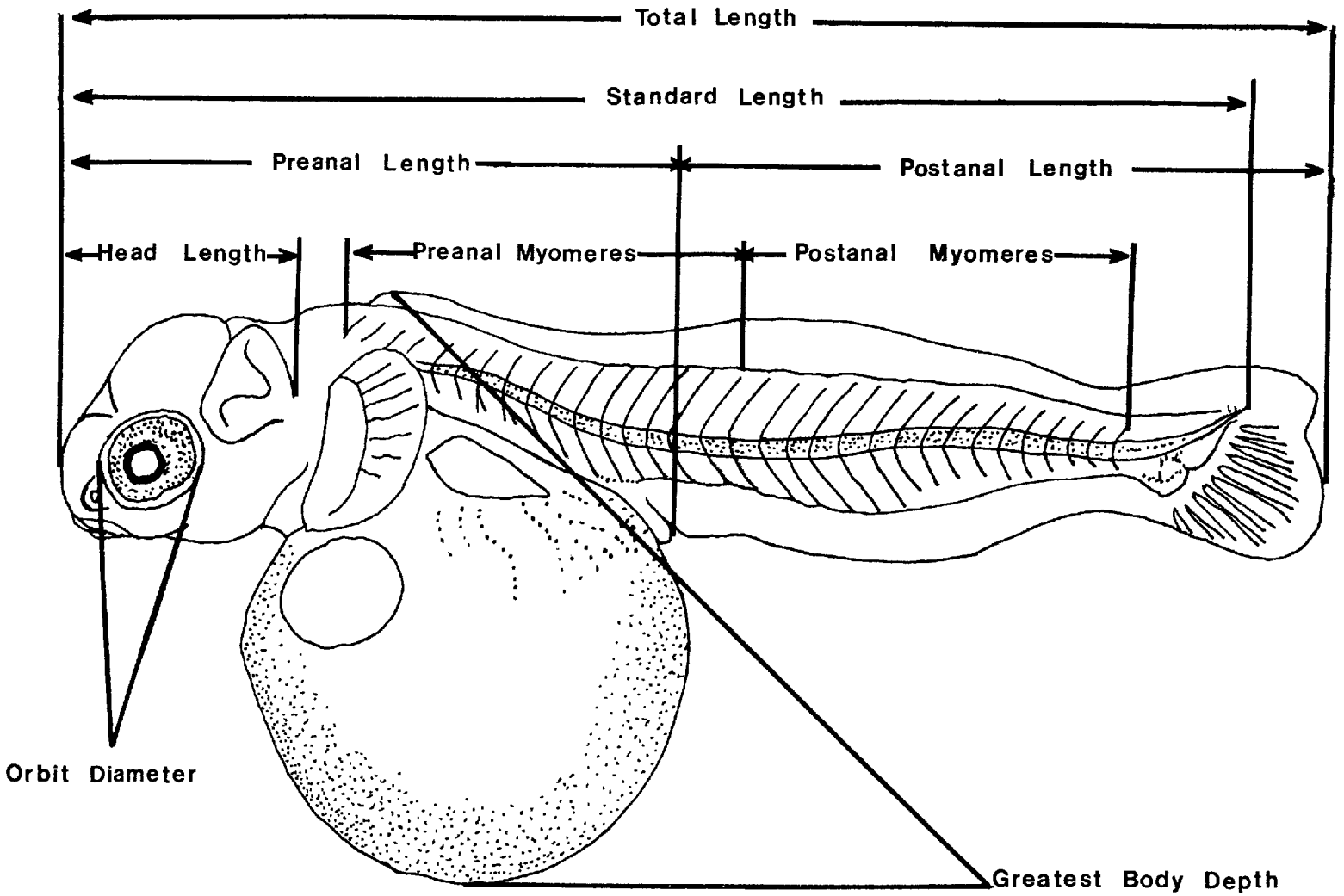

Figure 1. Selected morphometrics and meristics examined for description of *Cottus carolinae* larvae.

