PROCEEDINGS OF THE FOURTH ANNUAL LARVAL FISH CONFERENCE

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Cover by Lee A. Fuiman

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PREFACE

The value of studying the early life history of fishes has been suspected for quite some time. However, it has been only in the last decade, or so, that we have come to show our appreciation of the need for such studies. Most investigators will acknowledge the strong role of environmental consciousness (that is, concern for the impact of civilization on the environment) in initiating and supporting these researches. But now, the study of larval fishes is coming of age. Research is taking on an academic orientation, while applied studies are continuing to break new ground. Research productivity is growing. Thus, it has become necessary to provide a means of communication whereby investigators can keep abreast of current findings, discuss their own ideas, formally present research results, and publish such work for wider distribution. Annual conferences and their proceedings have been instituted to serve these purposes.

There is no cohesive organization, at present, which organizes or supports the larval fish conferences, but it appears that they have become an annual event. Therefore, it seems appropriate to put forth a brief history of the meetings.

On February 24 and 25, 1977, the First Symposium on Freshwater Larval Fish was held in Charlotte, North Carolina. The meeting was sponsored by the Southeastern Electric Exchange and hosted by Duke Power Company. Several speakers, mostly from the southeastern United States, were invited to present research on larval fishes. The presentations were oriented primarily toward fishery science aspects of larval fishes, such as entrainment, distribution, and population dynamics. The Proceedings of the First Symposium on Freshwater Larval Fish contained ten papers and was published late in 1978.

The 1978 meeting was hosted and sponsored by the Tennessee Valley Authority on February 21 and 22. The theme of the meeting, as stated in the proceedings, was current trends in larval fish taxonomy, and early life history studies. Several speakers from northern states traveled southward to present their work, only to find it snowing in Knoxville, Tennessee. Nine of the papers were published in 1979 in the Proceedings of a Workshop on Freshwater Larval Fishes.

Western Kentucky University hosted and sponsored the 1979 meeting on February 20 and 21. The theme was taxonomy, life histories, and methodologies. A large number of potential attendees were unable to secure transportation to Bowling Green, Kentucky because of a blizzard which rendered most of the airports in the northeastern United States helpless. This unfortunate circumstance notwithstanding, the meeting went on successfully. The Proceedings of the Third Symposium on Larval Fish was published within a few months of the meeting and contained eleven technical papers.[1]

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[1]Copies of some of the previous year's proceedings are available. See the final page of these proceedings for the appropriate mailing address.

For the fourth consecutive year, the larval fish conference was held in the southern United States. This circumstance was in no way intended to instill a regional priority to the series of meetings; it was merely a coincidence. The University of Mississippi campus in Oxford was host of the conference. The sponsors were the National Power Plant Team, the Sport Fishing Institute, and the University of Mississippi. Eighteen technical papers were presented to an audience which came from as far away as Colorado, Montana, Minnesota, and Ontario, Canada. Once again, snow in the north prevented a few people from being in attendance. The conference had no specific theme, but rather, accepted papers dealing with any phase of larval fish biology. Presentations were arranged in groups of similar subject matter (taxonomy, distribution, feeding and growth, and methodology), and for the first time included a talk on a marine species.

As in all previous years, authors were required to submit their papers for external peer review prior to publication. This year each paper was reviewed by two or three scientists whose own interests were similar to those of the authors. Only fifteen papers and one abstract are included here because two authors chose only to present their papers orally. Because of the unprecedented number of papers this year and a desire to increase distribution of the proceedings, substantially, the editor has chosen a format which utilizes page space most efficiently. The result is a document which appears to be shorter than any of the previous proceedings. But the reader will soon find that there is more here than first meets the eye.

A firm commitment has been made by John V. Conner, Louisiana State University, for hosting the Fifth Annual Larval Fish Conference in Baton Rouge (March 2 and 3, 1981). Tentative arrangements have been made for hosting the 1982 meeting by F. Douglas Martin, Chesapeake Biological Laboratory, and the 1983 meeting by Darrel E. Snyder, Colorado State University. This sustained interest in the conferences confirms their annual nature. Therefore, it is urged that we adopt a standard title for the meetings and their proceedings so that readers can recognize the relationship of the events to one another and their nature.

Many people from many organizations were instrumental in making the meeting successful and putting together the proceedings. Ronald A. Fritzsche, Luther A. Knight, and Bruce J. Bellande of the University of Mississippi made all arrangements for the conference. Much of the typing for the proceedings was done by Christina R. Fuiman. Technical assistance with the proceedings came from Eugene S. Fritz and Kathy A. Gilden of the National Power Plant Team. Financial contributions for the conference and the proceedings were made by the U.S. Fish and Wildlife Service, National Power Plant Team; the Sport Fishing Institute; Joseph Sam, Dean of the Graduate School, University of Mississippi; and Edmund D. Keiser, Chairman, Department of Biology, University of Mississippi. Their assistance is gratefully acknowledged.

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LARVAL EVIDENCE FOR NATURAL REPRODUCTION OF THE GRASS CARP
(CTENOPHARYNGODON IDELLA) IN THE LOWER MISSISSIPPI RIVER

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Abstract.- Certain protolarvae and early mesolarvae found
in late spring and summer ichthyoplankton samples from the
lower Mississippi River, Louisiana and Arkansas, are
identified as those of the exotic grass carp, Cteno-
pharyngodon idella (Valenciennes). These larvae have 41 to
44 (usually 42 or 43) myomeres which readily distinguishes
them from young of most native or naturalized cypriniforms
that could conceivably be in the lower mainstem Mississippi
River. Grass carp larvae are superficially similar to those
of Cyprinus carpio and the ictiobine suckers (Carpiodes
spp., Ictiobus spp.), but Ctenopharyngodon has 30 to 33
(usually 31 or 32) preanal myomeres as opposed to 24 to 30.
Ctenopharyngodon larvae first appeared in 1975 and became
common and abundant, relative to other cypriniform young, by
1977. Our observations indicate natural spawning by grass
carp somewhere upstream of Eudora, Arkansas, and thus
confirms predictions of Stanley (1976) and Stanley et
al. (1978), except that spawning occurred three years
earlier.

Stanley (1976) and Stanley et al. (1978) predicted that natural
reproduction of grass carp, Ctenopharyngodon idella (Valenciennes), would
occur in United States waters, particularly those of the Mississippi River
system. This paper reports the occurrence of larval grass carp in the
plankton of the lower Mississippi River of Louisiana and Arkansas. We also
briefly describe wild-caught Ctenopharyngodon larvae and compare them with
hatchery-reared specimens as well as selected cypriniform young with which
they might be confused . Finally, we discuss the significance of these find-
ings in light of predictions about naturalization of grass carp in the United
States.

MATERIALS AND METHODS

Putative grass carp larvae were found among ichthyoplankton collected in
in the Mississippi River near St. Francisville, Louisiana (River Miles 260 to
280), and Eudora, Arkansas (River Miles 509 to 515), as well as in the
Atchafalaya River (a Mississippi distributary) at Simmesport, Louisiana
(Fig. 1). Specimens from the Eudora, Arkansas, site were collected and
provided by the Waterway Habitat and Monitoring Group, Environmental
Laboratory, United States Army Engineer Waterways Experiment Station. Samples
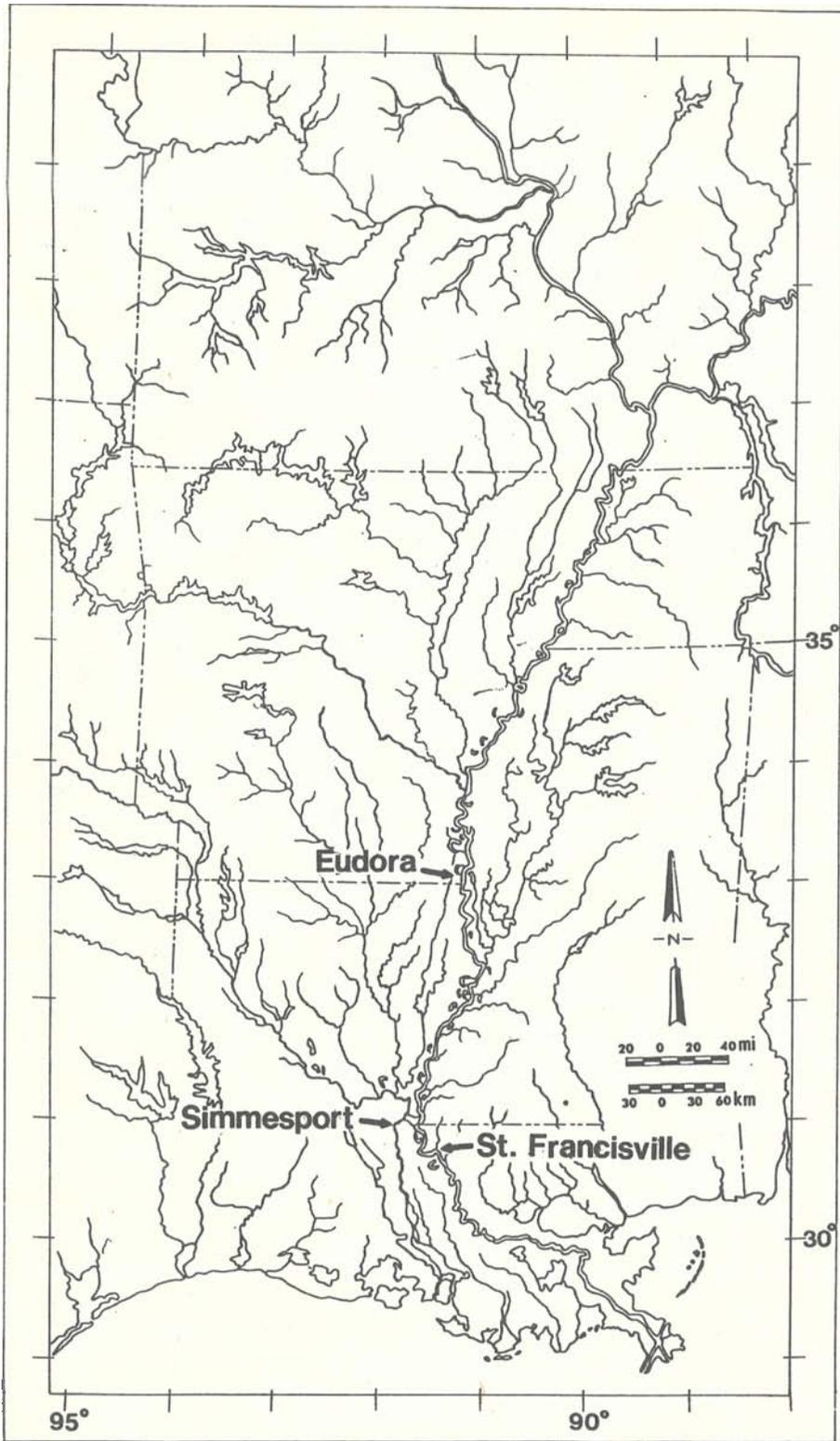
Figure 1. Lower Mississippi River system showing localities from which putative Ctenopharyngodon idella larvae have been collected.

were collected with 0.5 to 1.0-meter diameter conical nets (0.505 to 0.571-mm nylon mesh) towed or pushed at the surface at various hours of the day and night.

Hatchery-reared eggs and larvae of C. idella were obtained from the larval fish collection of the Tennessee Valley Authority (TVA) and from the Florida State Museum. The former were reared in 1978 at Joe Hogan State Fish Hatchery, Lonoke, Arkansas. The latter were cultured in 1979 at Austin Cary Forest, School of Forest Resources and Conservation, University of Florida (UF), near Gainesville. All material was initially fixed in 10% formalin. Wild-caught specimens and those from TVA were transferred to 3 to 5% buffered formalin for storage, whereas the UF samples were rinsed and then stored in 50% isopropanol.

Juvenile grass carp used for vertebral counts were borrowed from Auburn University (AU 11599). These fish and certain representatives of other taxa were x-rayed with a Philips-Norelco industrial machine with long-wave capabilities, according to procedures described by Miller and Tucker (1979). Vertebral counts were made over a light table with a magnifying lens following criteria established by Jenkins and Lachner (1971). That is, we included four Weberian and one urostylar vertebrae.

Measurements were made to the nearest 0.01 mm with the aid of an ocular micrometer mounted in a stereo-zoom dissecting microscope. Dimensions were measured according to Jones et al. (1978: fig. 2) with one addition, depth behind vent, the vertical thickness of a larva (excluding fin folds) immediately posterior to the anus. Specimens that could not be straightened with the aid of a coverglass were excluded from morphometric analyses. All specimen sizes referred to are total lengths (TL). Myomere counts were made according to Siefert (1969). Terminology for developmental phases follows Snyder (1976). Illustrations were based on microprojector tracings (Buynak and Mohr 1978a) of individual specimens (i.e., they were not composites) considered to be representative of various stages.

RESULTS AND DISCUSSION

RATIONALE FOR IDENTIFICATIONS

Without complete developmental series, from recently-hatched individuals to recognizable juveniles, it is sometimes difficult to identify wild-caught fish larvae below familial or even ordinal levels. This is especially true of representatives of large, complex groups like the Cypriniformes. By careful consideration of distributional, ecological, and morphological information it is nevertheless possible to make certain reasonable determinations through the process of elimination.

Among the several types of unidentified cypriniform larvae found by Gallagher (1979) and Hall (1979) in the lower Mississippi and Atchafalaya Rivers there was a form that had been temporarily designated "cyprinid A". Although clearly referable to Cypriniformes, this fish was quite dissimilar to most known larvae of lower Mississippi Drainage minnows and suckers. In light of the close relationship between ultimate vertebral totals and larval

Table 1. Selected morphological and ecological data for lower Mississippi
drainage cypriniform fishes known or expected to have at least 42 myomeres
(myomere counts based on protolarvae and mesolarvae only).

| SPECIES | TOTAL LENGTH (mm) AT | | MYOMERES | | SPAWNING SEASON |
	Loss of Yolk	1st Ray (Caudal)	Preanal	Postanal	
Campostoma anomalum (stoneroller)	< 9.2[a]	6.6-8.1[b]	26-28[a,b]	11-15[a,b]	March-May[c-f]
Ctenopharyngodon idella (grass carp)	< 9.0[f]	7.0-8.8[f]	30-33[f]	9-13[f]	May-September[f]
Hybopsis gelida (sturgeon chub)					June?[c-e]
Hybopsis g. gracilis (flathead chub)					July-August?[c,d]
Hybopsis meeki (sicklefin chub)					"spring"?[d]
Notropis atherinoides (emerald shiner)	< 8.0[f]	7.0-7.5[f]	23-26[f,g]	10-14[f,g]	April-July[c-f]
Notropis chrysocephalus (striped shiner)	< 8.0[h]	7.0-7.9[h]	26-28[f,h]	12-14[f,h]	April-June[c-f]
Semotilus atromaculatus (creek chub)	<10.0[b,i]	7.6-8.6[b,i]	27-29[b,i]	12-15[b,i]	March-May[c-f]
Catostomus commersoni (white sucker)	>11.0[j,k]	12.0-15.1[j,k]	35-42[j,k]	5-13[j,k]	March-May[d,e]
Cycleptus elongatus (blue sucker)	>12.0[f]	12.5-15.0[f]	37-42[f]	10-13[f]	March-May[d-f]
Erimyzon oblongus (creek chubsucker)	< 9.5[j]	7.6-8.4[j]	30-33[j,l]	7-10[j,l]	March-May[c-f]
Hypentelium nigricans (northern hog sucker)	>12.0[j,m]	12.2-12.4[j,m]	33-40[j,m]	3-11[j,m]	March-May[c-f]
Minytrema melanops (spotted sucker)	>10.0[f,n]	11.5-11.8[f,n]	31-35[f,n]	4-9[f,n]	March-May[c-f]
Moxostoma anisurum (silver redhorse)					May[e]
Moxostoma carinatum (river redhorse)					April[d]
Moxostoma duquesnei (black redhorse)					April-May[c]
Moxostoma erythrurum (golden redhorse)	>13.0[o]	12.0-12.5[o]	31-37[o]	6-9[o]	April-May[d,e]
Moxostoma macrolepidotum (shorthead redhorse)	>13.0[j,p]	12.8-13.0[j,p]	30-39[j,p]	5-9[j,p]	May[e]

a = Hogue et al. 1976; b = Perry and Menzel 1979; c = Cross 1967; d = Pflieger 1975; e =
Smith 1979; f = original observations, present study; g = Snyder 1979; h = Yeager 1979; i =
Kranz et al. 1979; j = Fuiman 1979a; k = Buynak and Mohr 1978b; l = Fuiman 1979b; m = Buynak
and Mohr 1978c; n = Hogue and Buchanan 1977; o = Fuiman and Witman 1979; p = Buynak and Mohr
1979.

segmentation (Snyder 1979) we reasoned that the identity of cyprinid A, which
typically had 42 or 43 myomeres, would most logically be sought among taxa
known to have at least 42 vertebrae.

We began by compiling a list of all cyprinids and catostomids that could
conceivably have larvae in the lower Mississippi River. Initial screening was
based on purely zoogeographic considerations. A species was included if its
known range encompassed any part of the mainstem Mississippi River below
St. Louis, backwaters and floodplain swamps, or alluvial-valley reaches of
tributaries. Distributional information was obtained from older

ichthyological literature cited in Conner and Bryan (1975) as well as from Pflieger (1975) and Smith (1979). We incorporated all available information on total myomere and/or vertebral meristics of the 69 taxa (Fig. 2). Snyder's (1979) review was of great value, as were Cross (1967) and several revisionary studies of infrafamilial groups (Fingerman and Suttkus 1961; Gilbert and Bailey 1962, 1972; Gilbert 1964; Al-Rawi and Cross 1964; Suttkus and Clemmer 1968; Snelson 1970; Swift 1970; Clemmer 1971; Jenkins and Lachner 1971; Bailey and Robison 1978). In instances where no myomere or vertebral counts had been published, as well as in several cases where we sought to improve the zoogeographical relevance of the data, we included original counts based on local material.

Applying the 42-vertebrae criterion to the information summarized in Figure 2 we arrived at a list of 8 minnows and 10 suckers, including 11 native taxa whose larvae have been described, and/or are otherwise familiar to us (e.g., blue sucker), as well as the exotic C. idella (Table 1). Despite its high vertebral counts, the blacktail redhorse Moxostoma poecilurum was discounted because its range extends up the Mississippi Drainage (exclusively in tributaries) only to about the latitude of Vicksburg, and we had cyprinid A records somewhat farther upstream in the main channel (Fig. 1).

Cyprinid A larvae were very similar to certain stages of the grass carp described and illustrated by Lin (1935), Nakamura (1969), and Soin and Sukhanova (1972). However, because of lack of detail in these descriptions, superficial similarity exhibited by young of many cypriniforms, and possible occurrence of at least six undescribed larvae with overlapping myomere counts in the study areas, we were reluctant to conclude that cyprinid A was C. idella.

The six undescribed cypriniform larvae were tentatively eliminated on various morphological and/or ecological grounds. For example, considering what is known of other Moxostoma spp. we presumed that M. anisurum, M. carniatum, and M. duquesnei retain conspicuous yolk and lack complete fin rays until they are much longer than 10 mm. Cyprinid A lost all yolk and had at least one caudal ray by 9 mm (usually <8.5 mm). The redhorses in question were also known to have short spawning seasons in the spring (Table 1), whereas cyprinid A larvae occurred over a long period, mainly in the summer.

On the other hand, it was likely that some or all of the Hybopsis spp. with undescribed larvae were summer spawners. Confirmed and probable Hybopsis larvae from our collections represented at least two, and perhaps as many as four species. They shared the following traits which strongly contrasted with cyprinid A of comparable stages: small to moderate-sized, elliptical, and usually supralateral eyes; small, inferior to subinferior mouths; long, fleshy ("bulbous") snouts; conspicuous nares; long, expansive, and usually ventrolateral pectoral fins. Whether the undescribed larvae of H. gelida, H. gracilis, and H. meeki possessed these traits remained moot, but our experience supported the expectation that they would be structurally similar to those of other Hybopsis spp.

Cyprinid A protolarvae and early mesolarvae were very similar to hatchery-reared C. idella (Tables 2 and 3, Fig. 3) in all attributes except intensity of pigment and body proportions that reflect robustness. These inconsistencies were probably due to differences in environmental conditions
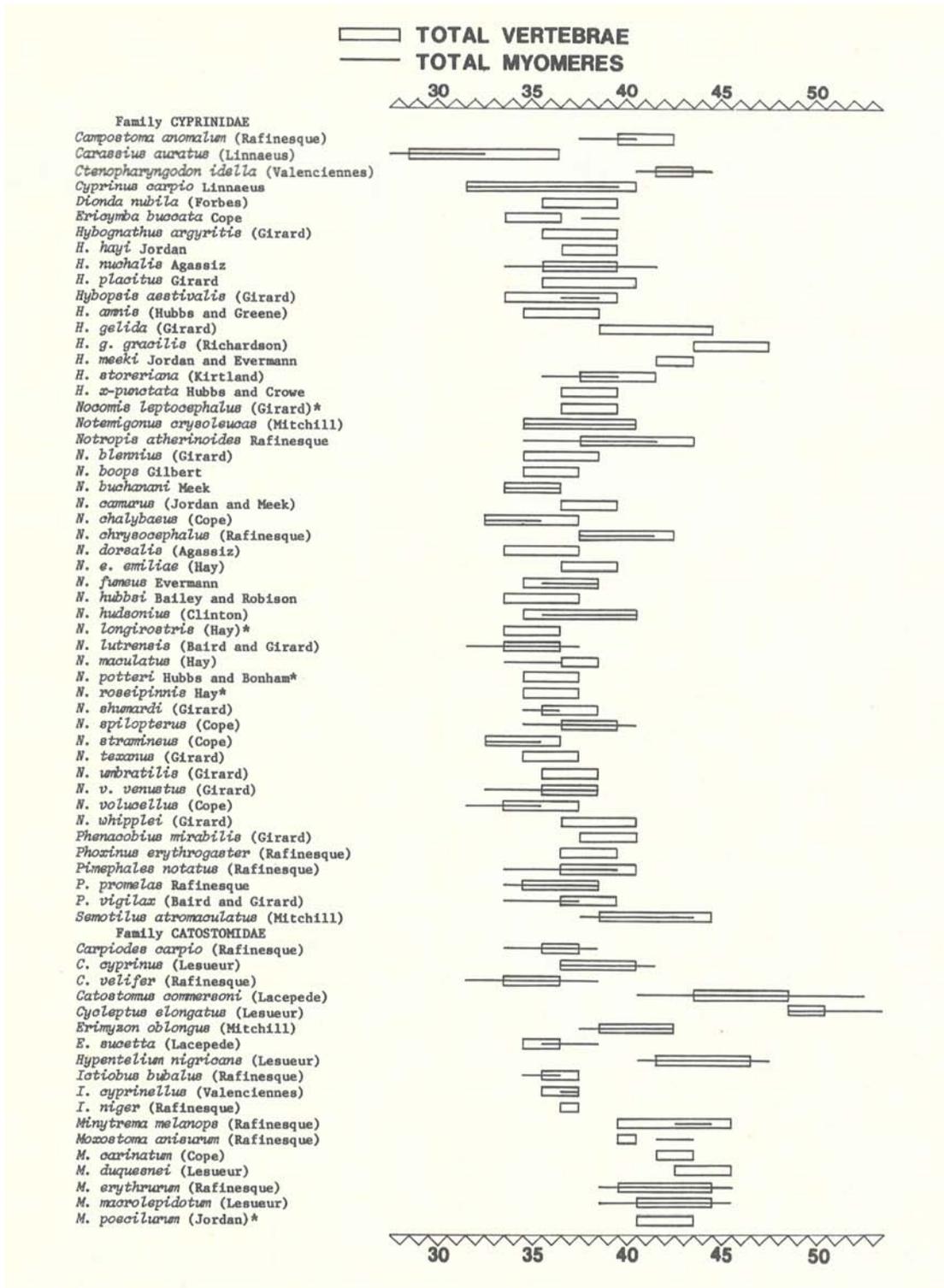
Figure 2. Ranges of vertebral and myomere totals for cypriniform fishes that could have larvae in the lower Mississippi River. Taxa marked by asterisks are limited to the area south of the Arkansas-Louisiana border.

Table 2. Frequency distributions of myomere counts for hatchery-reared *Ctenopharyngodon idella* and putatively conspecific larvae from two areas of the lower Mississippi River.

	Preanal				
	30	31	32	33	mean±SE
Hatchery-reared grass carp					
Florida (N=53)		6	29	8	31.85±0.09
Arkansas (N=19)		13	6		31.71±0.11
Total		29	35	8	31.71±0.08
Wild-caught "Cyprinid A"					
Eudora (N=69)	2	24	39	4	31.65±0.08
St. Francisville (N=57)		30	24	3	31.53±0.08
Total	2	54	63	7	31.59±0.05

	Postanal					
	9	10	11	12	13	mean±SE
Hatchery-reared grass carp						
Florida (N=53)	3	20	29	1		10.53±0.09
Arkansas (N=19)		6	10	3		10.84±0.16
Total	3	26	39	4		10.61±0.08
Wild-caught "Cyprinid A"						
Eudora (N=69)	1	23	37	8		10.75±0.08
St. Francisville (N=57)		18	30	8	1	10.86±0.10
Total	1	41	67	16	1	10.80±0.06

	Total				
	41	42	43	44	mean±SE
Hatchery-reared grass carp					
Florida (N=53)	6	21	25	1	42.40±0.10
Arkansas (N=19)	3	11	4	1	42.16±0.18
Total	9	32	29	2	42.33±0.09
Wild-caught "Cyprinid A"					
Eudora (N=69)	6	31	30	2	42.41±0.08
St. Francisville (N=57)	4	29	22	2	42.39±0.09
Total	10	60	52	4	42.40±0.06

during rearing and/or varying histories of preservation. A Student's t-test revealed no significant differences in preanal and total myomere counts between cyprinid A and hatchery-reared _C. idella_ (Table 2). Postanal myomeres did vary slightly (P<0.1) between cyprinid A and pooled hatchery-reared grass carp, but a difference was discernible at the same confidence level between the two cultured series. The extreme similarity between cyprinid A and positively identified grass carp, coupled with highly probable eliminations of undescribed larvae of native taxa (Fig. 2, Table 1), led us to conclude that cyprinid A was _C. idella_.

RECOGNITION OF GRASS CARP LARVAE

We have shown that protolarval and mesolarval _C. idella_ are not likely to be confused with native cypriniforms having overlapping myomere or vertebral counts (Table 1). In our experience, the only larva of a native species in Table 1 that is relatively common during at last part of the summer is _Notropis atherinoides_. Figure 4 illustrates late protolarvae or early mesolarvae of recognizable types of cypriniforms that we find in the summer plankton of the lower Mississippi River. A few additional types, believed to be _Notropis_ spp., are not shown. These are superficially similar to the two shiners illustrated. Protolarval and early mesolarval grass carp closely resemble only _Cyprinus carpio_ (Fig. 4G) and the ictiobine suckers (_Carpiodes_ spp., _Ictiobus_ spp., Figs. 4I-J). Another form that achieves comparable development at the same sizes as _Ctenopharyngodon_ is a putative _Hybopsis_ sp. (Fig. 4E). However, this "chub" differs markedly from the grass carp in several aspects of head morphology. The putative _Hybopsis_ species also has only 25 to 28 (usually 26) preanal myomeres and appears in the plankton earlier (April) than _Ctenopharyngodon_.

The resemblance of grass carp larvae to those of _Cyprinus_ and the ictiobines is largely a reflection of head morphology, certain proportional measurements, and the tendency for overlap in sizes at developmental milestones (Table 4). In the absence of comparative material, confident recognition of _Ctenopharyngodon_ requires preanal or total myomere counts. Some additional characters of practical value are:

1) Grass carp larvae have 9 to 14 (usually 11 or 12) predorsal myomeres, _Cyprinus_ have 6 to 10 (usually 7 or 8).

2) _Ctenopharyngodon_ larvae have round eyes; most (especially protolarval) carpsuckers have elliptical eyes.

3) Most grass carp larvae retain at least remnants of yolk until about 7.5 mm; _Carpiodes_ tend to use all yolk by about 7.2 mm.

4) _Ctenopharyngodon_ larvae lack midventral pigment between the pectoral region and the vent; all _Ictiobus_ and some _Carpiodes_ (_C. cyprinus_, _C. velifer_) have at least a few midventral melanophores along the trunk.

5) Most grass carp larvae have at least one complete caudal ray by 8.5 mm; _Ictiobus_ tend to lack caudal rays until at least 9.5 mm.
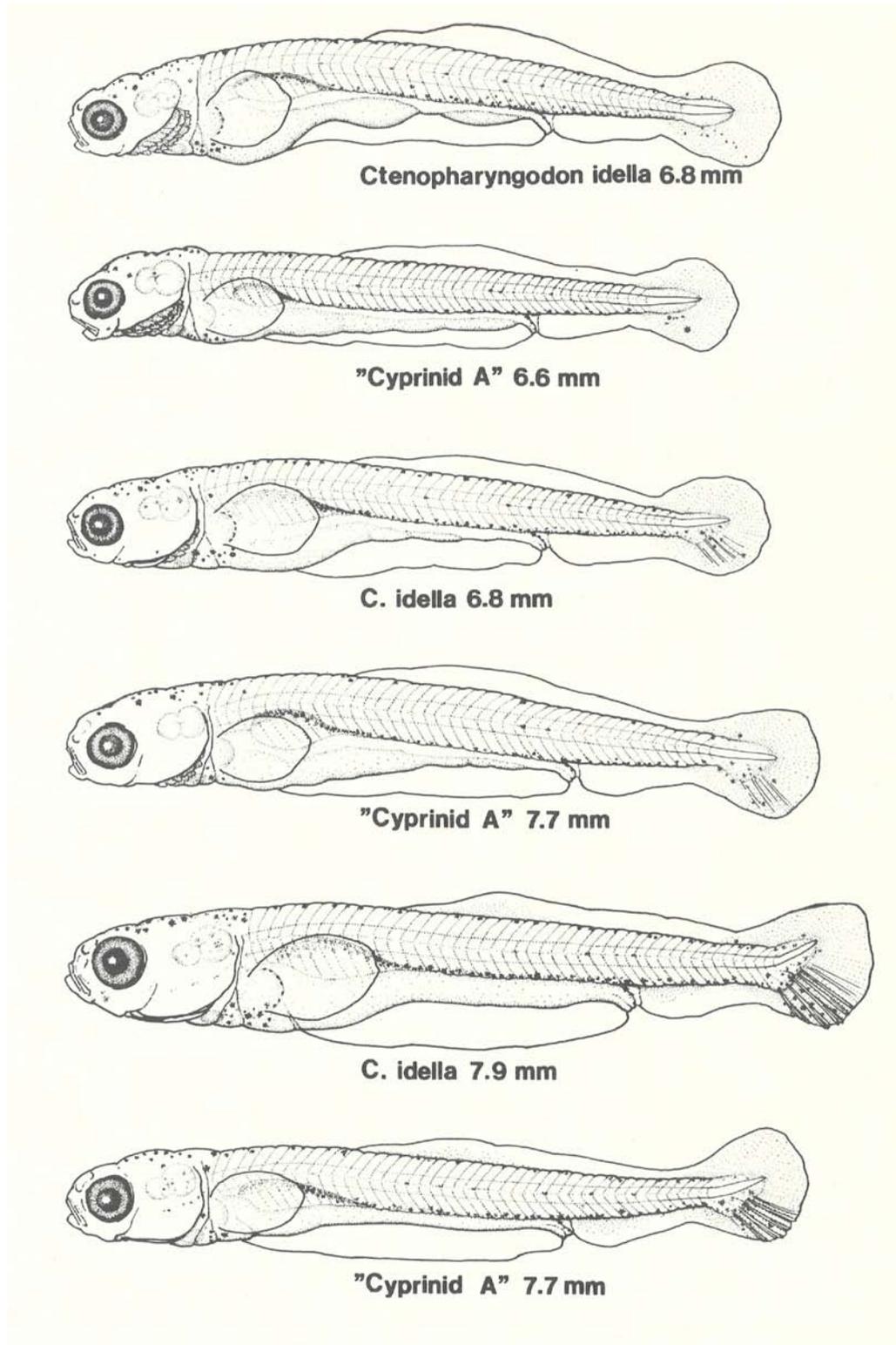
Figure 3. Lateral views of selected stages of hatchery-reared _Ctenopharyngodon idella_ (University of Florida series) and putatively conspecific fish from the lower Mississippi River.

Table 3. Morphological comparisons of hatchery-reared grass carp and putatively conspecific larvae from the lower Mississippi River.

	Ctenopharyngodon idella		"Cyprinid A"	
	Protolarvae (N=51)	Mesolarvae (N=21)	Protolarvae (N=86)	Mesolarvae (N=40)
Total length (TL,mm)				
mean	7.5	8.0	7.8	8.2
range	6.6-8.4	7.6-8.9	6.8-8.8	7.8-8.8
Preanal length (%TL)				
mean	70.2	70.3	69.2	70.9
range	67.6-73.5	69.0-71.6	67.4-73.3	69.0-73.0
Predorsal length (%TL)				
mean	41.2	43.4	41.5	43.0
range	36.6-45.4	41.7-45.5	37.7-44.4	39.8-48.0
Head length (%TL)				
mean	20.0	22.4	21.2	21.0
range	14.3-23.1	21.4-23.2	19.8-22.2	19.6-22.0
Eye diameter (%TL)				
mean	6.2	7.0	6.4	6.5
range	4.3-7.2	6.4-7.4	5.6-7.1	5.8-7.1
Body depth (%TL)				
mean	14.3	13.8	12.6	11.4
range	12.0-17.6	12.3-16.1	10.5-15.6	10.2-13.8
Depth behind vent (%TL)				
mean	5.8	5.7	5.8	4.9
range	4.8-7.2	4.8-6.3	4.3-7.5	4.2-6.9

Cyprinus and Ictiobus larvae appear in Mississippi River plankton as early as late March and are usually absent by late June or early July (Conner 1976, 1978; Gallagher 1979). Stages of carp and buffalo that occur with Ctenopharyngodon are thus, for the most part, more advanced in development. However, there is a long period during which grass carp and Carpiodes of comparable stages co-occur.

OCCURRENCE, RELATIVE ABUNDANCE, AND CONDITION

Grass carp first appeared in lower Mississippi River ichthyoplankton samples in 1975 and we have caught them every year thereafter. We carefully rechecked all late spring and summer samples from 1973 and 1974 with negative results. There was relatively less sampling effort in 1973, but that of 1974
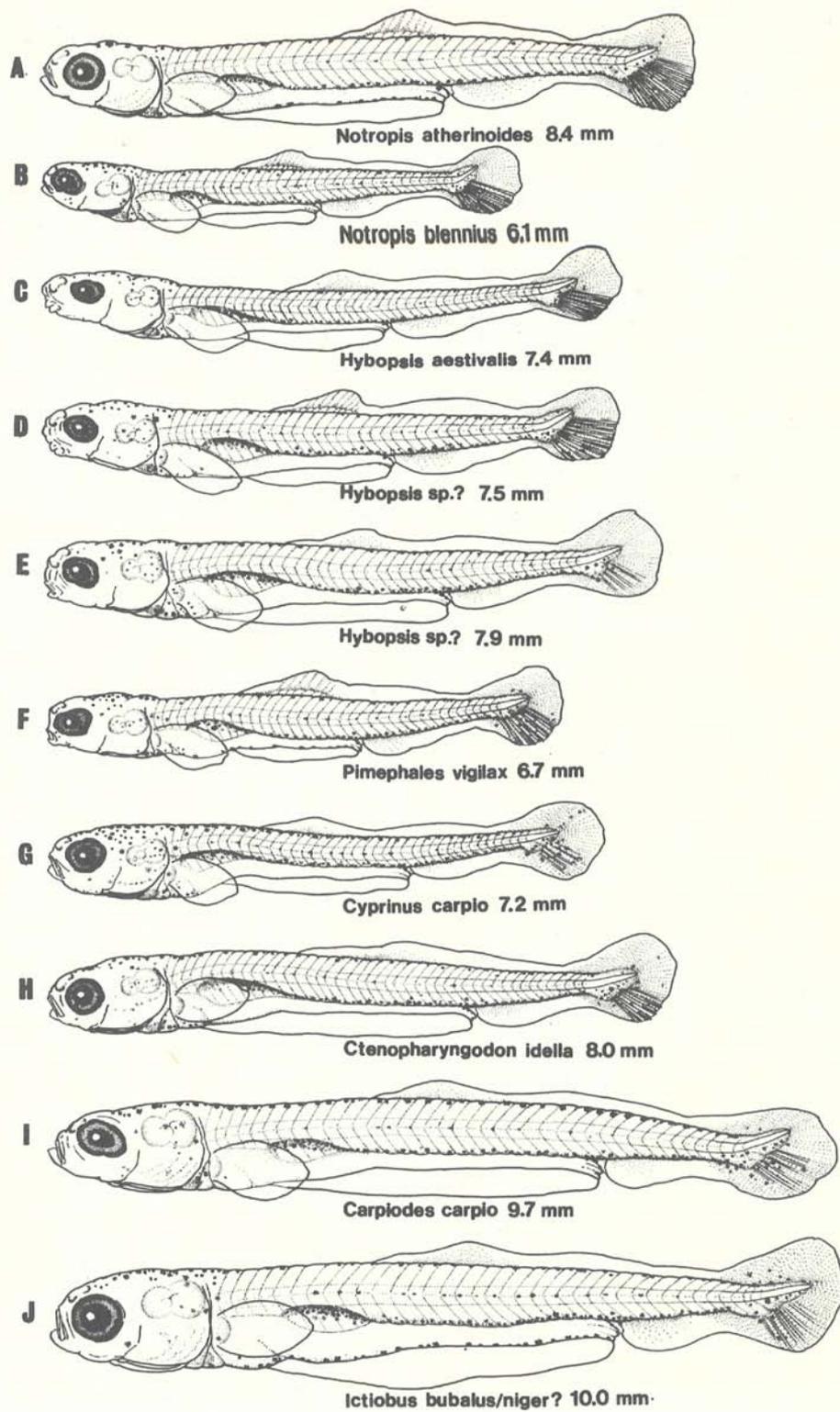
Figure 4. Late protolarvae or early mesolarvae of selected cypriniforms known to occur in the summer plankton of the lower Mississippi River.

was comparable to those of subsequent years. In 1975, 1977, and 1979
Ctenopharyngodon larvae first appeared in mid-May, while in 1976 and 1978 they
were present by early June. They persisted until mid- or late September in
two years (1977, 1978), while in 1975 and 1976 they were absent from
collections after July.

On the basis of the hatchery-reared material, as well as Russian studies
(Martino 1974; Nezdoliy and Mitrovanov 1975), we estimated the posthatching
ages of most of our wild-caught grass carp larvae to be 6 to 10 days. This
means that spawning occurred as early as the beginning of May in some years
and continued through at least the first week in September. Lin (1935)
reported spawning of grass carp from late April to the middle of August in
China. Among fishes known or expected to spawn in the Mississippi River, only
the freshwater drum, *Aplodinotus grunniens*, has a longer breeding season
(April through September) than *Ctenopharyngodon*. *Hybopsis aestivalis* (mid-May
through mid-September), *Notropis blennius* (late May through early September),
and *Carpiodes carpio* (late April through early August) are the only other
river spawners that rival grass carp in duration of spawning season.
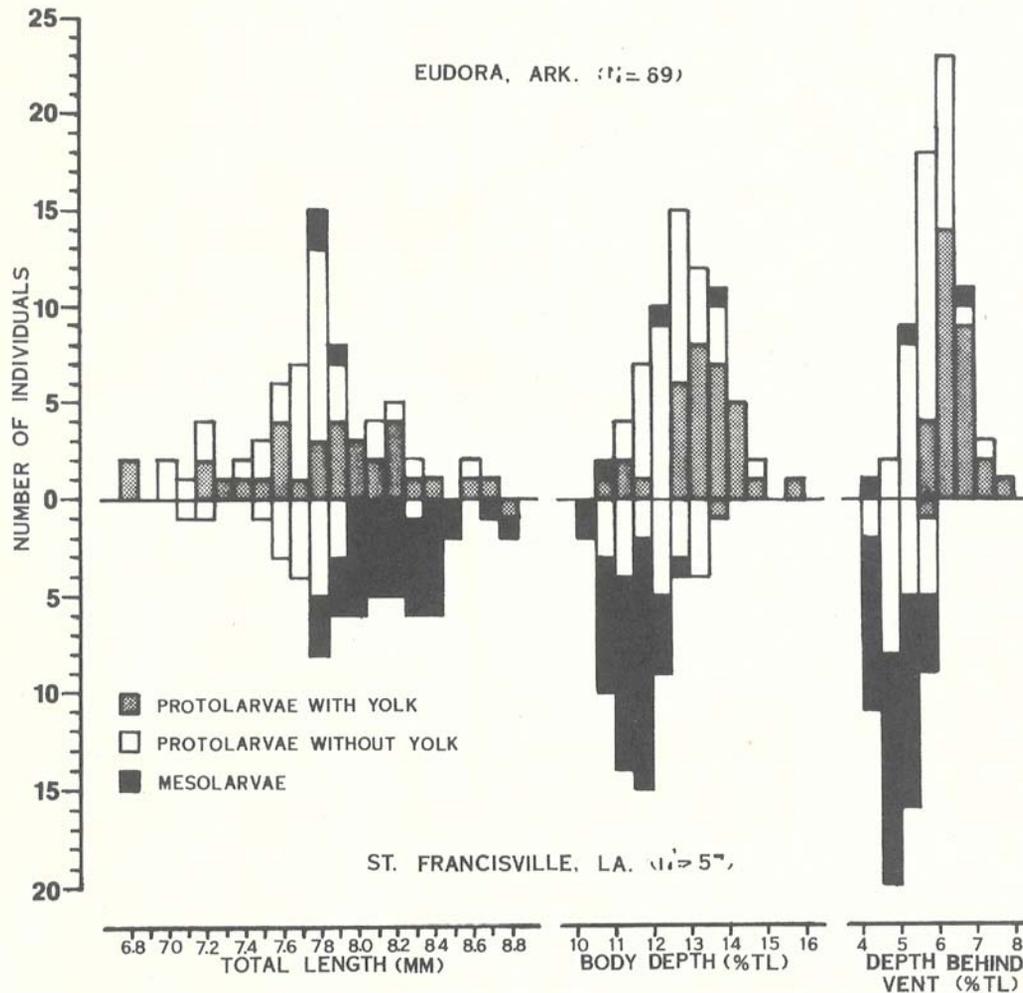
Figure 5. Frequency histograms of total lengths and two morphometric
expressions of robustness for *Ctenopharyngodon idella* from two localities
along the lower Mississippi River.

Table 4. Morphological comparisons of protolarvae and mesolarvae of four cypriniform taxa occurring in the summer plankton of the lower Mississippi River (data for grass carp are pooled observations from hatchery and wild material).

	Cyprinus carpio (N=65)	Ctenopharyngodon idella (N=198)	Carpiodes carpio (N=69)	Ictiobus spp. (N=127)
Preanal length (%TL)				
mean	68.1	70.3	70.2	71.3
range	64.7-71.4	67.4-73.5	63.1-74.5	66.3-74.7
Head length (%TL)				
mean	21.9	20.7	21.1	18.7
range	17.6-25.7	14.2-23.2	17.7-26.0	14.9-25.6
Eye diameter (%TL)				
mean	7.1	6.5	6.2	6.0
range	5.9-8.1	4.3-7.4	5.1-7.2	3.8-7.2
Body depth (%TL)				
mean	14.5	12.9	12.6	11.9
range	11.6-18.8	10.2-17.6	10.1-17.5	8.1-18.1
Total length (mm) at				
yolk loss	6.3-7.8	7.0-8.8	6.6-7.7	7.2-9.1
1st caudal ray	7.6-8.2	7.8-8.8	8.3-9.1	9.5-10.2
Preanal myomeres				
mean	25.7	31.6	27.6	27.6
range	24-27	30-33	25-30	26-29
Postanal myomeres				
mean	11.2	10.7	7.3	7.1
range	10-13	9-13	6-9	5-9
Total myomeres				
mean	36.9	42.4	34.8	34.6
range	35-38	41-44	33-37	32-37

We have not compiled and critically analyzed all of the catch per effort information on Ctenopharyngodon larvae and therefore cannot present detailed estimates of their abundance. However, inspection of the data shows that the larvae were relatively sparsely distributed in 1975 and 1976 and were much more abundant, with no discernible differences among years, from 1977 through 1979. In a given year, the fish appeared in fairly low densities (<1 per 100

m^3, based on flowmeter estimates) throughout much of their period of occurrence, but there was a pulse of abundance (ca. 1 to 5 per 100 m^3) around mid-June through early July. At this time of peak abundance grass carp tended to be more numerous than any of the other recognizable kinds of cyprinid larvae.

There was a strong tendency for less-developed specimens of Ctenopharyngodon to be more common and abundant at the Eudora, Arkansas, site (Fig. 5). Very few yolk-bearing individuals (or specimens <7.5 mm) were taken at the St. Francisville, Louisiana, site. Conversely, few mesolarvae or individuals without at least some yolk (regardless of size and stage) were caught near Eudora. All very "young" individuals, or those <7.0 mm with large yolk masses, incomplete jaws, and incomplete gill covers, which we found among wild-caught material came from the Eudora site. Even at Eudora, however, we found no eggs or individuals that we could confidently estimate to be less than 2 days past hatching. Thus most, if not all, grass carp spawning may have occurred farther upstream.

Most individuals taken near St. Francisville were distinctly less robust than those of comparable length and developmental stage from Eudora (Figs. 5 and 6). This relationship did not seem entirely attributable to presence or absence of yolk (Fig. 5) and may be further explained by one or more of the following:

1) It may partly reflect the tendency for the fish to become more slender, regardless of yolk, as development progresses (Table 4, Fig. 3), inasmuch as the St. Francisville material included a preponderance of more advanced larvae.

2) It may reflect gear selectivity. The mesolarval phase encompasses transitional individuals that are gradually assuming the mobility necessary to abandon an obligatory planktonic existence. We might have caught a disproportionate number of weaker, abnormal specimens at St. Francisville.

3) It is possible that few, if any, grass carp larvae that drift as far as St. Francisville are normal. Our catches may have been fairly representative of a wild population that consisted largely of emaciated individuals which had passed the hypothetical "point of no return" (Blaxter and Hempel 1963; May 1974) and were malnourished. Most grass carp larvae from St. Francisville resembled those from starvation experiments described and illustrated by Makeeva and Muravleva (1969).

NATURALIZATION OF GRASS CARP

Discovery of C. idella larvae in late spring and summer plankton at two sites along the lower Mississippi River constitutes proof that grass carp have spawned somewhere upstream each year since 1975. To our knowledge, no agencies or individuals have been stocking grass carp larvae less than 10 days old in the Mississippi River immediately upstream from our sampling sites. Even if they were, it seems unlikely that they have been doing this more or less continuously from May through late summer of every year.
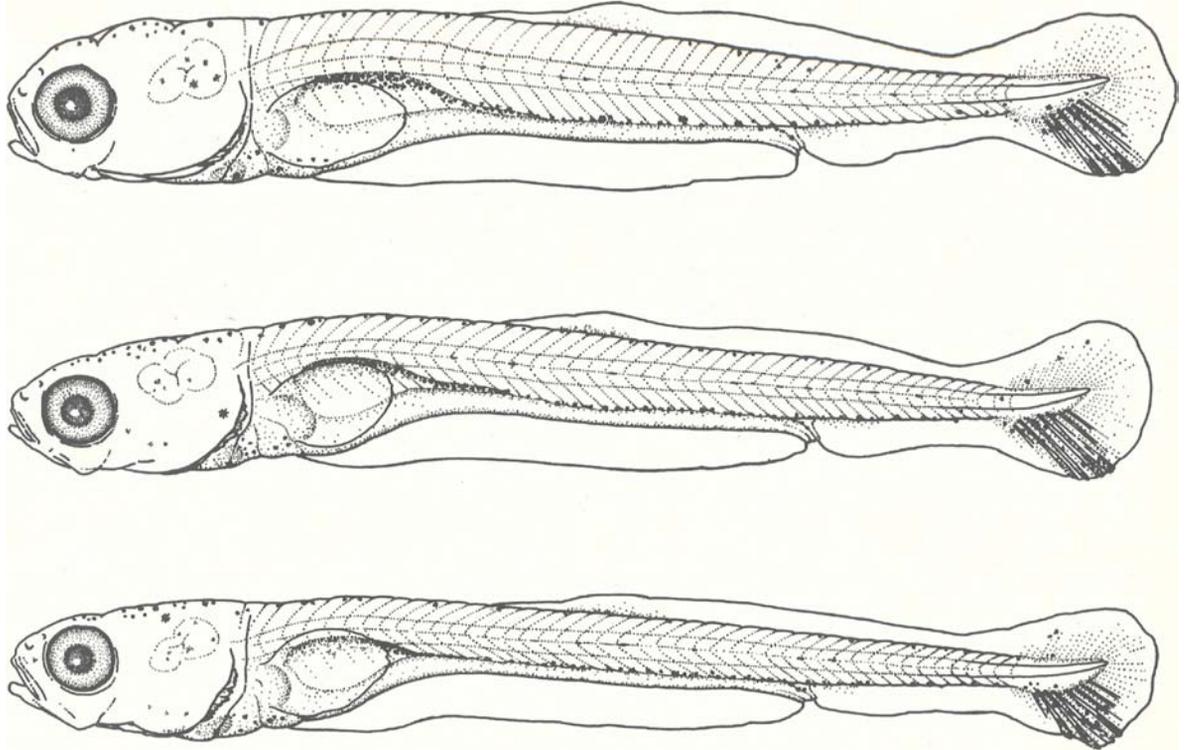
Figure 6. Three 8.3 mm-TL early mesolarvae of _Ctenopharyngodon_ _idella_ collected in the Mississippi River near St. Francisville, Louisiana, depicting the extremes of apparent condition from "normal" (above) to extremely "emaciated" (below).

Our findings fulfill the predictions of Stanley (1976) and Stanley et al. (1978). One exception is that spawning occurred at least three years earlier than expected. Our findings may also shed some light on the observations of Pflieger (1978), who felt that scales of some commercially-caught grass carp in Missouri indicated growth histories that were more typical of wild than hatchery-reared fish.

Nevertheless, the principal remaining question is that of the fate of the larvae. Some of our observations suggest that many of the mesolarval grass carp we catch are in poor nutritional condition. Intensive sampling of nektonic fishes at both the Eudora and the St. Francisville sites has yielded no juvenile or adult _C._ _idella_. However, TVA survey teams have recently taken juvenile grass carp less than 40 mm in a Mississippi River backwater lake near Memphis (LeRoy Koch, TVA, personal communication).

ACKNOWLEDGEMENTS

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DEVELOPMENT OF LARVAL BULL CHUB, NOCOMIS RANEYI

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Abstract.- Larval development of the bull chub, Nocomis raneyi is described. Bull chub larvae were reared from artificially spawned adults collected from Elliot Creek, Virginia. Pigment patterns and morphological characters examined were similar to those of two other Nocomis species examined and described in the literature. The large, robust Nocomis larvae are similar to those of other genera and cannot be separated from the others with confidence.

The central Appalachian region is inhabited by four Nocomis species: N. micropogon (river chub), N. platyrhynchus (bigmouth chub), N. raneyi (bull chub), of the micropogon species group, and N. leptocephalus (bluehead chub). All of the micropogon group species are sympatric with N. leptocephalus in one or more drainages. Until recently, information on the larval development of Nocomis was limited to a description of a young (22 mm) river chub by Fish (1932). Cooper (1978) and Buynak and Mohr (in press) described and illustrated the larval development of the river chub and Loos et al. (1979) provided illustrations of the mesolarval phase of the river and bluehead chubs.

The purposes of this study were to describe the larval development of the bull chub and to compare this description to those of other Nocomis species with which it occurs. In addition, a generic identification for Nocomis was attempted.

MATERIALS AND METHODS

Specimens of the bull chub were reared from artificially spawned adults collected from Elliot Creek, a tributary of the Roanoke River, Virginia. Specimens of the river chub and bluehead chub were obtained from the Academy of Natural Sciences of Philadelphia whose staff had reared larvae from eggs obtained in the field. No specimens of the bigmouth chub were available.

Morphometric and meristic characters were made using a dissecting microscope, ocular micrometer, and dial calipers. Total length, standard length, and snout length are as defined by Hubbs and Lagler (1958). Head length, preanal length, and preanal and postanal myomeres are as defined by Mansueti and Hardy (1967). Body depth at the anus is as defined by Fuiman (1979). Predorsal length is the distance from the snout to the base of the insertion of the first dorsal fin ray. Head width is measured immediately posterior to the eyes. Develop-mental terminology follows that of Snyder et al. (1977).

RESULTS

DESCRIPTIONS

Protolarvae

Protolarval bull chub (6.0 to 6.6 mm TL) were without melanophores. The yolk sac was bulbous and the head was deflected downward over its anterior portion. Larger protolarvae (7.6 to 7.8 mm TL) had pigmented eyes. Melanophores were scattered on top of the head, in two rows along the dorsal body margin, along the horizontal myoseptum, and on the dorsal surface of the reduced yolk sac. A ventral row of melanophores followed each side of the median fin fold, posterior to the vent. Cooper (1978) and Buynak and Mohr (in press) provided illustrations and descriptions for protolarval river chub. Their descriptions were similar to that for the bull chub, however they noted that melanophores were present along the dorsal surface of the yolk sac. Specimens of the bluehead chub examined for comparison were very similar to the river and bull chubs. No distinguishing character was determined for these three chubs.

Mesolarvae

Bull chub (8.0 to 9.4 mm TL) mesolarval pigment patterns followed those of the protolarvae, though increased. The gas bladder, which had filled, was moderately pigmented on the dorsal surface. Scattered melanophores were present along the developing caudal fin rays. A divergent double row of melanophores originating in the gular region followed the sides of the yolk sac to the dorsal surface of the sac, posterior to the gas bladder. Larger bull chub mesolarvae developed melanophores on the snout, internal pigmentation from the eye to the gas bladder, and melanophores concentrated at the base of the caudal fin. Bull chub mesolarvae could be easily represented by the illustrations for either the river or bluehead chub presented in Loos et al. (1979). Pigment patterns were also similar to illustrations by Cooper (1978) and Buynak and Mohr (in press).

Metalarvae

Metalarval bull chub (11.0 to 11.3 mm TL) began to assume the pigmentation and body form of the juvenile. The snout was blunt, with the upper jaw extending over the lower jaw. Lateral pigment formed a band ending with a distinct spot at the base of the caudal fin. Body form and pigmentation of the bluehead chub examined, and river chub described by Cooper (1978) and Buynak and Mohr (in press) were similar to the bull chub

Table 1. Selected morphometrics (as percent of total length) and meristics for larval bull chub.

	Protolarvae		Mesolarvae		Metalarvae	
	Mean	Range (mm)	Mean	Range (mm)	Mean	Range (mm)
Total length (mm)	7.0	6.0-7.8	8.7	8.0-9.4	11.2	11.0-11.3
Standard length	96	5.5-7.5	92	7.5-8.5	88	9.7-9.8
Snout length	1	0.1-0.2	2	0.2-0.3	4	0.4
Head length	16	0.9-1.2	17	1.4-1.6	21	2.3
Predorsal length			53	4.3-4.9	48	5.4-5.5
Preanal length	69	4.0-5.1	62	5.0-5.8	66	7.4
Head width	11	0.8	11	0.9-1.1	16	1.7-1.8
Body depth at anus	7	0.4-0.6	7	0.4-0.8	12	1.4
Preanal myomeres	26.6	26-27	27.0	27	27.0	27
Postanal myomeres	14.7	14-15	14.2	14-15	15.0	15
Total myomeres	41.3	40-41	41.2	41-42	42.0	42

description above. Metalarval specimens examined during the present study had scattered melanophores on the dorsal fin. Buynak and Mohr (in press) reported melanophores on the breast of metalarval river chub. Melanophores were found on the breast of some bluehead chub and most of the river chub metalarvae examined in the present study. None were observed on bull chub larvae. However, this characteristic probably would be found with the examination of more metalarval specimens.

MERISTICS AND MORPHOMETRICS

Preanal and postanal myomere counts averaged 26.6 and 14.7 for protolarvae, 27.0 and 14.2 for mesolarvae, and 27.0 and 15.0 for metalarvae, respectively (Table 1). River chub described by Buynak and Mohr (in press) generally averaged less for both preanal and postanal myomere counts, with the greatest difference being the postanal myomeres. These differences may be due to the technique used for determining preanal and postanal myomeres, since river chub examined in the present study averaged 27.0 and 14.5 for mesolarvae and 15.0 postanal myomeres for metalarvae. Bluehead chub protolarvae averaged 25.4 preanal and 14.0 postanal myomeres, mesolarvae 27.2 and 14.8, and metalarvae 26.3 and 15.0.

Buynak and Mohr (in press) presented some morphometric data for the river chub which might suggest some differences between the bull chub (Table 1) and river chub. Since Buynak and Mohr (in press) used different developmental terminology and characters these may not be real differences. Data for river and bluehead chubs taken from specimens obtained for the present study were similar to those taken for the bull chub.

DISCUSSION

Generic identification of Nocomis larvae in protolarval and metalarval stages is difficult. Pigment patterns are variable and the larvae are large and robust as in Rhinichthys, Campostoma, Exoglossum, and Semotilus. Buynak and Mohr (in press) separated metalarval river chub from other genera by using pigment patterns. Since pigment patterns are variable, including the breast pattern used as a key character, and are present on other genera, they should be used with caution even for metalarvae.

Preanal myomeres (usually 27 in bull chub) are less numerous than in Semotilus (Kranz et al. 1979) but are numerically similar to those in many other genera (Snyder 1979). Morphological differences are difficult to use since the data are scattered in various publications, often with few characters common among studies. Identification of Nocomis larvae will require detailed studies of local larval assemblages using more than basic meristic and morphological comparisons. Development of more characters, perhaps based on clearing and staining techniques, will no doubt be important in future investigations.

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LARVAL DEVELOPMENT OF THE BANDED KILLIFISH (FUNDULUS DIAPHANUS) WITH NOTES ON THE DISTRIBUTION IN THE HUDSON RIVER ESTUARY

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Abstract.- In 1978, banded killifish from the Hudson River were artifically spawned and larvae were reared in the laboratory. Larval development, for size ranges from 4.7 to 19.8 mm total length, was observed through time. Selected meristic and morphometric characters, pigmentation patterns, and fin development are described and compared with relevant literature. Pertinent illustrations of larval killifish are included.

The banded killifish (Fundulus diaphanus) is a shore zone inhabitant of tidal freshwater portions of the Hudson River estuary. Greeley (1937) and Texas Instruments (1976) recorded adults as abundant in beach seine sampling. However, larvae have been encountered rarely because ichthyoplankton sampling was concentrated in deepwater areas (Texas Instruments 1976, 1977). Figure 1 presents the reported Hudson River distribution for banded killifish larvae in 1976. These data (Texas Instruments 1977) showed a maximum mean of $4.376 \times 10^{-3}/1000 \text{ m}^3$ for composite tows which captured banded killifish larvae and young. This concentration would have been greatly reduced if all ichthyoplankton samples not capturing banded killifish had been included. These data do show that larvae were captured in tidal, predominantly freshwater, portions of the estuary.

Larval stages of the banded killifish have been described but, no single, continuous developmental sequence has been presented. Because of this, we attempted to describe various meristic and morphometric characteristics, and pigmentation patterns, of banded killifish larvae. The purpose of this study was to provide a description of a developmental series of larvae useful for future identification of the species.

MATERIALS AND METHODS

Banded killifish larvae were obtained by artificially propagating fish collected from the Hudson River. Ripe adults were collected with beach seines in tidal freshwater above the Beacon-Newburgh Bridge on 12 June 1978 (Fig. 1). Females were stripped of their ova and fertilization occurred by mixing ova with spermatozoa obtained by dissecting and macerating male gonads. The adhesive eggs were incubated for 9 days on glass slides in laboratory aquaria at 20.0 to 24.0 C. Upon hatching, larvae were periodically preserved in 10 percent buffered formalin. Examination and measurement of the larvae were made using a variable power (10 to 70X) binocular dissecting microscope with
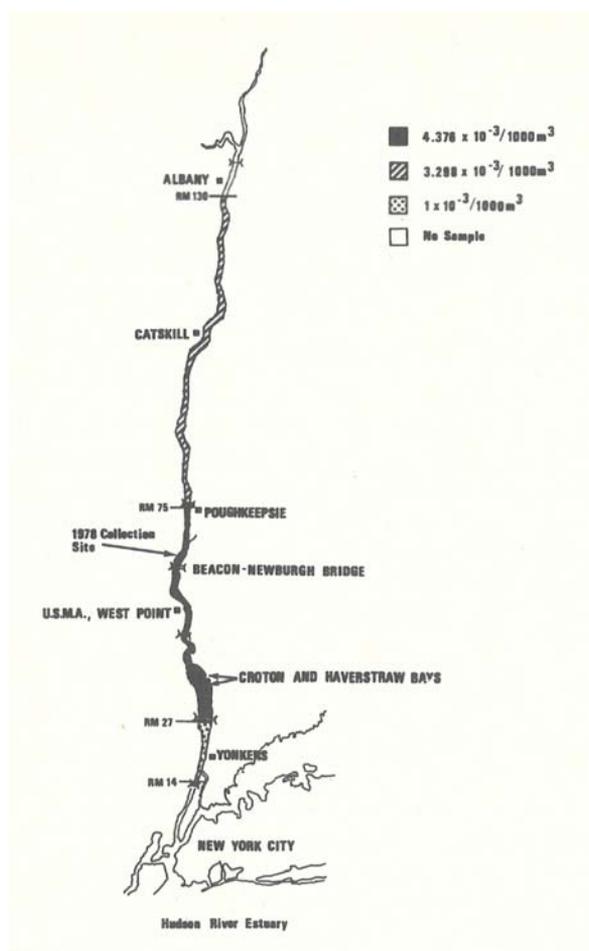
Figure 1. Typical larval banded killifish distribution in the Hudson River estuary based on 1976 collections and including the 1978 collection site for adults.

an ocular micrometer. Measurements were made to the nearest 0.1 mm and expressed as percentages of total length (TL). Most terminology used for the description and measurement of specimens was from Mansueti and Hardy (1967); however, enumeration of myomeres followed Siefert (1969).

RESULTS

Tables 1 and 2 summarize pertinent meristic and morphometric characters for each size group described below. Illustrations are presented to facilitate comprehension of pigmentation patterns and other relevant identification criteria.

Two larvae removed at the day of hatching were 4.7 and 5.0 mm TL (Fig. 2). They possessed a large round yolk sac with several tiny oil droplets scattered throughout the yolk. The head was flexed over the yolk sac, eyes were pigmented, and the mouth was incomplete. The median fin fold originated dorsally at the 13th myomere and ventrally at the posterior end of

Table 1. Mean measurements (mm) of larval banded killifish. Parenthetic values represent mean percentage of total length.

	Size range (mm, total length)				
	4.7-5.0	7.6-8.2	9.5-10.0	11.6-14.5	15.9-19.8
Number of fish	2	3	3	7	11
Total length	4.9	7.9	9.7	12.8	17.7
Standard length	4.5 (91.8)	6.7 (84.8)	8.0 (82.5)	10.5 (82.0)	14.3 (80.8)
Snout-vent length	2.1 (42.9)	3.3 (41.8)	4.2 (43.3)	5.8 (45.3)	8.5 (48.0)
Head length	1.1 (22.4)	1.8 (22.8)	2.3 (23.7)	3.0 (23.4)	4.3 (24.3)
Eye diameter	0.5 (10.2)	0.8 (10.1)	0.9 (9.3)	1.1 (8.6)	1.6 (9.0)
Greatest body depth	1.9 (38.8)	1.4 (17.7)	1.8 (18.6)	2.2 (17.2)	2.9 (16.4)
Caudal peduncle depth	0.4 (8.2)	0.5 (6.3)	0.7 (7.2)	1.1 (8.6)	1.5 (8.5)

the yolk sac. Large pectoral buds were present and few caudal fin rays were evident. Ten preanal and 24 postanal myomeres were counted. Pigmentation on these killifish consisted of a light scattering of small stellate melanophores on top of the head and along the middorsal surface. Pigmentation was sparse or lacking along the ventral line from the vent to the caudal fin. Pigmentation on the ventral surface of the yolk sac was limited to melanophores on the vitelline vessels. Scattered pigmentation was present on the lateral surface.

By 6 to 15 days from hatching, yolk was totally absorbed and specimens ranged from 7.6 to 10.0 mm TL. For smaller larvae (less than 8.3 mm TL), the head and mouth were well developed, with teeth present on the premaxilla and mandible (Fig. 3). The air bladder was partially obscured by coiling of the gut. Exogenous feeding had commenced at this size, as evidenced by food in the gut. The dorsal and ventral fin folds were continuous and considerably wider than in the previous stage. Fin ray differentiation was limited to the caudal fin. The adult complement of six branchiostegal rays had formed, with the interbranchiostegal membrane between the second and third rays being the widest. There were 11 preanal and 24 postanal myomeres. Pigmentation on larvae in this size range (7.6 to 8.2 mm TL) was less than that for recently

Table 2. Range and mean of selected meristic characters for larval banded killifish. LP_1 represents larval pectorals, LP_2 represents larval pelvics, and FF represents fin fold.

	Size range (mm, total length)				
	4.7-5.0	7.6-8.2	9.5-10.0	11.6-14.5	15.9-19.8
Number of fish	2	3	3	7	11
Total length	4.9	7.9	9.7	12.8	17.7
Pectoral rays range	LP_1	LP_1	9.7 7-12	12 11-13	13.3 12-15
Pelvic rays range				LP_2	5.8 4-6
Dorsal rays range	FF	FF	6.7 6-7	12 11-13	13.6 13-14
Anal rays range	FF	FF	5.7 5-7	10.1 10-11	11.8 11-12
Preanal myomeres range	10.0 10-10	11.0 11-11	12.7 12-13	14.0 13-15	13.9 13-15
Postanal myomeres range	24.0 24-24	24.0 24-24	22.3 22-23	21.3 21-22	20.6 20-22
Total myomeres range	34.0 34-34	35.0 35-35	35.0 35-35	35.3 34-36	34.5 33-36

hatched specimens. Only an 8.2 mm TL specimen possessed dorsal pigmentation. This consisted of a scattering of light melanophores in the occipital region, and more sparse middorsal pigmentation over the caudal fin. Scattered melanophores were present midventrally from the vent to the caudal fin. All of these specimens possessed a dark line of melanophores extending midventrally from the isthmus to the vent, melanophores on the dorsal surface of the air bladder, and small chromatophores on the margin of the caudal fin rays.

Development of the mouth had progressed so that the lower jaw extended beyond the upper jaw by 9.5 mm TL. The upper jaw was protractile. Ray development was now evident in the dorsal and anal fins (Fig. 4). Incipient rays were visible in the pectoral fins. Preanal myomeres ranged from 12 to 13 and postanal myomeres ranged from 22 to 23. Pigmentation to the occipital region had increased to form a distinct triangle of stellate melanophores on the dorsal surface of the head extending laterally to the opercular region.
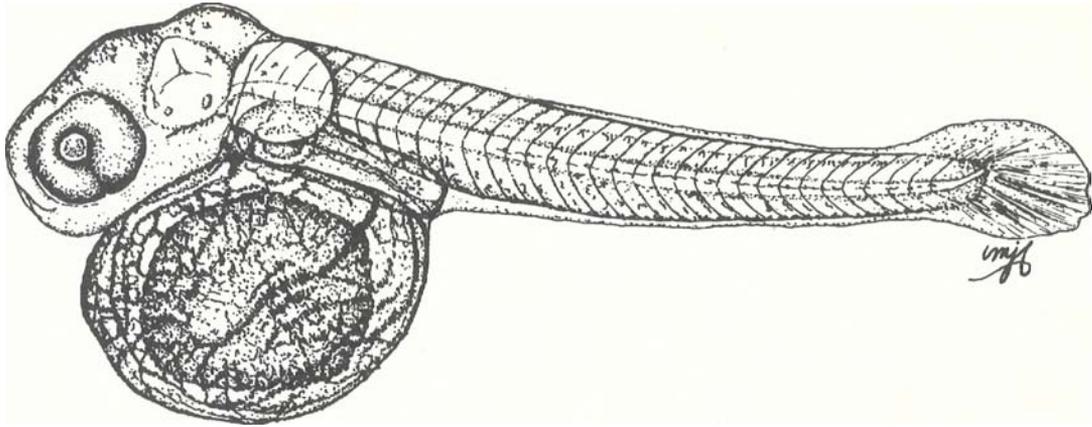
Figure 2. Laboratory spawned larva of the banded killifish, 4.7 mm TL.

An irregular series of stellate melanophores was present on the dorsal and ventral surface. Melanophores on the midventral surface had formed a dense triangle of pigment extending from the isthmus into the midthoracic region. An interrupted line of pigment extended midventrally from the isthmus posteriorly to the vent. However, on a 10.0 mm TL specimen, this line was reduced to several large melanophores scattered on the surface of the abdomen. All specimens had sparse pigmentation on portions of the visceral cavity and the air bladder was lightly pigmented. Small stellate melanophores were present on the myosepta and along the midlateral line. Some pigmentation was evident on the developing dorsal, anal and caudal fin rays.

Banded killifish larvae 17 to 25 days from hatching ranged from 11.6 to 14.5 mm TL. Fin ray development progressed in the dorsal, anal, caudal, and pectoral fins (Fig. 5). All specimens lacked anal and dorsal fin folds but possessed pelvic buds on the abdomen. At 14.5 mm TL anal and dorsal fin ray development was completed, having 11 and 13 rays respectively (cf. Scott and Crossman 1973; Eddy and Underhill 1974). Larvae in this size range were generally opaque and myomeres were difficult to count. Preanal myomeres ranged from 13 to 15 and postanal myomeres ranged from 21 to 22. Total myomeres ranged from 34 to 36. Pigmentation increased on the dorsal surface of the head, especially along the upper and lower jaws and the nasal region.
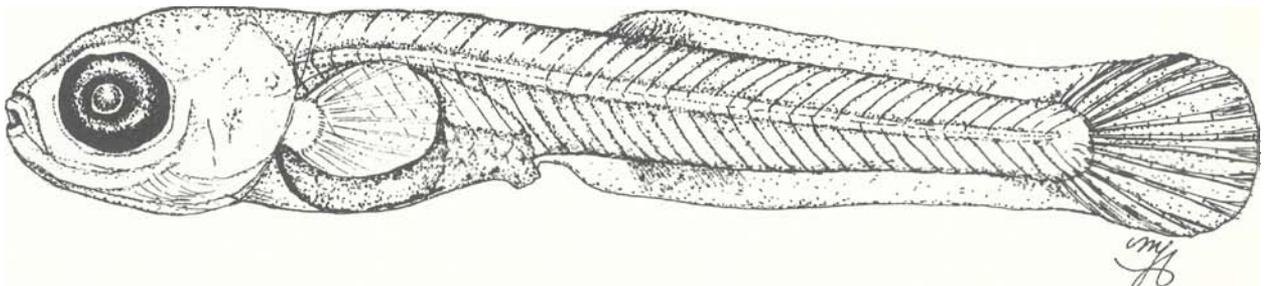
Figure 3. Laboratory spawned larva of the banded killifish, 8.0 mm TL.
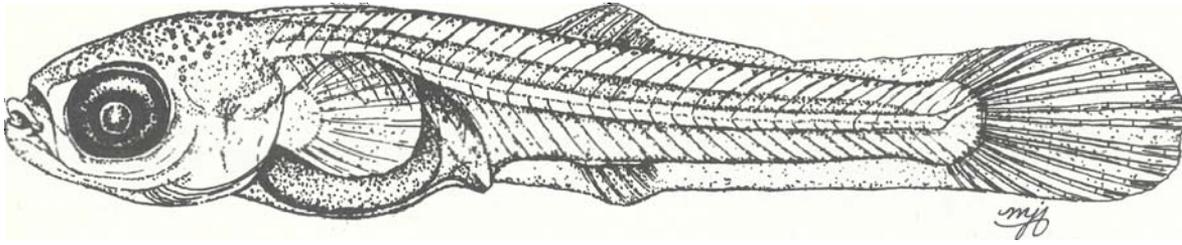
Figure 4. Laboratory spawned larva of the banded killifish, 9.5 mm TL.

Pigmentation was concentrated on the dorsal body surface and the ventral region posterior to the anus. The line of pigment extending across the abdomen to the vent was absent, but the triangle of pigmentation extending from the isthmus onto the midthoracic ventral surface persisted. Stellate melanophores increased in number and size along the midlateral line, and myosepta. Vertical bars of pigment were not discernable at this size. Small melanophores occurred along individual fin rays and near the bases of the pectoral, dorsal, anal and caudal fins. No pigmentation was visible on the developing pelvic buds.

Caudal, anal, dorsal and pelvic fin ray development was completed by 23 to 37 days from hatching. These specimens ranged from 15.9 to 19.8 mm TL (Fig. 6). Cycloid scale formation occurred between the dorsal and caudal fin in specimens 15.9 to 17.4 mm TL. By 17.9 mm TL scale formation was completed. Preanal myomeres ranged from 13 to 15, postanal myomeres from 20 to 22 and total myomeres from 33 to 36. Seven to 13 distinct vertical bars of pigment were evident on the fish. Ventral pigmentation was lacking from the snout to the anus, but occurred as an elongated row along the midventral line extending from the vent to the caudal fin. All fins possessed pigmentation along the rays and their bases as in the previous size. Pigmentation increased along the upper jaw, nasal region, and occipital region.
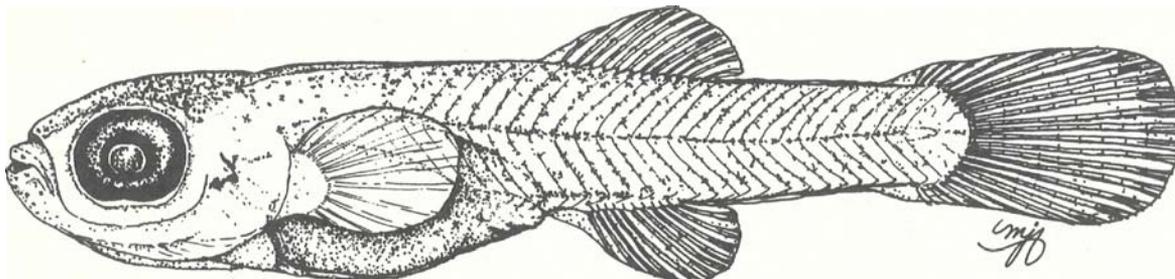
Figure 5. Laboratory spawned larva of the banded killifish, 12.8 mm TL.
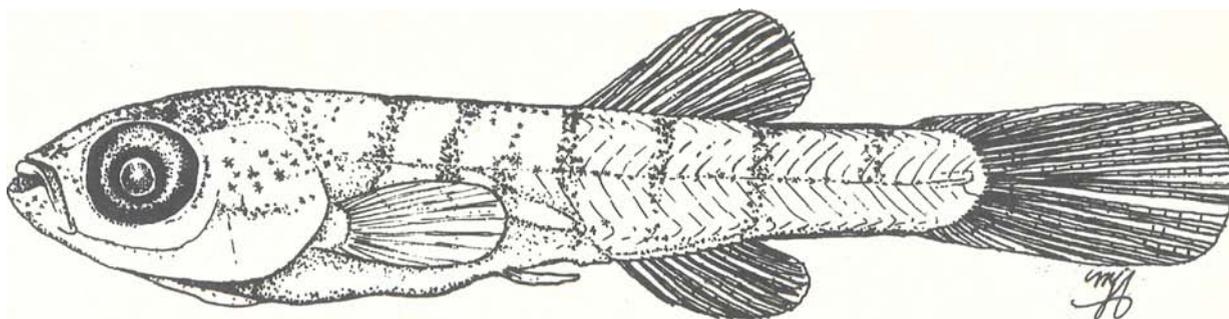
Figure 6. Laboratory spawned larva of the banded killifish, 18.8 mm TL.

DISCUSSION

Newly hatched larvae from the present study (4.7 and 5.0 mm TL) were smaller than any previously recorded. Wang and Kernehan (1979) reported hatching lengths of 5.5 to 6.0 mm TL. Hudson and Hardy (1975) found hatching sizes of 5.3 to 6.4 mm TL. Foster (1974) approximated the hatching size at 5.0 to 5.5 mm TL, but stated that the actual size was unknown. Apparently the 4.7 and 5.0 mm TL specimens described in our study were younger than any specimen previously recorded. Supportive evidence exists since illustrations of 5.3 mm TL larvae were provided by Hudson and Hardy (1975) indicating a bulbous yolk sac and pectoral fin ray development. Our specimens exhibited a considerably larger yolk sac, and no ray differentiation was evident in the pectoral buds. Additionally, Hardy (1978) stated incubation was 11 to 12 days at 22.0 to 26.5 C. The incubation period for our study was 9 days at 20.0 to 24.0 C. These incubation periods and associated temperatures indicate that our specimens were prematurely hatched.

Existing literature emphasizes pigmentation patterns as a useful character for identification of larvae. Pigmentation described by Wang and Kernehan (1979) for newly hatched specimens is typical of all literature reviewed. Pigmentation is sparse, with few melanophores along the flanks, large dark melanophores in the occipital regions, and on the vitelline vessels of the yolk sac. Similar pigmentation was observed on newly hatched larvae in our study. Not all authors, however, have agreed on pigmentation development in the caudal fin region. Hudson and Hardy (1975) described the pigmentation patterns of a living 5.3 mm TL larva. This specimen had dark pigmentation along the developing rays of the caudal fin. Our newly hatched specimens possessed no such caudal pigmentation. Furthermore, Foster (1974) described a 5.6 mm TL specimen and stated that absence of caudal fin ray pigmentation was a characteristic for separating the banded killifish from the mummichog (F. heteroclitus). Fish (1932) also described this caudal fin ray pigmentation for a 7.1 mm TL specimen. Foster (1967) stated that Fish's (1932) description did not differ significantly from his own and elaborated further that each caudal fin ray had a row of small melanophores above and below it. Our specimens first possessed caudal fin ray pigmentation at 7.6 mm TL, in agreement with the findings of Fish (1932) and Foster (1967).

Certain pigmentation for the 7.6 to 8.5 mm TL larvae in our study differed with previous literature. Fish (1932) and Foster (1967) stated that by 7.1 mm TL banded killifish exhibit distinctive pigmentation on the dorsal, ventral, and lateral surfaces. Fish (1932) described chromatophores being distributed over the whole body, especially on top of the head and in irregular series on dorsal and ventral ridges. Foster (1967) described three stripes of melanophores down the length of the body, a middorsal stripe, a ventral stripe, and a less well developed lateral stripe. Specimens observed in this study had sparse pigment on the dorsal surface while lateral pigmentation was virtually lacking. They did, however, possess a dark line of melanophores extending from the isthmus to the vent, similar to that described by Fish (1932).

In larger fish, the existing literature indicates disagreement associated with the development of vertical bars of pigment. Foster (1974) reported that vertical bars had not developed by 12.0 mm TL. Wang and Kernehan (1979) illustrated vertical bars in a 12.5 mm TL specimen, while Hardy (1978), illustrated no vertical bars at approximately 14.0 mm TL. Foster (1967) reported that the first signs of vertical black bars occurred about 10 days after hatching. In our study, vertical bars appeared as a function of age and size. At 35 days from hatching , all specimens (range 15.9 to 19.8 mm TL) possessed vertical black bars. At 23 days old (range 13.4 to 17.4 mm TL), only one 17.4 mm larva had vertical bars.

The most comprehensive meristic and morphometric data we found was presented by Fish (1932). These were detailed descriptions of a 7.1 mm and 12.3 mm TL specimen which compared with our 7.6 to 8.2 mm and 11.6 to 14.5 mm TL size groups, respectively (Table 3). For the purpose of comparison, we converted Fish's (1932) meristic data to percentages of total length. Mean body proportions of the smaller of our larvae were in close agreement with the body measurements for the 7.1 mm TL specimen provided by Fish (1932). Myomere counts differed slightly. Fish (1932) reported 10 preanal and 22 postanal myomeres while all three specimens in our study had 11 preanal and 24 postanal myomeres. Comparison of the larger fish, however, showed many differences. Mean proportions of standard, snout to vent and head lengths were smaller for our specimens than reported by Fish (1932). Additionally, Fish (1932) reported considerably fewer preanal myomeres than we found. A possible explanation for the morphometric discrepancies would be that our methods for obtaining body measurements differed from those methods employed by Fish (1932). The reason for preanal myomere differences could be because Fish (1932) cleared and stained some of her specimens, whereas we did not.

SUMMARY AND CONCLUSIONS

Our newly hatched larvae were smaller than previously described, evidently due to premature hatching. Descriptions of pigmentation on newly hatched larvae were consistent except for Hudson and Hardy's (1975) reported caudal fin ray pigment when observing a live specimen. Caudal fin ray pigmentation was evident on specimens greater than 7.0 mm TL. The development of vertical bars of pigment was a function of both size and age. Additional studies should be conducted to adequately describe meristic and morphometric

Table 3. Comparison of selected banded killifish meristic and morphometric data with those of Fish (1932). Parenthetic values represent the mean percentage of total length.

	Size range (mm, total length)			
	7.6-8.2	7.1[a]	11.6-14.5	12.3[a]
Number of fish	3	1	7	1
Total length	7.9	7.1	12.8	12.3
Standard length	6.7 (84.8)	6.0 (84.5)	10.5 (82.0)	11.1 (90.2)
Snout-vent length	3.3 (41.8)	2.8 (39.4)	5.8 (45.3)	5.8 (47.2)
Head length	1.8 (22.8)	1.6 (22.5)	3.0 (23.4)	3.4 (27.6)
Eye diameter	0.8 (10.1)	0.7 (9.9)	1.1 (8.6)	1.1 (8.9)
Preanal myomeres range	11.0 11-11	10	14.0 13-15	10
Postanal myomeres range	24.0 24-24	22	21.3 21-22	20-22
Total myomeres range	35.0 35-35	32	35.3 34-36	30-32

[a]data from Fish (1932).

characters for larvae greater than 10.0 mm TL. As resources permit, simultaneous rearing of banded killifish, mummichog and striped killifish (_F. majalis_) will be attempted.

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SOME FEATURES OF LARVAL ROCK BASS, AMBLOPLITES RUPESTRIS (RAFINESQUE), DEVELOPMENT IN CENTRAL ONTARIO

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Abstract.- Rock bass, Ambloplites rupestris, eggs, prolarvae, and postlarvae to 17.0 mm (TL) from Chandos Lake, central Ontario, are described and compared to larvae from the Susquehanna River, Pennsylvania. Eggs from central Ontario averaged 2.0 mm in diameter, with a centrally located oil globule (0.76 mm) in the yolk. Prolarvae from Pennsylvania have a posterior oil globule and are larger at hatching (5.6 mm, as opposed to 4.9 mm). Pigmentation first appears in 5.8 mm Ontario prolarvae and 6.8 mm Pennsylvania fish; pelvic fin buds are noticable at 9.0 mm (Ontario) and at about 10.5 mm (Pennsylvania). For central Ontario rock bass, juvenile caudal peduncle pigment squares are noted at 40 mm. The SL:TL relationship of central Ontario fish is linear (SL= 0.264 + 0.818 TL, r= 0.998). Snout length to SL and eye diameter to SL plots (curvilinear) are discussed, and morphometrics are presented.

Few descriptions of the common rock bass, Ambloplites rupestris (Rafinesque), larval stages have been published. Buynak and Mohr (1979), however, have recently described and illustrated 5.6 mm (TL) to 13.5 mm (TL) stages from the Susquehanna River, Pennsylvania, and Hogue et al. (1976) have included photographs and descriptions of 8.0 and 10.0 mm rock bass in their larval identification guide for the Tennessee River.

This study provides measurements of the egg, some representative stages of development from newly-hatched larvae to juveniles, and morphometric data from central Ontario. The SL:TL relationship is quantified and presented along with the snout length and eye diameter to SL relationships. We compared our larval descriptions with those of Buynak and Mohr (1979) and have found some interesting differences in detail.

MATERIALS AND METHODS

The emphasis in this study was on eggs and young stages which were collected from Chandos, a Precambrian shield lake near Peterborough, Ontario. Samples were removed by "slurp gun" (available at most diving gear stores) from the nests (1 to 2 m depth). Bottom temperatures were 17 to 21 C during the sampling period, 10 to 30 June 1979. Representative eggs were reared at

20 C in an environmental chamber. A few juveniles which had left the nest were collected from nearby rock crevices. The bulk of the larvae leaving the nest we could not thereafter locate.

Drawings, by author Vandeloo, were made with a camera lucida on a Wild M 20 microscope. Drawings were made on a grid system to facilitate body proportion analysis, and cleared larvae of rock bass and other species could also be projected on this grid of 1-mm squares for easy comparison. Color photographs were taken to check pigment patterns using a Polaroid Land Camera ED 10.

Of the numerous larval definitions (Balon 1975, Mansueti and Hardy 1967, Snyder et al. 1977, and others) we selected terminology of Mansueti and Hardy. Morphometric terms were as in Houde et al. (1974) but we arbitrarily excluded predorsal and prepelvic lengths. We also omitted myomere counts from Table 1 because most of these were obtained from specimens from another lake, and we cannot, at this time, explain certain inconsistencies between lakes and in the literature. The descriptions are kept simple, by documenting only new main developmental features, because we felt the figures would clarify the presence or absence of most diagnostic features. All lengths given are total lengths (TL), but conversions can be easily made using Fig. 5.

DESCRIPTIONS

EGGS

Fertilized eggs were clear, pale yellow, or partially opaque-yellow, to whitish in color. Even rather opaque to white eggs often hatched quite successfully if they did not collect debris or become infected with fungus. Ripe, yellow spherical ova removed from an ovary ranged from 1.3 to 0.9 mm in diameter. Of 21 blastula-stage eggs, the diameters ranged from 1.98 to 2.14 mm (mean, 2.04); 14 tailbud-stage eggs ranged from 1.90 to 2.00 mm (mean, 1.98). Oil globules ranged in diameter from 0.71 to 0.79 mm (mean, 0.76).

PROLARVAE

Newly hatched larvae 4.9 to 5.1 mm were devoid of pigment on the body and yolk sac. The body and notochord were distinct from the fin fold. The head was straight and the primordial fin fold was clearly defined. No gut or pectoral buds were apparent, but unpigmented optic swellings were present. Early prolarvae measuring 5.5 mm showed two advances: mid-yolk myomeres, and developed, though unpigmented, eye cups. In prolarvae measuring 6.4 mm eyes became pigmented and part of the head was free from the yolk sac. Pectoral buds were evident for the first time and the notochord was flexed upward at a slight angle (less than 10 degrees). By 6.7 mm (Fig. 1) late prolarvae had their yolk partly absorbed and displayed about 40 stellate or branched melanophores on each side of the yolk. The epural and hypural elements were first evident at this size. The anus was faintly visible and the maxilla and mandible had commenced development.
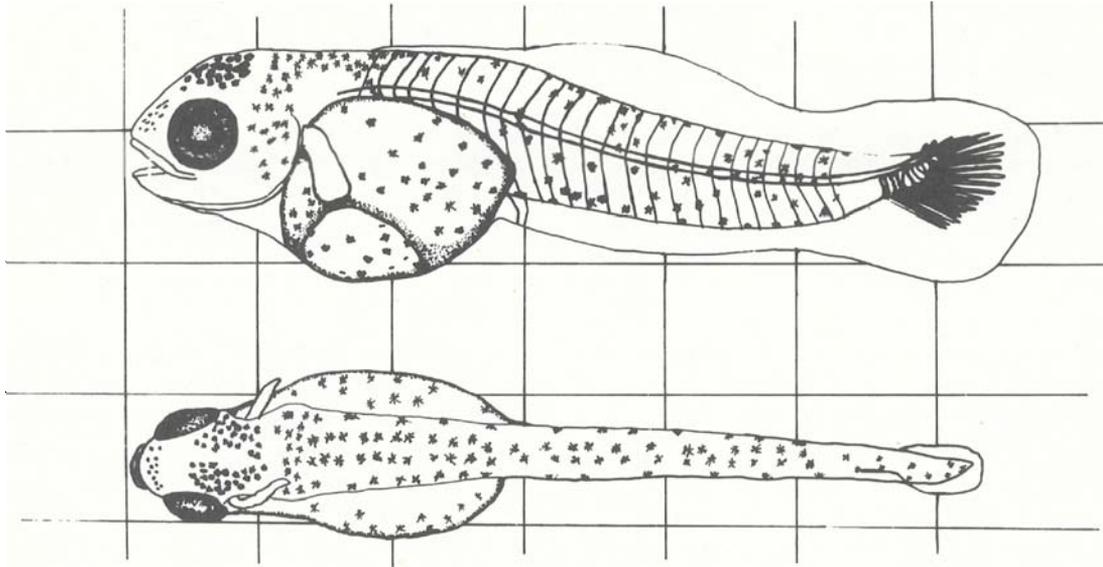
Figure 1. Lateral and dorsal views of a 6.7 mm TL rock bass.

POSTLARVAE

By the postlarval stage of 7.4 mm (Fig. 2) the operculum showed faint branchiostegal rays and melanophore patterns were more distinct. This size showed "dorsal double body contours" (Russell 1976), two oval patterns behind the eyes and a less dense rectangular snout patch (Fig. 2B). The dorso-posterior part of the swim bladder also exhibited melanophores at this size and the oil globule was hidden by pigment. Very faint rays with melanophores were apparent in the dorsal, anal, and caudal fins. The dorsal fin was becoming well defined and the anus was more obvious. By 9.0 mm (Fig. 2C) the dorsal fin had nine short anterior spines and eight or more soft rays. Fins began to become crenate. Pelvic fin buds were present at 9.0 mm, but there were no countable rays until 11.0 mm.