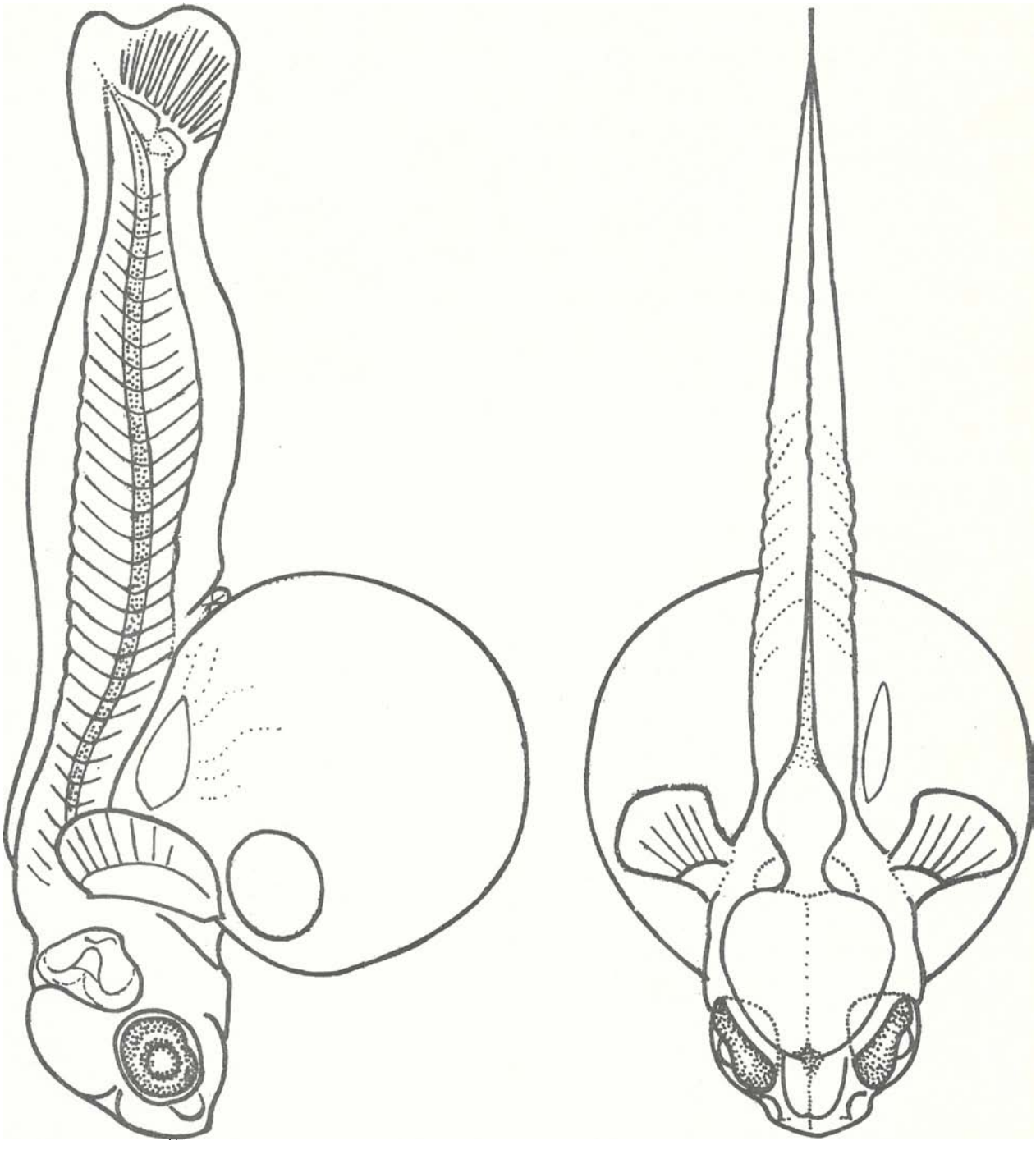

Figure 2 *Cottus carolinae* at hatching (6.8 mm TL); dorsal and lateral views.