By 12.9 to 14.0 mm the head proportions were almost adult (Fig. 3A). The vent was stout and obvious, dorsal spines were 10 to 11, and the rays 9 to 11. The caudal fin was already forked with pigmented rays. By 13.0 mm 50% of the fish had formed scales on the lateral portions of the caudal peduncle. Six to seven pectoral rays were evident. Pigmentation zones had produced saddle-like patterns (Fig. 3B) by 16.5 mm. At 21.0 mm all vertical fin rays were developed, and except for the pelvic fin, the numbers of fin rays were similar to the adult.

From 22.0 to 40.0 mm, pelvic fins achieved the adult complement (one spine, five rays). At 32.0 mm 50% of the fish had scales on their operculum, and at 36.0 mm scale formation was complete. A final pigmentation change (Fig. 4) was noted at the end of the caudal peduncle at 40.0 mm when two definite squares were formed.
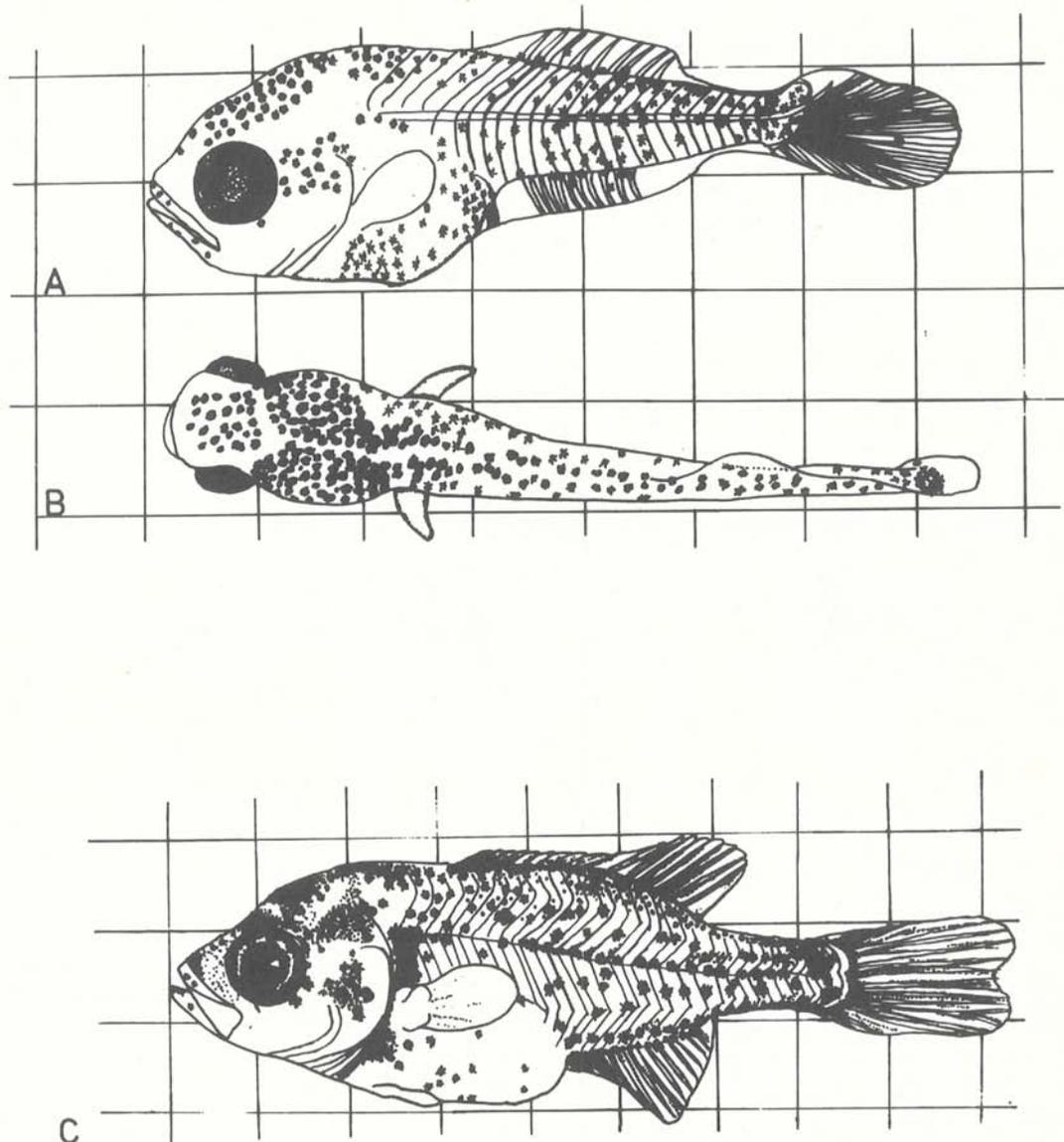
Figure 2. Lateral (A) and dorsal (B) views of a 7.4 mm TL rock bass, and a 9.3 mm TL postlarva (C).

DISCUSSION

QUANTITATIVE ASPECTS

Figure 5A indicates a very good linear regression (r= 0.998) of SL on TL for rock bass (SL= 0.264 + 0.818 TL). The 95 % confidence limits of eye diameter to SL were narrower than those for snout length to SL (Fig. 5B). Of the common simple curves, the type $Y= aX^b$ gave best fit (r= 0.994) for these two relationships. However, above 25 mm SL the lines did not tail down close to the data points. A high correlation coefficient (0.994) was realized only below 25 mm SL. That is why an eye-fit was used in Fig. 5B. Obviously, a
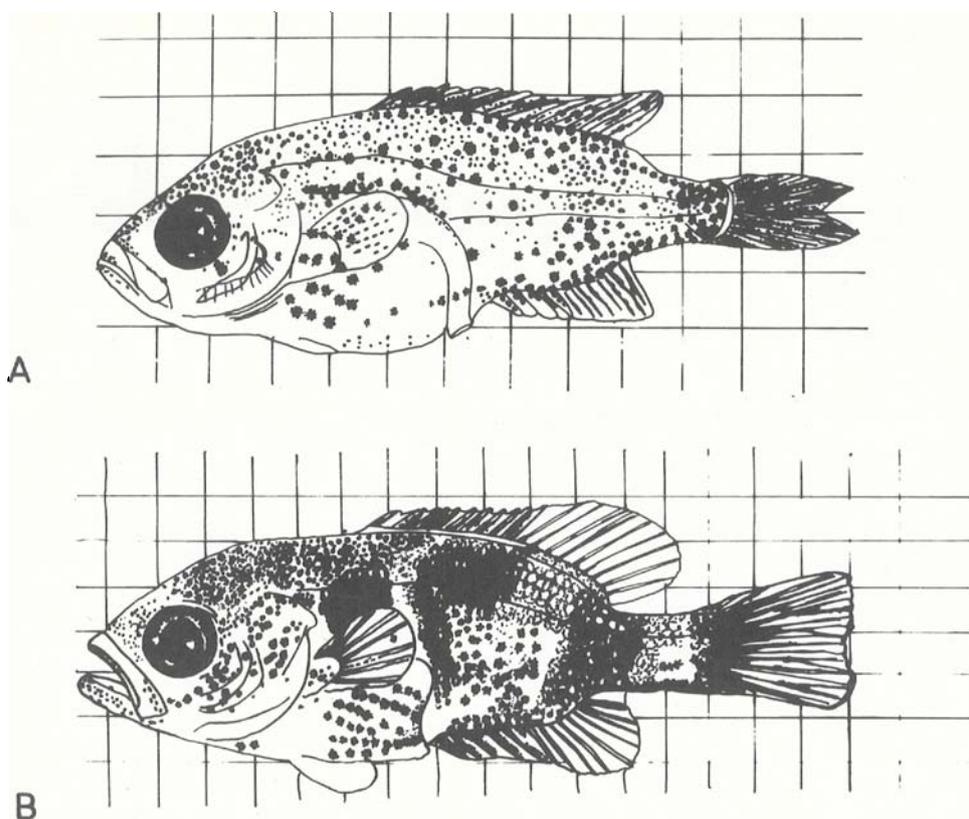
Figure 3. A) A 12.9 mm TL postlarval rock bass. B) A 16.4 mm TL postlarval rock bass showing scales and saddle pattern.

suitable compound curve should be employed for future applications of this type, although it is not in the scope of this paper to do so. In Harengula jaguana (Houde et al. 1974) both snout and eye length appear to follow a curve of $Y = aX^b$ when plotted against SL and do not tail off like the rock bass data. The eye diameter to SL ratios showed better correlation than snout length to SL, probably because eye diameter is less variable since it is a shape less subject to deformity during preservation or capture.

In our area of central Ontario (the Kawartha Lakes District) four other species of centrarchids are common (although white and black crappies occur only about 50 km to the south). These are: pumpkinseed (Lepomis gibbosus), bluegill (L. macrochirus), smallmouth bass (Micropterus dolomieui), and largemouth bass (M. salmoides). Rock bass prolarvae are much deeper per body length and larger at hatching (Taubert 1977) than Lepomis. Larger ones have a bigger mouth and larger melanophores than Lepomis (Buynak and Mohr 1979).

Some rather interesting differences in developmental patterns and proportions were found between central Ontario rock bass larvae and those from the Susquehanna River, Pennsylvania Buynak and Mohr 1979). Presumably our hatching temperatures were cooler in Ontario because our rock bass hatched at smaller sizes, 4.7 to 4.9 mm (TL), yet the eggs were collected at about the same time of the year, albeit in 1975. Unfortunately, Buynak and Mohr did not mention water temperatures from which their sample was taken, but their fish
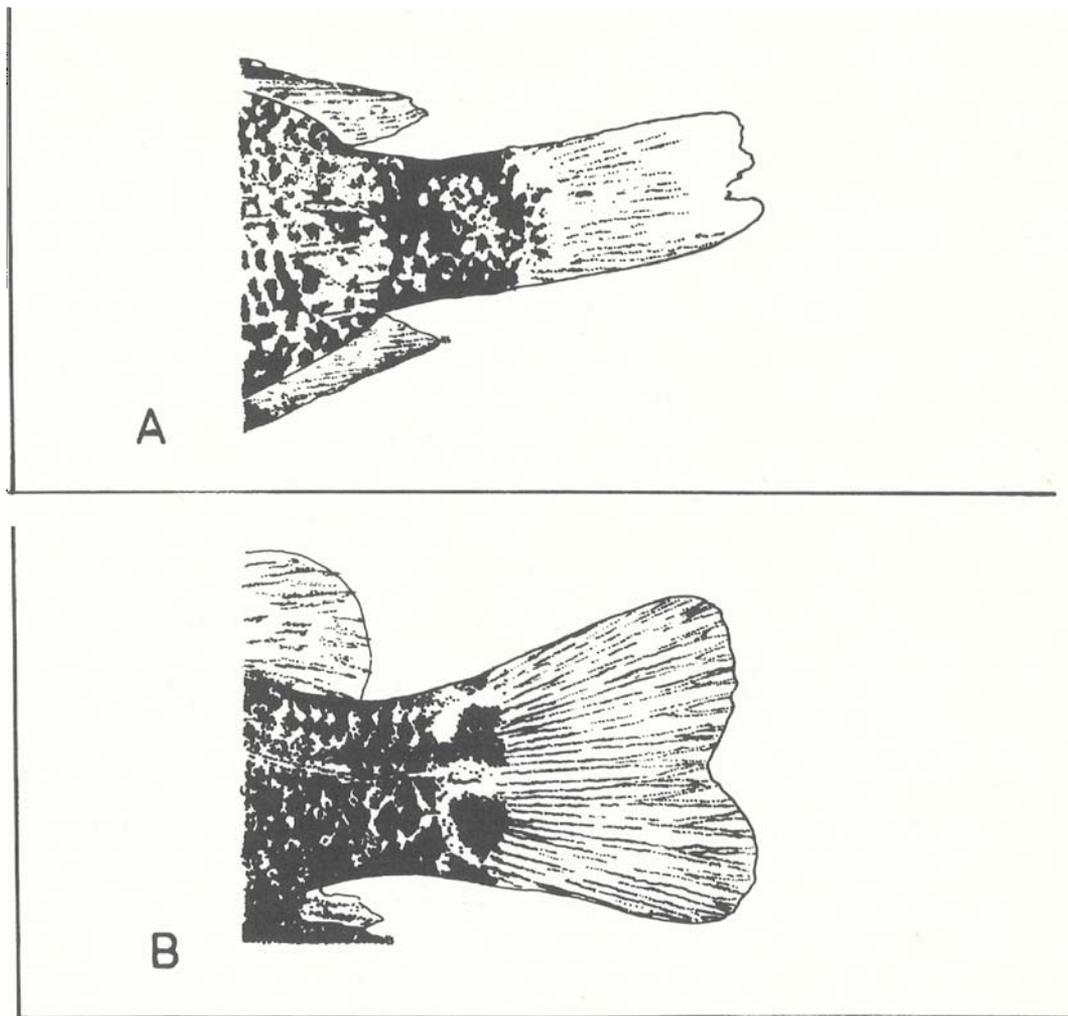
Figure 4. A) The juvenile pigment pattern (22 mm TL), and B) the final pattern on the caudal peduncle of rock bass, showing the two small squares.

hatched at 5.6 mm (TL). Ontario rock bass possessed a central oil globule, while those from Pennsylvania were characterized by a posterior oil globule (dimensions not given). The ventral and occipital melanophore patches were much denser in Pennsylvania rock bass, but their lateral yolk sac melanophores were less dense at comparable sizes (6.8 to 8.6 mm TL). First pigmentation occurred at 5.8 mm in Ontario fish and 6.8 mm in Pennsylvania prolarvae. Definitive patterns in pigment clustering were similar for both areas but took place at a larger size in Pennsylvania (8.6 mm as opposed to 7.5 mm in central Ontario). These sizes and sequences in pigmentation were consistent with the first appearance of the pelvic fins (9 mm for central Ontario and 10 to 11.0 mm for Pennsylvania). It is hoped that more and further details of such comparisons can be explored in the future.
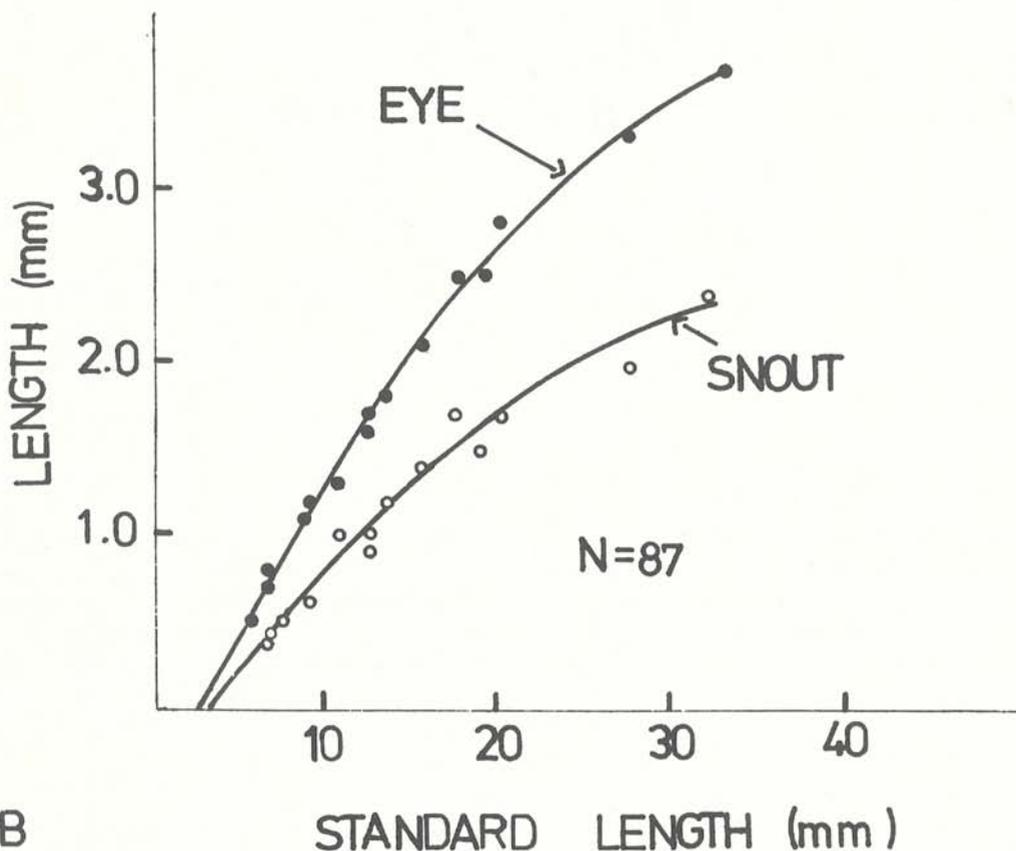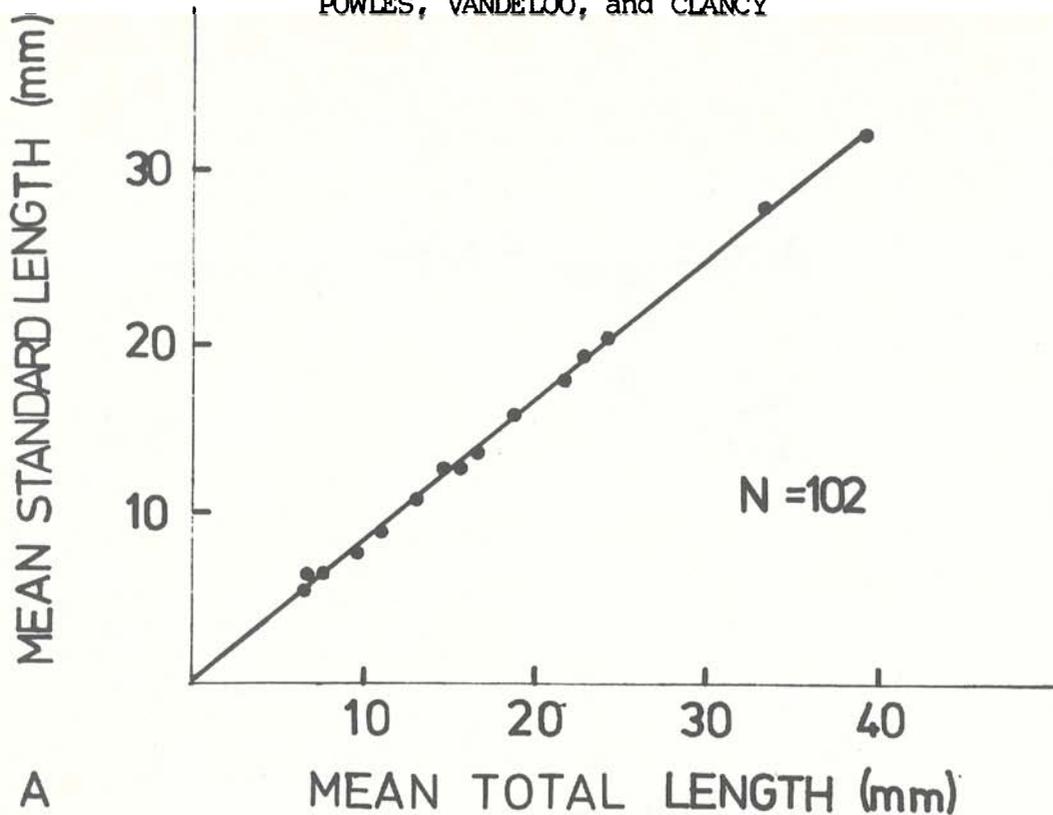
Figure 5. A) Relationship between standard length and total length in early larval to juvenile rock bass. B) Snout and eye diameter relationships to standard length. (Curves are fitted by eye.)

Table 1. Typical morphometric and meristic values (means in mm) of larval and postlarval *Ambloplites* *rupestris*, the common rock bass, from Chandos Lake, central Ontario, 1979.

| Sample size | Lengths | | | | | Fin rays | | | | |
	Total	Standard	Yolk	Head	Snout to vent	Dorsal	Caudal	Anal	Pectoral	Pelvic
8	4.9		2.5							
7	5.5		2.4							
2	6.4	5.5	2.5							
15	6.7	6.3	1.5	1.4	3.0					
15	7.4	6.3	1.5	1.7	3.1	9.0	17.0	8.2		
24	7.6	6.5	1.3	2.0	3.1	9.0	18.0	9.5		
7	9.5	7.8		2.6	4.3	IX,9.0	17.0	V,9.5		
4	11.0	9.0		3.2	5.6	IX,10.0	17.0	V,0		
3	13.0	10.7		3.6	6.4	XI,10.0	17.0	VI,10.0	6.5	
1	14.5	12.5		4.0	6.2	X,10	18	V,10	10	
4	15.5	12.6		4.3	6.4	XI,10.0	17.0	VI,10.0	11.0	4.5
2	16.5	13.3		5.2	7.6	XI,10.0	17.0	VI,10.0	11.0	4.5
2	18.5	15.8		6.8	8.4	X,12.0	17.0	VII,10.0	11.0	5.5
1	21.5	17.6		6.9	9.0	X,10	19	VI,10	12	I,5
2	22.5	19.0		7.5	9.6	X,10.0	19.0	VI,9.0	13.0	I,5
1	24.0	20.0		7.6	10.2	X,10	20	VI,9	13	I,5
2	33.0	27.5		10.3	14.0	X,10.0	20.0	VI,10.0	12.0	I,5.0

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COMPARATIVE DEVELOPMENTAL MORPHOLOGY OF THE CRAPPIES, POMOXIS ANNULARIS AND P. NIGROMACULATUS

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Abstract.- Lab-reared and wild-caught larvae of Pomoxis annularis and P. nigromaculatus from southeastern Louisiana are compared in terms of general morphology, pigment, and osteology. White and black crappie can be distinguished earliest as fully straightened yolk sac protolarvae (ca. 2.5 to 3.8 mm TL) by the position of the oil globule. In P. annularis the oil globule is generally in the posterior half of the yolk sac and in P. nigromaculatus the oil globule is centrally or anteriorly placed. From about 4.0 to 13.0 mm TL separation of the two species is possible on the basis of the distance from the posterior margin of the eye to the anteriormost portion of the swim bladder. This distance, when expressed in terms of total length, is greater than 15% in white crappie and less than 15% in black crappie. For larvae about 13.0 to 16.0 mm TL the only diagnostic character is the number of predorsal bones, which requires clearing and staining to observe. P. annularis has seven or more predorsal bones (rarely 6) and P. nigromaculatus has six or fewer. Larvae and early juveniles 16.0 mm TL and larger can be identified by using the ratio of dorsal fin length to the distance from the eye to the leading edge of the dorsal fin. Length of the dorsal fin is equal to or included in the eye to dorsal fin distance in white crappie, whereas the dorsal fin length in black crappie is always greater than the eye to dorsal fin distance. Sizes at which certain developmental milestones occur can aid in discriminating the two Pomoxis species. Certain inconsistencies with the literature are noted, emphasizing the need for comparative study and consideration of geographic variation.

The purpose of this work is to compare the posthatching developmental morphology of two closely related fishes of the family Centrarchidae, the white crappie, P. annularis Rafinesque, and the black crappie, P. nigromaculatus (LeSueur), from southeastern Louisiana. Since they are popular game fishes there is a wealth of information available comparing morphology, distribution, ecology, and spawning behavior of adults of both

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species (Trautman 1957, Hubbs and Lagler 1958, Scott and Crossman 1973, Pflieger 1975). Moran (1954) and Taber (1969) described the larvae of *P. annularis* and Faber (1963) the larvae of *P. nigromaculatus*. In addition, Siefert (1969) attempted to differentiate the two larvae. Despite these works, there remains no method by which the larvae and early juveniles of the two species can be reliably distinguished in southeastern Louisiana (Conner 1979) as well as in other parts of the United States (Hogue et al. 1976, Kindschi et al. 1979).

White and black crappie frequently occupy the same habitats within Louisiana (Douglas 1974). Also, their spawning seasons overlap and their nest site preferences are similar (Breder and Rosen 1966). These behavioral similarities, coupled with their morphological resemblance, have caused problems in recent ichthyoplankton surveys (Gallagher 1979, Hall 1979) due to the inability of the investigators to distinguish *Pomoxis* larvae.

In previous larval descriptions of white and black crappie, the fishes examined were either lab-reared or obtained from localized populations involving only one or two habitats. As a result, no consideration was given to morphological differences between lab-reared and natural populations, as found in *Etheostoma* (Strawn 1961), or variation due to differing environments as found in *Micropterus* (Bryan 1969). Morgan (1954), Faber (1963), and Taber (1969) stressed different characters, limiting the usefulness of their larval descriptions for the purpose of distinguishing the two species. Siefert (1969) attempted the only comparative study and it was limited because only a single genetic stock was used. For these reasons we have done a comparative study of the two species using lab-reared and wild-caught specimens, with the latter collected from several localities including a wide range of habitats.

MATERIALS AND METHODS

LAB-REARED LARVAE

Ripe *P. annularis* and *P. nigromaculatus* were collected by electro-fishing at two sites in the Mississippi River, near St. Francisville and near St. Gabriel, during March 1979. Trauma in the shocked fishes was minimized by using pulsed direct current. Ripe adults were transported to the lab and after temperature acclimation (from approximately 16 to 20 C) males and females of each species were paired in 85-liter aquaria. Characters used for sexing the fishes were the distended abdomen of females and profuse black pigmentation on the opercles and in the pelvic region of males. Photoperiod in the lab was maintained at 14 h of light daily. After the fishes became accustomed to laboratory conditions (3 to 5 days), females were injected intraperitoneally with 2 mg lutenizing hormone (LH). Both species spawned within 24 hours. After spawning, females were removed from the aquaria but the males were left to fan the eggs until hatching. Approximately 50 larvae were removed every 6 h for the first 2 days posthatching and every 8 h thereafter. Larvae were fixed in 10% buffered formalin and later transferred to 3 to 5% buffered formalin.

Both species developed normally until yolk absorption, when all larvae died. The cause of mortality was probably our inability to present a suitable food. White crappie lived 7 days posthatching and reached a total length (TL)
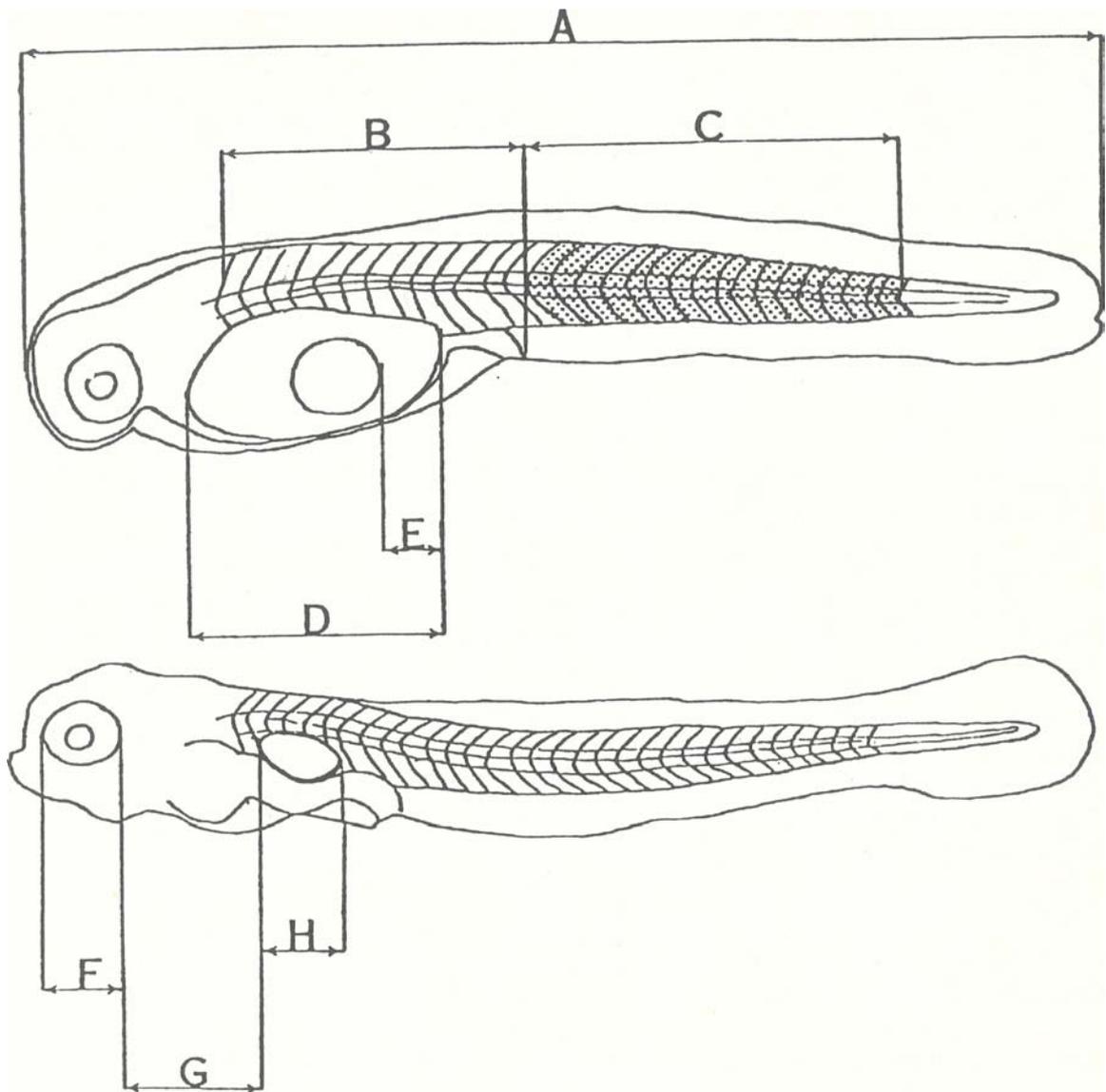
Figure 1. Morphometric and meristic characters for typical yolk sac protolarvae and late protolarvae. (A-total length, B-preanal myomeres, C-postanal myomeres, D-yolk sac length, E-oil globule to yolk sac distance, F-eye diameter, G-eye to swim bladder distance, and H-swim bladder length.)

of about 4.4 mm. Black crappie lived 9 days and reached 4.1 mm. Larvae removed in the last 24 h prior to mortality were not used for study purposes due to their emaciated condition. Measurements were made on 140 white crappie from 2.2 to 4.2 mm TL and 139 black crappie from 2.3 to 4.0 mm TL.

WILD-CAUGHT LARVAE AND JUVENILES

All wild-caught larvae, from samples in the fisheries collection of the School of Forestry and Wildlife Management, Louisiana State University, were collected in the following locations in southeastern Louisiana: Mississippi River and tributaries near St. Francisville; Simmesport, Ramah, and Bayou Petite Prairie within the Atchafalaya Basin; and Angola Lake near Angola. Collections were made in the spring of 1 or more years from 1972 to 1979. The species, numbers, and size ranges of larvae examined from each location were as follows:

	P. annularis	*P. nigromaculatus*
St. Francisville	120 (4.4-20.9)	61 (4.3-15.2)
Atchafalaya Basin	110 (4.1-20.9)	80 (4.4-19.7)
Angola Lake	54 (4.1-11.0)	2 (7.4-7.5)
Total	284 (4.1-20.9)	143 (4.3-19.7)

Identifications of wild-caught larvae were tentative. However, by working forward and backward from known yolk sac protolarvae and juveniles, respectively, we were able to develop continuous series.

Juvenile white and black crappie from seven rivers in the south central United States were examined for osteological differences. They were obtained from the Museum of Natural History, Tulane University, as well as from the fisheries collection of the School of Forestry and Wildlife Management, Louisiana State University.

MORPHOLOGICAL OBSERVATIONS

Terminology for developmental phases follows Conner (1979), however we found further subdivision within the protolarval phase appropriate:

1) Yolk sac protolarvae- from hatching until discrete bulbous yolk mass is no longer apparent.

2) Late protolarvae- with no yolk sac (scattered remnants of yolk may persist) and no complete caudal rays.

3) Early mesolarvae- with at least one complete caudal ray but fewer than the adult complement (17) of principal caudal rays.

4) Late mesolarvae through early juveniles- with adult complement of principal caudal rays.

Measurements (Figs. 1 and 2) were made to the nearest 0.01 mm with an ocular micrometer mounted in a stereo-zoom dissecting microscope, according to Hardy (1978), with the following additions:
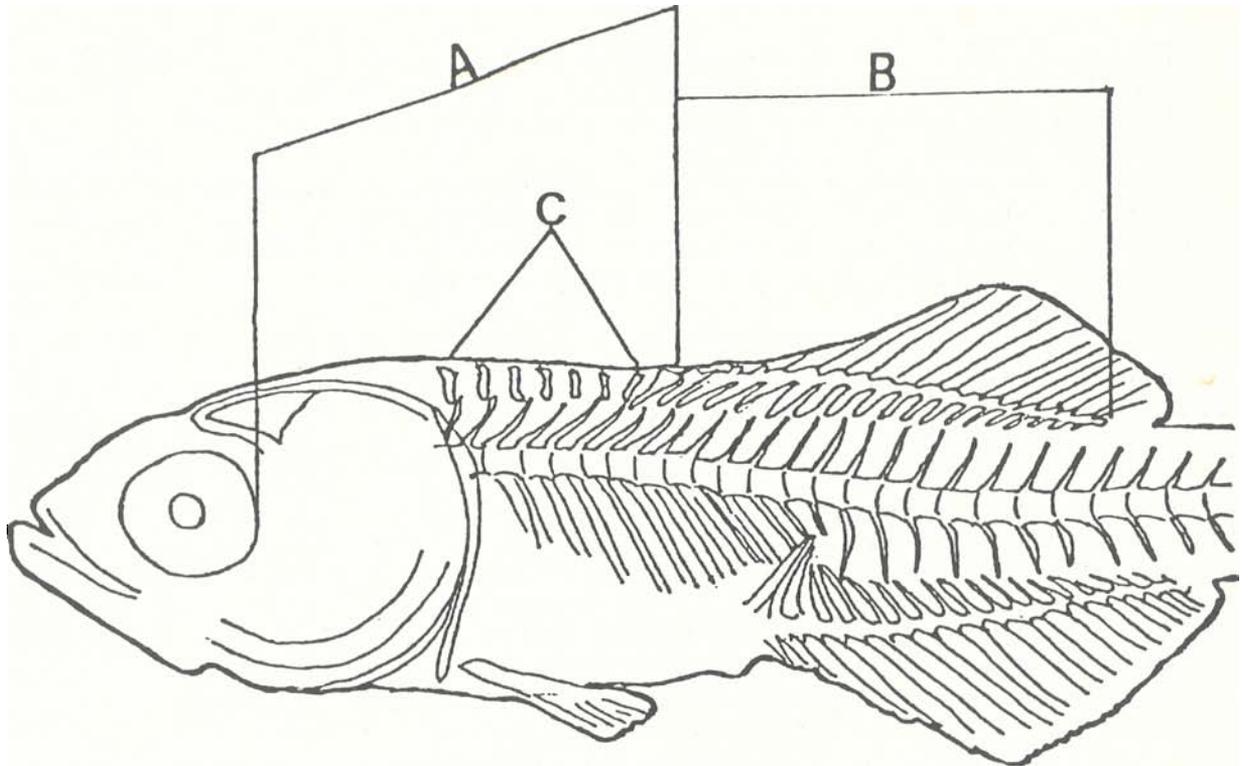
Figure 2. Morphometric and meristic characters for late mesolarvae through early juveniles. (A-eye to dorsal fin distance, B-dorsal fin length, C-predorsal bones.)

1) Yolk sac length- longest anterior to posterior dimension.

2) Oil globule to yolk sac distance- posterior margin of oil globule to posteriormost portion of yolk sac.

3) Eye diameter- greatest diameter of pigmented portion of eye.

4) Eye to swim bladder distance- posterior margin of eye to anteriormost portion of swim bladder.

5) Swim bladder length- longest anterior to posterior dimension.

6) Dorsal fin length- origin of dorsal fin fold or first dorsal spine to base of posteriormost dorsal ray.

7) Eye to dorsal fin distance- posterior margin of eye to origin of dorsal fin fold or first dorsal spine.

All specimen sizes are total length unless stated otherwise.

Observations were also made of several meristic characters (Figs. 1 and 2). Preanal, postanal, and total myomere counts were made according to Siefert (1969). Myomeres were not counted, however, for the smallest yolk sac larvae due to the faintness of myosepta and for some early juveniles due to

the opacity of the flesh. Complete dorsal and caudal rays and dorsal spines were counted. Number of predorsal bones, caudal vertebrae, and total vertebrae were recorded from x-rayed and cleared and stained fishes.

Pigment on the head, visceral mass, and ventrolateral region was recorded as present or absent. Since most of the larvae examined were wild-caught and had been preserved for different lengths of time, the state of pigmentation was highly variable. Thus, we were careful not to draw specific conclusions concerning pigmentation.

Developmental series of both species were drawn using a Bausch and Lomb Microprojector according to Buynak and Mohr (1978). The larger, more opaque specimens were partially cleared with a 5% KOH solution prior to drawing.

Osteological development was followed by means of differential staining of cartilage and bone and subsequent clearing of tissue. Alcian blue and alizarin red, stains specific for cartilage and bone, respectively, were used according to the methods given by Fritzsche and Johnson (1979). Osteology of the two species was further compared by x-radiography of juveniles. For this purpose a Philips-Norelco industrial x-ray machine with long-wave capabilities was used according to techniques given by Miller and Tucker (1979).

Computer programs based on Statistical Analysis System (SAS) of Barr et al. (1976) were used to perform stepwise regression analysis of morphometric data. Regression lines were plotted and compared when the coefficient of determination (r^2) was greater than 0.80.

RESULTS AND DISCUSSION

Our comparative studies indicate that black and white crappie are superficially similar throughout most of their larval development. In fact, there is no single character that will reliably separate them throughout all larval phases. It is necessary to use different characters depending upon developmental phase or size of the larva.

In fully straightened yolk sac protolarvae prior to appearance of the swim bladder (about 3.5 to 3.7 mm), it is usually possible to recognize the species by the position of the oil globule. The oil globule in P. annularis is most often in the posterior half of the yolk sac and in P. nigromaculatus it is centrally or anteriorly placed (Fig. 3). Separation of yolk sac protolarvae <4.0 mm is tenuous due to occasional variation in oil globule position. However, it should be noted that Pomoxis larvae less than 4.0 mm are seldom caught during conventional ichthyoplankton sampling. This was reported by Conner (1979) for sunfishes in general and is reflected in the lower size limits of wild-caught material in our study.

At about 4.0 mm the swim bladder is distinct and the eye to swim bladder distance will separate the species. The distance, when expressed as percent total length, is greater than 15% in white crappie and less than 15% in black crappie (Fig. 4). This character is diagnostic to approximately 12.5 mm, at which size both species are well into the late mesolarval phase.

YOLK SAC PROTOLARVAE

3.47 mm   P. annularis

3.42 mm   P. nigromaculatus

LATE PROTOLARVAE

7.05 mm   P. annularis

6.98 mm   P. nigromaculatus

EARLY MESOLARVAE

8.71 mm   P. annularis

8.80 mm   P. nigromaculatus

LATE MESOLARVAE/EARLY JUVENILE

12.38 mm   P. annularis

12.42 mm   P. nigromaculatus
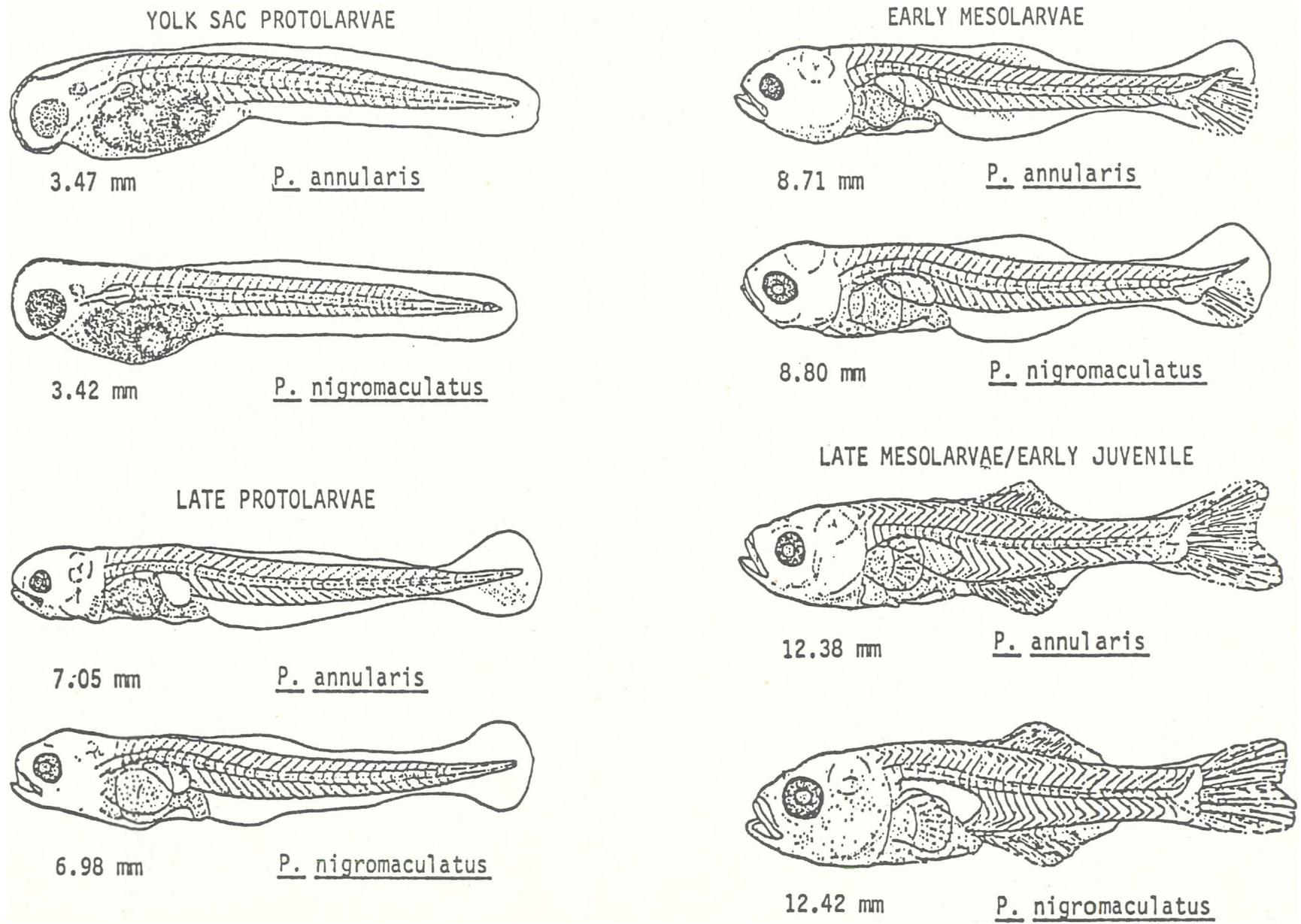
Figure 3.   Representative _Pomoxis_ larvae.
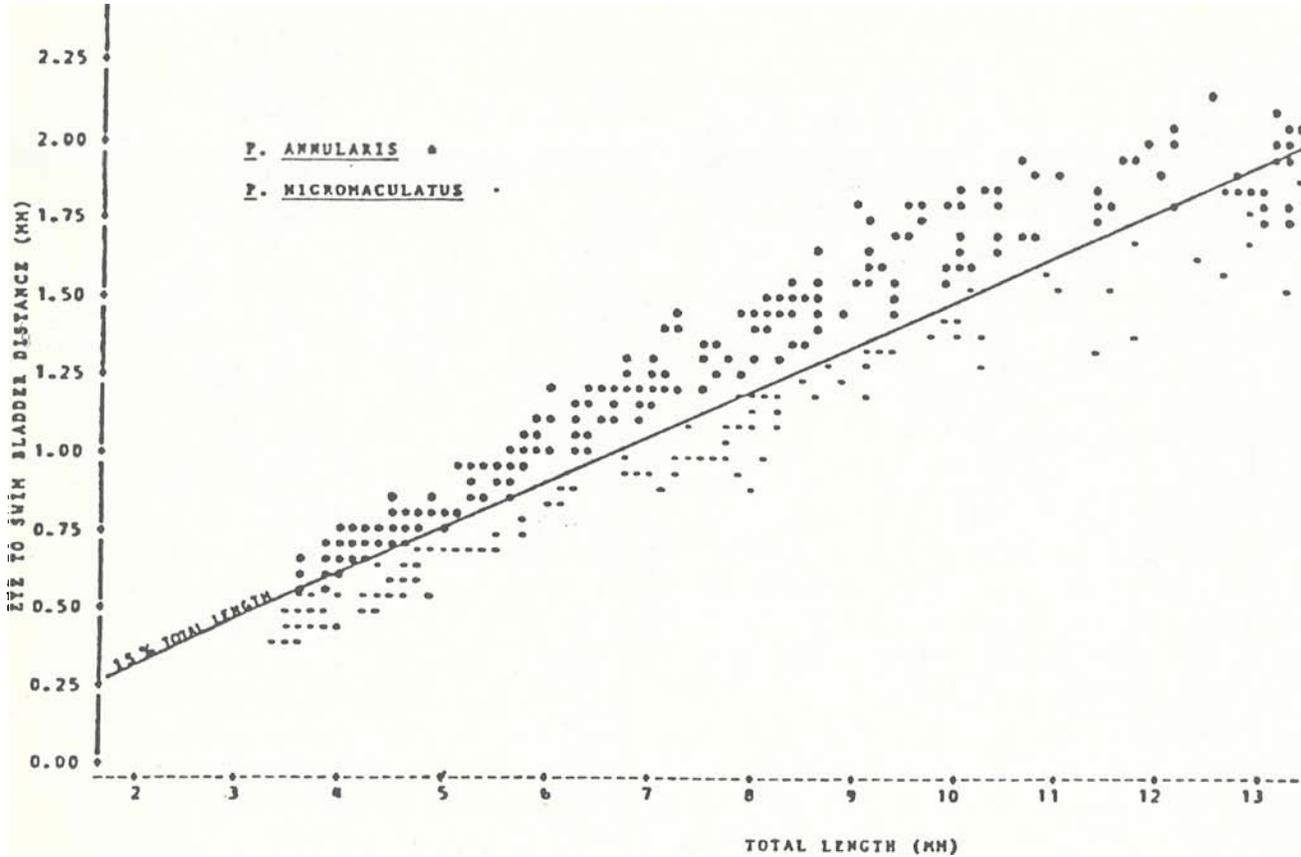
Figure 4. Regression of eye to swim bladder distance on total length for *Pomoxis annularis* and *P. nigromaculatus*. Line represents 15% total length.

There is no reliable external character for the separation of white and black crappie during much of the late mesolarval phase (about 13.0 to 16.0 mm). If such larvae are cleared and stained, however, there is almost complete separation based on the number of predorsal bones. *P. annularis* has seven or more (rarely six) and *P. nigromaculatus* has six or fewer (Table 1). Dorsal spines, caudal vertebrae, and total vertebrae are less reliable as diagnostic characters than is number of predorsal bones (Table 1).

Larval and early juvenile crappies 16.0 mm and larger can be identified using the ratio of dorsal fin length to the eye to dorsal fin distance. Length of the dorsal fin is equal to or less than the eye to dorsal fin distance in *P. annularis* and always greater than the eye to dorsal fin distance in *P. nigromaculatus*. Therefore a larva or early juvenile over 16.0 mm, having a fin length/eye to fin distance ratio of one is *P. annularis*. Note that in larger juveniles and adults such a specimen would be identified as *P. nigromaculatus* (Trautman 1957).

In addition to the usually diagnostic characters discussed above, differences in rates of development can aid in discriminating the two *Pomoxis* species. Sizes at which certain developmental milestones occur depend upon

Table 1. Frequency distribution of selected skeletal counts of juvenile Pomoxis from seven rivers in the south central United States.

	Dorsal spines						Caudal vertebrae				Total vertebrae				Predorsal bones			
	5	6	7	8	9	10	17	18	19	20	31	32	33	34	5	6	7	8
P. annularis																		
Mississippi		17					3	14			3	14				2	15	
Atchafalaya	1	48	1				1	46	3		1	47	2			50		
Neches	1	41	1					42	1			42	1				42	1
Pearl		19	1					20				20					20	
Alabama		4	1					5				5					5	
Arkansas		29					1	27	1		1	27	1				29	
P. nigromaculatus																		
Mississippi			23	14	1	1		11	27	1		13	25	1	3	36		
Atchafalaya			23	3				1	21	4		3	23			26		
Neches			6	1				3	4			3	4			7		
Pearl			15	3				1	17			1	17			18		
Alabama			12	12				8	14	2		17	7			24		
Ouachita			6	4					10			1	9			10		
Totals																		
P. annularis	2	159	4				5	155	5		5	156	4			2	162	2
P. nigromaculatus			85	37	1	1		24	93	7		38	85	1	3	117		

the species (Table 2.). These differences in rates of development are not constant between the species but rather depend upon the structure in question. For example, P. annularis tends to have a complete caudal ray, caudal fin, and dorsal ray at smaller sizes. On the other hand, the swim bladder and the fifth dorsal spine tend to appear at smaller sizes in P. nigromaculatus.

Our observations of developmental rates are contrary to those of Siefert (1969) who found that black crappie consistently attained fin structures at a smaller size than white crappie. We also witnessed greater variability and overlap in myomere counts than did Siefert (1969). In fact, we only found strong modal differences in late mesolarval through early juveniles (Table 3). Thus, Siefert's widely used character for separation of Pomoxis species (Anjard 1974, Hardy 1978) is unreliable in southeastern Louisiana. These inconsistencies emphasize the importance of considering geographic variation when developing identification criteria, as noted by Conner (1979).

Table 2. Developmental changes in _Pomoxis_ larvae. (SD^{50} represents the actual size interval in which a structure appeared or disappeared in more than 50% of specimens examined; parenthetic numbers are actual percentages having or lacking the structure.)

Structure	Size range involved in structural changes	Number of fish in each range	Minimum TL at which structure developed	Maximum TL at which structure not developed	SD^{50}
P. annularis					
Yolk sac	4.00-4.39	30	4.08[a]	4.30[b]	4.30-4.39 (66)
Swim bladder	3.60-3.99	44	3.65	3.91	3.90-3.99 (86)
Caudal rays	7.00-7.99	22	7.31	7.50	7.00-7.99 (56)
Complete caudal fin	9.00-10.99	41	9.32	10.61	10.00-10.99 (80)
Dorsal rays	9.00-10.99	41	9.84	10.35	10.00-10.99 (80)
Five dorsal spines	13.00-15.99	34	13.20	15.69	15.00-15.99 (90)
P. nigromaculatus					
Yolk sac	3.50-3.89	78	3.58[a]	3.85[b]	3.80-3.89 (71)
Swim bladder	3.40-3.79	84	3.41	3.74	3.60-3.69 (93)
Caudal rays	7.00-8.99	39	7.74	8.00	8.00-8.99 (95)
Complete caudal fin	10.00-11.99	12	10.96	11.55	11.00-11.99 (83)
Dorsal rays	10.00-10.99	6	10.18	10.86	10.00-10.99 (66)
Five dorsal spines	12.00-14.99	18	12.59	14.52	14.00-14.99 (85)

[a]Minimum length at which yolk disappeared.
[b]Maximum length at which yolk persisted.

The criteria we have outlined for separation of _P. annularis_ and _P. nigromaculatus_ makes possible positive identification of most specimens throughout their larval development. As a result, differences in the ecology of the two larval forms can now be better understood. For example, in all of the locations from which larvae of both species were obtained during the same year, black crappie were consistently earlier and white crappie later. Also, judging from the scarcity of black crappie in our samples, _P. nigromaculatus_ may be less likely to occur near the surface in pelagic areas. This was supported by the behavior of the lab-reared crappie because _P. nigromaculatus_ were more substrate oriented than were _P. annularis_.

Table 3. Frequency distribution of myomere counts of larval and early juvenile _Pomoxis_.

	Preanal myomeres						Postanal myomeres							Total myomeres							
	9	10	11	12	13	14	17	18	19	20	21	22	23	28	29	30	31	32	33	34	35
Yolk sac protolarvae																					
P. annularis	1	18	28	10			5	26	27	8	1			1	5	30	29	4			
P. nigromaculatus	2	32	29	4				7	26	27	6	1				18	31	16	2		
Late protolarvae																					
P. annularis	27	45	32	9			1	10	22	37	36	4		4	9	16	31	27	11		
P. nigromaculatus	1	20	38	31	1				5	9	43	24	9			1	27	41	30	8	2
Early mesolarvae																					
P. annularis		19	32	9			1	8	26	22	4	1			1	15	24	18	5		
P. nigromaculatus	1	5	16	7					2	11	11	4	2				4	13	8	3	1
Late mesolarvae-early juveniles																					
P. annularis		3	16	21	3		17	19	9	4					3	18	16	4	1		
P. nigromaculatus		8	7	2					9	9	1					2	10	3	2		

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A COMPARISON OF LARVAL COTTUS BAIRDI AND COTTUS COGNATUS FROM SOUTHEASTERN LAKE MICHIGAN.[1]

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Abstract.- Larvae of Cottus bairdi (8.1 to 14.7 mm) and Cottus cognatus (6.6 to 14.4 mm) from southeastern Lake Michigan are described and morphometric and meristic characters compared. All C. bairdi larvae have five pelvic fin elements. At comparable lengths, C. cognatus larvae have four pelvic fin elements. Although less reliable, other characters useful in distinguishing larvae of C. bairdi and C. cognatus include: anal fin ray count, dorsal fin ray count, and degree of separation of first and second dorsal fins. Our study suggests that an initial investigation of the stability of meristic characters of adult C. bairdi and C. cognatus in any locality is necessary before the aforementioned distinguishing characters can be applied to identification of larval fishes. Larvae of these two species can be readily distinguished from C. carolinae and Myoxocephalus quadricornis by myomere count.

The mottled sculpin, Cottus bairdi Girard, and the slimy sculpin, Cottus cognatus Richardson, are widely distributed in northern North America and exhibit many areas of distributional overlap (Scott and Crossman 1973). Both are common in the Lake Michigan drainage basin (Becker 1976). Deason (1939) found that in Lake Michigan the mottled sculpin inhabits "inshore marginal areas" and "mouths of shallow tributaries" while the slimy sculpin occurs near shore and to a depth of 50 fathoms (100 m).

As with many other members of the genus Cottus, relatively few studies have been published describing the early life history of mottled or slimy sculpin. Koster (1936) provided photographs, morphometric measurements, and descriptions of larval C. cognatus and two subspecies of mottled sculpin larvae, C. bairdi bairdi Girard and C. b. kumlieni Hoy from central New York. Khan (1971) described and illustrated 7.5 and 10.3 mm larvae of C. bairdi from a northern Wisconsin lake. He also presented convincing evidence that descriptions of C. bairdi presented in Fish (1932) actually may have been based on misidentified specimens. The most comprehensive study of the ecology of C. cognatus was performed by Van Vliet (1964) who presented photographs of 7.3 and 8.5 mm specimens. Previous studies have not attempted to determine

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[1] Contribution number 267, Great Lakes Research Division, University of Michigan.
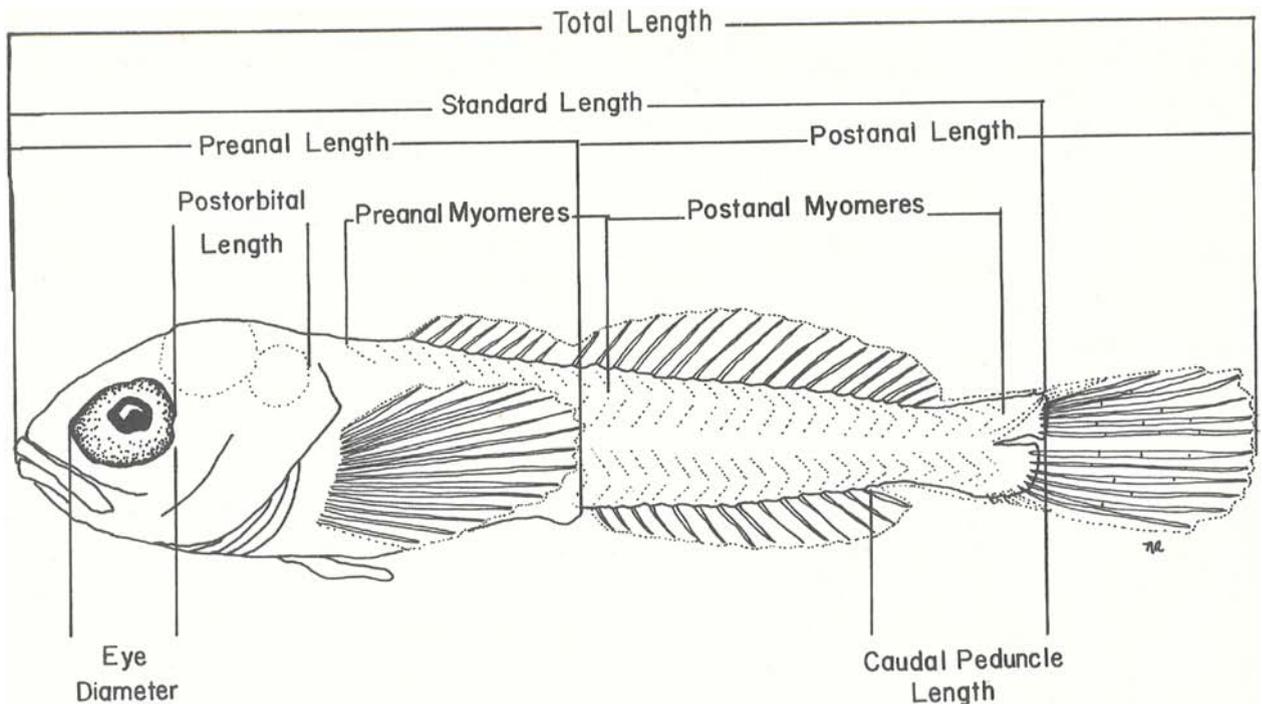
Figure 1. Morphometric and meristic characters examined for <u>Cottus</u> <u>bairdi</u> and <u>Cottus</u> <u>cognatus</u>.

diagnostic characters which could be used to identify the larvae of these species where they coexist. The present study reports preliminary findings of diagnostic characters which can be used to identify larval mottled and slimy sculpin from southeastern Lake Michigan.

MATERIALS AND METHODS

Larvae collected from the D. C. Cook Nuclear Power Plant (Bridgman, Michigan) and the J. H. Campbell Power Plant (Port Sheldon, Michigan) monitoring studies were preserved in 10% buffered formaldehyde solution and stored in the Great Lakes Research Division Fisheries Laboratory. Sculpin larvae were also recovered in entrainment samples at the Cook plant (unpublished data) and in sled tow samples at 6 to 15 m near the Campbell plant (unpublished data) during May to August 1979. Water temperatures at time of collection never exceeded 15 C. A mass of slimy sculpin eggs and the attending adults were recovered from inside a hollow log in a 12 m bottom trawl haul near the Campbell plant in May 1979. These eggs were incubated at 15 C and the larvae maintained for 7 days. All specimens were preserved in 10% buffered formaldehyde solution.

Specimens were referred to as larvae because vestiges of the median fin fold were present (Balon 1975, Snyder 1976). Larvae were examined with a stereo-microscope equipped with an ocular micrometer. Specimens were photographed using a Nikon EFM camera attached to an M-5 Wild microscope. Drawings of representative specimens were made using these photographs. In

order to accent certain features and to facilitate illustration, specimens were occasionally stained with Alizarin Red S or Lignin Pink and examined using polarizing filters. Morphometric and meristic characters examined (Fig. 1) include: total (TL), standard, preanal, postanal, head, postorbital, and caudal peduncle lengths; eye diameter (measured horizontally from the anterior to posterior margin of the iris); number of preanal and postanal myomeres (according to Siefert 1969, and Wallus and Granneman 1979), and number of fin elements.

RESULTS

Mottled sculpin in our study ranged from 8.1 to 14.7 mm TL while slimy sculpin ranged from 6.6 to 14.4 mm TL. Our results indicated complete yolk absorption in both C. bairdi and C. cognatus at lengths greater than 8.0 mm. At this time both species resembled the adult and possessed the full complement of adult fin elements. Pigmentation was well developed in specimens of this size with dorsal and lateral saddle markings present (Figs. 2 and 3).

A comparison of morphometric measurements of 8.1 to 9.6 mm larval mottled and slimy sculpin (Table 1) indicated no significant differences between these species. Examination of meristic data however, revealed some distinct differences (Table 2), particularly in the number of pelvic and anal fin elements. A comparison of pelvic fin elements (Table 3) permitted 100% separation of these two species. These elements were difficult to see due to branching near the point of attachment and proximity of the spine to the first ray. Clearing in 5% KOH and subsequent staining with Alizarin Red S revealed five elements (one spine and four rays) in mottled sculpin larvae and four elements (one spine and three rays) in slimy sculpin larvae. Examination of over 100 adult specimens from southeastern Lake Michigan confirmed that the complement of pelvic fin elements observed in 8.1 to 9.6 mm individuals was equal to that seen in the adult phase and that this character can be effectively used to separate 100% of both larval and adult specimens from this area.

Another character which helped to distinguish C. bairdi from C. cognatus for 90% of the specimens was the number of anal fin rays. C. cognatus had 12 anal fin rays whereas C. bairdi had 13 or 14. Only 2 of 17 C. cognatus examined had more than 12 anal fin rays and only 1 of 13 C. bairdi exhibited a low count (12 rays). Examination of adult specimens from the area confirmed the consistency of this character throughout the life of the fishes. Anal fin rays alone separated over 90% of adult specimens in southeastern Lake Michigan.

A comparison of the number of spines in the first dorsal fin (Table 2) also offered a fairly reliable character (80% separation) for distinguishing C. bairdi from C. cognatus. This character, however, is difficult to see in newly hatched larvae and its development closely coincides with the appearance of the more reliable pelvic fin ray elements. The second dorsal fin developed at approximately the same time as the anal fin and offered as much as 80% discrimination (Table 3). The degree of separation between the first and second dorsal fins can be used as a distinguishing feature as well (Figs. 2 and 3). These fins are broadly connected by a membrane in C. bairdi but are
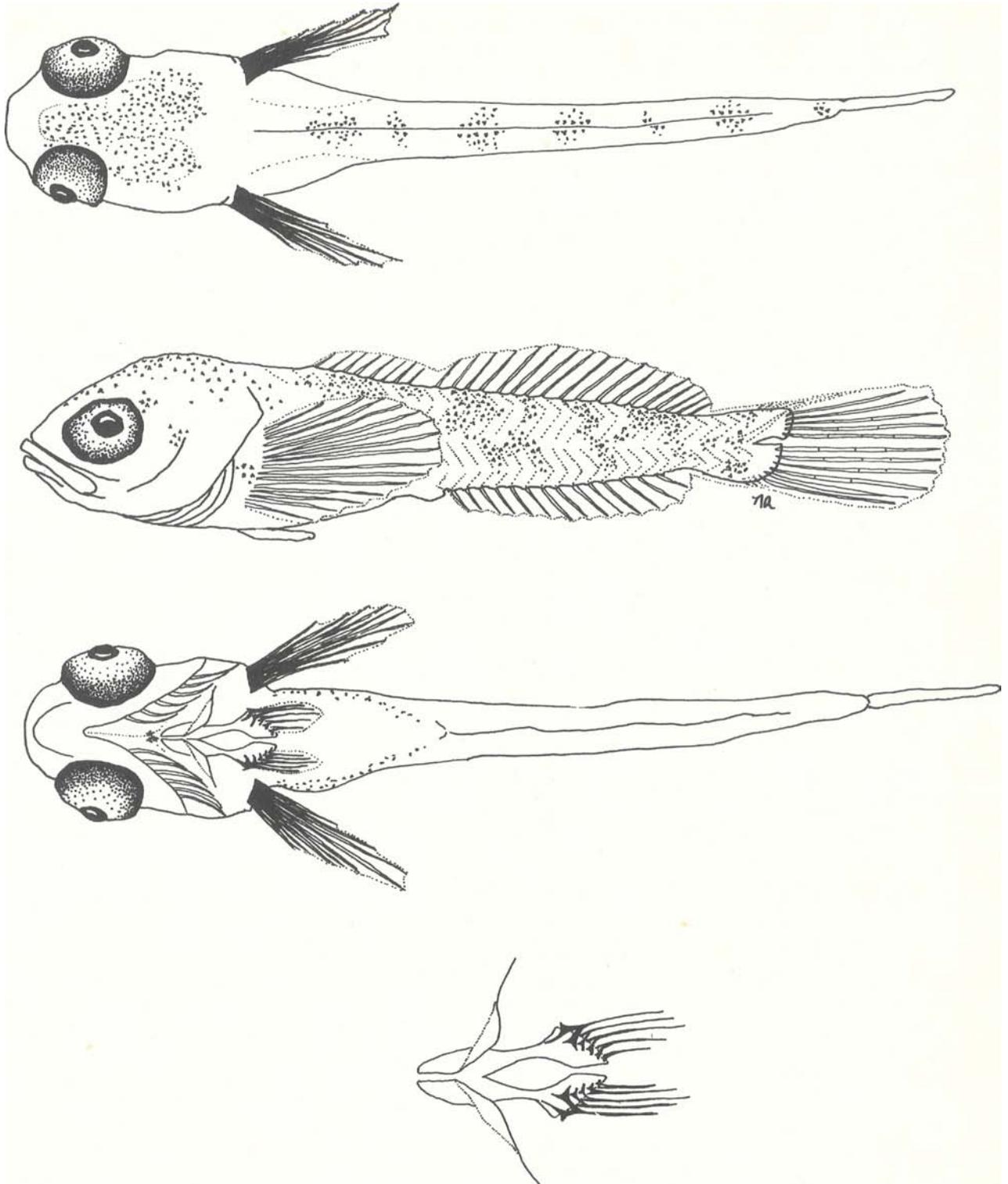
Figure 2. _Cottus bairdi_ (9.0 mm TL) dorsal (top), lateral (middle), and ventral views. Enlargement shows pelvic girdle with five elements.
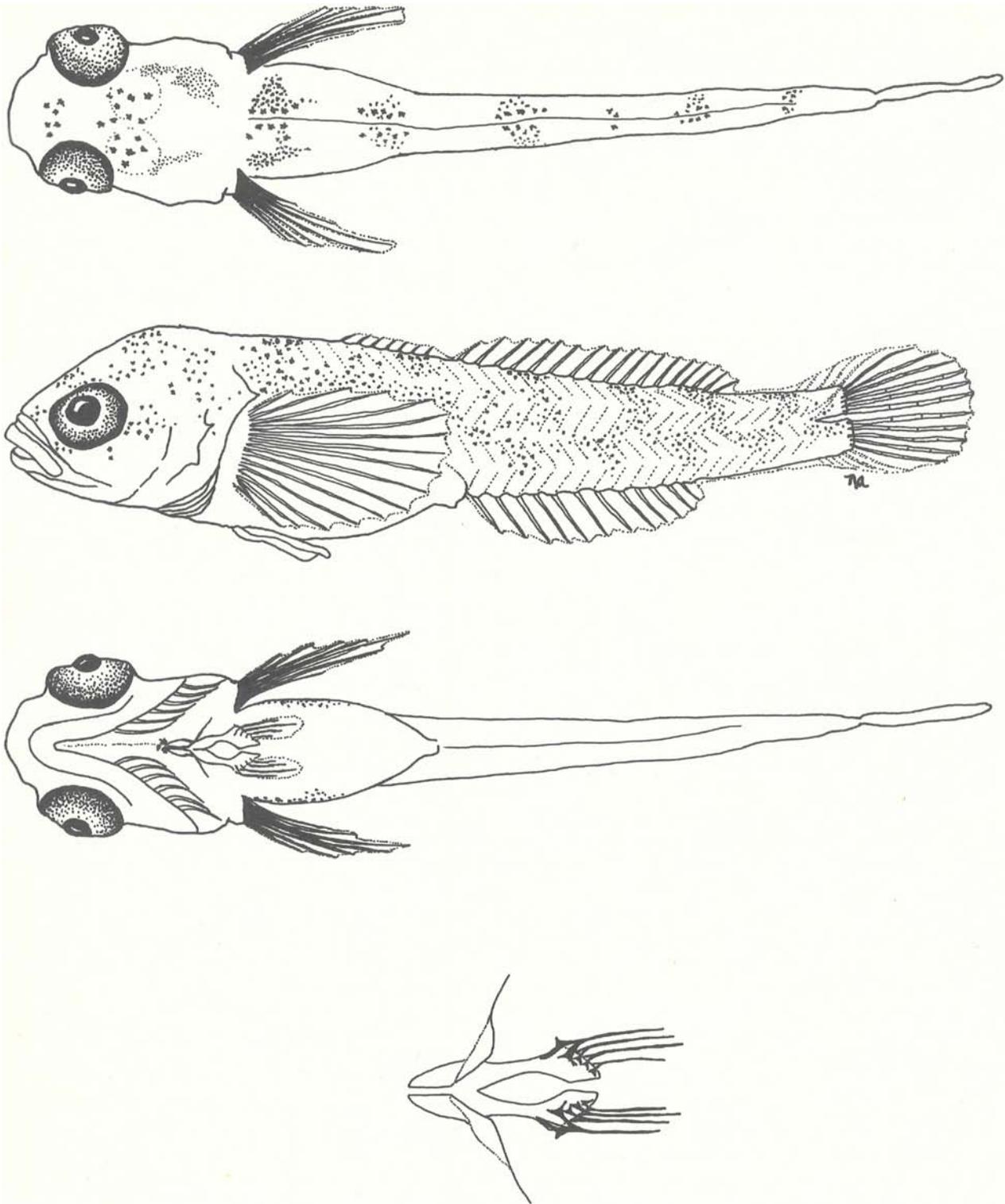
Figure 3. _Cottus cognatus_ (9.4 mm TL) dorsal (top), lateral (middle), and ventral views. Enlargement shows pelvic girdle with four elements.

Table 1. Selected morphometric measurements of larval Cottus bairdi and C. cognatus from southeastern Lake Michigan.

	Lengths (mm)						
	Total	Standard	Preanal	Post-orbital	Caudal peduncle	Head	Eye diameter
C. bairdi							
mean (N=6)	8.6	7.2	3.7	0.9	1.2	2.1	0.7
range	8.1–8.9	6.7–7.6	3.4–4.0	0.8–0.9	1.2–1.3	1.8–2.2	0.7–0.8
mean (N=6)	9.2	7.6	3.9	0.9	1.3	2.1	0.8
range	9.0–9.6	7.4–8.0	3.8–4.0	0.7–1.0	1.2–1.4	2.0–2.3	0.7–0.8
(N=1)	14.7	12.0	6.2	1.6	2.2	3.4	1.1
C. cognatus							
(N=1)	6.6[a]	5.4	2.7	0.5	1.1	1.2	0.4
(N=1)	7.9	6.9	3.4	0.8	1.6	1.8	0.6
mean (N=6)	8.6	7.2	3.7	0.8	1.4	1.9	0.7
range	8.3–8.9	7.0–7.5	3.5–4.0	0.8–0.9	1.2–1.6	1.6–2.1	0.5–0.8
mean (N=7)	9.2	7.7	4.0	0.8	1.4	2.1	0.8
range	9.0–9.4	7.2–8.4	3.5–4.5	0.7–1.0	1.3–1.5	1.7–2.3	0.7–0.8
(N=1)	11.2	9.0	4.7	1.0	2.0	2.3	0.9
mean (N=2)	14.4	12.1	6.6	1.2	2.1	3.1	1.1
range	14.3–14.4	11.9–12.2	6.4–6.7	1.1–1.2	1.9–2.2	3.0–3.2	1.0–1.1

[a] laboratory reared larva.

almost completely separate in C. cognatus. Preanal and postanal myomere counts do not allow for separation of these two species with an acceptable degree of reliability.

DISCUSSION

The absence of earlier developmental stages of C. bairdi and C. cognatus in our collections was probably due to the tendency of newly hatched larvae to remain in or around the protected nests until the yolk was absorbed (Koster 1936). In contrast to findings of Koster (1936), which indicated that yolk was approximately half absorbed in 8.7 mm C. bairdi and 8.8 mm C. cognatus,

Table 2. Selected meristic characters of larval Cottus bairdi and C. cognatus from southeastern Lake Michigan.

	Total length (mm)	Myomeres		Fin rays					
		Preanal	Postanal	First dorsal	Second dorsal	Anal	Caudal	Pectoral	Pelvic
C. bairdi									
mean (N=6)	8.6	9.7	20.3	8.2	17.5	13.5	12	15	5
range	8.1-8.9	9-10	19-21	8-9	17-18	13-14	12	15	5
mean (N=6)	9.2	10.7	20.2	7.7	17.7	13.2	12	14.8	5
range	9.0-9.6	9-12	20-21	7-8	17-18	13-14	12	14-15	5
(N=1)	14.7	11	20	8	16	12	12	13	5
C. cognatus									
(N=1)	6.6[a]	10	20	7	16	11	12	12	3
(N=1)	7.9	11	19	7	17	12	12	14	4
mean (N=6)	8.6	11.2	19	7	15.8	11.5	12	13.7	3.8
range	8.3-8.9	9-12	19	7	15-17	10-13	12	12-15	3-4
mean (N=7)	9.2	11.1	19.5	7.0	16.2	12.2	12	14.9	4
range	9.0-9.4	10-12	19-20	6-8	16-17	12-13	12	14-15	4
(N=1)	11.2	13	20	8	17	12	12	15	4
mean (N=2)	14.4	11.0	19.5	7.5	16.0	11.5	11.5	14.5	4.0
range	14.3-14.4	11	19-20	7-8	15-17	11-12	11-12	14-15	4

[a]laboratory reared larva.

our results show complete yolk absorption and indication of active feeding by approximately 8.0 mm in both species. It is possible that temperature differences could be responsible for differential rates of yolk absorption.

The extent of pigmentation found on our specimens closely corresponds to that reported elsewhere. Khan (1971) observed prominent saddle markings on 7.5 mm C. bairdi, as did Koster (1936) on 8.0 mm larvae. Koster (1936) indicated that upon hatching only a few melanophores were present on the head and one large melanophore was on the right side of the yolk near the vent of a 6.9 mm specimen. Thus pigmentation develops rapidly in C. bairdi; the characteristic saddle markings present by the time of yolk absorption. A similar rate of pigment development probably occurs in C. cognatus because an

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Table 3. Frequency distribution of meristic characters of larval Cottus bairdi and C. cognatus from southeastern Lake Michigan.

	Fin rays														
	First dorsal				Second dorsal				Anal					Pelvic		
	6	7	8	9	15	16	17	18	10	11	12	13	14	3	4	5
C. bairdi		2	10	1		1	5	7			1	8	4			13
C. cognatus	1	13	3		3	9	5			1	4	10	2		2	15
% Separation	83				80				90					100		

	Myomeres							
	Preanal					Postanal		
	9	10	11	12	13	19	20	21
C. bairdi	3	5	4	1		1	8	4
C. cognatus	1	3	7	6	1	11	6	
% Separation	71					77		

8.5 mm specimen photographed by Van Vliet (1964) exhibited prominent saddle markings similar to our 7.9 mm specimen. We also examined a newly hatched laboratory reared specimen of C. cognatus (6.4 mm) which had few melanophores on the top of the head, similar to a recently hatched (7.2 mm) C. cognatus described by Koster (1936).

Although newly hatched larvae of both species could not be obtained for comparison, our results comparing later larval stages could have important implications in distinguishing yolk sac larvae of C. bairdi and C. cognatus. The fact that anal fin ray counts offered as high as 90% reliability in separating C. bairdi and C. cognatus in late larval and adult stages in southeastern Lake Michigan may be extremely important. Among laboratory reared C. cognatus, incipient anal fin rays (actinotrichia) corresponding to the number of anal fin rays in adult forms were present in one day old larva (6.4 mm) when pelvic fin formation was restricted to buds. If comparable development occurred in C. bairdi and C. cognatus in their natural habitats, separation of these early life stages could be correctly performed for approximately 90% of the specimens using anal fin ray counts alone. Evidence of incipient anal fin ray development in yolk sac stages of C. bairdi is given by Koster (1936).

C. bairdi and C. cognatus are closely related, both belonging to the bairdi species group (Bailey and Bond 1963). Variability in meristic characters of both species throughout their range has often resulted in difficulties in identification of adults (Scott and Crossman 1973). McAllister (1964) could find only one diagnostic character for separating C. bairdi and C. cognatus in all cases. He reported that caudal peduncle length was always less than the postorbital length in C. bairdi and always more in C. cognatus. Our examination of this ratio in larval sculpin indicates that caudal peduncle length was greater than postorbital length in larvae of both species.

A review of geographic variability as well as a description of Cottus hubbsi (=bairdi) was presented by McAllister and Lindsey (1959). Their study of adult sculpin suggests that in parts of their ranges, other than the Lake Michigan drainage basin, a knowledge of adult meristic variability may be necessary for the successful differentiation of larval stages.

Within the Lake Michigan drainage there are two additional cottids. Cottus ricei (Nelson), the spoonhead sculpin, is uncommon in Lake Michigan and is absent from the southern tip of the lake (Becker 1976). Fish (1932) described and illustrated a 27.5 mm specimen from Lake Erie. There have been no other published descriptions of juvenile or larval C. ricei. Specimens of Myoxocephalus quadricornis, the fourhorn sculpin, from Lake Michigan were described by Khan and Faber (1974) and can be most easily distinguished from C. bairdi and C. cognatus by their more elongate appearance and greater number of myomeres. M. quadricornis has 33 to 43 myomeres with 28 to 32 myomeres in mottled and slimy sculpin. Other differences between these two genera include: the later appearance of the first dorsal fin ray (14 to 16 mm), the later appearance of piscine myomeres (10 to 12 mm), and the absence of extensive lateral pigmentation in M. quadricornis at 8.0 to 10.0 mm.

Our study does not support Wallus and Granneman (1979) who suggest that differentiation of larval C. bairdi from C. carolinae (Gill) may be difficult based on comparatively similar developmental rates. Myomere counts of C. carolinae indicate a range of 15 to 17 preanal and 14 to 17 postanal (Wallus and Granneman 1979). Ranges reported here for C. bairdi are 9 to 12 preanal and 19 to 21 postanal, suggesting that this character can be used to distinguish these larvae.

SUMMARY

Larval C. bairdi and C. cognatus, 8.0 to 10.0 mm from southeastern Lake Michigan, are differentiated by pelvic fin ray count, anal fin ray count, and degree of separation of the first and second dorsal fins. Evidence presented suggests that an examination of adult meristic characters of these two species may be necessary to determine reliability of these characters in distinguishing larval forms in other geographic locations. Although C. ricei is sympatric, it rarely occurs in southeastern Lake Michigan. Currently late larval and juvenile C. ricei cannot be distinguished from those of C. bairdi and C. cognatus where their ranges overlap in the northern section of Lake Michigan and the rest of the Great Lakes because they have not been described.

Mottled and slimy sculpin can be separated from M. quadricornis (another sympatric species) by myomere count as well as by comparing the developmental rate of certain morphometric characters.

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OBSERVATIONS ON THE EARLY LIFE OF THE GOLDEN SHINER, NOTEMIGONUS CRYSOLEUCAS (MITCHILL), IN LAC HENEY, QUÉBEC

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Abstract.- Larvae of golden shiners were observed in a lake in Québec, Canada, from 17 June through 18 August 1979, when they appeared to be the dominant larvae in shallow bulrush bays. Golden shiners started their life in shallow water and moved progressively into deeper water as they grew. Small larvae (5 to 10 mm) were observed in the hyponeustonic zone, at the water's edge, and in deeper water with older larvae. After a length of about 10 mm, they developed schooling aggregations that remained stationary among emergent macrophytes in slightly deeper water. At an average length of 30 mm, golden shiners left the shallow littoral region and took up residence offshore among submerged macrophytes. It is suggested that the stationary aggregations of golden shiner larvae in littoral areas contribute toward ecologic isolation.

The golden shiner, Notemigonus crysoleucas (Mitchill), is a widespread species of minnow in North America (Scott and Crossman 1973) and is a valuable forage fish. Its early life history in the wild has not been well studied mainly because its larvae have been difficult to identify from among other Cyprinidae. During a summer's study of the larval fishes of Lac Heney, Quebéc, some of the movements and behavior of larval golden shiners in two areas of the lake were observed. Previous studies concerning spawning and early life of fishes in Lac Heney include Legault and Delisle (1967 and 1968), Delisle (1969), and Van Vliet and Qadri (1970).

There is increasing interest in the early life of fishes because of environmental concerns, but little detailed knowledge is available on the early life of most fishes. A considerable body of knowledge is available on spawning and associated activities of adult fishes (Breder and Rosen 1966, Balon 1975a) but little is known about the first few weeks following hatching. Most species disperse widely during this time in limnetic regions after hatching (Faber 1967, Werner 1969, Amundrud et al. 1974, Storck et al. 1978) but golden shiners, and other species, remain almost sedentary within littoral regions. These larvae might be termed "littoral larvae" in contrast to "limnetic larvae."

This paper is a portion of a larger study concerning the ecology of all larval fishes in Lac Heney. The results presented here provide information about the early life of golden shiners. They show that golden shiners start their larval life in shallow weedy regions next to shore and with growth they

move into deeper water. Early larvae were observed living in the hyponeustonic zone of shallow weedy bays, a unique habitat for fish larvae. Results also suggest that golden shiners were among the most stationary larvae in the lake. Carlander (1969) lists other information known about their early life in breeding ponds.

MATERIALS AND METHODS

Lac Heney is located 96.5 km north of Ottawa within a complex of lakes and rivers. Its known fish population of 24 species is considerably more than nearby lakes (0 to 12 species) in adjacent Gatineau Park (Rubec 1975). Lac Heney's ice cover varies from year to year but normally the surface freezes during December and breaks open during late April or early May. The surface water temperature regime over the deeper part of the lake in 1979 ranged from 0 C in late April to 27 C in late July and then to 20 C in August. During this summer the water level of Lac Heney gradually decreased about 70 cm, slightly changing the shoreline habitat.

From June to August 1979, two areas in Lac Heney were monitored weekly for the occurrence of fish larvae. One area on the north end of the lake (Fig. 1) was designated Lab Dock Study Area which extended abut 20 m on each side of the boat dock of the University of Ottawa's Biological Station. The other area, designated Estuary Study Area, was on the south end of the lake within an extensive shallow bay. At the south end of this bay was a river that led to another lake. In both study areas the dominating aquatic plants were bulrushes (Scirpus spp.) and floating water lilies (Nymphaea spp.). The numbers of stems of Scirpus varied considerably from area to area, but reached up to 500 stems/m^2 in several places.

Since larval fishes living in the littoral region were unable to be collected with tow nets, they were observed directly from a 4.25 m outboard motorboat. Normally larvae were visible with Polaroid glasses but sometimes a hand-held underwater viewer was used. Larval fishes were regularly collected alive with dip nets, identified in the field with a binocular microscope, and released, but occasionally samples were preserved in 10% formalin for later study. Field observations were made on behavior, local movements, morphological development, and larval co-habitants. A fright response was always apparent at the approach of the boat but this disappeared after a wait of several minutes. In addition, other methods of collection were used as a comparison, that is, towing a conical net (0.5 mm mesh) offshore in limnetic regions, setting out a small waterproof flashlight after dark, and quickly surveying all the bulrush bays in the lake to determine their widespread distribution.

RESULTS

Larvae of three of the four known cyprinids (bluntnose minnow, Pimephales notatus (Rafinesque); blackchin shiner, N. heterodon (Cope); and golden shiner) were collected by various means. Those of the blacknose shiner, N. heterolepis Eigenmann and Eigenmann, were never located although adults were captured in shoreline seine hauls. For this study, however, there can be no confusion about the identification of the larvae because golden shiners
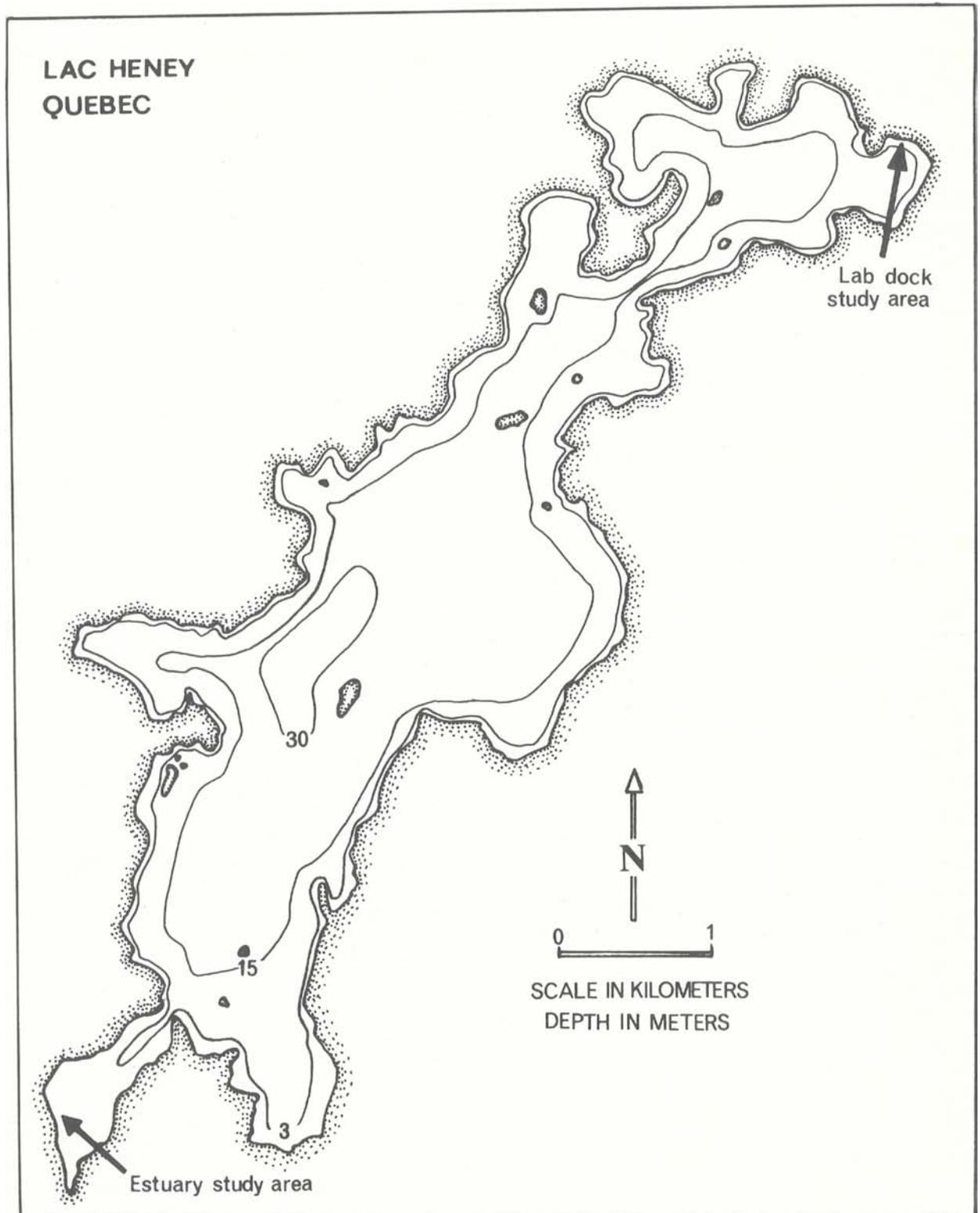
Figure 1. Hydrographic map of Lac Heney, Québéc, Canada, showing locations of the two study areas.

develop significantly more anal fin rays than do any of the others and possess a unique ventral line of melanophores. Some aspects of the larval development of the golden shiner have been presented by Fish (1932), Snyder et al. (1977), and Jones et al. (1978).

Golden shiner larvae were collected first on 17 June in the two study areas when they were 5.0 to 5.5 mm SL, had absorbed their yolk, showed distinct pigmentation, and were able swimmers. They were last observed at those sizes on 18 August. They were never collected with large yolk reserves, so it was surmised that golden shiner larvae remained on the lake bottom until most of their endogenous nutrition had been assimilated. Loos et al. (1979) indicate that they possess cement glands on their heads since they adhered to the walls of rearing chambers. Eggs were never observed during this study although it has been reported that they can be found on vegetation, on pebbles, and even in centrarchid nests (Loos et al. 1979). Quick surveys of all the bulrush bays throughout the lake suggested that larval golden shiners were ubiquitous in these bays and that they appeared to be the most abundant larval fish in the lake. Other species of fish larvae and juveniles were observed and captured in these littoral areas but not in such large numbers. Daytime and nighttime tows of conical nets in surface limnetic areas resulted in the collection of larval yellow perch, Perca flavescens (Mitchill); Iowa darter, Etheostoma exile (Girard); rainbow smelt, Osmerus mordax (Mitchill); and pumpkinseed, Lepomis gibbosus (Linnaeus) but not golden shiner. In experiments after dark, several different species of larval fishes, including golden shiners, were attracted to a small light, but adult or large juvenile golden shiners were never observed in the vicinity of the light. This suggests that golden shiners are positively phototaxic during certain periods of their life.

The time that golden shiner larvae and juveniles remained within the littoral region among the emergent macrophytes can be divided into two phases: a "shallow phase" when larvae occurred mainly near the surface or within a few centimeters of the edge of the lake and a "deep phase" when larvae occurred several centimeters below the surface in distinct schooling aggregations. There appeared to be no specific size as one phase finished and the other began, but instead a gradual transition. Sufficient time was not available to determine an exact length-frequency relationship between the two phases. During this posthatching period, very little dispersion was evident and the significant biological implications of this will be examined in the discussion.