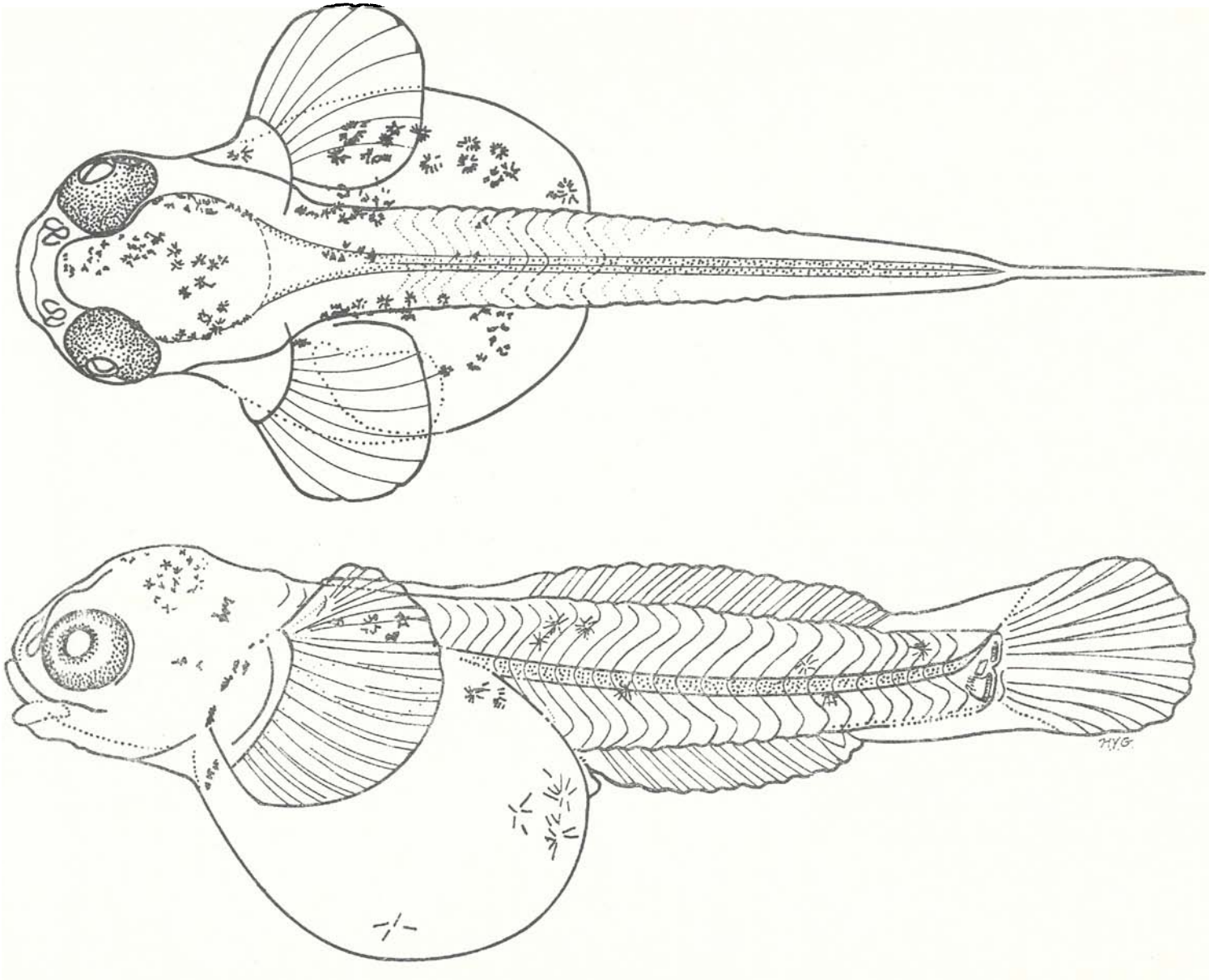

Figure 3 *Cottus carolinae* mesolarva two and one-half days old (8.1 mm TL); dorsal and lateral views.