SHALLOW PHASE

The shallow phase occurred at a size range of 5 to 10 mm, after yolk absorption when larvae began a free-swimming existence. Larval golden shiners were observed during both day and night, swimming individually at the water's edge at a depth of 10 cm and less. At this size they showed no relationship or mutual attraction for one another. Shorelines where larvae were observed were sandy and free of algae or debris. One particular place where they could always be found was at the water's edge which extended under a thicket of alder trees (Alnus rugosa). They also were observed in an adjacent habitat, the hyponeustonic zone (several millimeters below the surface film), but over slightly deeper water (0.25 to 1 m). No other species was ever observed during the year in this habitat. Golden shiner larvae were regularly

Figure 2. View of dorsal pigmentation of golden shiner larvae taken after midday on a near cloudless day from habitats with contrasting light conditions. A. Larva (7.6 mm SL) collected from water's edge under shade of alder tree. B. Larva (7.5 mm SL) collected just below surface film above water depth of 0.3 m receiving direct sunlight. Some parts of the bodies were cut off of the photographs to better show dorsal pigmentation.

collected in this unique habitat between patches of bulrushes and water lilies. The fright response of these shallow phase larvae always evoked random scattering at the surface. They were never observed going from the surface into deeper water. Finally, some larval golden shiners in the surface phase were observed schooling with larvae in the deep phase.

There was a striking difference between the dorsal pigmentation of larvae that were captured at the lake's surface and those that were collected in deeper water or in shady areas at the water's edge. Larvae collected from the surface showed more expanded melanophores than larvae taken from a shady habitat (Fig. 2). These observations appear to be in contradiction with well known observations that a dark background or albedo (the proportion of incident light which is reflected or dispersed from a given surface) causes an expansion of melanophores and a light background causes a contraction of melanophores in fishes (Sumner 1940). Perhaps the extremely high irradiance of sunlight at the surface (about 45,000 lux with full sunlight and 10,000 lux with heavy clouds) interface caused the difference.

DEEP PHASE

This phase occurred when golden shiners ranged from 10 to 30 mm. Larvae and juveniles at these lengths displayed distinct schooling behavior within and between patches of bulrushes and water lilies in water depths of 0.25 to 1.0 m. Shallow phase larvae were located at the surface in the same vicinity. Only a few aggregations of these larvae were ever observed within the lab dock area but large numbers were regularly observed in the estuary area. Individual larvae within aggregations normally showed very little activity but displayed mutual attraction for one another by moving in synchrony. These aggregations were typically elliptical with a vertical major axis, but

variations of this shape occurred often. Occasionally separate aggregations were seen to coalesce in varying amounts. The fright response of these larvae was a slow or sometimes rapid movement of the entire aggregation away from the boat. Schooling aggregations were composed of widely varying numbers of individuals completely independent of adults. Adults and older juveniles, which were not visible within the shallow littoral region, were observed 10 m or more offshore among submerged macrophytes. One large area of larval golden shiner aggregations within the estuary area was at the border of bulrushes and deeper water, facing toward the lower littoral region where adults lived. On windy days aggregations were observed to retreat into the protection of the emergent bulrushes, while on calmer days they moved a short distance away from the bulrushes into an adjacent area of submerged pondweeds (Potamogeton spp.). Regular visual transect surveys within the estuary area showed that golden shiner aggregations were localized and relatively stationary.

LARVAL FISH ASSOCIATES

Other species besides golden shiners were observed and collected during 1979 within shallow littoral regions in both study areas. Similar schooling aggregations of larval blackchin shiners were observed and collected in the same areas as deep phase golden shiners. There did not appear to be any mixing of the two species but this could not be ascertained because both golden and blackchin shiners appear identical from above and it was impossible to collect them in large discrete aggregations because of their fright response at the approach of the investigator. Small blackchin shiner larvae were collected with dip nets at least 15 cm below the surface, alone or in groups of two or three. Blackchin shiner larvae were collected below the shallow phase golden shiners which occurred in the hyponeustonic zone. Larval pumpkinseeds also occurred in the same area as the blackchin larvae but were always in looser aggregations. Larval pumpkinseeds were less pigmented than shiners and their aggregations appeared to be always moving from one place to another rather than remaining stationary. Larval killifish, Iowa darters, and one species of tadpole were also captured in the vicinity of the deep phase golden shiners. None of these species appeared to be in aggregations but rather occurred individually.

DISCUSSION

Fishes ordinarily pass through five distinct morphologic "periods" during their life (Balon 1975b). Apparently golden shiners change habits during their life in Lac Heney. The "embryonic period" (Balon's terminology) of golden shiners is presumably found among vegetation or upon pebbles in the littoral region although eggs were never searched for during this study. The early "larval period" was also found in the littoral region but specifically in the hyponeustonic zone and at the water's edge. The later "larval period" and early "juvenile period" were found in deeper water very nearby. The older "periods" were observed offshore among submerged macrophytes in the lower littoral region. Exactly which environmental components are preferred, perceived, or selected by golden shiners during the various stages of their life is not known, but Klopfer and Hailman (1967) state "habitat-selection, like other forms of important perceptual behavior, seems to be neither

completely learned nor completely unlearned." Whatever the cause and effect, habitat selection for weedy littoral regions appears to be species specific for golden shiner larvae in Lac Heney.

Among many fishes and aquatic invertebrates the early free-swimming stage of the posthatching period is well known and characteristic for its extensive dispersive movements. In lakes such as Lac Heney, the fish larvae that roam the limnetic region would certainly display such dispersive behavior. Other species show certain degrees of ecologic isolation and this study suggests that golden shiner larvae are restricted in their dispersive movements. Their movement within individual bulrush bays was limited. Steep, rocky, and rough-water habitats between bays would severely restrict their movement from bay to bay. Williams (1960) studied the dispersal of young marine fishes in the Woods Hole region and concluded that the species showing the least movement during their youth displayed the greatest variation in meristic and morphological features. In comparison to other larvae in Lac Heney (Faber, unpublished data), golden shiner larvae displayed minimal, if not the least dispersion of all. Hubbs (1921), Schultz (1926), and Scott and Crossman (1973) have indicated that golden shiners, in comparison to many other freshwater fishes, possess unusually large meristic variability throughout parts of North America. Although temperature effects may be important, confinement or ecologic isolation by their behavior to certain specific home territories during their youth, division of the lake into distinct and separate habitats, and possibly their return to the same home territory for spawning could contribute greatly to increased genetic variation among golden shiners. Perhaps each bay acts as a separate nursery ground or home territory for a portion of the golden shiner population in the lake. The possibility exists that the same individuals that were hatched and raised in certain bays might return there to spawn, although no tagging studies were carried out to substantiate this. Perhaps some imprinting occurs during their extended residence to bring them back.

The entire spawning season for golden shiners in natural lakes is still uncertain. In Lac Heney newly hatched golden shiners were collected from 17 June through 18 August and since the incubation period of golden shiner eggs is probably about 1 week, these observations indicate that spawning occurred from the second week in June until the second week in August. These dates are similar to observations of Hubbs and Cooper (1936) on mature adults in a river in northern Michigan, so perhaps this 2-month period is close to the normal spawning season at these latitudes. These dates correlated closely with a surface temperature of 20 C in Lac Heney and Carlander (1969) lists several references that indicate that 20 to 21 C is the minimum temperature for the spawning of golden shiners in artificial breeding ponds. Some other Lac Heney fishes spawn during a period of only 1 or 2 weeks (yellow perch, Perca flavescens; white sucker, Catostomus commersoni; and others) and continuous spawning for 2 months should produce a wider range of sizes of young at the end of the year. Cooper (1936) recorded age group I golden shiners from the Huron River on 19 May 1934, ranging from 49 to 90 mm SL.

ACKNOWLEDGEMENTS

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DIEL PATTERNS OF ICHTHYOPLANKTON LENGTH-DENSITY RELATIONSHIPS IN UPPER WATTS BAR RESERVOIR, TENNESSEE[1,2]

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Abstract.- A diel ichthyoplankton sampling program was conducted in upper Watts Bar Reservoir during 1978 to obtain information on (1) diel changes in abundance of fish larvae in the planktonic drift and (2) the extent of visually mediated sampling gear avoidance by motile larvae. Two-way analysis of variance tests revealed few significant diel differences in densities of individual taxa (all sizes combined) but showed consistently significant diel differences in mean total lengths of fish larvae.

Size-specific, day-night density ratios were used to elucidate diel patterns in clupeid larvae densities. Clupeids in the 5 to 18 mm total length range were more abundant in surface samples during the day than during the night. Clupeid larvae either smaller or larger were relatively more abundant during the night. It is likely that the greater nocturnal densities of larger larvae were due to the inhibition of visual gear avoidance during the night. Although no direct evidence is available, we believe that diel vertical migration also influenced the observed patterns in size-specific, day-night density ratios.

Knowledge of diel variations in the rate and composition of ichthyoplankton drift is important in describing the dynamics of early life history stages of fishes in a river system. Nocturnal increases in drift rates have been reported for a variety of freshwater fish larvae (Lindsey and Northcote 1963, Geen et al. 1966, Clifford 1972, Gale and Mohr 1978). Diel changes in drift rates bias the results of ichthyoplankton field studies which are limited to day or night sampling, and these changes must be accounted for in investigations of production and stability of fish populations or in assessment of water-use impacts.

Diel sampling is also useful for gaining insight into the extent of sampling gear avoidance by motile organisms. For example, visual gear avoidance is common when sampling plankton in surface waters during daylight hours (Clutter and Anraku 1968), and it can result in underestimates of true organism densities. Large fish larvae are more capable of avoiding a plankton net than are small larvae, and this difference may be reflected not only in decreased daytime sample densities but also in smaller mean lengths of larvae in daytime samples as compared to nighttime samples.

In view of these considerations diel ichthyoplankton studies were incorporated into a comprehensive biological sampling program conducted in upper Watts Bar Reservoir, Tennessee, during 1977 and 1978. In this paper we present results from that study and make recommendations on methods of comparing day and night densities of ichthyoplankton on both a species and size-specific basis.

MATERIALS AND METHODS

Watts Bar Reservoir is an impoundment of the Tennessee, Emory, and Clinch Rivers in eastern Tennessee. At full pool the reservoir has a surface area of 15,621 ha and an elevation of 225.8 m above mean sea level. Quality and flow of water in the study area (that is, the Clinch River tributary of Watts Bar Reservoir) is influenced by releases from Melton Hill Reservoir, beginning at Clinch River Kilometer (CRK) 37.2 (Clinch River Mile, CRM, 23.2) and by minor tributaries downstream from Melton Hill Dam.

Diel collections of fish larvae were made at two stations in upper Watts Bar Reservoir (Fig. 1). Station 1 was located in Poplar Creek, a tributary of the Clinch River, approximately 0.8 km (0.5 mile) upstream from its mouth at CRK 19.3 (CRM 12.0). Station 2 was located in the main channel of the Clinch River at CRK 18.5 (CRM 11.5).

All samples were collected at the surface by towing a 2-m long, 0.5-m mouth diameter plankton net approximately 18 m behind a boat. The net had a 0.75-m diameter expanded collar and was composed of 0.243-mm mesh Nitex. Sample volumes and towing velocities were determined by means of an impeller-type flowmeter (General Oceanics number 2030) mounted in the center of the mouth of the net. The net was towed for 2 to 5.5 min at velocities of 70 to 220 cm/s, generally resulting in sample volumes of between 40 and 120 m^3.

Diel samples were taken on three dates (6 June, 15 June, and 6 July 1978) at station 2 and on five dates (16 May, 23 May, 6 June, 15 June, and 6 July 1978) at station 1. Triplicate day samples were collected between 1015 and 1440 hours on each date and comparable triplicate night samples were taken on the following evening between 2320 and 0200 hours.

Filtered samples were washed down into a screened collecting bucket at the cod end of the net. Samples were field preserved in 5 percent formalin solution for later identification, enumeration, and measurement. Total lengths (mm) of larvae were measured by means of a grid attached to the stage of a binocular dissecting microscope. In some samples large numbers of larvae

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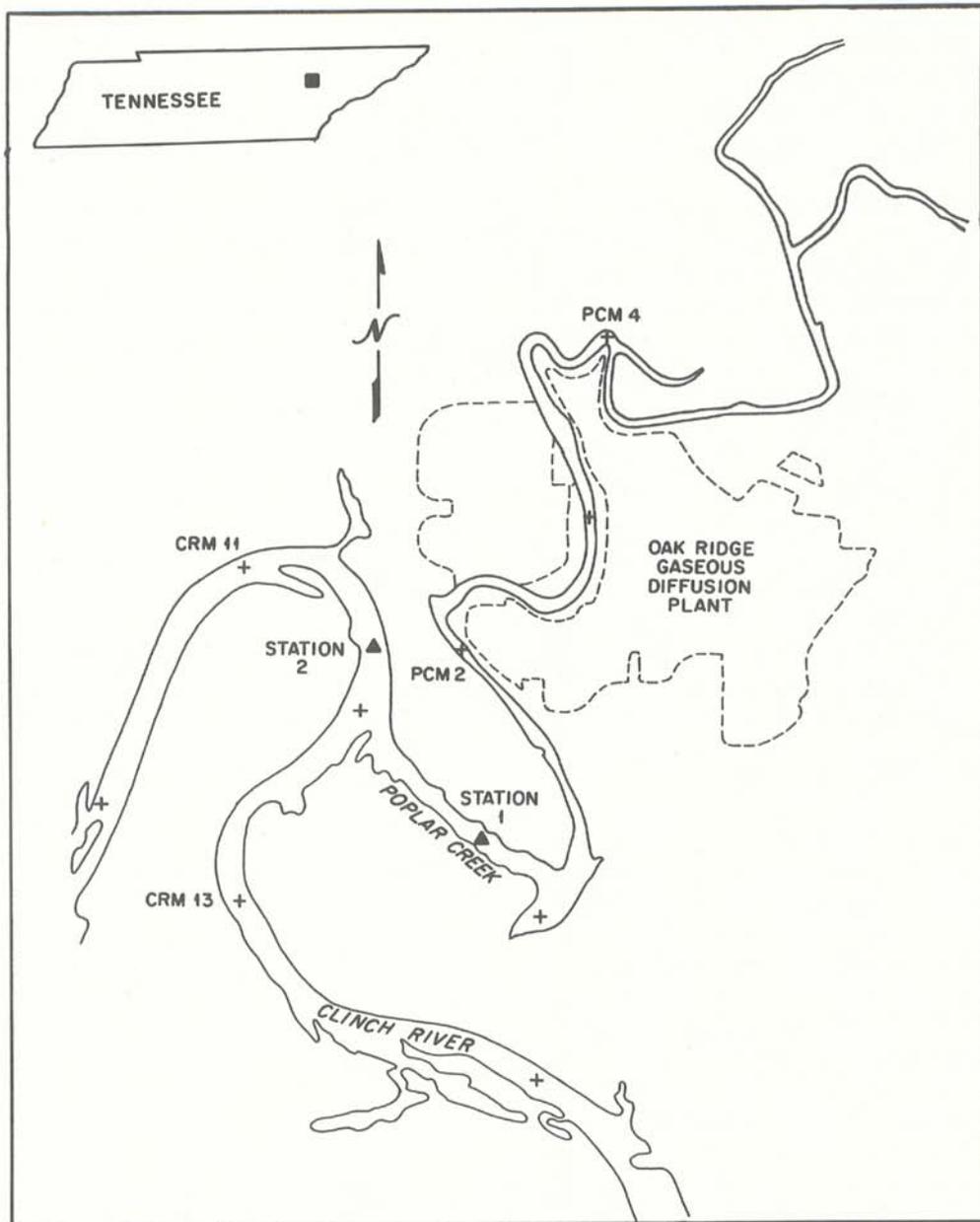
Figure 1. Map of the study site in upper Watts Bar Reservoir, showing the locations of the sampling stations in Poplar Creek and the Clinch River. (CRM and PCM represent Clinch River and Poplar Creek miles, respectively.)

precluded counting and measuring of all organisms. Those samples were either halved or quartered with a Folsom plankton splitter (McEwen et al. 1954) and all larvae in one of the subsamples were counted and measured.

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RESULTS

Clupeid yolk-sac and post yolk-sac larvae were the most abundant ichthyoplankters, accounting for 96 percent of the 7602 larvae collected in this study. In descending order of abundance, larval Cyprinus carpio, Morone, Lepomis, Pomoxis, and Ictiobinae were also collected during the diel sampling.

Two-way analyses of variance (blocked on date) were performed to detect diel differences in the mean densities (log-transformed data) and mean total lengths of Clupeidae, Morone, Cyprinus carpio, and Lepomis larvae (Table 1). Fishes in the family Clupeidae were categorized as either yolk-sac larvae (all were members of the genus Dorosoma) or post yolk-sac larvae (genus could not be determined) in an attempt to ascertain any differences in diel patterns between the two developmental stages. Night densities were significantly greater than day densities for Cyprinus carpio at station 1, whereas density differences in the seven remaining day-night comparisons were not statistically significant (P >0.05).

While density differences between day and night samples were frequently not significant, the diel differences in mean total lengths were significant in all of the six possible comparisons (Table 1). Mean total lengths of post yolk-sac clupeid larvae and Lepomis were significantly greater in the night samples at both stations. Conversely, mean total lengths of Morone and Dorosoma yolk-sac larvae at station 1 were significantly smaller in the night samples.

Table 1. Comparisons of mean densities and mean total lengths of ichthyoplankton collected in diel sampling, 1978.

Station	Taxon	Sample size	Mean density (number/m^3) Day	Night	Critical probability[c]	Mean total length (mm) Day	Night	Critical probability[c]
1	Clupeidae[a]	5699	2.81	2.55	0.79	6.4	9.7	<0.01
	Dorosoma[b]	1140	0.69	0.85	0.26	4.4	4.0	0.02
	Morone[b]	103	0.07	0.03	0.09	3.9	3.6	<0.01
	C. carpio	122	0.00	0.12	0.01		6.9	
	Lepomis	23	0.01	0.01	0.13	6.5	14.1	<0.01
2	Clupeidae[a]	437	0.18	0.43	0.28	10.5	13.1	<0.01
	Dorosoma[b]	2	0.01	0.01	0.97			
	Lepomis	14	0.01	0.01	0.09	6.3	14.4	<0.01

[a] Post yolk-sac larvae.
[b] Yolk-sac larvae.
[c] Critical probability value at which one would reject the null hypothesis of equal densities (mean lengths) between day and night.

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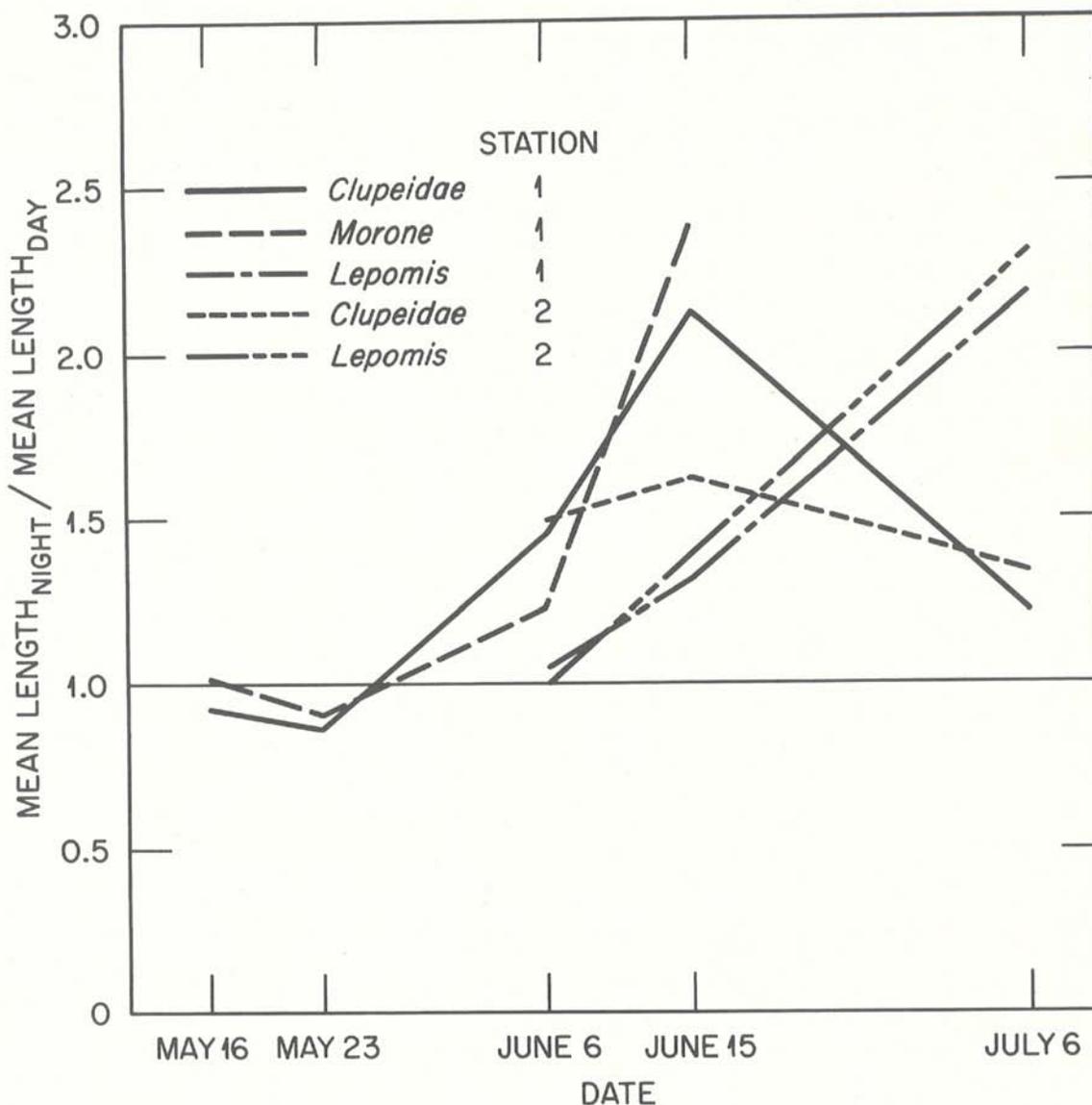
Figure 2. Ratios of mean total lengths in night samples to mean total lengths in day samples (all sizes combined) of larval fish taxa collected at stations 1 and 2 in upper Watts Bar Reservoir, 1978.

This preliminary analysis indicated that diel changes in characteristics of the ichthyoplankton community were better detected by an examination of the lengths of fish larvae than by comparisons of day and night densities. Consequently, the following discussion will be concerned with techniques for comparing total lengths of fish larvae in paired day and night samples as a means of elucidating diel patterns in the ichthyoplankton drift.

On 16 May and 23 May 1978, the ratios of mean total lengths of clupeid and Morone larvae in night versus day samples at station 1 were close to 1.0 (Fig. 2), that is, the mean total lengths in the day and night samples were nearly equal. Most of the larvae on these two dates were in the 3 to 6-mm total length range. However, total length ratios were greater than 2.0 for these taxa in the 15 June samples, in which clupeid larvae were 4 to 27 mm and Morone were 4 to 9 mm long. The same trend was evident for Lepomis larvae at stations 1 and 2 (Fig. 2). Total lengths of Lepomis ranged from 4.5 to 6.5 mm on 6 June, and mean lengths in the day and night samples were virtually identical (ratios were approximately 1.0). By 6 July Lepomis larvae ranged from 5 to 18 mm in length and larger mean-length ratios were noted on that date.

While the ratios plotted in Fig. 2 are useful, they sacrifice valuable information on the specific size structure of organisms in the samples. For instance, it is impossible to determine from these ratios whether the relatively greater mean length of fishes in night samples is due to greater numbers of large larvae or fewer numbers of small larvae relative to the day collections. Similarly, ratios of densities (all sizes combined) are insensitive to size-specific diel patterns in distribution. For example, on 23 May the night to day density ratio for all clupeid larvae was 0.99, indicating that equal mean densities were collected in the night and day samples. This same ratio calculated for 3.5-mm larvae alone was 22.92, and for 6.0-mm larvae the ratio was 0.09. Thus, simple ratios of total densities may provide the investigator with little information on the diel behavior of specific sizes of ichthyoplankton. One means of obtaining this information is to examine estimated densities for specific length categories and thus determine where the divergences between day and night samples occur.

Graphs of the mean day and night densities of clupeid larvae at station 1, plotted at 0.5-mm total length intervals, indicate that the range of total lengths was relatively narrow on 16 May and 23 May (Fig. 3). On subsequent dates growth and continued spawning had resulted in a wider size range of clupeid larvae. A nocturnal increase in the density of larger larvae (in this case $\geq$ 9 mm TL) was observed on 6 June, 15 June, and 6 July 1978. Also apparent from plots on the later dates, however, is a nocturnal decrease in densities of clupeid larvae in the approximate length range of 5 to 8 mm, that is, relatively more of these larvae were caught during the day than during the night.

Density ratios can again be used to condense the size-specific information displayed by the histograms in Fig. 3. The ratio (r_i) in this case takes the form:

$$ r_i = \frac{X_{d,i}}{X_{d,i} + X_{n,i}} $$

where $X_{d,i}$ = mean density in day samples of size interval i, and $X_{n,i}$ = mean density in night samples of size interval i.
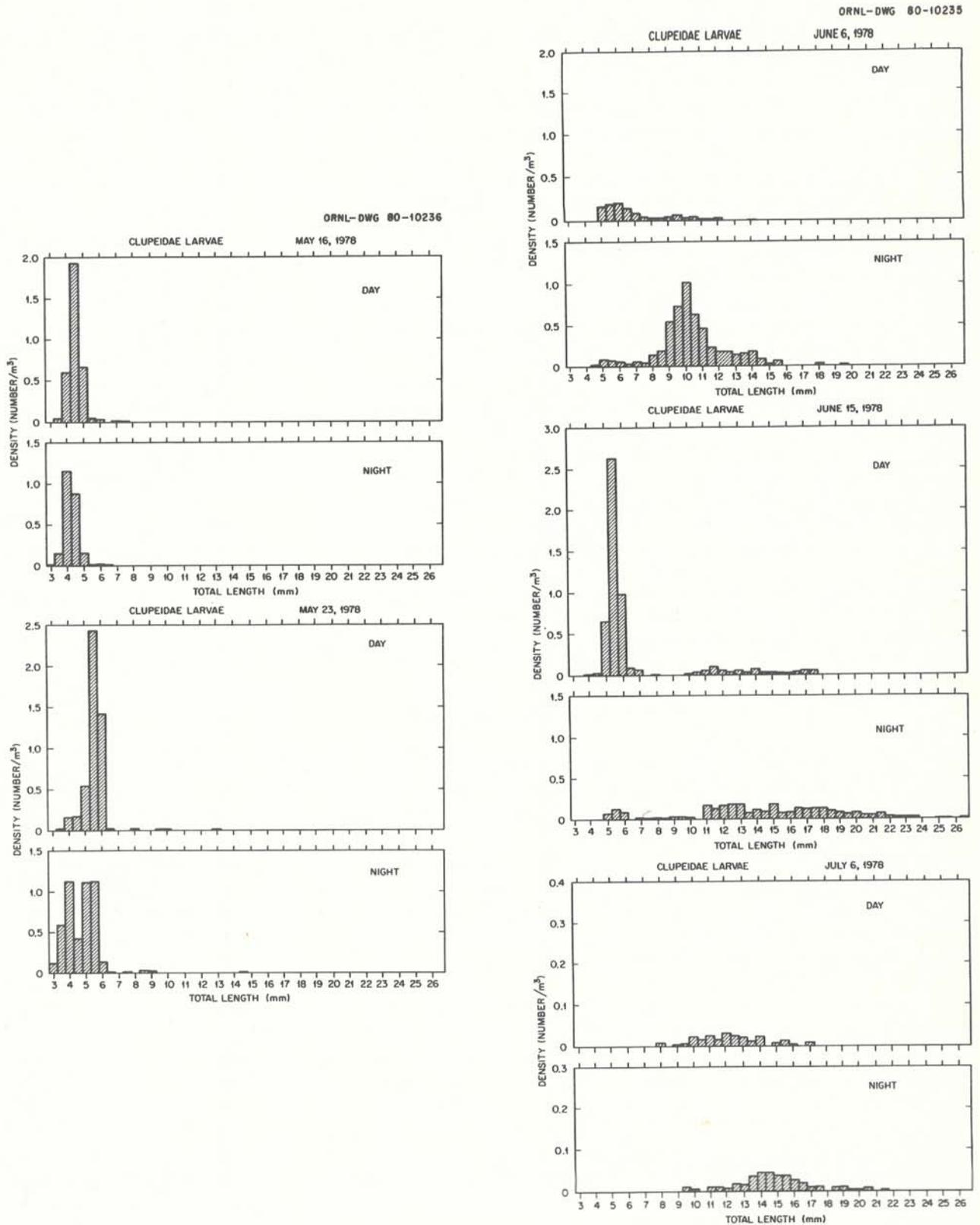
Figure 3. Length-density distributions of clupeid larvae at station 1 in upper Watts Bar Reservoir.

Expressing the day-night density ratio in this form has the advantage of limiting the range of possible values to between 0.0 and 1.0 (unlike the ratio used in Fig. 2). If mean densities of a given length group are equal in day and night samples, the resultant r_i will be 0.5. Values of r_i greater than 0.5 indicate higher densities during the day, while values less than 0.5 indicate higher densities during the night.

A comparison of size-specific clupeid density ratios on the five diel sampling dates at station 1 (Fig. 4) reveals some consistent patterns. On the first three dates relatively larger numbers of the smallest larvae (approximately 3 to 5 mm in length) were collected in the surface samples at night, resulting in r_i values of less than 0.5. This was not seen on the two later dates because of low numbers (8 larvae less than 5.0 mm TL on 15 June) or an absence of these small yolk-sac larvae in the samples (6 July). Values of r_i in excess of 0.5 were found among clupeids ranging from 5.0 to 8.0 mm in length on most dates (Fig. 4), indicating that these early post yolk-sac larvae were found in greater densities during the day than during the night. On 6 July the entire curve was shifted to the right such that r_i values greater than 0.5 were found among clupeids in the length range of 9.0 to 12.5 mm. Finally, r_i values decreased with increasing length of fish, eventually reaching a value of 0.0 (fishes in these particular length groups were collected only at night). The length of post yolk-sac clupeid larvae at which r_i first became zero varied among dates, ranging from 8.5 to 18.0 mm (Fig. 4).

Samples from station 2 were also used to calculate r_i values for clupeid larvae. Although relatively few larvae were collected at this station, the same patterns were apparent as on corresponding dates at station 1.

DISCUSSION

There can be two fundamental reasons for the differences between day and night ichthyoplankton densities found in the present study: (1) diel changes in the true abundance of fish larvae in the sampling areas, and (2) diel changes in sampling bias (due to factors such as extrusion and avoidance). Extrusion (loss of organisms through the meshes of the net) was probably not a significant factor in this study because of the small mesh size used (0.243 mm). It would not be a significant biasing factor in the calculation of r_i in any case, since the degree of extrusion would be similar among day and night samples taken on the same date.

Avoidance of the net can be visually mediated (organism sees the net and swims out of its path) or nonvisually mediated (organism detects a zone of turbulence ahead of the net). While nonvisually mediated avoidance is doubtless an important biasing factor in estimating the true densities of ichthyoplankton in the reservoir, like extrusion it would not be expected to vary substantially between day and night samples on the same date and therefore it would not affect the calculation of r_i. Visually mediated avoidance, however, would be inhibited at night and would result in lower r_i values, particularly among larger, stronger swimming larvae. In the present study, visual avoidance is the simplest explanation for the r_i values of 0.0 among the largest larvae (Fig. 4). In fact, increasing ability to avoid the sampling net with increasing length may be the primary reason for the decline in r_i values following peaks at total lengths of 5 to 10 mm.

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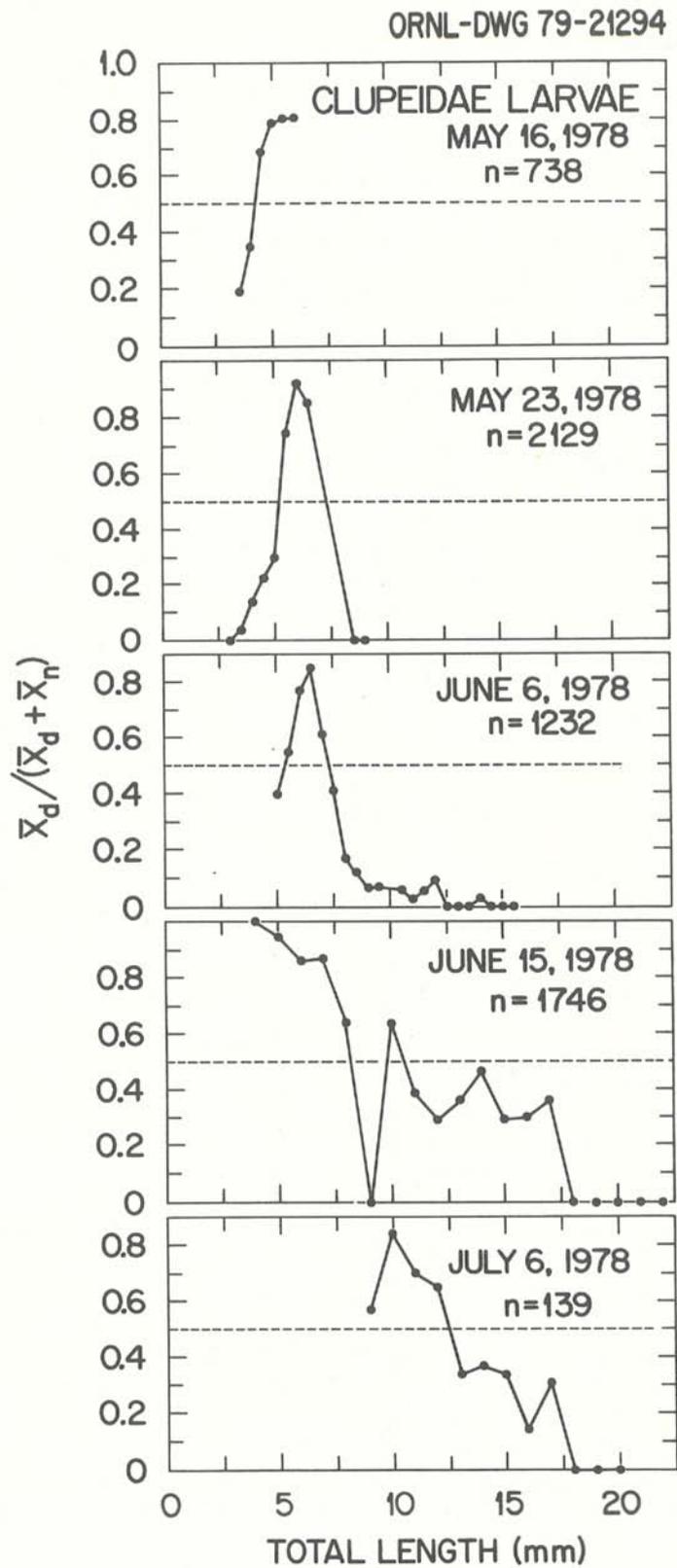
Figure 4. Plots of size-specific day-night density ratios, $\bar{X}_d/(\bar{X}_d + \bar{X}_n)$, for clupeid larvae at station 1 in upper Watts Bar Reservoir, 1978.

The relatively wide range of towing velocities at which samples were taken also could have affected the observed length-density distributions. For example, Clutter and Anraku (1968) cited studies in which both the density and length distributions of planktonic animals were related to towing velocity. Although this relationship was not consistently observed it is likely that in many instances higher velocity tows will collect more larger organisms. In our study, mean towing velocities were significantly different (Student's t-test, $P < 0.05$) between day and night on two of the five sampling dates at station 1. On 6 June the mean night towing velocity was significantly greater than the mean day towing velocity. The converse was true of 15 June. These disparities did not appear to affect observed distributions, however, since trends in r_i values (Fig. 4) are very similar between these two dates and the three dates on which towing velocities were not significantly different.

Diel changes in spatial distribution of ichthyoplankton also would have an effect on r_i values. For example, vertical migration which would result in the concentration of larvae in different depth strata between night and day, would not have been detected by the surface samples taken in this study. There is, in fact, reason to believe that diel vertical migration of clupeid larvae may have occurred at these stations. Storck et al. (1978), Graser (1979), and Tuberville (1979) have all reported finding clupeid larvae concentrated in surface waters during the day and becoming more dispersed at night. Graser (1979) observed a daytime surface orientation among larvae in the 2 to 15-mm total length range, while Tuberville (1979) noted higher daytime surface densities among larvae 6 to 10, 11 to 15, and >16 mm total length. This migratory pattern would have resulted in r_i values, calculated from surface samples only, greater than 0.5. Values of r_i in excess of 0.5 were found in the present study for clupeid larvae in the approximate length range of 5 to 8 mm (Fig. 4). It is possible that a concentration of larvae in the surface waters during the day, modified by increasing ability to avoid the sampling gear with increased length, may have been responsible for the pattern of r_i values observed among larvae $\geq$ 5 mm total length in upper Watts Bar Reservoir.

It is noteworthy that Tuberville (1979) did not see this strong surface orientation among clupeid larvae less than 5 mm in length. In his study, these smallest larvae showed a trend toward deeper waters during the day with relatively uniform distribution at night. His observations are in agreement with our findings in upper Watts Bar Reservoir in which r_i values for the smallest yolk-sac larvae were generally less than 0.5 (Fig. 4). This apparently anomalous vertical migration behavior of clupeid yolk-sac larvae warrants further investigation, however, since it was not observed in the study by Graser (1979).

Thus, diel vertical migration and visually mediated gear avoidance appear to be the two primary factors influencing the assessment of diel changes in ichthyoplankton drift in upper Watts Bar Reservoir. Visual gear avoidance, as evidenced by declining r_i values, appears to begin among clupeid larvae as small as 5 to 10 mm long and increases with increasing length. In view of recent findings on diel vertical migration of clupeid larvae (Storck et al. 1978, Graser 1979, and Tuberville 1979) it is possible that our assumption of a consistent vertical migration pattern of larvae between day and night may

have been inappropriate. Analysis of samples from the 1979 diel ichthyoplankton study at these stations, which included vertical sampling, will help resolve this question.

In summary, field studies that require accurate assessments of the structure and dynamics of the ichthyoplankton community should include both day and night collections. Such a program would provide a means of determining true changes in drift of ichthyoplankton over a 24-h period as well as assessing the extent of visual gear avoidance that can bias sampling limited to daylight hours. Studies of the spatial distribution of ichthyoplankton should be incorporated in those instances where it is likely to change on a diel basis. Finally, this study has shown that it may not suffice to restrict the analysis to day-night comparisons of total densities in the search for a simple correction factor. Diel changes in the length-frequency structure must be examined in order to assess gear efficiency as well as to detect actual diel variations in the size structure of the ichthyoplankton drift.

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DETERMINATION OF THE VERTICAL DISTRIBUTION OF ICHTHYOPLANKTON IN LAKE NORMAN, NORTH CAROLINA, USING A DISCRETE-DEPTH SAMPLING DESIGN

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Abstract.- During 1977 and 1978 vertical distribution of larval shad (Dorosoma spp.), crappie (Pomoxis spp.), and percids (mostly Perca flavescens) in Lake Norman, North Carolina, varied with length of individuals in each taxon and water temperature. Dissolved oxygen concentration did not appear to influence the vertical distribution of the taxa studied. The discrete-depth sampling design, using 2.5-m depth increments, was adequate for comparing vertical distribution of larval fishes with physical variables. Although a precise estimate of larval fish density for the complete water column was not possible, changes in vertical distribution of ichthyoplankton were detected.

Monitoring of ichthyoplankton densities in Lake Norman, North Carolina, was initiated in 1974. The program was designed to determine relative abundance of larval fishes at the surface and the 5-m depth at several locations in the vicinity of the proposed McGuire Nuclear Station. Towing for ichthyoplankton at 5-m depth increments down to 15 m has been a common sampling technique for determining the vertical distribution of larval fishes (Netsch and Kersh et al. 1971, Edwards et al. 1978, Ruelle et al. 1977). Since the mouth of most ichthyoplankton nets has been 1 m or less in diameter, a relatively large stratum sampled between 5-m depth increments has been left unsampled. Tuberville (1979) stated that missed strata may result in poor estimates of abundance and misinterpretations of distributional patterns. Tuberville (1979) further recommended using oblique tows within sample strata for determining vertical distribution of ichthyoplankton. However, for our purposes discrete tows at 2.5-m depth increments were employed, because these data could be better related to the existing monitoring program.

The vertical distribution study was initiated in 1977 to: (1) determine vertical distribution of ichthyoplankton in the vicinity of the McGuire Nuclear Station discharge during preoperational and operational periods, (2) compare vertical distribution of ichthyoplankton with water temperature, dissolved oxygen concentration, and total length of individuals in each taxon, and (3) address the suitability of a discrete-depth sampling design in meeting these objectives.

Table 1. Two-way analysis of variance of density of ichthyoplankton collected from April through August 1977 and April through June 1978 in Lake Norman, North Carolina. Hypotheses were tested using transformed data ($\log_{10}$ of the sum of the number per 10 m^3 plus 1).

Taxon	Variable	df	F
Shad	Date	7	39.33***
	Depth	6	33.72***
	Interaction	42	9.30***
	Error	55	
	Corrected total	110	
Crappie	Date	7	39.14***
	Depth	6	29.33***
	Interaction	42	16.39***
	Error	55	
	Corrected total	110	
Perch	Date	7	28.76***
	Depth	6	25.96***
	Interaction	42	10.45***
	Error	55	
	Corrected total	110	

***Significant ($P < 0.0001$)

STUDY AREA

Lake Norman was impounded on the Catawba River in 1963 by Duke Power Company. The reservoir is 54 km long, has a surface area of 13,157 ha, and a storage volume of 1.35×10^9 m^3. Lake Norman has 840 km of shoreline and a maximum depth of 36.6 m at Cowan's Ford Dam. At full pond, the surface of Lake Norman is 232 m above mean sea level.

METHODS AND MATERIALS

Vertical distribution studies were conducted approximately 1 km northeast of the mouth of the McGuire Nuclear Station discharge. At full pond the depth along the trawling path varied from 18 to 24 m.

A conical nylon net with a mesh size of 794 micrometers, a mouth diameter of 0.91 m, and a length of 2.4 m was used to sample ichthyoplankton. Volumes of water filtered were estimated using a General Oceanics flowmeter suspended in the mouth of the net. The net was towed at approximately 1 m/sec. A depressor, as described by Netsch and Houser et al. (1971), was attached to the net bridle and a predetermined amount of cable was payed out depending on stratum to be sampled.
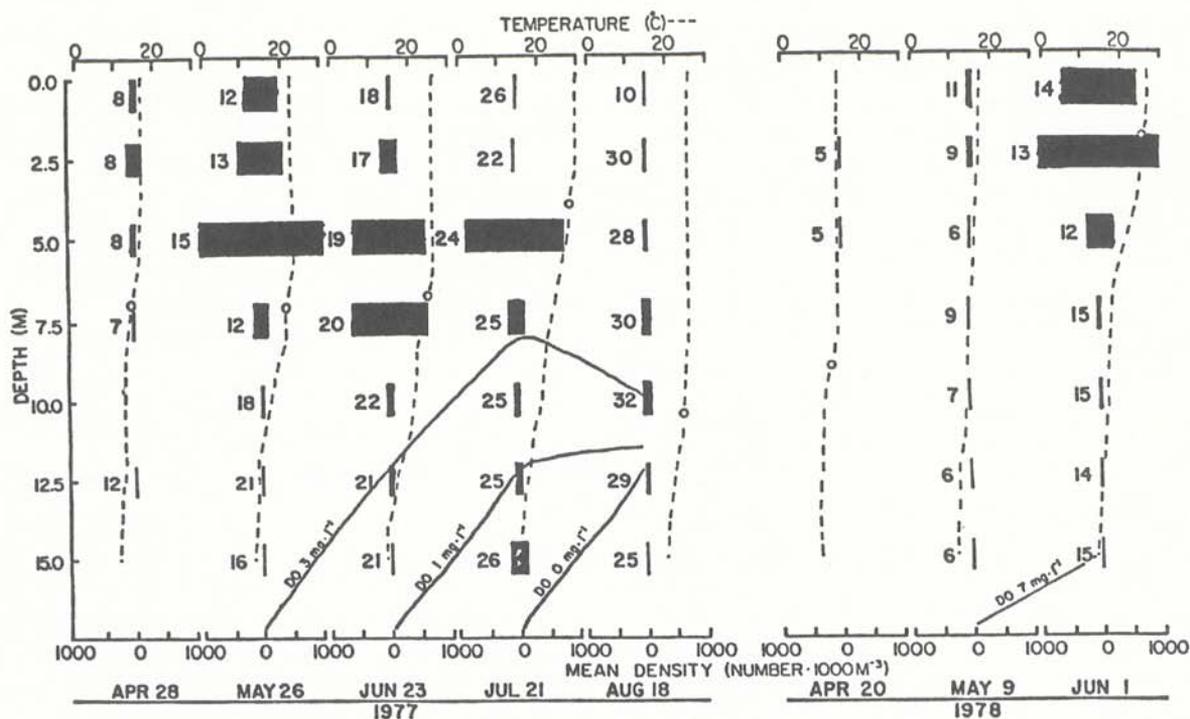
Figure 1. Mean density of larval shad collected from Lake Norman, North Carolina. The number to the left of each block is the mean total length of larval shad (mm) corresponding with respective depth. DO denotes dissolved oxygen concentration isopleths. Circles denote depth of the thermocline.