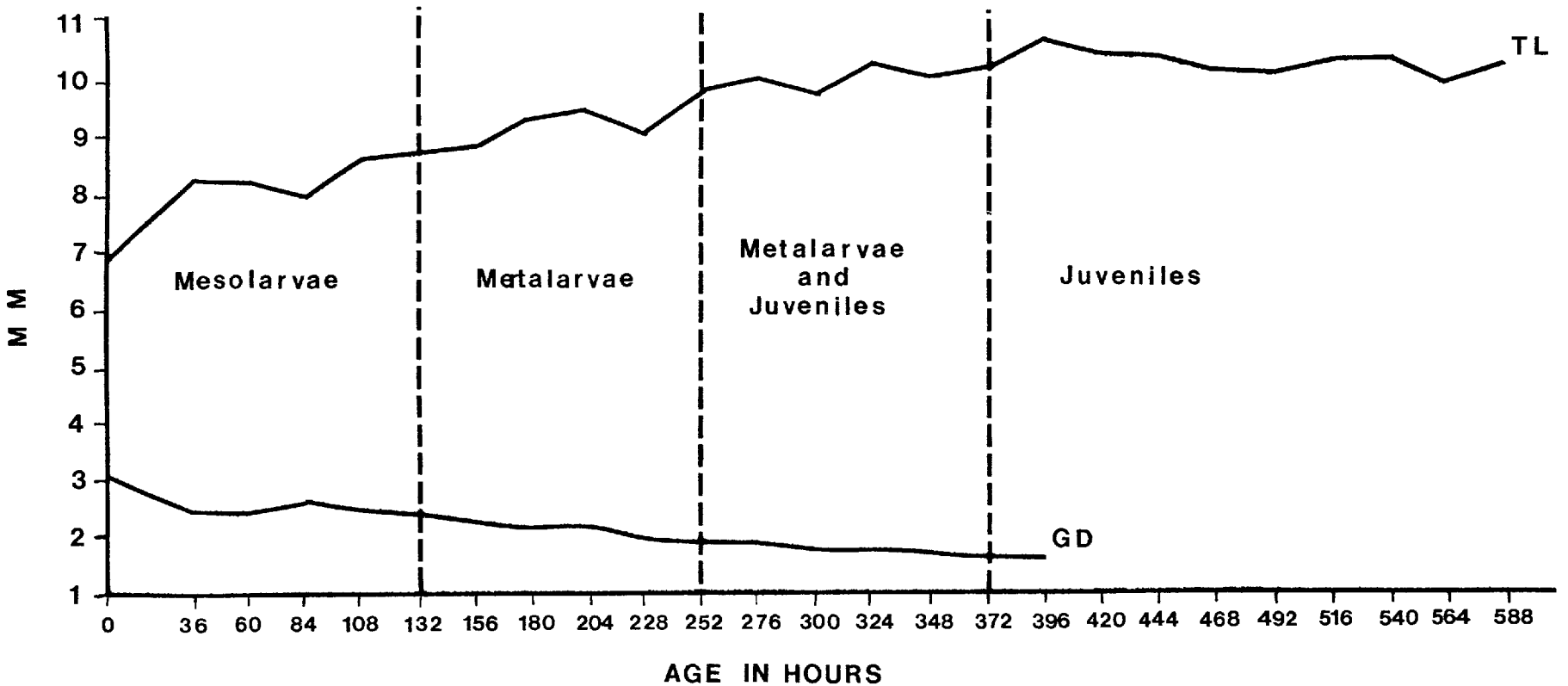

Figure 4 Mean size of Total Length (TL) and Greatest Depth (GD) of larvae and juvenile *Cottus carolinae* by age.

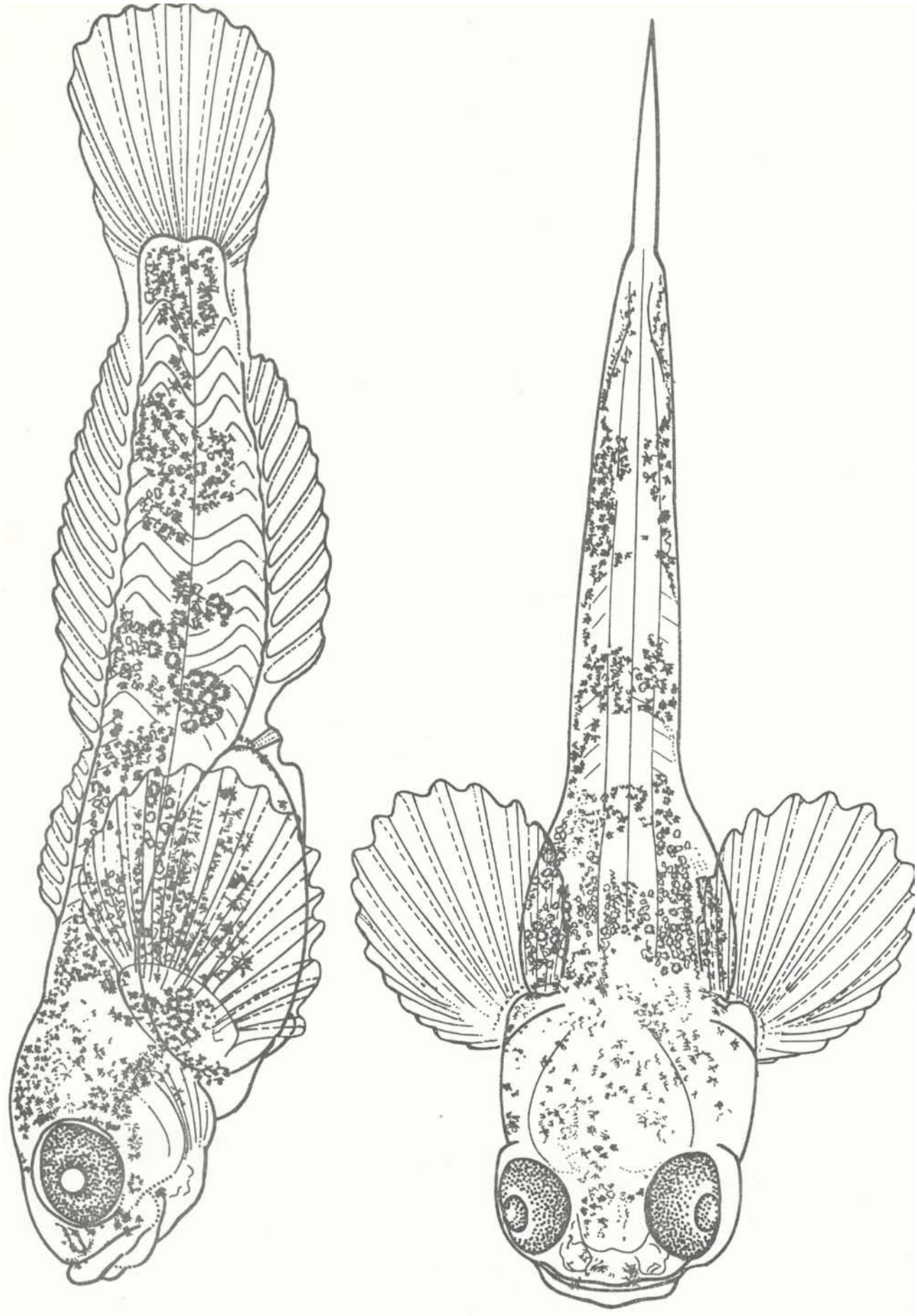

Figure 5 Typical *Cottus carolinae* metalarva (9.6 mm TL); dorsal and lateral views.