Consecutive duplicate 10-min tows were taken at 2.5-m depth intervals from the surface to 15 m. Samples were collected monthly from April through August in 1977 and April through June in 1978. The sampling program was reduced in 1978, since after June 1977 mostly juvenile shad were collected. All collections were taken at night between 2200 and 2400 hours (EDT), because few larval fishes were collected during the day. Sampling order with respect to depth was chosen at random. All samples were preserved in 10% formalin.

A Hydrolab model TDO-2 was calibrated and used on each sampling date to measure water temperature and dissolved oxygen concentration. Measurements were recorded from the surface to 15 m in 1 m increments. Although a water temperature change of at least 1 C/m was observed at several depths on most sample dates, the depth where this change first occurred was considered the depth of the thermocline.

In the laboratory, ichthyoplankton were identified to the lowest practicable taxon and total length measured to the nearest millimeter. Volumes for each sample were calculated and ichthyoplankton density was expressed as number per unit volume of water filtered.

A Bartlett's test (Helwig and Council 1979) was used to test for heterogeneity of variance with respect to depth and sampling date for each taxon. When the test indicated significant heterogeneity of variance, a logarithmic transformation of larval density was used to produce homogeneous

Table 2. One-way analysis of variance and multiple range tests comparing densities of larval shad among depths during each sampling date in Lake Norman, North Carolina. Hypothesis was tested using transformed data ($\log_{10}$ of the sum of the number per 10 m^3 plus 1), but mean densities are expressed by number per 1000 m^3. Mean densities that are underscored by the same line were not significantly different.

Sample period	F	Variable	Multiple range test						
1977									
28 April	3.99[*]	Depth	2.5	0.0	5.0	7.5	12.5	10.0	15.0
		Mean density	220	78	63	5	3	0	0
26 May	26.08[**]	Depth	5.0	2.5	0.0	7.5	10.0	12.5	15.0
		Mean density	2091	733	567	213	46	42	22
23 June	23.15[**]	Depth	7.5	5.0	2.5	10.0	12.5	15.0	0.0
		Mean density	1244	1167	263	123	44	32	33
21 July	16.92[*]	Depth	5.0	7.5	15.0	2.5	12.5	10.0	0.0
		Mean density	1612	248	121	81	64	63	31
18 August	1.91								
1978									
20 April	0.09								
9 May	0.52								
1 June	25.95[**]	Depth	2.5	0.0	5.0	10.0	12.5	15.0	7.5
		Mean density	2008	1266	407	51	40	39	38

[*]Significant (P < 0.05)
[**]Highly significant (P < 0.001)

variances (Keppel 1973). Two-way analyses of variance (ANOVA) were used to compare larval fish densities among sampling dates and depths (Helwig and Council 1979). When simple main effects analysis (Keppel 1973) indicated significant differences (P<0.05), means were compared using Duncan's multiple range test (Helwig and Council 1979).

RESULTS AND DISCUSSION

Larval shad (gizzard and threadfin shad), crappie (primarily black crappie), and percids (primarily yellow perch) were the most numerous larval fish taxa collected. Two-way ANOVA indicated that these taxa varied significantly among sampling dates and depths (Table 1).
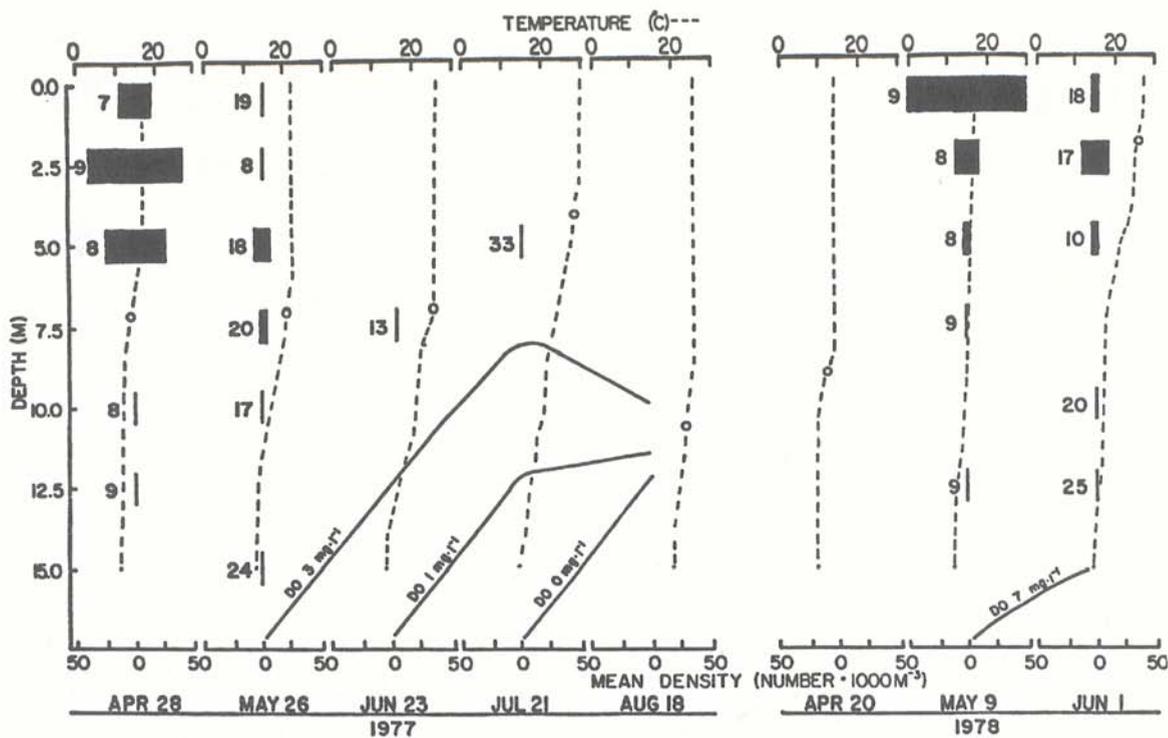
Figure 2. Mean density of larval crappie collected from Lake Norman, North Carolina. The number to the left of each block is the mean total length of larval crappie (mm) corresponding with respective depth. DO denotes dissolved oxygen concentration isopleths. Circles denote depth of the thermocline.

The variation in vertical distribution of these taxa appeared to be influenced by the length of individuals of each taxon and water temperature, while dissolved oxygen concentrations did not appear to have an effect on the taxa.

SHAD

When higher densities of larval shad were collected at and above the 5-m stratum (April and May 1977 and June 1978), mean total length of larval shad was 15 mm or less (Fig. 1, Table 2). For a given sampling date no distinct size difference of larval shad among depths was apparent, but the increase in size of larval shad in June, July and August 1977 may have contributed to the shift in densities to the lower depths (Fig. 1). Densities of larval shad (less than 10 mm total length) were evenly dispersed down to 15 m during May 1978, when no distinct thermocline was present (Fig. 1). During April 1977, when higher densities of larval shad less than 10 mm total length were collected from the upper 5-m strata, the water temperature was uniform down to 6 m (Fig. 1, Table 2). Taber (1969) observed in night samples that larval shad of 10.5 mm total length or greater were most abundant at mid-depth (4 to 8 m), and larval shad ranging from 6 to 10 mm total length were evenly dispersed in the water column of a well-mixed reservoir.
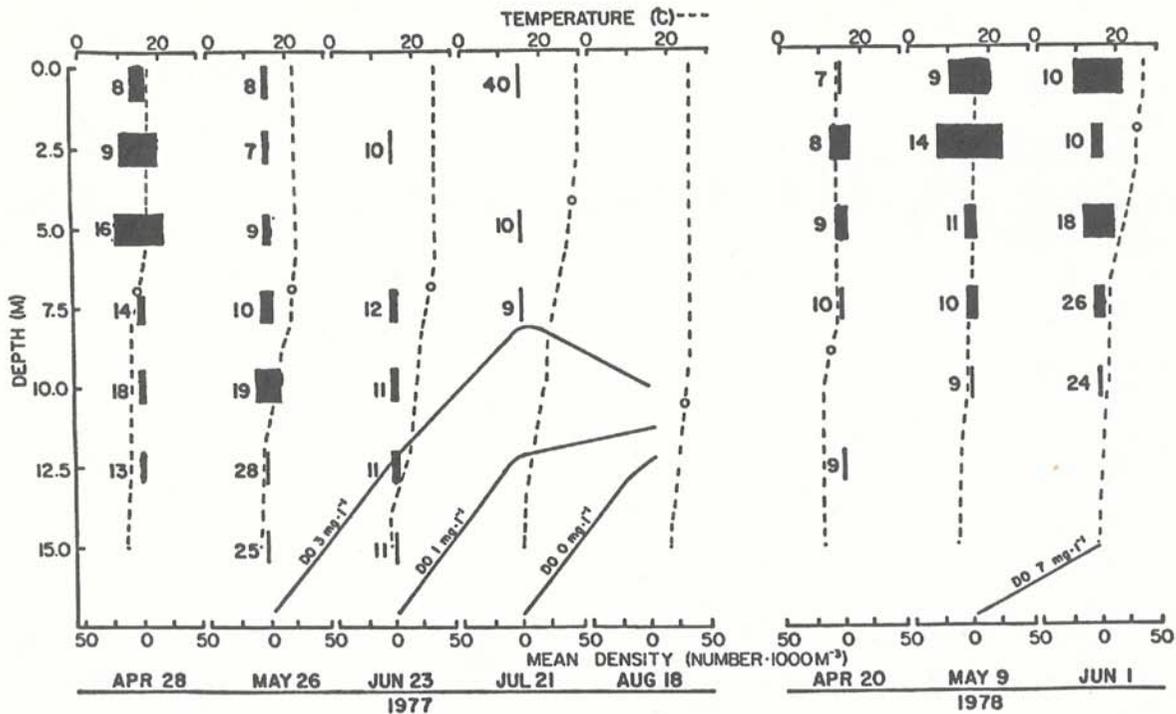
Figure 3. Mean density of larval perch collected from Lake Norman, North Carolina. The number to the left of each block is the mean total length of larval perch (mm) corresponding with respective depth. DO denotes dissolved oxygen concentration isopleths. Circles denote depth of the thermocline.

The vertical distribution of larval shad appeared to be related to the thermocline. Significantly higher densities of larval shad were collected at or near the thermocline during May, June, and July 1977 and June 1978 (Fig. 1, Table 2). However, Edwards et al. (1978) noted that highest densities of larval shad were collected at the surface on Lake Norman, North Carolina, when the thermocline was at 5 m. Netsch and Kersh et al. (1971) noted a fairly consistent pattern of highest numbers of young gizzard shad occurring at the 5-m depth, which was the approximate upper limit of the thermocline in Beaver Reservoir, Arkansas, and also observed a temporary shift of greatest numbers of young gizzard shad to the 15-m depth after complete mixing of the upper 9 m of water due to very high winds.

CRAPPIE

Although no distinct size difference in larval crappie among depths of the upper 5-m strata was evident for any sampling date, growth of larval crappie between consecutive sample dates may have contributed to the shift in densities to a deeper stratum (Fig. 2). Higher densities of larval crappie of similar size were collected at 2.5-m, 5.0-m, and surface in April 1977, when the thermocline was at 7 m. In May 1978 larval crappie were collected at the surface, when no thermocline was present (Fig. 2, Table 3). Ruelle et al. (1977) also noted that the number of larval crappie was generally higher near the surface when the thermocline was not well developed. High densities of larval crappie of similar size were collected in May 1977 and in June 1978,

Table 3. One-way analysis of variance and multiple range tests comparing densities of larval crappie among depths during each sampling date in Lake Norman, North Carolina. Hypothesis was tested using transformed data (log_{10} of the sum of the number per 10 m^3 plus 1), but mean densities are expressed by number per 1000 m^3. Mean densities that are underscored by the same line were not significantly different.

Sample period	F	Variable	Multiple range test						
1977									
28 April	66.02**	Depth	2.5	5.0	0.0	12.5	10.0	7.5	15.0
		Mean density	78	48	27	1	1	0	0
26 May	1.08								
23 June	0.08								
21 July	0.02								
18 August	a								
1978									
20 April	a								
9 May	70.58**	Depth	0.0	2.5	5.0	12.5	7.5	10.0	15.0
		Mean density	96	19	4	4	1	0	0
1 June	7.88**	Depth	2.5	0.0	5.0	12.5	10.0	7.5	15.0
		Mean density	26	4	4	1	1	0	0

*Significant (P <0.05)
**Highly significant (P <0.001)
a No larvae collected.

and were concentrated at or near the depth of the thermocline (Fig. 2, Table 3). Taber (1969) noted that larval crappie ranging from 5 to 10 mm total length were equally distributed from surface to bottom (15 m), while larval crappie at 10.5 mm total length or greater were collected primarily on the bottom.

PERCH

Small larval perch (less than 15 mm total length) were collected throughout the water column down to 15 m, and larger larval perch (15 mm total length or greater) were generally collected from the cooler deeper strata (Fig. 3). When densities of larval perch were high at two strata (April and May of 1977 and April, May, and June of 1978), larval perch of the deeper stratum were longer (Fig. 3, Table 4). During April 1977 the majority of larval perch were collected at or above the thermocline, while in May and June

Table 4. One-way analysis of variance and multiple range tests comparing densities of larval perch among depths during each sampling date in Lake Norman, North Carolina. Hypothesis was tested using transformed data ($\log_{10}$ of the sum of the number per 10 m^3 plus 1), but mean densities are expressed by number per 1000 m^3. Mean densities that are underscored by the same line were not significantly different.

Sample period	F	Variable	Multiple range test						
1977									
28 April	32.51**	Depth	5.0	2.5	0.0	7.5	10.0	12.5	15.0
		Mean density	42	35	13	5	5	2	0
26 May	5.19**	Depth	10.0	7.5	5.0	0.0	2.5	15.0	12.5
		Mean density	19	11	6	4	4	3	1
23 June	0.95								
21 July	0.12								
18 August	a								
1978									
20 April	3.02*	Depth	2.5	5.0	7.5	12.5	0.0	10.0	15.0
		Mean density	12	9	3	3	2	0	0
9 May	37.08**	Depth	2.5	0.0	7.5	5.0	10.0	12.5	15.0
		Mean density	50	27	9	8	2	0	0
1 June	18.72**	Depth	0.0	5.0	7.5	2.5	10.0	12.5	15.0
		Mean density	40	25	9	6	3	0	0

*Significant (P <0.05)
**Highly significant (P <0.001)
aNo larvae collected.

of 1977 the majority of larval perch were below the thermocline (Fig. 3). During April 1978, small larval perch were concentrated above the thermocline (Fig. 3). During May 1978 no distinct thermocline was apparent and larval perch were concentrated at the surface and 2.5-m (Fig. 3). During June 1978 high densities of small larval perch were collected just above the thermocline, while high densities of large larval perch were collected just below the thermocline (Fig. 3). Noble (1968) observed a shift by yellow perch larvae (8 to 22 mm total length) from the surface during calm condition to 6 m during windy conditions (35.2 km/hour). Such windy conditions did not occur on Lake Norman during the periods of larval perch conditions.

DISCRETE-DEPTH SAMPLING DESIGN

Ichthyoplankton sampling programs designed to compare the preoperational and operational periods of power plants need to take into account distributional shifts which may occur throughout the sampling period and from year to year. These shifts could be the result of changes in physical, chemical, and biological variables. Since each collection taken in our study was at a specific depth, a direct comparison of the vertical distribution of larval fishes to physical variables was possible (Figs. 1-3). This discrete-depth sampling design did not sample the entire water column and consequently may not be a completely reliable integrator of larval fish density over depth. However, the objective was to determine vertical distribution of larval fishes, which was possible.

Studies concerned with estimating larval fish abundance should consider the oblique sampling design, because catches would not be affected by changes in vertical distribution. Vertical distribution studies using oblique sampling within vertical strata, as pointed out by Tuberville (1979), seem to be the best approach. However, when support data are needed for existing studies, a discrete-depth sampling design may be preferable.

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SPATIO-TEMPORAL DISTRIBUTION OF ICHTHYOPLANKTON IN THE LOWER MISSISSIPPI RIVER, LOUISIANA

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Abstract.- Planktonic young of fishes were sampled monthly or semi-monthly with a 1-m conical tow net in the lower Mississippi River near St. Francisville, Louisiana, during 1976 and 1977. Representatives of Clupeidae, Cyprinidae, Catostomidae, and Sciaenidae contributed roughly 98 percent of all fishes. Fishes tended to be most abundant at shoreline stations with greatest turbulence. Younger fishes appeared in greater densities during daylight at fastwater stations, while older larvae and juveniles were most numerous at the slackwater station at night. Threadfin shad and suckers were more abundant at night, while gizzard shad and drum were more abundant in day samples. Minnows and carp exhibited no diel periodicity. Recognizable (though not always identifiable) lower taxa in meter net collections accounted for roughly half of the species known to be resident in the river channel as adults. Apparently many riverine fishes either did not have planktonic immature stages or they tended to use extrariverine areas as spawning and/or nursery habitats. Generally, fishes which appeared in the spring (for example, gizzard shad, carp, buffalos, crappies, and percids) had short spawning periods and were more abundant in the higher-water year of the study (1977), whereas summer spawners (for example, some minnows, river carpsucker, and freshwater drum) had more protracted breeding seasons and were more abundant in the lower-water year. There was an inverse relationship between relative abundance of total ichthyoplankton and changing river stages.

Conner (1976) reported preliminary observations of immature fishes from the Mississippi River near St. Francisville, Louisiana. However, to date there has been no detailed description of the distribution of ichthyoplankton from this reach of the Mississippi River.

MATERIALS AND METHODS

Five transects were established in a 10.2 km stretch of the Mississippi River near St. Francisville, Louisiana (Fig. 1). A transect consisted of a station near each shoreline and a third at midriver. A 1-m diameter, conical plankton net of 0.505 mm nylon mesh was towed downstream for roughly 2 min to
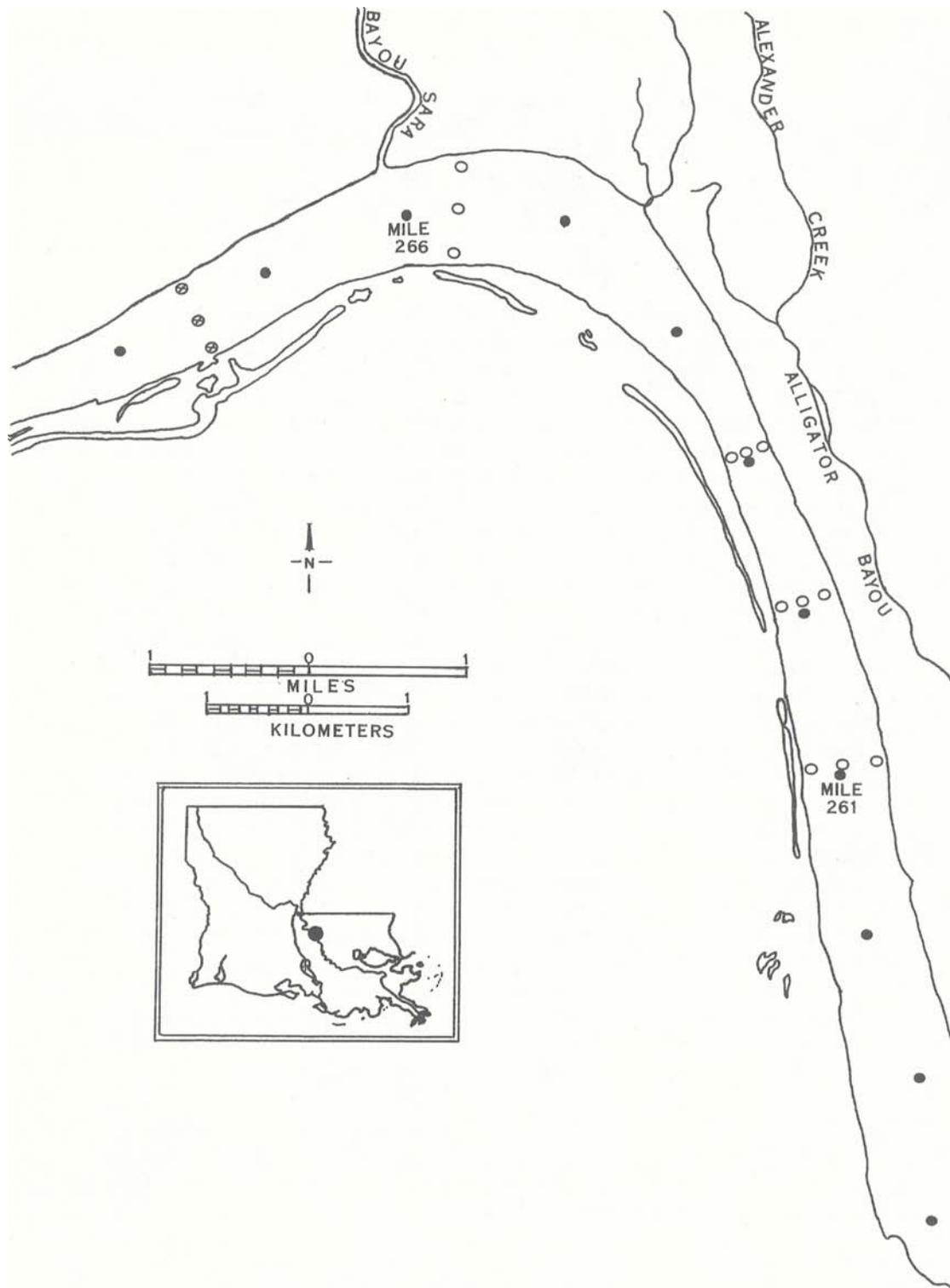
Figure 1. Mississippi River near St. Francisville, Louisiana. Circles mark those stations visited semi-monthly. An "X" indicates diel sampling sites.

collect all samples. The volume of water filtered (sample volume) was estimated using a General Oceanics model 2030 flowmeter mounted in the mouth of the net 25 cm from the edge. Surface current velocities were estimated at each station using a General Oceanics model 2035 digital flowmeter.

Since previous work indicated that fish larvae typically were present from late March through September (Conner and Bryan 1976), our collections were made during those months in 1976 and 1977. Single surface tows were made at each station during daylight hours at a semi-monthly frequency (only one visit in September 1976). To evaluate the diel distribution of ichthyoplankton, five 24-h studies were conducted monthly from April through August 1977. All visits were made at roughly mid-month to the transect established at river mile 267.5. Triplicate tows were made at each station at roughly 6-h intervals. Sampling began in late afternoon and ended the following afternoon.

Fishes were assigned to a developmental phase according to Snyder et al. (1977). All specimens were preserved in 3 to 5 percent buffered formalin and were deposited in the Louisiana State University Fisheries Collection.

Stage history was defined as the average daily change in river stage during the 72-h period preceding sampling. An interval scale was developed for standardized comparison of changing river stage:

Average daily change in stage		Stage history
Rapid fall	($\geq$ 30 cm)	-3
Moderate fall	($>$ 15 cm)	-2
Slow fall	($\geq$ 3 cm)	-1
Static	(change $<$ 3 cm)	0
Slow rise	($\geq$ 3 cm)	1
Moderate rise	($>$ 15 cm)	2
Rapid rise	($\geq$ 30 cm)	3

RESULTS

TAXONOMIC COMPOSITION

Representatives of ten families of fishes were encountered in 2 years of meter net sampling. Four of these appeared in most of the collections and were considered to be of major importance: Clupeidae, Cyprinidae, Catostomidae, and Sciaenidae. Major taxa accounted for roughly 98 percent of all fish larvae collected during the study. Representatives of Lepisosteidae, Hiodontidae, Atherinidae, Percichthyidae, Centrarchidae, and Percidae were present in rather low densities and were judged to be minor taxa (Tables 1 and 2).

Clupeids consisted almost entirely of two species, gizzard shad (Dorosoma cepedianum) and threadfin shad (D. petenense). Larvae of these species were similar in appearance and could be accurately identified to species level only as late metalarvae and juveniles (when adult anal fin ray counts were possible). The family Cyprinidae was treated as a whole, except for the carp (Cyprinus carpio) which was the only form recognizable in all phases of development. Other cyprinids which were recognized in at least some phases of

Table 1. Relative abundance of ichthyoplankton (number/100 m^3) collected in the lower Mississippi River, per sampling visit (stations combined), 1976.

Taxon	March 23	April 9	April 27	May 17	May 31	June 11	June 24	July 8	July 22	August 10	August 24	September 16
Clupeidae												
Alosa chrysochloris (Rafinesque)				0.1								
Dorosoma cepedianum (LeSueur)	1.7			0.1		0.3						
D. petenense (Gunther) Dorosoma spp.		4.6	1.3	7.0	7.0	1.0	1.0	6.9	3.8	0.1		
Hiodontidae												
Hiodon alosoides (Rafinesque)		0.1		0.3								
H. tergisus LeSueur			0.1	0.5								
Cyprinidae												
Unidentified minnows	0.3	1.7	1.5	0.9	1.3	2.0	1.8	4.4	3.4	5.2	3.2	0.7
Cyprinus carpio Linnaeus	0.3	6.3	0.1	0.4				0.1				
Catostomidae												
Carpiodes carpio (Rafinesque)			0.1	0.4	1.3	6.0	8.7	11.2	0.6	0.1		
Ictiobus spp.	0.1	0.1	0.5	0.3	0.6	0.1						
Percichthyidae												
Morone spp.	0.1		0.1	0.1	2.8	0.4						
Centrarchidae												
Lepomis spp.			0.1	0.1	0.1	0.1	0.2		0.2	0.1		
Micropterus sp.	0.1											
Pomoxis spp.	0.4	0.1										
Percidae												
Tribe Etheostomatini		0.1										
Stizostedion canadense (Smith)		0.1	0.1									
Sciaenidae												
Aplodinotus grunniens Rafinesque			0.5	1.7	46.6	47.4	45.0	7.5	4.6	4.8	5.7	1.0
Sample Volume (m^3)	1278	1396	1381	1042	1396	1413	1253	1365	1246	1399	1447	1258
Stage History	-2	0	+1	-1	-1	+2	-1	+1	-1	0	-1	-1

their development included grass carp (Ctenopharyngodon idella), speckled chub (Hybopsis aestivalis), silver chub (H. storeriana), emerald shiner (Notropis atherinoides), river shiner (N. blennius), silverband shiner (N. shumardi), mimic shiner (N. volucellus), and golden shiner (Notemigonus crysoleucas). Larval catostomids included buffalos (Ictiobus spp.), river carpsucker (Carpiodes carpio), and a single spotted sucker (Minytrema melanops). The buffalos were probably a mixture of bigmouth buffalo (I. cyprinellus) and smallmouth buffalo (I. bubalus), since both were common in the study area. The Sciaenidae were represented by freshwater drum (Aplodinotus grunniens) which accounted for nearly half of the total fishes taken during the entire study.

Of the minor taxa, temperate basses (Morone spp.) and centrarchids were most common. Yellow bass (Morone mississippiensis) and striped bass (M. saxatilis) occurred in the study area, but the white bass (M. chrysops) was reported to be the only common adult percichthyid (Guillory 1974, Conner et al. 1978). Centrarchids were represented by sunfishes (Lepomis spp., mostly bluegill L. macrochirus), black bass (Micropterus sp., probably M. salmoides), and white and black crappies (Pomoxis annularis and P. nigromaculatus, respectively). The goldeye (Hiodon alosoides), mooneye (H. tergisus), and

Table 2. Relative abundance of ichthyoplankton (number/1000 m^3) collected in the lower Mississippi River, per sampling visit (stations combined), 1977.

Taxon	March 24	April 5	April 26	May 5	May 24	June 8	June 28	July 7	July 26	August 9	August 23	September 9	September 26
Lepisosteidae													
Lepisosteus sp.			0.1			0.1							
Clupeidae													
Dorosoma cepedianum	8.2	3.8		0.1	0.1			0.1					
D. petenense				0.2	0.8	0.1	0.1	1.2	0.1	0.1	0.2		
Dorosoma spp.			114.3	9.9	10.5	0.6	0.2	0.3					
Hiodontidae													
Hiodon alosoides				0.2	0.1			0.1					
H. tergisus			0.1	0.3	0.1								
Hiodon spp.			0.1	1.1									
Cyprinidae													
Unidentified minnows	0.2	0.8	0.4	1.1	2.6	4.0	8.4	11.1	7.5	8.8	4.5	0.8	0.4
Cyprinus carpio	0.5	1.1	4.8	0.4	0.1			2.7					
Catostomidae													
Carpiodes carpio			0.2	0.1	1.4	4.3	1.4	1.0	0.5	0.5	0.1		
Ictiobus spp.	5.1	0.1	5.4	2.2		0.1							
Minytrema melanops		0.1											
Atherinidae													
Menidia audens			0.2	0.1									
Percichthyidae													
Morone saxatilis								0.1					
Morone spp.	0.9	0.2	1.4	0.4			0.1	0.1					
Centrarchidae													
Lepomis spp.			0.6	0.1	0.4	0.1	0.1	0.1	0.1				0.1
Micropterus sp.			0.4										
Pomoxis annularis				0.1									
P. nigromaculatus				0.1									
Pomoxis spp.	0.3	0.3	4.7	0.4	0.1								
Percidae													
Tribe Etheostomatini		0.4		0.1									
Stizostedion canadense			1.3	0.3									
Sciaenidae													
Aplodinotus grunniens		0.2	6.2	2.0	18.4	32.5	44.8	11.4	10.6	19.8	4.6	0.9	0.5
Sample Volume (m^3)	1164	1322	1260	1227	1319	1417	1306	1425	1478	1588	1383	1436	1466
Stage History	0	+1	-3	-2	-3	-1	0	+1	-1	-1	+2	0	+3

sauger (Stizostedion canadense) were encountered in very low densities. Only two gar larvae (Lepisosteus sp.) and three Mississippi silverside larvae (Menidia audens) appeared in plankton collections.

SEASONAL DISTRIBUTION

Fish larvae were most abundant from late May through early July in both years (Fig. 2). Diversity, as evidenced by the estimated number of lower taxa, was greatest from early April through early May (Tables 1 and 2). Spring spawners included shads, carp, buffalos, crappies, temperate and black basses, sunfishes, Hiodon spp., darters, and sauger. Summer collections were dominated by minnows, river carpsucker, and freshwater drum (Fig. 3).

Shads were most abundant from late March through May. Gizzard shad appeared first but were joined by threadfin shad in early May. By late June all identifiable clupeid larvae were threadfin shad.

Protolarval carp were present from late March through May and in early July, but were most abundant in April. Mesolarvae were found in April and early May. The appearance of 38 protolarvae in early July 1977 indicated that
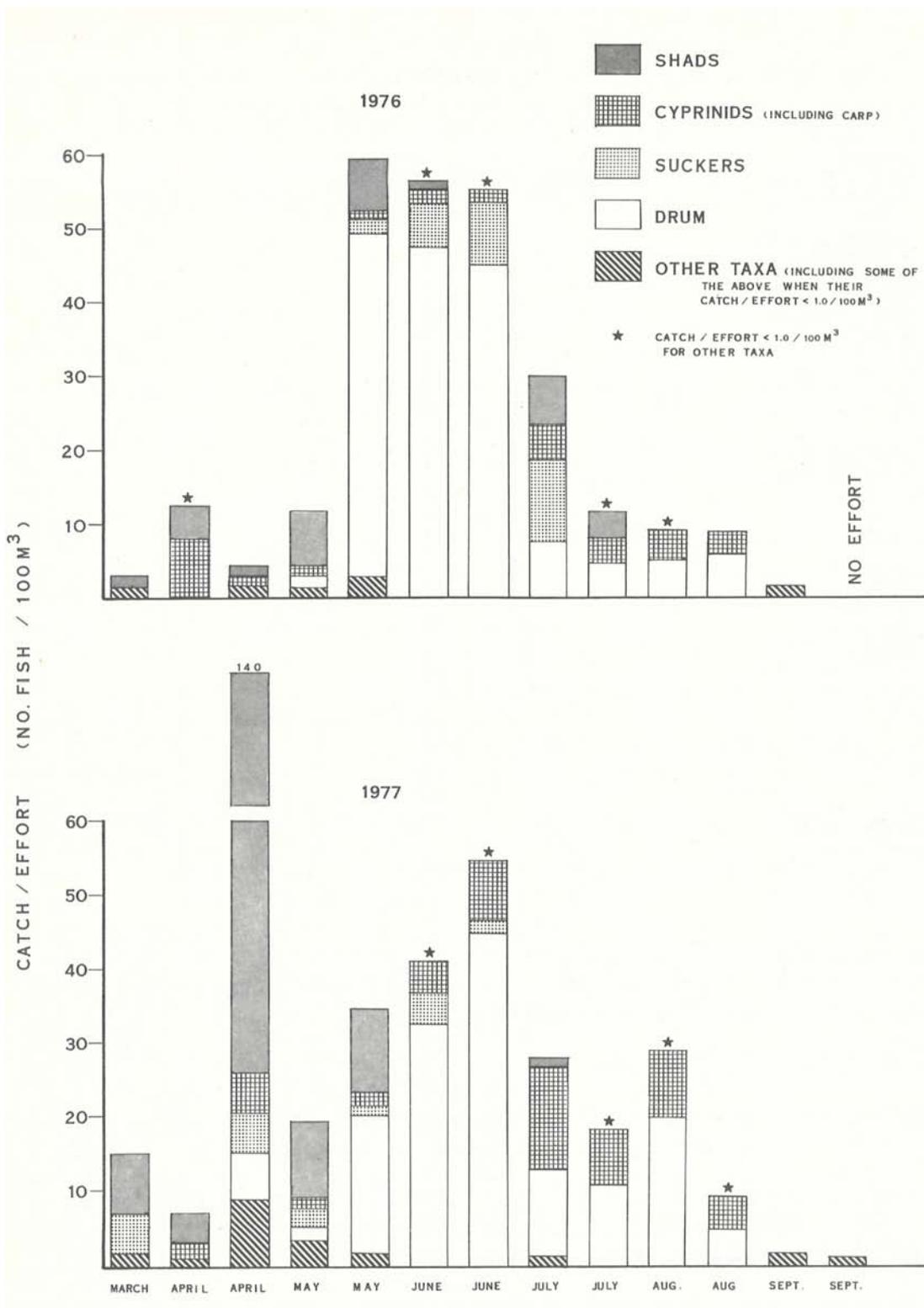
Figure 2. Relative abundance of ichthyoplankton (number/100 m³) in the lower Mississippi River during each collecting trip (stations combined) in 1976 and 1977.
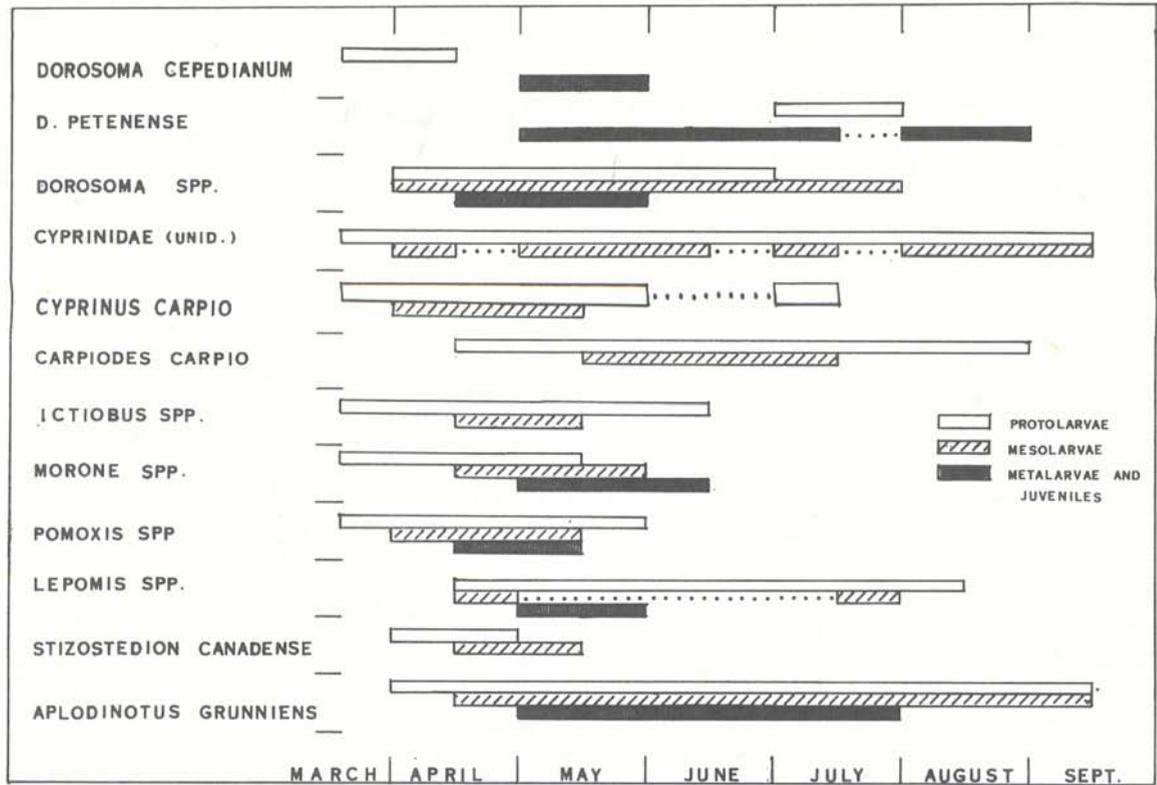
Figure 3. Temporal occurrence of the larval phases of selected taxa encountered in meter net collections from the lower Mississippi River.

spawning in this reach of the Mississippi River must have continued well into June. Taber (1969), Mundy (1973), and Walker (1975) found carp larvae to be most abundant in spring, but also encountered larvae in late June or early July. Minnows, though encountered every trip, were abundant during mid and late summer.

Buffalo larvae were more abundant in 1977. Greatest densities of protolarvae occurred from late March through early May, although these earliest stages persisted into June. Mesolarvae were found only in late April and early May. Larvae of the river carpsucker were most abundant in 1976. Protolarvae first appeared in April and persisted through August. Mesolarvae were collected only from late May until early July.

Spawning activity of freshwater drum was probably most intense in late May and early June. However, there was a slight increase in the numbers of protolarvae and mesolarvae in August, suggesting a minor spawning peak. This result was also witnessed by Conner and Bryan (1976). Swedberg and Walburg (1970) reported that drum spawn several times during the breeding season which could account for their protracted occurrence in our samples.

DIEL DISTRIBUTION

Total numbers of ichthyoplankton seemed to differ among diel sampling periods (ratio of day:night totals = 1.65). Minnows and carp showed no diel periodicity (day:night = 1.02). Suckers, especially river carpsucker, were more plentiful at night (0.64), as were threadfin shad (0.40). However, gizzard shad appeared in greater densities during the day (1.24) and drum (4.11) were clearly more abundant in day samples (Table 3). Higher densities of gizzard shad and drum in daylight collections reflected greater relative abundance of younger fish (protolarvae and mesolarvae), whereas older fish (metalarvae and juveniles) were more numerous in night collections. The day versus night ratio for older shad and older drum was 0.37 and 0.40, respectively.

Fishes were consistently most abundant at the west-shore station. The remaining stations were essentially alike during all periods except early night when the east-shore station showed a somewhat greater relative abundance (Table 4). Variation among stations was greatest during afternoon sampling, at least partly due to the higher relative abundance of drum at that time. Results of diel sampling suggested that differences in relative abundance among stations were minimized at night. Perhaps fishes were more successful at avoiding the net during daylight sampling (especially at the slackwater east-shore station). Older fishes were more abundant at night at the slackwater station, whereas protolarvae were more abundant during the day at fastwater stations (midriver and west-shore).

In this study, although only sampling at the surface, we found fish larvae to be more abundant during the day. However, in their study of the Susquehanna River, Gale and Mohr (1978) found drifting fish larvae to be more abundant at night (day:night = 0.26). Faber (1963) and Taber (1969), sampling at the surface and at discrete depths in lentic environments, also reported fish larvae to be more abundant at the surface at night.

Taber (1969), Storck et al. (1978), Tuberville (1979), and Graser (1979) all found shads to be more abundant at the surface during daylight sampling, but Netsch et al. (1971) and Kindschi et al. (1979) found them to be more concentrated at night.

In one diel study at a nearby Mississippi River transect, Conner and Bryan (1976) found cyprinoids (minnows and suckers) to be more abundant at night, as did Gale and Mohr (1978). In the present study suckers were more abundant in night collections, but densities of minnows and carp were unchanged during a diel cycle.

Taber (1969) and Tuberville (1979), sampling at discrete strata, found freshwater drum to be more abundant at the surface at night in lentic environments. However, in our study drum were more abundant in daylight samples; perhaps this behavior pattern was in response to increased turbulence and turbidity in the river.

Table 3. Relative abundance of ichthyoplankton (number/100 m^3) collected from the lower Mississippi River, during each diel sampling period. (* represents relative abundance <0.1/110 m^3)

Taxon	Late afternoon	Early night	Predawn	Postdawn	Late afternoon
Clupeidae					
Dorosoma cepedianum	8.6	7.4	3.3	6.9	5.3
D. petenense	0.2	0.7	0.6	0.3	0.4
Dorosoma spp.	0.7	0.3	0.3	0.7	0.4
Hiodontidae					
Hiodon alosoides	*				
Cyprinidae					
Unidentified minnows	6.2	5.8	5.8	5.6	5.7
Cyprinus carpio	1.6	1.2	1.7	1.8	1.3
Catostomidae					
Carpiodes carpio	1.8	3.4	4.1	2.8	2.5
Ictiobus spp.	0.1	0.3	0.5	0.4	0.4
Ictaluridae					
Ictalurus furcatus		0.1	0.1		
Pylodictis olivaris			*		
Cyprinodontidae					
Fundulus sp.				*	
Atherinidae					
Menidia audens	0.1		*		0.1
Percichthyidae					
Morone spp.	0.2	0.2	*	0.1	0.1
Centrarchidae					
Lepomis spp.	0.1	*	0.1	0.1	*
Pomoxis spp.	0.4	0.3	0.2	0.2	0.2
Percidae					
Etheostomatini	0.1				
Stizostedion canadense	0.2	0.1	0.1	0.2	0.1
Sciaenidae					
Aplodinotus grunniens	30.5	4.7	4.7	11.1	15.4
Total ichthyoplankton	50.5	24.2	21.5	30.2	31.7
Samle volume	4062	3786	3735	3803	3775

Table 4. Relative abundance of ichthyoplankton (number/100 m^3) at each station across RM 267.5 during each sampling period of the monthly diel visits to the lower Mississippi River.

Sampling period	East shore	Midriver	West shore
Late afternoon	18.3	17.7	117.9
Early night	200.4	14.6	38.2
Predawn	16.0	15.8	33.1
Postdawn	25.1	26.7	38.6
Late afternoon	16.1	17.3	62.5

SPATIAL DISTRIBUTION

Horizontal distribution of ichthyoplankton was similar in both years (Fig. 4). In general, fish larvae tended to be more abundant at shoreline stations, particularly those characterized by high surface current velocities (east-shore stations at the three lower transects and west-shore stations at the upper two transects). There was a marked difference in the distribution of ichthyoplankton during high-water versus low-water conditions (Fig. 5). In each year, high-water conditions obtained from mid-March through mid-April, and low-water conditions from June through August (Fig. 6). Variations in relative abundance among stations was more pronounced at low river stages.

HYDROGRAPHY

Sampling was conducted during two typically low-water years, as compared to the high-water conditions in 1975 (Fig. 6). However, such flooding as occurred during this study was of slightly greater amplitude and duration in 1977. Flooding in 1977 occurred when days were longer and mean surface temperatures in the river were higher.

DISCUSSION

Guillory (1974) listed 54 fishes as residents in the study area. However, only about half this number of lower taxa was represented in our samples, suggesting that many of the resident forms either spawned outside the study area or had life history stages that were not planktonic. Incidental dip net and seine collections made in quiet vegetated areas along the river and the floodplain (when inundated) showed that larvae of some species (including gar, shads, buffalos, spotted sucker, blue sucker (Cycleptus elongatus), creek chubsucker (Erimyzon oblongus), Mississippi silverside, and centrarchids were more abundant in these extrariverine areas than in our plankton samples.