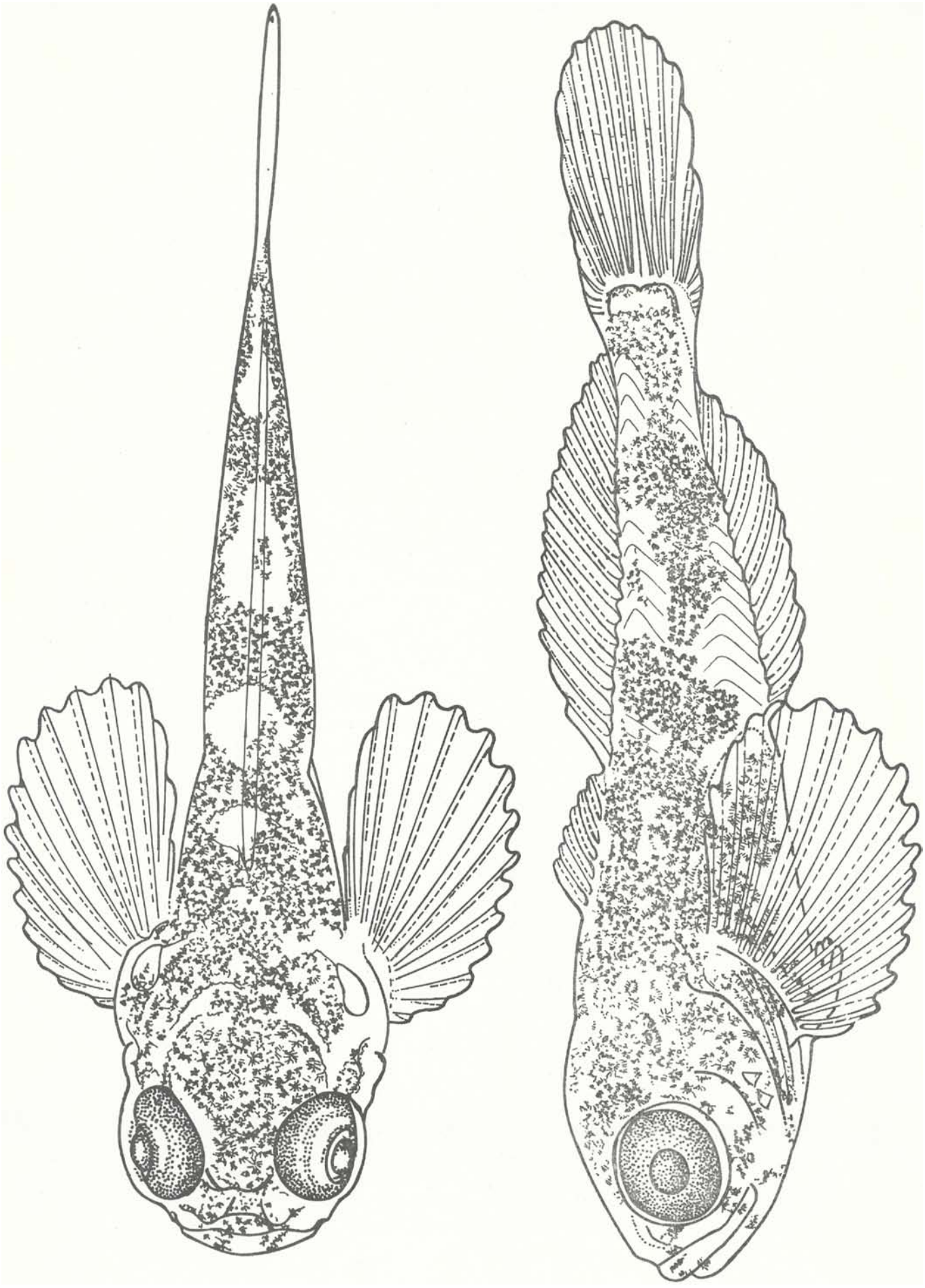

Figure 6 *Cottus carolinae* near completion of metalarval development (10.2 mm TL); dorsal and lateral

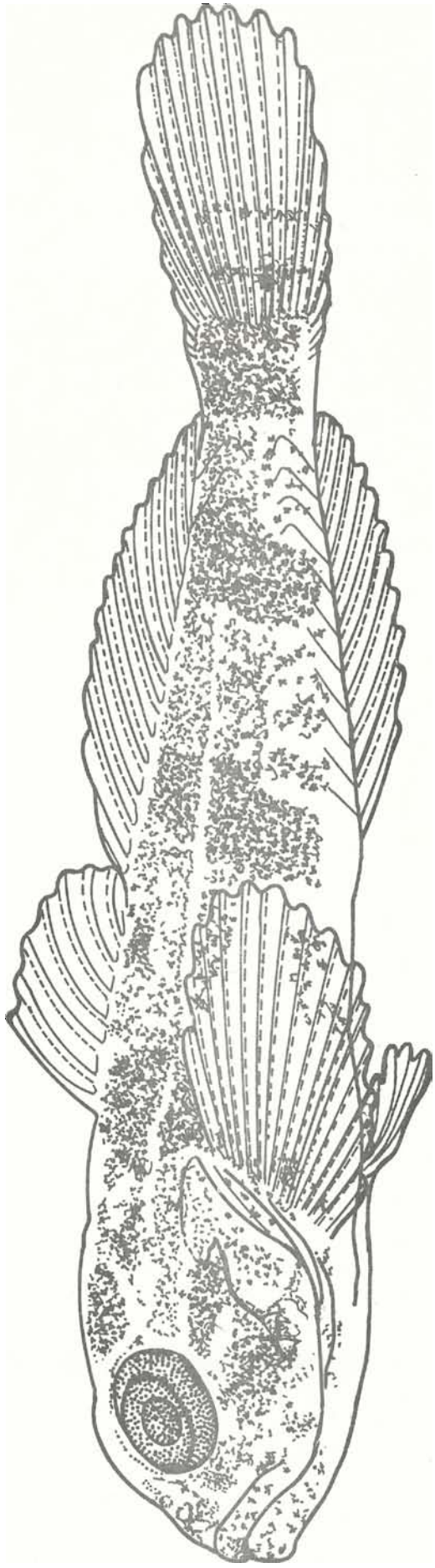

Figure 7 *Cottus carolinae* juvenile (20.0 mm TL).

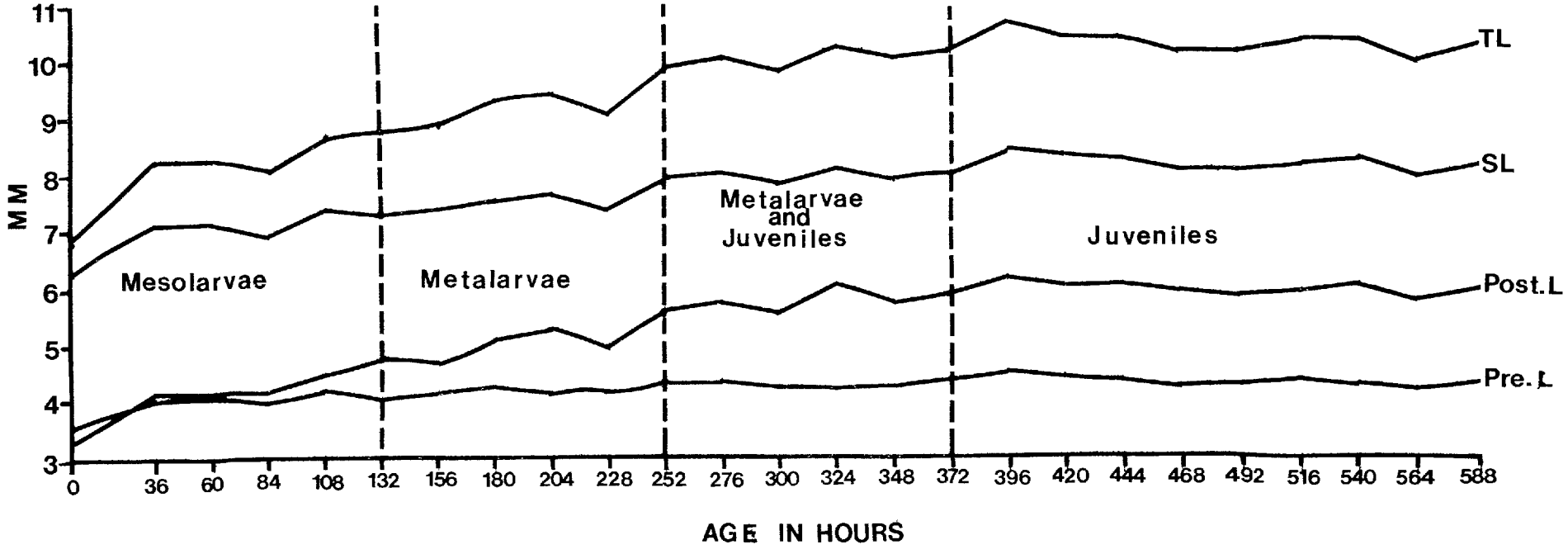

Figure 8 Mean size of Total Length (TL), Standard Length (SL), Preanal Length (Pre. L), and Postanal Length (Post. L) of larval and juvenile *Cottus carolinae* by age.