The appearance of certain taxa in relatively high densities (Dorosoma, Morone, Lepomis, Micropterus, Pomoxis, Stizostedion canadense, and Aplodinotus grunniens) in late April 1977 (Table 2) was associated with changing
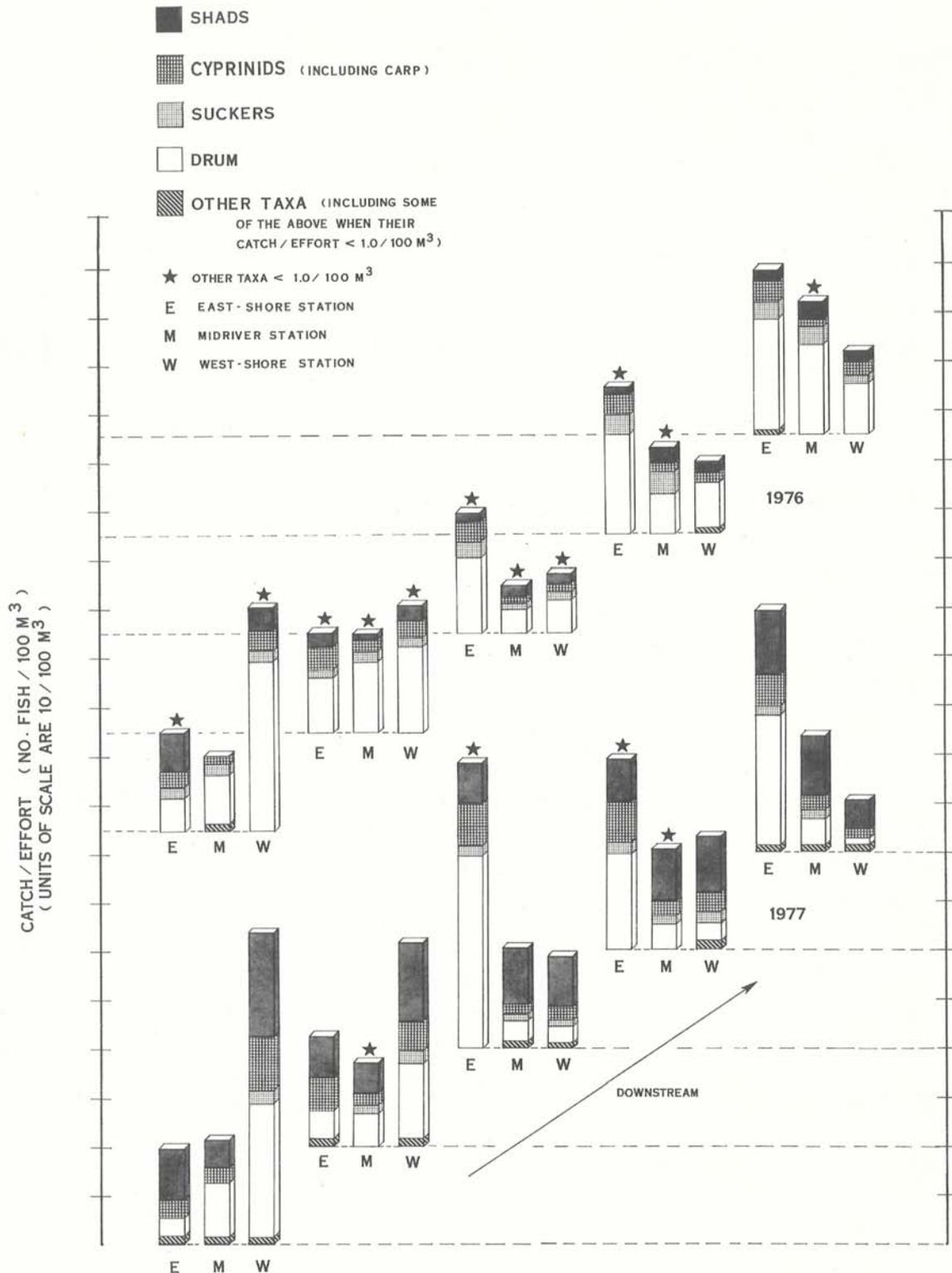
Figure 4. Relative abundance of ichthyoplankton (number/100 m^3) at each station (sampling trips combined) in 1976 and 1977.
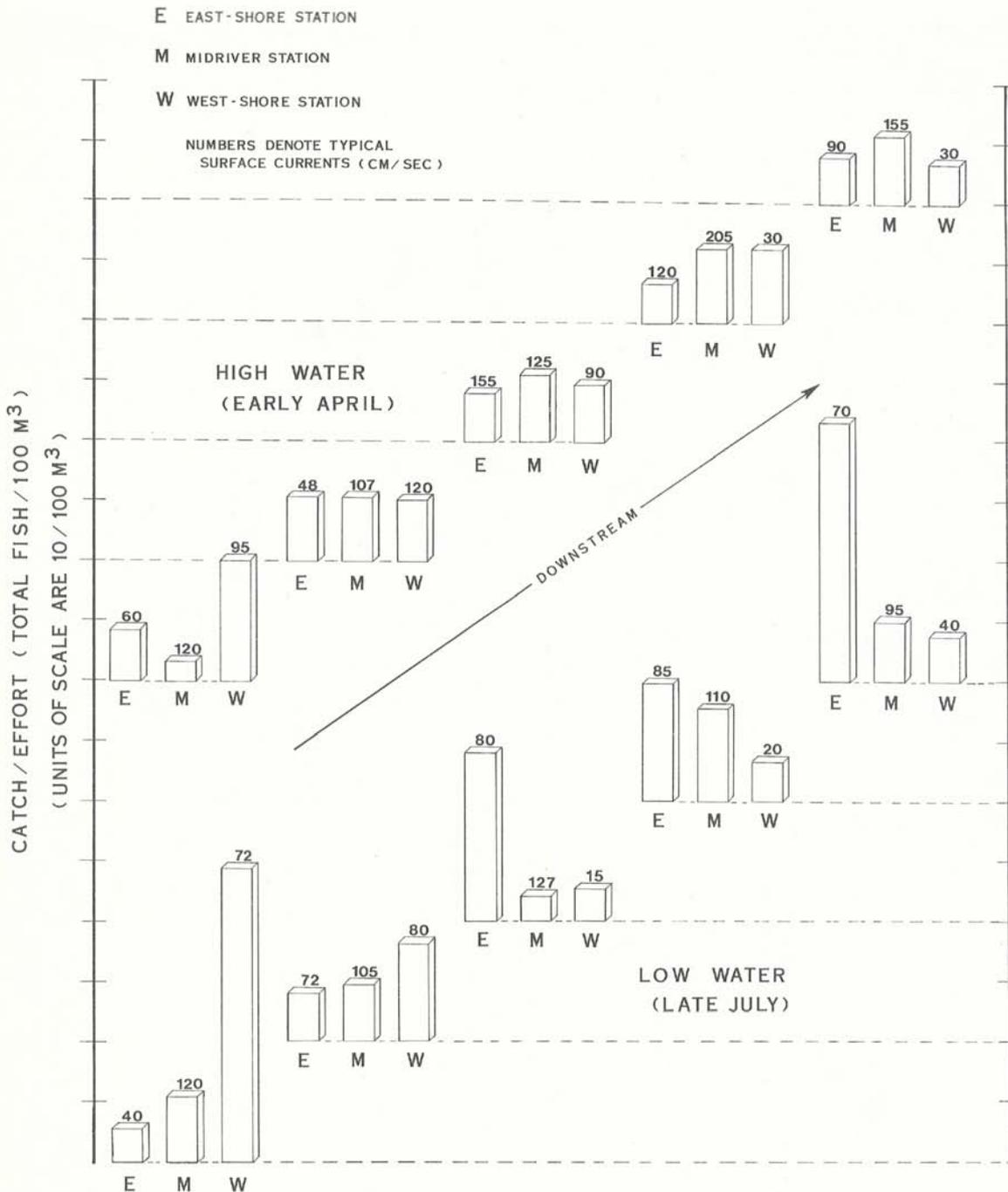
Figure 5. Relative abundance of ichthyoplankton (number/100 m³) at each station during typical high water and low water conditions.
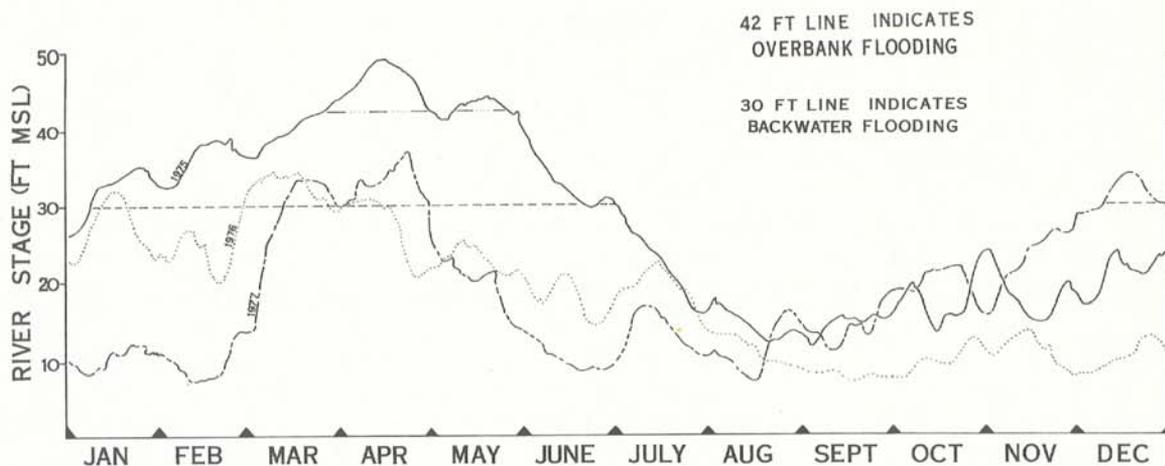
Figure 6. River stage hydrography for the Mississippi River (Bayou Sara gauge), for 1975, 1976, and 1977.

hydrographic conditions. At that time the river had been falling faster than 30 cm per day (Fig. 6). Perhaps fish larvae were being flushed out of the floodplain, causing greater densities to appear in the river. Indeed, for the entire study there was a negative correlation ($r = -0.46$, $P < 0.001$) between relative abundance of total ichthyoplankton and stage history.

Hynes (1970:362) related water temperature, day length, and discharge to timing of reproduction in riverine fishes. Walburg and Nelson (1966) indicated that rising water levels during the breeding season will enhance the reproductive success of certain species (for example, carp, river carpsucker, and buffalos).

Judged by their relative abundance in the plankton, some spring-spawning taxa (shads, carp, buffalos, temperate basses, centrarchids, and percids) tended to have short spawning periods and seemingly enjoyed greater spawning success in the high-water year of this study (1977). Summer spawners (some minnows, river carpsucker, and freshwater drum) tended to have protracted spawning periods and appeared to be more successful in the lower-water year (1976).

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DIEL, VERTICAL, AND HORIZONTAL VARIATIONS IN ABUNDANCE OF LARVAL DOROSOMA SPP. IN CENTER HILL RESERVOIR, TENNESSEE

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Abstract.- Larval Dorosoma spp. were collected at five depths from one midchannel station and from the surface at two inshore stations during May and June 1979. Collections were made six times during each of three 24-h periods. Catches were highest at night and lowest at midday, and the larvae were always most abundant in the surface or 2-m samples. Diel variations in catch rates were believed to result primarily from changes in catchability rather than vertical migrations. Midchannel densities were lower than shoreline or nearshore densities during two of the three sampling periods. Median lengths of shad larvae showed no consistent vertical or diel patterns, but specimens collected along the shoreline were usually shorter than those collected at the midchannel station.

Knowledge of spatial and diel variations in abundance of larval fishes is important for understanding fish behavior and for developing efficient sampling programs. Routine assessments of larval fish abundance should be designed to control or account for these variations. Larval shad (Dorosoma spp.) generally occur above the thermocline in stratified waters, but their density usually is not uniform. Larval shad have been found to be aggregated near the surface during the day and more dispersed at night by Taber (1969), Netsch et al. (1971), and Edwards et al. (1977). Positive phototaxis by larval Dorosoma spp. may be responsible for a strong surface orientation during the day. Shad may also exhibit small scale horizontal migrations on a diel schedule or as they grow in size. Taber (1969) reported that young shad were less abundant in shoreline seine samples at night. Shelton (1972) and Edwards et. al (1977) found that larval shad were most abundant near shore soon after spawning and that offshore densities increased with time. Storck et al. (1978), however, reported that gizzard shad (D. cepedianum) larvae were equally abundant at midlake and nearshore stations.

Objectives of this study were to describe diel and vertical variations in abundance of larval shad in one embayment of Center Hill Reservoir, Tennessee. Variations between shoreline, nearshore, and midchannel densities were also examined on a diel basis. Gizzard shad (D. cepedianum) and threadfin shad (D. petenense) were the only clupeids known to occur in Center Hill Reservoir and larvae of both species were treated as a single group.
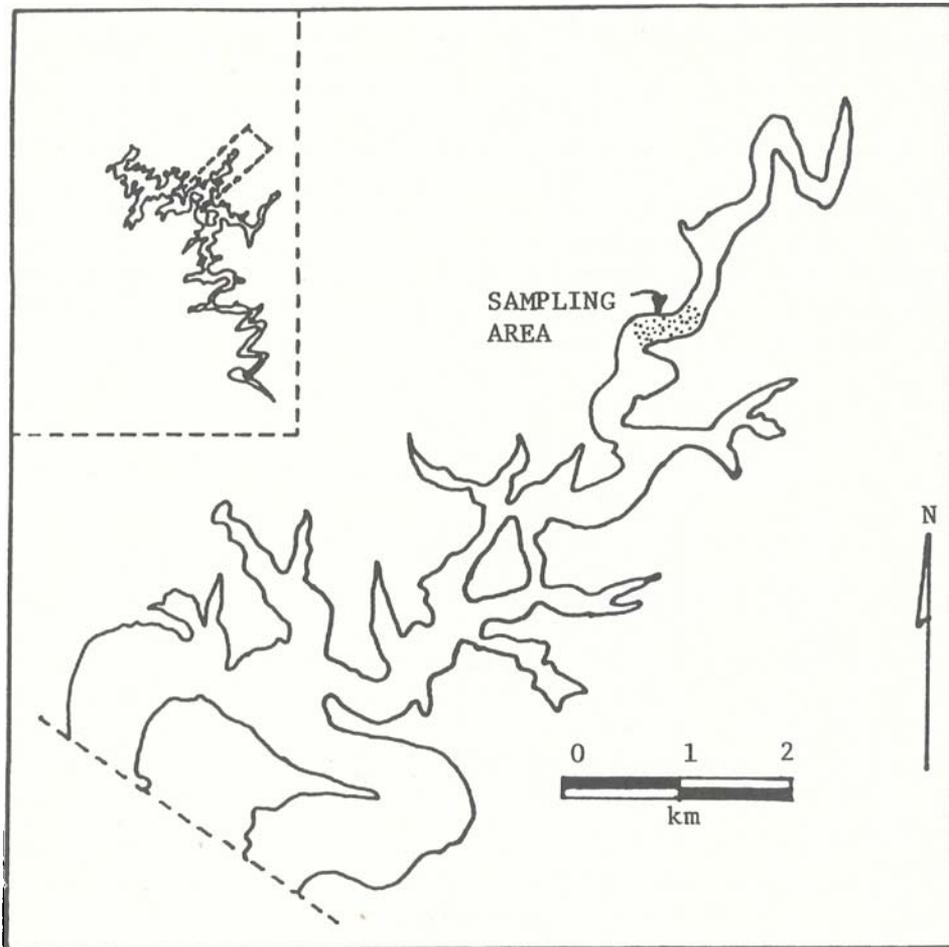
Figure 1. Center Hill Reservoir (inset) and the sampling area in Mine Lick Creek embayment.

STUDY AREA AND METHODS

Center Hill Reservoir was impounded in 1948 by the U.S. Army Corps of Engineers for flood control and power generation. Surface area is 7,373 ha and mean depth is 29 m at maximum power pool elevation. The reservoir has a narrow, meandering mainstream channel and several large embayments associated with major tributaries (Fig. 1). Variations of inflow often cause extreme fluctuations of water level during the spring.

Midchannel and inshore sampling sites were established in the upper end of the Mine Lick Creek embayment (Fig. 1). Larvae were collected biweekly from early May through August 1979, but results are presented only for the late May and June samples, when larval shad were most abundant. Samples were collected six times during each of three 24-h periods: predawn, postdawn, midday, predusk, postdusk, and midnight. Sampling times were coordinated with sunrise and sunset rather than clock time. Predawn and predusk sampling began 1.5 hr before sunrise and sunset, respectively, and predawn and postdusk collections were initiated immediately after sunrise and sunset.

A 0.25-m^2 Tucker trawl with a 0.505-mm mesh Nitex net was stern-towed at 1.0 m/sec to collect samples at the midchannel sites. One 5-min tow was made at each of five depths: surface, 2, 4, 6, and 8 m. A flowmeter was mounted in the mouth of the net to estimate water volumes sampled. Inshore samples were collected from the surface with paired 0.25 m^2 push nets (0.505 mm mesh Nitex). Nets were mounted on rigid outriggers that extended about 2.5 m to port and starboard of the boat's center line. The boat was maneuvered parallel to the shoreline so that the portside net was fished as close to the bank as possible in water that was 0.5 to 1.0 m deep. A flowmeter with an electronic readout was mounted in the mouth of the starboard net to maintain fishing speed at 1.0 m/s throughout each 5-min sample. The port sample was labeled "shoreline" and the starboard sample was labeled "nearshore". Push nets were also used at midchannel on all sampling occasions; port and starboard samples were regarded as replicates.

RESULTS

Catch data for late May and both June periods showed considerable diel variations. Total Tucker trawl catches (summed over all depths) were highest during either the postdusk or midnight periods (Fig. 2). Predusk catch rates were intermediate between day and night values, and predawn catch rates were more similar to daytime rates than nighttime rates except for 10-11 June. Larvae were apparently very abundant near the surface during the 10-11 June predawn period, when the highest surface trawl and push net catches were observed (Table 1).

Diel variations were most pronounced in the surface samples (Table 1). Only 6 larvae were collected at the surface by the trawl in all postdawn, midday, and predusk samples while 478 specimens were taken in the postdusk, midnight, and predawn series. The push nets showed essentially the same pattern.

Trawl catches were greatest at the 2-m sampling depth on all occasions except postdusk of 24-25 May and predawn of 10-11 June, when surface catches were slightly higher (Table 1). Catches below 2 m were always low. Since the trawl was towed from the stern, prop wash may have created a bias in the surface samples. Push nets usually collected more larvae at the surface than the Tucker trawl, and although it is likely that some differences in sampling efficiency of the two gear types exist (other than the prop wash concern), we judged the push net samples to be the best available indicators of surface densities. When push net data were compared to deeper trawl catches, it was found that catches from 2 m were consistently highest during the day and that surface and 2-m densities were generally similar during the postdusk, midnight, and predawn periods. Median lengths of larvae increased as the season progressed but there were no consistent diel or vertical trends within specific 24-h time periods (Table 1). Precise comparisons could not be made because of small sample sizes during the day and below 2 m. Push nets caught larger larvae than the trawl in 10 of 11 cases for which comparisons were possible (Table 1).

Midchannel catch rates were lower than the nearshore and shoreline catches during the 24-25 May and 24-25 June sampling periods, but during 10-11 June, the midchannel samples contained more larvae (Table 2). Catch rates
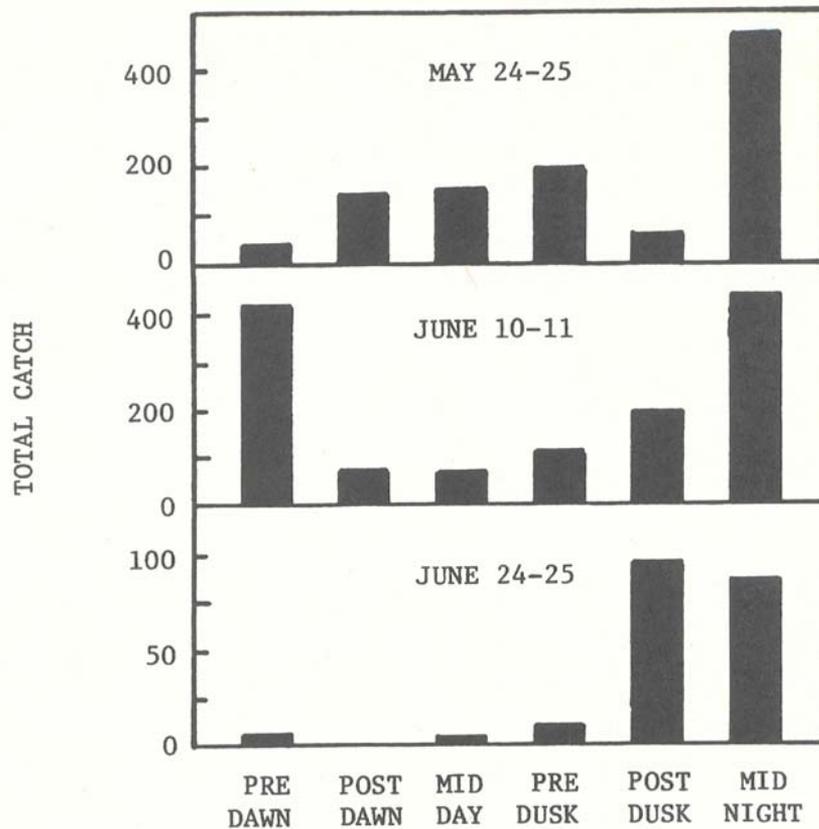
Figure 2. Total numbers of shad larvae collected with a Tucker trawl from the surface to a depth of 8 m in Center Hill Reservoir.

were so low during the day that diel changes in the horizontal pattern could not be assessed and the overall interpretation may be representative only of nighttime conditions. Larvae collected at midchannel were usually longer than specimens from the nearshore and shoreline samples.

DISCUSSION

The diel pattern we observed did not consistently agree with the findings of other researchers. Netsch et al. (1971) and Edwards et al. (1977) observed higher catches at night than during the day, but Graser (1979) and Tuberville (1979) found that catch rates were highest during the day or at dusk. The latter two studies were conducted in relatively lotic systems while ours and those of Netsch et al. and Edwards et al. were done in more lentic reservoirs. Graser (1979) suggested that flowing water may influence shad distributional patterns.

We believe that most of the diel variations in catch rates were related primarily to gear avoidance rather than changes in position of the larvae. Catches below 2 m were never substantial and larvae were primarily restricted to the upper 2 to 3 m of the water column. A thermocline was established at a depth of about 4 m during June. The similarity of catch rates between the

Table 1. Catch per tow and median total length (mm, in parentheses) of larval shad collected at mid channel during three 24-h periods in Center Hill Reservoir, 1979. (NC means not collected.)

| | Time of collection | | | | | |
	Predawn	Postdawn	Midday	Predusk	Postdusk	Midnight
24-25 May						
Surface (push net)	31(16)	0	1(9)	5(20)	260(14)	348(14)
Surface (trawl)	8(9)	0	0	1(6)	34(10)	93(11)
2m	28(9)	133(11)	146(10)	171(12)	25(9)	346(14)
4m	0	3(7)	2(8)	15(11)	0	15(14)
6m	1(8)	0	0	1(9)	0	NC
8m	0	0	1(5)	1(12)	1(5)	2(19)
10-11 June						
Surface (push net)	350(17)	1(23)	0	4(9)	141(13)	102(15)
Surface (trawl)	219(11)	2(13)	2(8)	0	71(11)	28(10)
2m	191(10)	58(9)	62(8)	93(8)	100(8)	398(15)
4m	7(10)	8(10)	0	21(8)	18(11)	3(20)
6m	0	0	1(6)	0	0	15(9)
8m	0	0	0	0	0	1(7)
24-25 June						
Surface (push net)	1(14)	0	0	0	29(17)	48(16)
Surface (trawl)	2(14)	0	0	1(13)	8(15)	15(14)
2m	4(17)	0	3(11)	2(13)	85(19)	71(20)
4m	0	0	0	8(15)	0	0
6m	0	0	0	0	0	0
8m	0	0	0	0	0	0

surface and 2-m samples during postdusk, midnight, and predawn periods supports the conclusions and Houser and Dunn (1967) and Netsch et al. (1971) that larval shad were more uniformly dispersed in the epilimnion during the night than during the day.

Other authors have attributed horizontal variations in shad density or size to inshore spawning and subsequent offshore migrations (Shelton 1972, Edwards et al. 1977). We found that median lengths of larvae were usually lowest along the shoreline and highest in the midchannel samples, but there was no trend toward relatively higher offshore densities as time passed. Catches were highest along the shoreline in late June. The lack of a

Table 2. Catch per tow and median total length (mm, in parentheses) of larval shad collected from the surface in push nets during three 24-h periods in Center Hill Reservoir, 1979.

Date/location	Time of collection						Total
	Predawn	Postdawn	Midday	Predusk	Postdusk	Midnight	
24-25 May							
Shoreline	32(9)	0	3(5)	0	811(11)	512(13)	1358(12)
Nearshore	36(10)	3(20)	4(16)	4(10)	1022(14)	605(13)	1674(14)
Midchannel	31(16)	0	1(9)	5(20)	260(14)	348(14)	645(14)
10-11 June							
Shoreline	63(10)	0	126(15)	5(17)	89(10)	73(11)	356(12)
Nearshore	61(11)	1(22)	94(14)	0	88(12)	31(14)	275(13)
Midchannel	350(17)	1(23)	0	4(9)	141(13)	102(15)	598(16)
24-25 June							
Shoreline	2(10)	0	0	0	154(15)	321(14)	477(14)
Nearshore	2(22)	0	0	0	108(17)	107(17)	217(17)
Midchannel	1(14)	0	0	0	29(17)	48(16)	78(17)

pronounced offshore migration may have been due to the small size of the larvae during May and June. Edwards et al. (1977) stated that midchannel densities were higher than shoreline densities after most larvae exceeded 20 mm. Median length of all larvae we collected in push nets during late June was 15 mm.

ACKNOWLEDGEMENTS

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SEASONAL OCCURRENCE, DISTRIBUTION, AND POWER PLANT ENTRAINMENT OF LARVAL FISHES IN PRESQUE ISLE HARBOR, LAKE SUPERIOR

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Abstract.- A study to determine seasonal occurrence, distribution and power plant entrainment of larval fishes in Presque Isle Harbor was conducted from April 1975 through July 1976. Larval fishes were found in the harbor during all months except September, October, and November. Larvae of most taxa appeared only between April and August, but coregonines and fourhorn sculpin occurred from December to July and December to June, respectively. In 1976, coregonines and fourhorn sculpin reached peak abundance about mid-May, followed by rainbow smelt in late May, lake trout and white sucker in early June, yellow perch in mid-June, burbot in late June, sculpins of the genus Cottus in mid-July, and ninespine stickleback in late July. Maximum estimated densities for the five most abundant taxa were (mean, SD): 28.8 $+$ 9.9 per m^3 for rainbow smelt, 0.313 $+$ 0.021 for yellow perch, 0.081 $\pm$ 0.003 for coregonines, 0.052 $\pm$ 0.0 for burbot, and 0.030 $\pm$ 0.002 for fourhorn sculpin. Larvae of most taxa exhibited clumped distributions during their respective periods of peak abundance. Only burbot larvae displayed a uniform distribution.

Total entrainment from August 1975 through 1976 was estimated at 8.8 $x10^6$ larvae (less than 30 mm SL). Rainbow smelt, coregonines, fourhorn sculpin, and lake trout accounted for 92.8%, 3.4%, 1.5%, and 1.2% of this estimate, respectively. Entrainment appeared to be associated with seasonal succession of larvae, behavioral characteristics of larvae, and physical factors such as river discharge, harbor circulation, and wave action.

Increased power plant construction and expansion to meet electrical power demands has led to an increased awareness of and concern for entrainment of larval fishes. Research reported here was part of a study conducted from April 1975 through July 1976 to assess effects of expansion and operation of the Presque Isle Power Station, Marquette, Michigan, on the aquatic biota of Presque Isle Harbor, Lake Superior. The purpose of this part of the study was
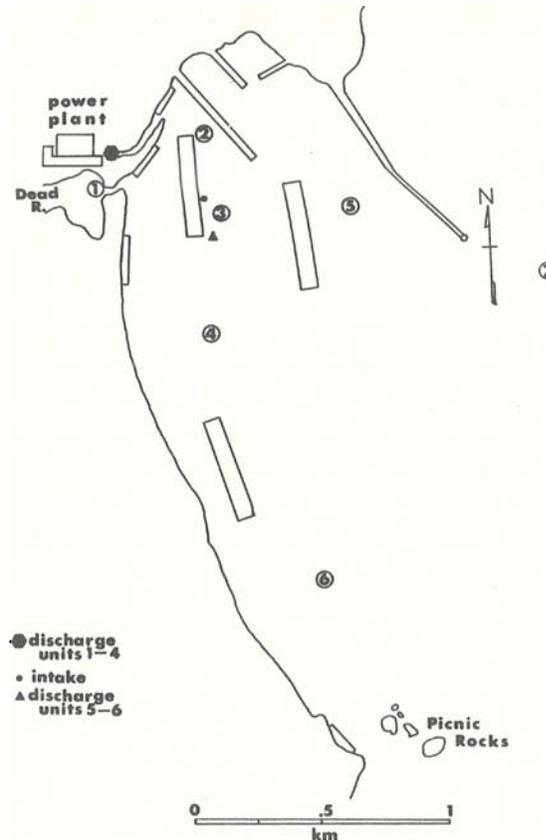
Figure 1. Presque Isle Harbor showing locations of the power plant, physical features, and sampling sites for tow net (circles), trawl (large rectangles), and beach seine (small rectangles) collections.

to determine the seasonal occurrence, succession, and distribution of larval fishes in the harbor and to estimate the magnitude of their entrainment through the power plant's cooling system.

To date, few studies concerning larval fishes in Lake Superior have been published (Anderson and Smith 1971, Selgeby et al. 1978). Furthermore, there is little information about seasonal succession and community distribution patterns of larvae in other northern lakes (Faber 1967 and 1970, Amundrud et al. 1974, Nelson and Cole 1975). Edsall and Yocum (1972), Jude (1976), and Teleki (1976) have presented limited data concerning entrainment in the Great Lakes. The only information relating entrainment to seasonal succession and distribution is that of Kelso and Leslie (1979). This research provides the first information concerning seasonal succession and entrainment of larvae in Lake Superior.

STUDY AREA

Presque Isle Harbor, Marquette, Michigan, is a natural indentation of Lake Superior's southern shoreline (Fig. 1). It is 2.7 km long, north to south, and extends 1.2 km eastward to the lake. An 858 m breakwater separates the harbor from Lake Superior to the northeast, and a group of granite rocks (Picnic Rocks) mark its southeastern limit. Discharge from the harbor's only tributary, the Dead River, is controlled for hydroelectric power and averages 5.6 m^3/s from September through March and 2.0 m^3/s from April through August.

Depths in the harbor range from 3 to 6 m at 360 m from the shoreline and from 9 to 15 m at 1200 m from the shoreline. Most of the harbor substrate is sand, but cobble and boulder areas exist along the breakwater, in a small area about 300 m south of the breakwater, along the power plant's intake and discharge pipes, and along the middle third of the shoreline.

The Presque Isle Power Station is located in the northern portion of the harbor. At the time of the study, the plant consisted of six fossil fuel units with a net generating capacity of 340 megawatts and employed once-through cooling at an approximate flow rate of 10.2 m^3/s. The cooling water intake was located 260 m offshore and was fitted with a velocity cap that reduced the intake velocity above the intake pipes. The velocity cap was approximately 2.5 m below the water's surface. Velocities measured outside the cap were consistently less than 0.01 m/s, and velocities measured across the six pump house screens ranged from 0.08 to 0.19 m/s.

MATERIALS AND METHODS

Ichthyoplankton was collected at the seven stations shown in Fig. 1 with 1:5 conical Nitex nets equipped with calibrated flow meters and 1-liter flow-through collecting buckets. In 1975, samples were taken with a 0.2 m^2 (563 micrometer mesh) net that was towed in the following manner: 3 min at the surface, 4 min descending to the bottom, 3 min near the bottom, 4 min ascending to the surface, and 2 min at the surface. In 1976, samples were taken with a 0.5 m^2 (355 micrometer mesh) net that was towed for 3 min at each of three depths (surface, mid-depth, and bottom). Normally, a second tow was made at each station. All tows were made during the day at speeds of 0.8 to 1.2 m/s. Samples were collected weekly from late April through July, biweekly during August and September 1975, five times from January through March, and weekly during April and May 1976.

Advanced larvae and juveniles of several species were collected with a 6-mm mesh beach seine and a 5-m semi-balloon otter trawl lined with a 6-mm mesh netting in the cod end. Seining was conducted monthly from June through October 1975 and once in April 1976. Trawling was conducted weekly during June, October, and November 1975 and April and May 1976. Biweekly trawling was conducted from July through September 1975 and in February and March 1976.

Entrainment samples were collected by suspending specially designed plankton nets in the intake water as it entered the cooling water forebay from the lake. Samples were taken at 4 TO 6-d intervals from August 1975 through July 1976, and additional samples were taken during periods of rapid environmental change (such as storms and high river discharge) or increased

Table 1. Phases and sizes (mm SL) of taxa from samples collected with several gear types. Phases are denoted by p (protolarva), m (mesolarva), or t (metalarva and juvenile).

Taxon	Entrainment net Phase	SL	Tow net Phase	SL	Otter trawl Phase	SL	Beach seine Phase	SL
Coregoninae	p m	10-25	p m	10-25				
Coregonus clupeaformis	p m	11-20	p m	10-18				
Salvelinus namaycush	m	21-28	m	24	m t	23-40		
Osmerus mordax	p m t	4-52	p m t	4-25	t	20-50	m t	26-50
Cyprinus carpio	p m	5-9	p m	7-8				
Notropis spp.	p	6-10	p	8			t	26
Catostomus commersoni	p	16-20	p	16-21			t	35-50
Percopsis omiscomaycus	t	31-33						
Lota lota	p m	4-11	p m	4-9				
Pungitius pungitius	m t	7-13			t	15-26		
Ambloplites rupestris	t	21-25					t	26-50
Lepomis macrochirus					t	22		
Micropterus dolomieui							t	23
Etheostoma nigrum					t	15-30	t	26-30
Perca flavescens	p m t	5-35	p m t	5-20	t	22-50	t	22-50
Cottus bairdi					t	20-35	t	26-35
Cottus cognatus	t	11-35	t	10	t	20-35	t	26-35
Cottus spp.	p m t	6-13	p m t	6-9				
Myoxocephalus quadricornis	p m t	8-26	p m t	8-31				

larval abundance in the harbor. Each sample was collected over a 24-h period. The plankton nets were made of Nitex and were attached to rectangular frames, 0.31 by 1.63 m. The net used from August through November was 2.1 m long and had a mesh size of 760 micrometers. In December this net was replaced by an 8-m long net of the same mesh size. Another 8-m long net of 355 micrometer mesh was used along with the second net from mid-January through July. Nine paired samples were taken with the 8-m long nets (three each in February, March, and May) to evaluate relative catch efficiencies. Student's t-tests (0.05 level) showed no significant differences in number of larvae caught by the two nets, except for protolarval rainbow smelt (Osmerus mordax) caught in May. Therefore, catches from both nets were utilized to estimate entrainment for all taxa except smelt and burbot (Lota lota), the only taxon not included in the above tests whose larvae were nearly as small as smelt. Catches from the 2.1-m net did not have to be corrected since larvae were not entrained during its use.

Only larvae 30 mm SL or less were included in entrainment estimates since larger fishes usually were caught on the pump house screens. Estimates were made by calculating the average monthly catch per m^3 and multiplying that

number by the actual cooling water volume in each month. Entrainment samples collected prior to August 1975 were not used to estimate entrainment, but were used in the analysis of seasonal succession.

RESULTS AND DISCUSSION

SEASONAL OCCURRENCE AND ABUNDANCE

Sixteen species of larvae were identified during this study (Table 1). It was not possible to separate lake whitefish (Coregonus clupeaformis) from other coregonines consistently; therefore, data were combined under the taxon Coregoninae. Adult and juvenile lake herring (C. artedii) and round whitefish (Prosopium cylindraceum) were present in the harbor and it is likely that larvae of these species were collected. Mottled sculpin (Cottus bairdi), slimy sculpin (C. cognatus), and spoonhead sculpin (C. ricei) were not distinguishable as protolarvae and mesolarvae (terminology of Snyder et al. 1977) and were combined under the taxon Cottus. Minnow larvae of the genus Notropis were not identified to species.

Figure 2 presents a composite picture of seasonal occurrence and succession. Data from both years were combined because one complete biological year was not sampled and patterns of occurrence from April through July were very similar in both calendar years. The data indicate that the larval biological year begins in December when coregonines and fourhorn sculpin (Myoxocephalus quadricornis) appear and ends in September when larvae either emigrate from the harbor or attain juvenile status.
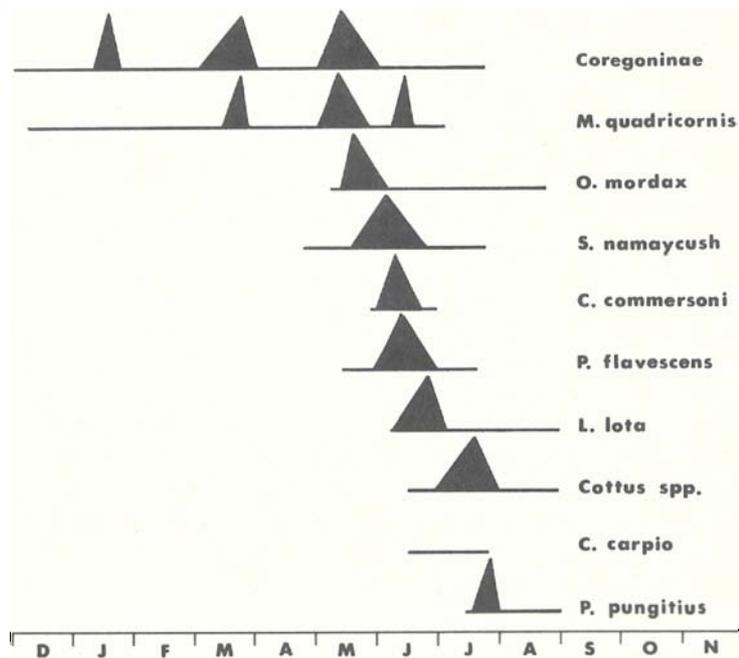
Figure 2. Seasonal succession and periods of peak occurrence of larval fishes in the Presque Isle Harbor area estimated from data collected by all methods in 1975 and 1976.

Although larvae of most taxa appeared in the harbor between April and August, protolarval and mesolarval coregonines occurred from December to July. These findings agree with observations on gonadal development in coregonines (Dryer and Beil 1968) and indicate that Lake Superior coregonines spawn over an extended period, perhaps all year. More importantly, these findings also indicate that some coregonine larvae reach their critical period (as defined by Hjort 1914) during the winter months when zooplankton food resources are low (Selgeby 1975). The presence throughout the winter of mesolarvae up to 25 mm SL indicates that growth took place at that time.

Fourhorn sculpin larvae appeared concurrently with coregonines from December to June, indicating a prolonged spawning period. Larvae ranging from 8 to 31 mm SL were collected from December through March, again indicating winter growth. Khan and Faber (1974) suggested that this species spawns throughout the winter, spring, and early summer in Lake Michigan.

Measurements of ichthyoplankton density reflected the heterogeneous distribution of larvae in time and space (Fig. 3). Densities in the harbor exceeded one larva per m^3 only during the peak occurrence of rainbow smelt larvae. Smelt predominated the ichthyoplankton community in the May through July period, accounting for 98% of the tow net catch and 96% of the entrainment catch. Smelt reached a peak density of 28.8 $\pm$ 9.9 (mean $\pm$ SD) in the vicinity of the Dead River outflow in late May 1976. Maximum densities in the harbor for other larval fishes were (larvae per m^3): 0.313 $\pm$ 0.021 for yellow perch (Perca flavescens), 0.081 $\pm$ 0.003 for coregonines, 0.052 $\pm$ 0.0 for burbot, and 0.030 $\pm$ 0.002 for fourhorn sculpin. Comparisons with estimates from other Lake Superior studies are difficult to make because of differences in sampling techniques. Anderson and Smith (1971) collected larval Coregonus spp. from Duluth-Superior Harbor and the Apostle Islands but did not measure volumes of water sampled. Selgeby et al. (1978) used a variety of plankton nets to collect lake herring larvae and reported peak densities (number per m^3) of about 0.017 in the Apostle Islands and 1.7 in Black Bay. Differences in density estimates probably reflect differences in local environment as well as differences in sampling efficiency.

DISTRIBUTION

Analysis of tow net samples showed that larvae of most taxa displayed clumped distributions (Figs. 3 and 4). Coregonine larvae were consistently more abundant near the open lake in water 12 to 18 m deep. Faber (1970) stated that lake whitefish larvae in South Bay, Lake Huron, were most abundant along steep shorelines in water 1 to 3 m deep and that numbers diminished rapidly away from shore. Hart (1930) reported similar information for whitefish larvae in the Bay of Quinte, Lake Ontario. Pritchard (1930) indicated that newly hatched lake herring in Lake Ontario occurred near the surface in deeper water than whitefish, and Wells (1966) indicated that larval bloater (Coregonus hoyi) in Lake Michigan were far more abundant in water deeper than 90 m. The distributional pattern from this study is similar to that of lake herring reported by Pritchard, and it may be that lake herring account for the majority of the catch. The observed pattern and the abrupt occurrence of 25-mm SL mesolarvae in December suggests that some larval coregonines were recruited from outside the harbor. Dispersal throughout the harbor was not observed.
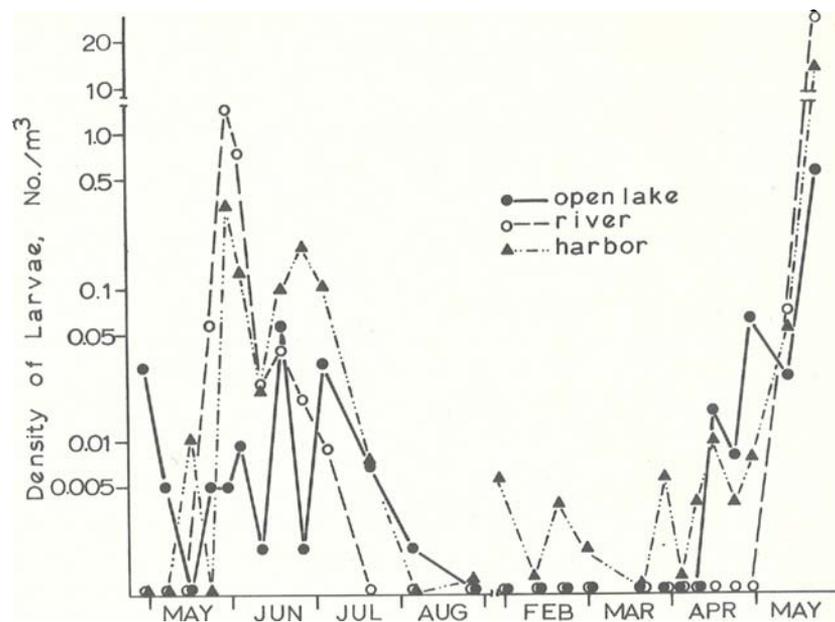
Figure 3. Density of larval fishes caught by tow nets in the Dead River (site 1 in Fig. 1), Presque Isle Harbor (sites 2 through 5), and Lake Superior (sites 6 and 7). Each point represents a weighted mean for a single sampling date.

Fourhorn sculpin were concentrated in the northern portion of the harbor, particularly in the vicinity of a potential spawning area south of the breakwater. Since newly hatched 8-mm SL larvae appeared before more advanced stages, it is possible that spawning occurred in or near the harbor. However, no adults were taken by trawling. The absence of adults and the prolonged hatching period suggest that some recruitment from outside the harbor occurred. Faber (1970) suggested that fourhorn sculpin larvae in South Bay were recruited from Lake Huron.

Cottus larvae were found only in areas of known spawning activity in the northern portion of the harbor. There was no evidence of dispersal as larvae, and juveniles were collected later in the same areas as were ripe adults and larvae.

Rainbow smelt and yellow perch larvae were most abundant in the Dead River and in the vicinity of its mouth. Neither species dispersed to the lake or to the south harbor to any great degree as protolarvae. Yellow perch remained in the northwest portion of the harbor throughout their developmental period. This area was 1 to 3 m deep, supported the only growth of Chara in the harbor, and received a thermal effluent from the power plant. Smelt eventually became dispersed throughout the harbor during mesolarval and metalarval phases. Juvenile smelt were collected in entrainment samples and on the pump house screens throughout the fall and winter. Seasonal patterns of these two species approximated those reported by Faber (1967).
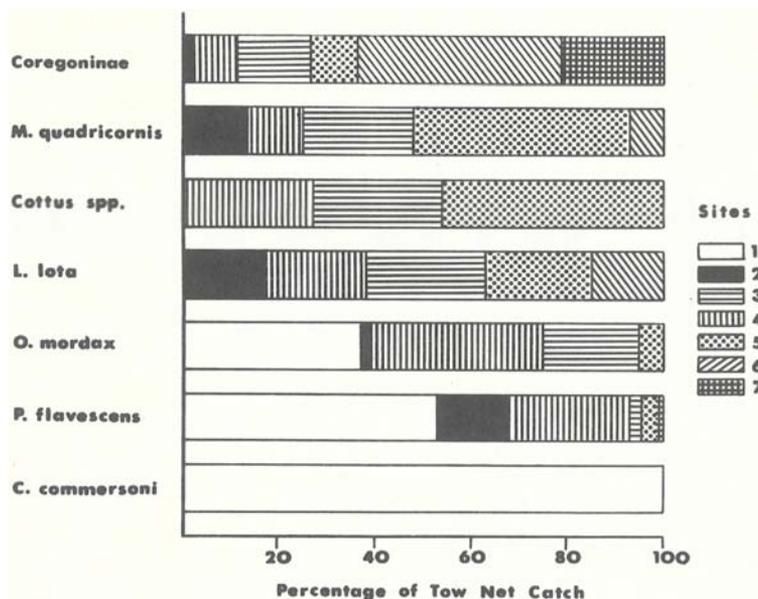
Figure 4. Distribution of some larval fishes at seven tow net sites during their respective peak abundance.