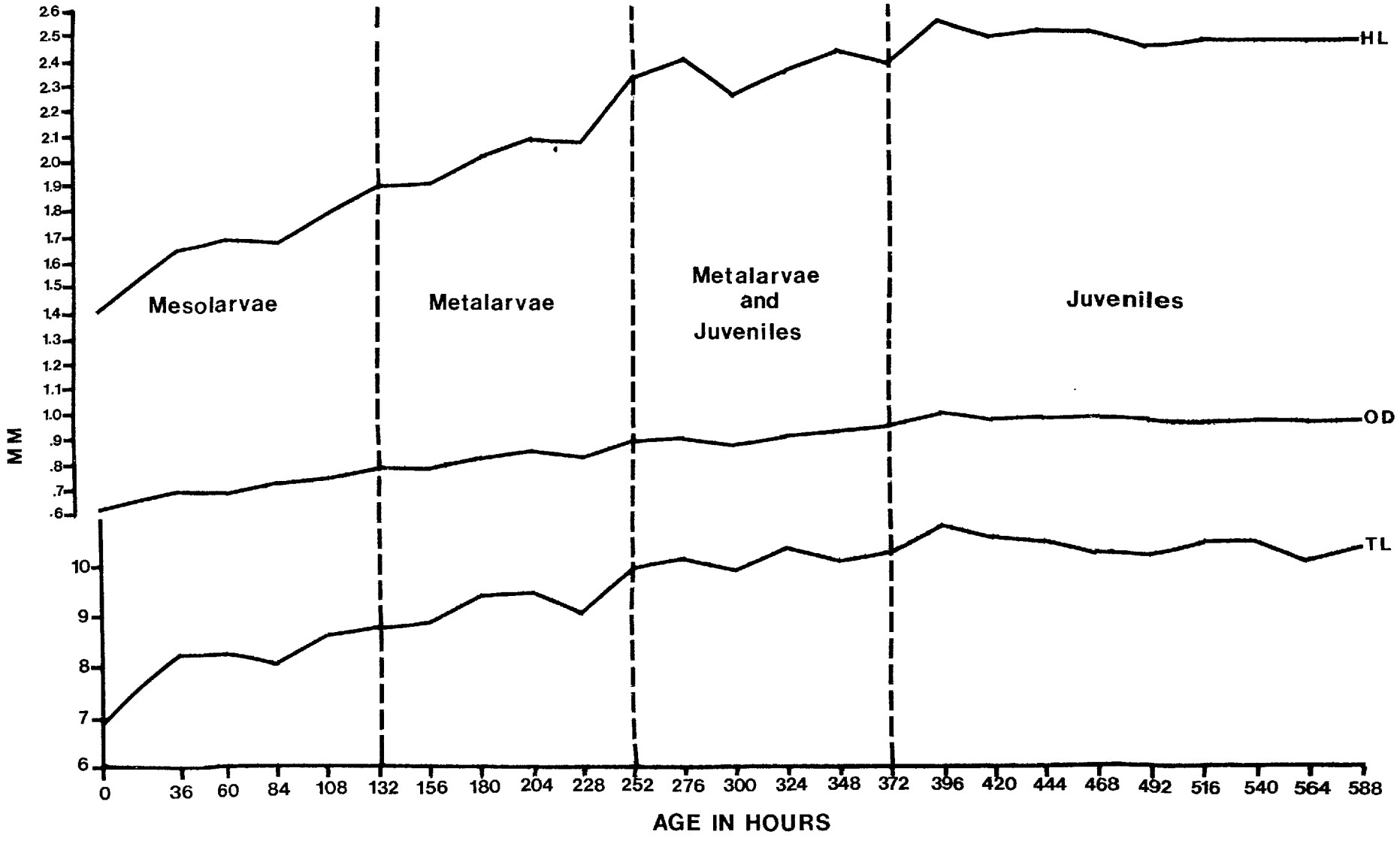

Figure 9 Mean size of Total Length (TL), Orbit Diameter (OD), and Head length (HL) of larval and juvenile *Cottus carolinae* by age.

APPENDIX A

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