White sucker (Catostomus commersoni) larvae were collected exclusively in the Dead River. In contrast to smelt, few white sucker larvae were carried into the harbor by the Dead River discharge. Juveniles migrated to the harbor in late July at about 35 mm SL.

Burbot was the only protolarval fish collected that demonstrated a uniform distribution in the harbor. Protolarvae were not found in the open lake, indicating little recruitment occurred from outside the harbor. Burbot usually spawn over sand or gravel substrate in water 1 to 3 m deep (Scott and Crossman 1973) and larvae generally are found throughout the water column in the littoral and limnetic areas (Fish 1932, Faber 1970).

Lake trout (Salvelinus namaycush) larvae were not included in Fig. 4 because their capture by tow net was rare. They were taken frequently by trawl in the vicinity of the plant intake and discharge pipes where adults were observed spawning in November 1976. In 1975 and 1976 mesolarvae swam up at about 25 mm SL (late May 1976) and remained in the northern half of the harbor until they reached 35 to 40 mm SL (early July). Mesolarvae were found in the harbor in water 3 to 9 m deep. Data from trawl samples collected by the Michigan Department of Natural Resources in 1976 indicated that juveniles dispersed toward the southern portion of the harbor and then to the open lake in early August (James W. Peck, personal communication).

ENTRAINMENT

A total of 232,394 fishes less than 30 mm SL was collected in entrainment samples from December 1975 through July 1976 (Table 2). No larvae were present in collections from August through November 1975. Total entrainment for the period, based on the plant's intake volume, was estimated to be slightly more than 8.8×10^6 larvae (Table 3). Rainbow smelt, coregonines,

Table 2. Monthly entrainment catch December 1975 through July 1976 given as number of larvae per 100 m^3 with number of larvae collected below. No larvae entrained from August August 1975 through November 1975.

Taxon	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Coregoninae	0.50	1.90	1.40	1.70	1.70	3.80	0.45	<0.01
	171	478	631	1080	400	2843	255	2
M. quadricornis	0.32	1.10	0.35	0.71	0.29	1.60	0.60	
	109	263	160	454	70	1172	366	
S. namaycush					0.02	1.00	3.10	0.01
					4	773	1766	4
P. flavescens						0.04	0.51	0.07
						29	287	23
O. mordax						280	19	9.30
						206,494	10,420	3182
Cottus spp.							0.03	0.80
							17	275
L. lota							0.64	0.66
							359	225
All larvae	0.84	3.00	1.70	2.40	2.00	290	24	11
	289	748	797	1540	474	211312	13481	3753

fourhorn sculpin, and lake trout accounted for 92.8%, 3.4%, 1.5%, and 1.2% of this estimate, respectively. Entrainment was highest in May when an estimated 7.6×10^6 larvae passed through the plant's condensers.

It is difficult to assess the impact of this entrainment loss on harbor and lake populations since spawning-stock size and natural mortality rates for early developmental stages are not known for the species involved. However, some perspective on the magnitude of entrainment can be gained by considering the following. If the average fecundity of smelt was 31,000 eggs (Bailey 1964) and if natural mortality from egg deposition to metalarval phase was 90% (an assumed figure that is probably low), the estimated smelt entrainment would equal the removal of about 2640 females by smelt fishermen. If an average fecundity of 6,000 eggs per fish was assumed for all coregonines (Scott and Crossman 1973) the estimated coregonine entrainment would equal the loss of about 500 females. While this number is nearly inconsequential as compared to commercial harvest figures (Baldwin and Saalfeld 1970) the continual decline of coregonine stocks in the Great Lakes makes any unnecessary reduction in their stock size undesirable. Compared to

Table 3. Monthly and total estimated entrainment December 1975 through July 1976. Calculated by multiplying each month's total intake volume by the monthly number of larvae entrained per volume. No larvae entrained from August 1975 through November 1976.

Taxon	Number X 10³								
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
O. mordax						7454.0	478.2	252.9	8185.1
Coregoninae	13.4	51.0	33.8	44.0	41.0	102.4	11.7	0.2	297.5
M .quadricornis	8.5	28.1	8.5	18.5	7.2	42.4	15.5		128.7
S. namaycush					0.4	27.9	81.2	0.3	109.8
L. lota							16.5	17.9	34.4
Cottus spp.							0.8	21.9	22.7
P. flavescens						1.0	13.2	1.8	16.0
Other larvae	0.7	0.8	0.3	0.4	0.1	14.0	3.2	4.2	23.7
All larvae	22.6	79.9	42.6	62.9	48.7	7641.7	620.3	299.2	8817.9

entrainment estimates at other Great Lakes facilities (Edsall and Yocum 1972, Teleki 1976, Jude 1976, Kelso and Leslie 1979) the magnitude of entrainment at Presque Isle is small.

Differences in collection periods and types of gear prohibit a quantitative seasonal comparison of entrainment catches to harbor catches. However, entrainment catches paralleled seasonal succession in the harbor and, with few exceptions, included the same species and stages as tow net, trawl, and seine catches (Table 1). Kelso and Leslie (1979) found the same to be true for entrainment at the Douglas Point plant in Lake Huron. One important exception to the above finding was that juvenile lake trout (31 to 40 mm SL) were not collected in entrainment but were collected in the harbor. These fish apparently were able to avoid entrainment perhaps through superior swimming ability or some other behavioral tendency.

Entrainment also was affected by the Dead River discharge and harbor circulation. Drogue studies showed that river discharge was frequently diverted toward the intake by a prevailing clockwise circulation in the harbor. Thus, larvae like rainbow smelt and yellow perch that drifted down the river after hatching were concentrated in an area of high entrainment risk. White sucker larvae, which remained in eddies and backwaters after swim-up, were not flushed from the river and therefore incurred little entrainment.

Another physical factor that appeared to affect entrainment was heavy wave action associated with storms. Lake trout eggs, which were located among the rocks covering the intake pipes, usually entered entrainment samples on days following winter storms. Entrainment of coregonines and fourhorn sculpin

also increased during some of these periods. Wave action may have contributed to these increases by displacing larvae from spawning substrates in the harbor or by increasing recruitment rates from the lake.

Factors that affect larval entrainment include location and design of the cooling water intake, velocity of inflow at the intake, volume of cooling water, physical characteristics of the water body from which water is drawn, and behavioral patterns of larvae. Marcy (1975) recognized volume reduction as the only effective means of minimizing entrainment-induced mortality at existing power plants. Recent research has demonstrated that entrainment also can be reduced by employing any of several larval exclusion systems (see Sharma and Palmer 1978). Fine mesh profile-wire screen systems have proved particularly effective in reducing entrainment at several power facilities (Ron Kernehan, personal communication). Results of this study and others indicate that entrainment from proposed plants can be minimized if care is taken in selecting the locations of intake structures. Knowledge of distribution and other behavioral characteristics of larval fishes at existing and proposed sites is essential if reasonable decisions are to be made about protecting fishery resources from entrainment-induced mortality.

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FEEDING ECOLOGY OF LARVAL SHAD, DOROSOMA, IN BEAVER RESERVOIR, ARKANSAS

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Abstract.- Larvae of threadfin and gizzard shad collected
by midwater trawl were pooled for this study. Plankton
samples were obtained by a metered Miller sampler with a #10
net on the same or adjacent day of trawl samples. All the
collections were made at weekly intervals from 17 May to 28
June 1972.

Gut contents of 547 larval shad were analyzed. This
study showed that zooplankton was the primary food of larval
shad. Relative abundance of zooplankters in larval shad
diet and Ivlev's electivity index indicated that smaller
shad (5 to 11 mm) consumed Cyclops, and with increase in
larval size (14 mm and above) the diet was comprised of
Bosmina, Ceriodaphnia, and finally rotifers (Keratella).
Diet of 35-mm shad ws exclusively Pediastrum.

Gizzard shad (Dorosoma cepedianum) and threadfin shad (D. petenense) are
considered to be excellent forage fishes for many sport fishes and in some
cases the presence of shad is a necessity for successful introduction of sport
fishes (Tatum 1957). Although all sizes of shad are utilized, they are most
valuable as forage during their first year. Year class strength and standing
crop are dependent upon survival of larval fishes, and availability of
suitable food organisms is an important factor influencing larval fish
survival.

To understand the survival of larval fishes and their subsequent
contribution to the standing crop, knowledge of larval food habits is
essential. Although many studies have been made on the food habits of shad
larvae (Forbes 1903, Tiffany 1920, Warner 1941, Dendy 1946, Kutkuhn 1957,
Miller 1960, Bodola 1966, Applegate and Mullan 1969), there has been no study
on the food habits of larval shad encompassing all length groups. Little is
known of the feeding niche occupied by larval shad in the plankton community.
This paper deals with food habits of larval shad from Beaver Reservoir,
Arkansas. Larval food was evaluated with respect to abundance of food
organisms in the environment and selectivity by shad larvae.

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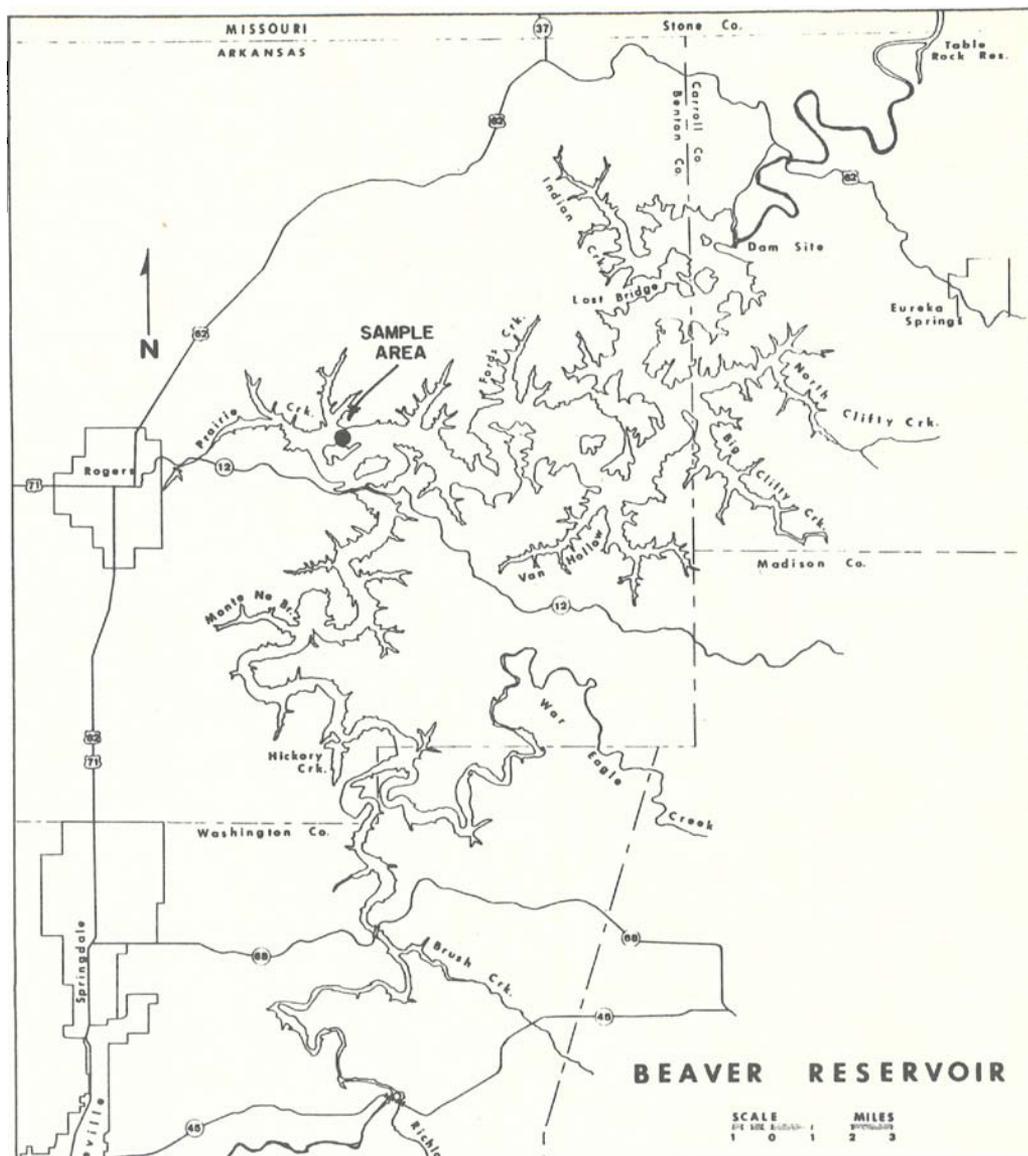
Figure 1. Map of Beaver Reservoir showing location of sample area.

MATERIALS AND METHODS

Beaver Reservoir is a 11,420 ha impoundment on the White River in
northwest Arkansas. Plankton and larval samples were collected from the
Prairie Creek area of the reservoir (Fig. 1). Plankton sampling was conducted
from 17 May to 28 June 1972 at weekly intervals with the exception of 31 May.
Oblique tows were made at night from a depth of 10 m using a metered Miller
sampler with a #10 mesh net. Each plankton sample was concentrated to 100 ml
and three 100-ml samples were obtained for each weekly period. Three 1-ml
subsamples from each 100-ml sample were taken by Hensen-Stipple pipette and
the zooplankton organisms were identified to genus or as specifically as
possible.

Shad in Beaver Reservoir spawn from April through June (Baglin and Kilambi 1968, Kilambi and Baglin 1969, Netsch et al. 1971). On this basis larval shad were collected from 17 May to 28 June, closely corresponding to the day of the plankton collections, by midwater trawl with 0.79-mm mesh size (Houser 1976). Larvae were collected at night by towing the trawl obliquely from a maximum depth of 10 m and were preserved in 10% formalin. Shad larvae were measured to the nearest 0.5 mm up to 20 mm total length and to 1 mm above this length. When trawl collections contained less than 100 larvae all were utilized. Random samples were taken to total at least 100 larvae when the abundance exceeded this number in a collection. Larval shad were not identified to species but were pooled as shad larvae.

Larval shad were separated into 5-mm length groups (5.0 to 9.9 mm, 10.0 to 14.9 mm, etc.) and these were referred to by the initial length in each of the length groups. From each length group, gut contents of five fishes were examined at a time and results were pooled for that length group. Gut contents were identified to the genus and when a certain portion of the diet was unidentifiable it was apportioned to genera based on the ratios of identifiable food organisms. Food habits of 547 larval shad in length groups 5 to 25 were analyzed because shad of 30 mm and above were considered juveniles (Kersh 1970). Relative abundance of zooplankters in the larval diet was expressed as a percentage of total food. Organisms contributing 1% or more to the larval diet were included in the analyses. Larval selection for food organisms in the ambient zooplankton, was estimated by Ivlev's electivity index (Ivlev 1961). Absence of electivity was expressed by an index value of zero and indicies above and below zero were indicative of positive and negative electivity, respectively.

RESULTS

AMBIENT ZOOPLANKTON

Abundance of ambient zooplankters per liter was expressed as a percentage of total zooplankton for the day of collection (Table 1). Members of the taxa Copepoda and Cladocera were most abundant in plankton. Among Copepoda, abundance of Cyclops decreased with time (correlation coefficient, r, = −0.91) but Calanoida showed no trend with time (r= −0.33). The cladocerans, Bosmina and Ceriodaphnia, showed no trends with time (r= −0.56 and 0.67, respectively). However, abundance of Ceriodaphnia increased until 14 June and declined in the last two collections.

ZOOPLANKTON IN LARVAL SHAD DIET

The diet of two shad in the 30-mm group was predominantly Bosmina (55%) and Keratella (25%). The remainder comprised Cyclops, Calanoida, Ceriodaphnia, Trichocera, and the phytoplankter Pediastrum. The diet of a single fish in the 35-mm group was exclusively Pediastrum.

LENGTH GROUP 5

The rotifer, Trichocera, was the dominant food item followed by Bosmina, Cyclops, and Codonella (Table 2). Codonella occurred only in the gut samples of 17 May. It comprised 50% of the diet and Bosmina contributed the

Table 1. Relative abundance of zooplankters (%) in the ambient zooplankton.

Organism	Date of collection					
	17 May	21 May	7 June	14 June	19 June	28 June
Copepoda	41.06	35.22	22.66	14.95	15.60	17.52
Calanoida	15.73	3.29	1.78	1.35	2.73	9.20
Cyclops	25.05	31.21	20.39	13.60	11.95	8.27
Nauplii	<1	1.00	<1		1.00	<1
Cladocera	43.98	61.94	76.86	78.03	75.71	62.91
Daphnia	7.66	3.43	4.54	2.98	2.51	8.27
Bosmina	33.97	46.20	32.66	30.52	38.95	21.34
Ceriodaphnia	2.03	12.20	39.62	44.42	34.04	29.33
Chydorus	<1	<1	<1	<1		
Holopedium						<1
Diaphnosoma			<1	<1	<1	3.92
Unidentified	<1					
Ciliophora						
Codonella				<1	<1	
Rotifera	14.96	2.84	0.48	7.00	8.58	19.57
Keratella	<1	<1	<1			
Asplanchna	14.92	2.78	<1	1.46	5.03	11.30
Trichocera		<1	<1			
Conochilus				5.50	3.45	8.27
Polyarthra				<1		
Kellicottia				<1		

remainder. Bosmina and Cyclops were equally dominant, each forming 46% of the gut contents of the 24 May sample, with Trichocera contributing 8%. In the 31 May sample Trichocera was most dominant (67%) followed by Cyclops (33%). Trichocera was the only organism found in the diet of larvae of 14 June. In general Bosmina and Cyclops were the major food items for the larvae of 17 and 31 May collections while Trichocera was the major constituent in the gut contents of 31 May and 14 June. Of the 131 larval shad examined 10 fishes in the 7 June sample contained no food.

Table 2. Composition (%) of zooplankters in the larval diet by length groups.

Organism in diet	Larval length group (mm)				
	5	10	15	20	25
Bosmina	26	6	18	26	40
Ceriodaphnia		5	6	33	19
Cyclops	19	50	45	8	12
Calanoida		9	7	9	10
Trichocera	42	25	8	2	2
Keratella			13	22	17
Codonella	13	5	3		

LENGTH GROUP 10

Cyclops was the major diet followed by Trichocera (Table 2). Cyclops was the most abundant food item in every weekly gut sample and comprised 80% of the diet of the 24 May sample. Codonella only occurred in the diet of the 17 May sample comprising 25% of the food items. Trichocera was present in all samples while Ceriodaphnia and calanoid copepods were noted in the diet beginning 31 May. Guts of 12 fishes in the 21 June samples were empty. A total of 142 larval shad were examined for diet analysis.

LENGTH GROUP 15

The 7 June sample was lost. Based on 137 shad, overall, Cyclops was the major food item followed by Bosmina and Keratella (Table 2). Although Cyclops was dominant from 17 May to 14 June, its contribution decreased with time (from 83% to 50%) and none were present in the 21 and 28 June stomach samples. Occurrence of Bosmina increased from 31 May reaching a peak (50%) on 21 June. Although the occurrence of Keratella and Trichocera was relatively low earlier, they comprised 63% and 21%, respectively, in the diet of larval shad of 28 June with Bosmina contributing the remainder (16%). Ceriodaphnia was noted in the gut contents of 14 June (22%) and 21 June (11%). Calanoid copepod occurrence in the diet was most (15%) in the 24 and 31 May collections. Codonella was present only in the 17 May gut contents.

LENGTH GROUP 20

Ceriodaphnia, Bosmina, and Keratella were the major food items (Table 2). The gut contents of the single fish of 24 May were unidentifiable. Food of 31 May larval fishes was comprised of calanoid copepods (45%), Bosmina (25%), Cyclops (15%), and Ceriodaphnia (15%). Ceriodaphnia was the dominant food organism (70%) in the 7 June collections followed by Bosmina (18%) and Cyclops (17%). Ceriodaphnia (61%) and Keratella (21%) were the major food items of the 14 June collection. The diet of larvae collected on 21 June was comprised of Bosmina (39%), Keratella (30%), and Ceriodaphnia (15%) with Trichocera and

Diaphnasoma contributing 7% and 3%, respectively. Keratella (58%), Bosmina (39%), and Trichocera (3%) were the only organisms in the diet of the 28 June larval shad. Gut contents of 93 larvae were examined in this length group.

LENGTH GROUP 25

Cladocera was the dominant taxon in the gut contents of 27 larvae followed by Copepoda and Rotifera (Table 2). Calanoid copepods (34%), Cyclops (22%), Bosmina (18%), Ceriodaphnia (13%), and Keratella (13%) were noted in the gut contents in the 31 May collections. The diet of the 7 June larvae was dominated by Bosmina (50%) and Ceriodaphnia (20%). The remainder comprised calanoid copepods (15%), Cyclops (10%), and Keratella (5%). In the 14 and 21 June collections, Bosmina and Ceriodaphnia were the major food items together contributing 86% and 65%, respectively, to the two collections, with Cyclops being second in importance. Trichocera and Keratella were also present. The diet was primarily Keratella (54%) and Bosmina (41%) with Trichocera (4%) and Cyclops (1%) also being found in the diet of the 28 June collection.

Percentage composition of various zooplankters in the diet of all size groups of shad larvae combined by date of collection is given in Table 3. In May, Cyclops was the major constituent of the diet. The food of larval shad of 7, 14, and 21 June was comprised of primarily cladocerans with abundance of Copepoda in the diet decreasing with time. The occurrence of Keratella increased during the same period. The diet of the larval shad of 28 June was mostly comprised of Keratella and Bosmina. Comparison of food composition and larval size indicated that shad larvae up to 11 mm consumed more of the members of Copepoda, and from 14 to 16 mm cladocerans were important diet constituents with increasing contribution by Keratella. The diet of 19-mm larvae was predominantly Keratella followed by Bosmina. Occurrence of Trichocera in May was probably due to incidental ingestion. Since Cyclops was the largest organism followed by Bosmina, Ceriodaphnia and rotifers (Ward and Whipple 1959, Pennak 1978), it was apparent that smaller larvae (5 to 11 mm) fed on large organisms (Cyclops), and with increase in larval size (14 mm and above) preference shifted to smaller zooplankters (Bosmina, Ceriodaphnia, and finally the rotifer, Keratella).

Ivlev's electivity indicies for Copepoda and Cladocera (Fig. 2) showed that Cyclops was moderately selected by larval fishes until 14 June and in the last two collections the shad larvae rejected this organism. A similar trend was apparent for calanoids with the exception of 17 May. Electivity trends for Bosmina were opposite those for Cyclops. Ceriodaphnia was rejected by shad larvae of all the collections. Larval shad selected Keratella from 7 to 28 June (electivity=0.98 to 1.00) and electivity for Trichocera was positive (1.00) during the entire study period.

DISCUSSION AND CONCLUSIONS

Shad larvae primarily fed on zooplankton, with phytoplankton (Pediastrum) noted only once in the diet. Larval shad showed preferential consumption of various zooplankters. Small larvae preyed on larger organisms (Cyclops and

Table 3. Change in percentage food composition with time for the combined larval length groups.

Organisms in diet	Date of collection						
	17 May	24 May	31 May	7 June	14 June	21 June	28 June
Bosmina	21	15	15	22	16	48	32
Ceriodaphnia			9	30	28	14	
Cyclops	40	66	33	24	25	7	<1
Calanoida		5	23	11	2	3	
Keratella			2	2	5	20	58
Trichocera	8	14	18	11	24	8	9
Codonella	31						
Mean shad length	6.6	8.7	11.0	13.6	15.6	15.7	18.6

calanoids), and as larvae grew in size they switched to the smaller Bosmina and Keratella. This pattern was evident from the diet composition estimated by larval size as well as time periods and Ivlev's indicies.

Forbes (1903) reported the 18-mm gizzard shad diet to be comprised of Cypris, Chydorus, Alona, Cyclops, etc. He found that Entomostraca comprised 90% of the diet of gizzard shad less than 52 mm with equal proportions of Cladocera and Copepoda. Kutkuhn (1957) noted Daphnia to be the main food of small gizzard shad (24 mm) followed by Bosmina, Moina, and Cyclops. Gizzard shad up to 26 mm mostly fed on protozoa, Bosmina, copepods, and ostracods, and beyond this size phytoplankton was the main food (Miller 1960). Bodola (1966) stated that young gizzard shad eat protozoans and unicellular algae as first food and zooplankton to be the main food for fish at 20 mm with more phytoplankton occurring in the diet of shad longer than 30 mm. Applegate and Mullan (1969) found 4 to 14 mm threadfin shad to feed mainly on subadult copepods and for the 15 to 37-mm fish Daphnia was the major part of the diet. Our findings agree with the above in that zooplankton constituted the primary first food of larval shad. However, none of these studies dealt with detailed food habits of larval shad, especially in the smaller size ranges. Shad larvae switch from zooplankton to phytoplankton as the larval gut assumes adult shape and size (Kutkuhn 1957, Bodola 1966, Miller 1960). The feeding pattern of larval shad from larger to smaller zooplankters with increase in larval size appears to be a gradual adaptation to adult food habits.

Electivity indicies showed selection for Trichocera throughout, and for Keratella in June collections. High selectivity for these rotifers was due to low occurrence or ineffective sampling of these organisms in the plankton collections. The index itself, although reliable under controlled laboratory conditions, loses some reliability under field conditions due to clustering of prey organisms and ineffective sampling of smaller organisms (O'Brien and Vinyard 1974). Further, reduction of prey population by predation and rapid digestion of prey in the gut also affect the electivity indicies (Strauss
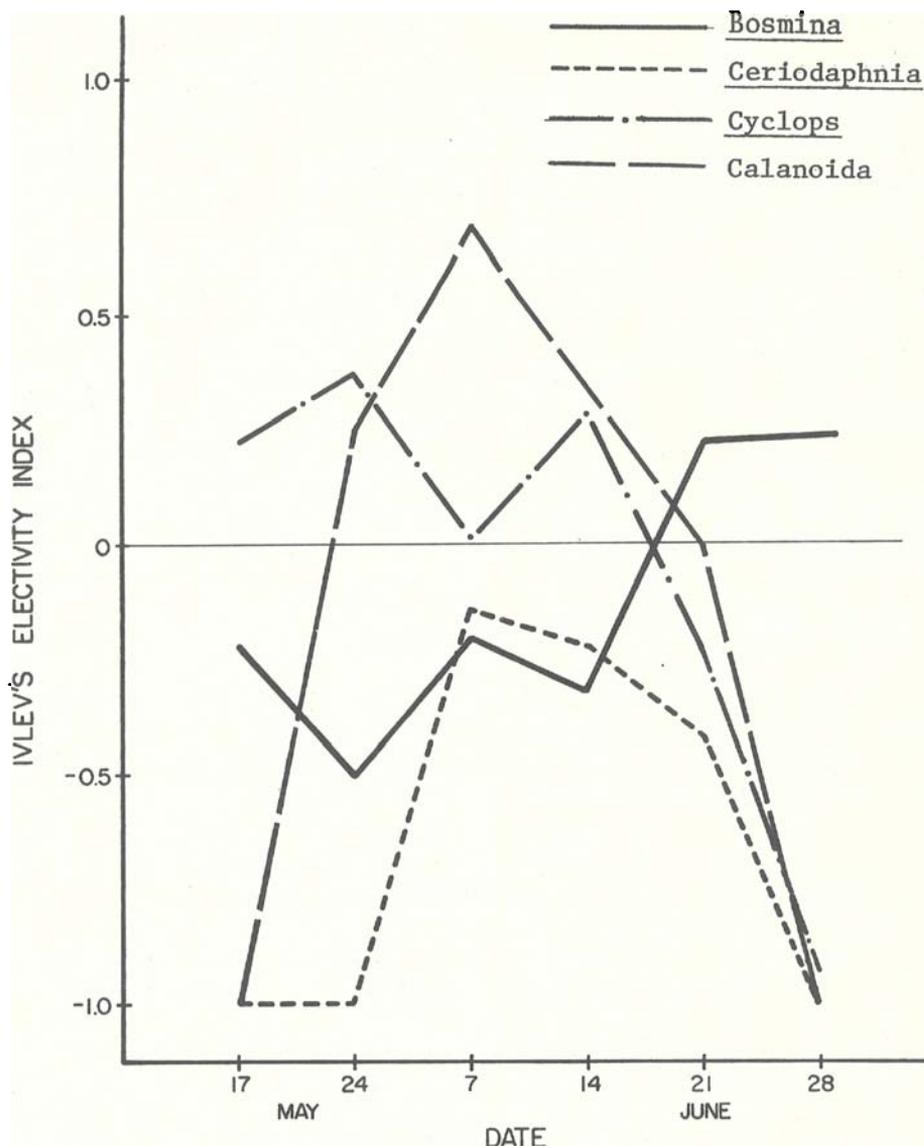
Figure 2. Ivlev's electivity indicies for zooplankton organisms.

1979). In this study two possible bias situations existed. Relatively low abundance of small zooplankters, such as copepod nauplii, Codonella, and rotifers, in the plankton community was probably attributable to the ineffective sampling by the #10 mesh of the Miller sampler (Ricker 1938). Some of the smaller zooplankters might have been digested rapidly thus making it difficult to interpret the electivity indicies for rotifers. Since the diet of shad above 30 mm was comprised of smaller zooplankters and phytoplankters (Miller 1960, Bodola 1966), it is reasonable to assume that occurrences of rotifers (Keratella) increased with larval size.

Larval shad showed positive selection for Cyclops until 14 June and negative selection in the last 2 weeks. The trend for Bosmina was opposite that of Cyclops. Abundance of Cyclops in plankton declined with time and occurrence of this organism in plankton and in the diet was positively correlated (r=0.96) indicating that Cyclops were probably not selectively chosen by larval shad but their consumption was dependent upon their abundance in the environment. Although Bosmina was relatively more abundant than Cyclops in plankton throughout the study, their occurrence in the diet did not increase until the larval size increased (r= -0.14) and Cyclops decreases in abundance. Hence, it is apparent that the trend in selection was from larger organisms (Cyclops) to the medium (Bosmina) and smaller rotifers (Keratella) as the larvae increased in size. Larval consumption of Ceriodaphnia was correlated with their abundance in the environment (r= 0.83); consumption being highest during 7 and 14 June and low on either side of this time period. Negative electivity values and the above correlation indicated that Ceriodaphnia occurrence in the diet was always less than in the environment and they were incidentally ingested depending upon their abundance in plankton.

ACKNOWLEDGEMENTS

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FOOD HABITS AND FEEDING SELECTIVITY OF LARVAL DOROSOMA SPP. IN CENTER HILL RESERVOIR

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Abstract.- Food habits and feeding selectivity of larval shad in Center Hill Reservoir were studied from May through July 1978. Copepods, cladocerans, and rotifers contributed at least 80% of the diet during each month. Major food items were Keratella, Trichocerca, Bosmina, and copepod nauplii, but electivity indices showed that Diaphanosoma and Trichocerca were selected for during all months while Diaptomus and Polyarthra were consistently selected against.

Temporal variations of food habits and selectivity were attributed to increased length of larvae rather than changes in abundance of prey organisms. Copepod nauplii were selected for in May; Cyclops, Bosmina, and Daphnia were preferred in June; and Bosmina and Trichocerca were selected for in July.

Knowledge of larval food habits and prey selectivity is needed for a more complete knowledge and understanding of energy flow, population dynamics, and impact of man's activities on fish populations. Larval gizzard shad (Dorosoma cepedianum) are known to consume zooplankton initially and change to a phytoplankton diet as they grow (Miller 1960, Kutkuhn 1957). Information for threadfin shad (D. petenense) is less common, but it is generally agreed that their larvae are also dependent on zooplankton. Cramer and Marzolf (1970) reported that larval gizzard shad selectively fed on some crustacean zooplankton and avoided others, and they evaluated the impact of shad predation on the zooplankton community. Few other studies, however, have quantified the larval shad diet or identified important prey items.

This study was designed to describe the principal dietary components and feeding selectivity of larval shad in Center Hill Reservoir, Tennessee. Temporal variations were evaluated on a monthly basis.

STUDY AREA

Center Hill Reservoir was impounded in 1948 by the U.S. Army Corps of Engineers for flood control and power generation. Surface area is 7,373 ha and mean depth is 29 m at normal power pool elevation. The reservoir has a narrow meandering mainstream channel and several large embayments associated with major tributaries (Fig. 1), but hydraulic and water quality
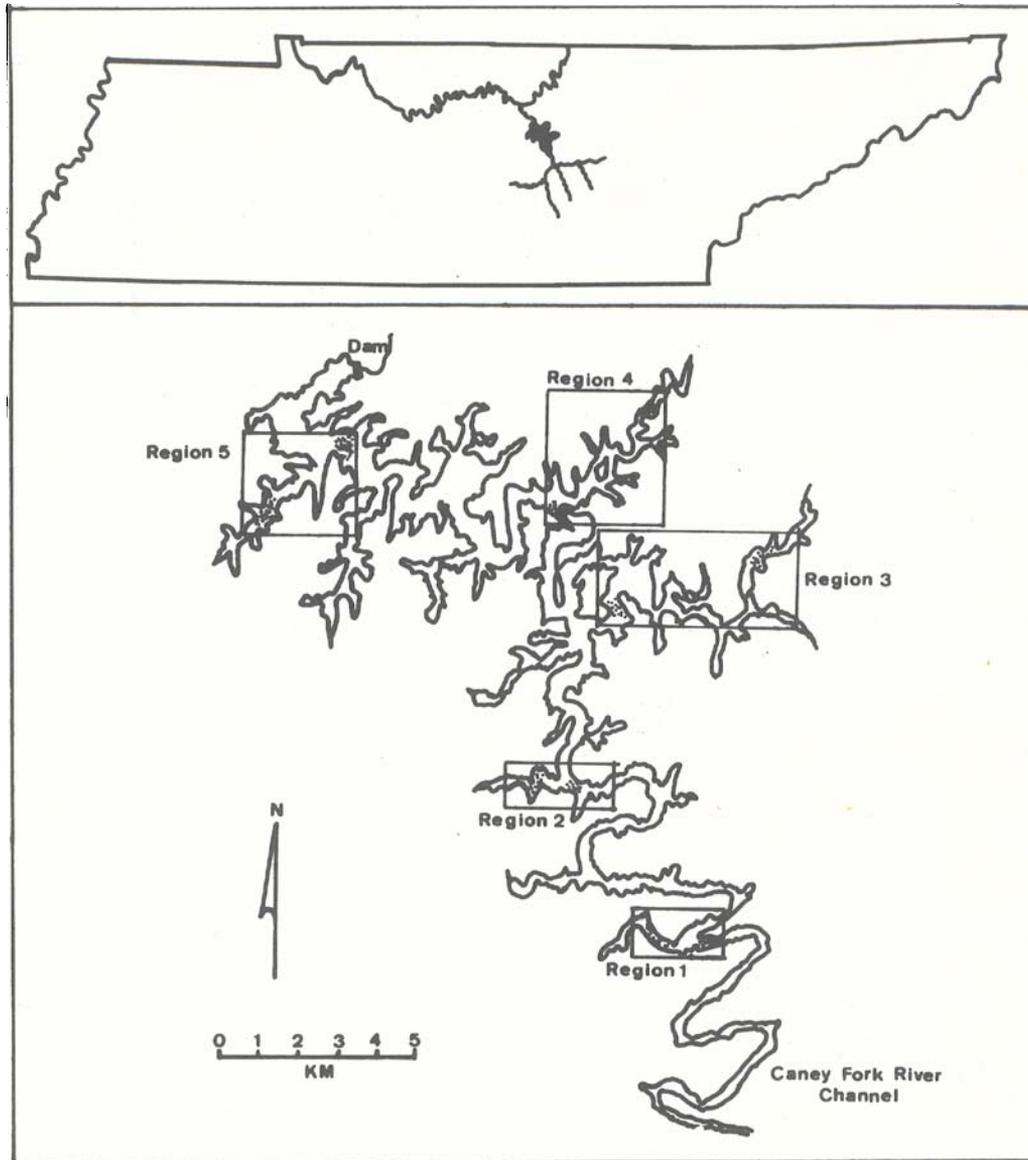
Figure 1. Location of Center Hill Reservoir, Tennessee (upper panel) and sampling regions (lower panel). Stippling indicates cove and mainstream stations where larval _Dorosoma_ spp. and zooplankton were sampled.

characteristics are dominated by inflow of the Caney Fork River. Variations of inflow and discharge cause wide fluctuations of water level during the spawning seasons of most game and forage fishes.

MATERIALS AND METHODS

Larval shad were collected bi-weekly from May through July at five mainstream and five cove sampling sites along the reservoir (Fig. 1), and collections were pooled for monthly analyses. A 0.25-m^2 Tucker trawl with a

0.505-mm mesh net was used to make oblique tows from 10 m to the surface at night. Further details of sampling procedures were described by Krause and Van Den Avyle (1979).

Shad larvae were identified using polarized light and measured to the nearest millimeter total length. Due to our inability to distinguish gizzard and threadfin shad at lengths less that 18 mm, all data for both species were combined. The maximum length of shad studied was 25 mm.

Larvae were rinsed in tap water before removal of the digestive tract; stomachs were excised with finely-pointed insect needles; and organisms consumed by each larva were identified and enumerated. Food items were usually identified to the genus level.

Composition of the zooplankton community was quantified monthly at each of the 10 sites where larval fishes were sampled. Hayward (1980) sampled zooplankton during the day with 2 vertical tows of a 0.064-mm mesh net from 8 m to the surface. He identified a random sample of 400 organisms at each site. Zooplankton and larvae were collected within a 3 or 4-day period of one another.

Food preference was evaluated using Ivlev's (1961) index of electivity (E):

$$E = \frac{r_i - p_i}{r_i + p_i}$$

where r_i was the percentage, by number, of the ith category relative to the 400 zooplankton identified at each sample site. A negative value indicates avoidance or selection against an item while a positive value indicates preference or selection for a food category.

Electivity indices were calculated for important prey taxa at each sample site and for composite samples. For the composite estimates, data from all stations were pooled before computing the relative proportions of prey items in the diets and environment. Confidence limits (95%) for the combined estimates were computed using Equation 5 of Strauss (1979).

RESULTS

Stomachs of 1,398 larval shad were examined from the May, June, and July collections. The percentage of empty stomachs ranged from 45 to 53 and was 49 for the combined samples (Table 1). The average number of food items per fish increased from 5.5 in May to 22.6 in July, and the maximum number of items consumed by a single larva was 300 for a 19-mm specimen.

Copepods, cladocerans, and rotifers contributed at least 80% of the diet during each month (Table 2). Insect larvae (Chaoborus and chironomids) and phytoplankton were consumed, but they were never numerically important components of the diet. During May, copepod nauplii, Polyarthra, and

Table 1. Sample sizes, lengths, and numbers of food items consumed by 4 to 25 mm Dorosoma spp. in Center Hill Reservoir, 1978.

	May	June	July	Total
Number examined	604	715	79	1,398
Percent empty	52	45	53	49
Number with food	291	396	37	714
Number of items consumed	1,587	7,940	837	10,364
Mean number of items consumed per fish[a]	5.5	20.1	22.6	14.5
Median fish length (mm)[a]	9	17	23	16
Length range (mm)[a]	4-23	4-25	11-25	4-25

[a]For fish which contained food.

unidentified copepods were the most important food items. The majority of unidentifiable food items, which represented 18% of all items consumed in May, were probably copepod nauplii in advanced stages of digestion.

The diet was more diverse during June. Keratella, Bosmina, and Trichocerca contributed over 60% of the diet, and Diaphanosoma, Cyclops, and unidentified copepods contributed 7 to 9% (Table 2). Copepod nauplii and Polyarthra were no longer important. In July, rotifers contributed 84% of the diet and the only important crustacean was Bosmina.

Electivity indices for specific taxa were variable between stations (Tables 3, 4, and 5), but the composite estimates (Table 6) were generally representative of the values at each station. Confidence intervals indicated that the composite electivity indices were different from zero for all but three cases (Table 6). Confidence limits could not be calculated when an organism was absent from the diet, and precision was poorest for organisms that were rare in the zooplankton samples (i.e., Diaphanosoma and Trichocerca). This feature is in accordance with Strauss (1979), who indicated that very wide confidence intervals are expected for prey that contribute less than 5% of the total community.

Diaphanosoma and Trichocerca were selected for during all months while Diaptomus and Polyarthra were consistently selected against (Table 6). Indices for the remaining five taxa were inconsistent between months. Copepod nauplii were selected for during May, eaten nearly in proportion to their relative abundance in June, and absent from the diet during July. Bosmina was avoided in May and selected for during June and July. Daphnia, Cyclops, and Keratella were avoided in May, preferred in June, and weakly avoided again in July.

Monthly variations in composition of the diet were apparently due to shifts in prey selection rather than changes in abundance or composition of the zooplankton. Although densities of most prey declined or remained relatively stable from May through June, there was only one pronounced shift

Table 2. Percentages of the total number of prey items consumed by 4
to 25 mm Dorosoma spp. in Center Hill Reservoir, 1978.

Prey	May	June	July	Total
Copepods	62	23	1	25
Cyclops spp.	1	8	<1	5
Diaptomus spp.	0	1	<1	1
nauplii	52	5	0	12
unidentified	9	9	<1	7
Cladocerans	2	27	9	20
Bosmina spp.	<1	16	8	12
Daphnia spp.	1	4	<1	3
Diaphanosoma spp.	1	7	<1	5
Ceriodaphnia spp.	0	<1	0	<1
Chydorus spp.	0	<1	0	<1
Leptodora spp.	0	<1	0	<1
unidentified	0	<1	<1	<1
Rotifers	17	47	84	45
Keratella spp.	1	35	33	29
Polyarthra spp.	14	<1	0	2
Trichocerca spp.	2	13	44	13
Filina spp.	0	<1	0	<1
Conochilus spp.	0	<1	0	<1
Brachionus spp.	0	0	<1	<1
unidentified	0	0	6	<1
Others				
Chaoborus spp.	1	<1	<1	<1
Chironomids	0	<1	0	<1
Phytoplankton	<1	<1	<1	<1
Unidentifiable	18	2	5	9

in zooplankton composition (Table 6). Polyarthra was about twice as abundant
as Keratella during May, but the relationship was reversed in June and July.
Density and relative abundance of prey that were always selected for
(Diaphanosoma and Trichocerca) increased with time, but these groups were
relatively minor components of the diets and zooplankton community except
during July, when Trichocerca constituted 44% of the shad diet (Table 2).

Changes in prey selection between months probably were related to shad
growth. During May, the median length of shad larvae that contained food was
9 mm, and copepod nauplii and Polyarthra were numerically important food
items. Nauplii and Diaphanosoma were preferred prey during this period, but
Polyarthra was selected against. Cyclops, Bosmina, Daphnia, Diaphanosoma, and
Trichocerca were numerically important and selected for during June, when

Table 3. Electivity indicies for cladocerans consumed by 4 to 25 mm _Dorosoma_ spp. in Center Hill Reservoir, 1978. Stations are coded by sampling region (see Fig. 1) and a cove (C) or mainstream (M) designation. NP indicates that the organism was absent from the environment and the diet. NF indicates that no fish containing food were collected.

Station	Daphnia			Bosmina			Diaphanosoma		
	May	June	July	May	June	July	May	June	July
1C	-1.00	0.00	-1.00	-0.33	0.87	-1.00	0.00	0.00	-1.00
1M	0.33	0.11	-1.00	-0.33	0.78	0.89	1.00	1.00	0.43
2C	-1.00	0.82	NP	-1.00	0.80	NP	-1.00	0.98	-1.00
2M	0.60	0.88	1.00	0.67	0.64	-1.00	NP	-1.00	-1.00
3C	0.67	1.00	-1.00	0.00	0.86	-1.00	NP	1.00	NP
3M	-1.00	1.00	NP	-1.00	1.00	-1.00	NP	-1.00	-1.00
4C	-1.00	1.00	NP	-1.00	0.82	-1.00	NP	1.00	-1.00
4M	-1.00	0.43	1.00	-0.54	0.84	0.00	NP	1.00	-1.00
5C	-1.00	-1.00	NP	-1.00	0.67	NP	NP	1.00	-1.00
5M	-1.00	-0.33	NF	-1.00	0.96	NF	1.00	1.00	NF

Table 4. Electivity indicies for copepods consumed by 4 to 25 mm _Dorosoma_ spp. in Center Hill Reservoir, 1978. Stations are coded by sampling region (see Fig. 1) and a cove (C) or mainstream (M) designation. NP indicates that the organism was absent from the environment and the diet. NF indicates that no fish containing food were collected.

Station	Cyclops			Diaptomus			Nauplii		
	May	June	July	May	June	July	May	June	July
1C	-0.67	0.33	-1.00	-1.00	1.00	-1.00	0.33	0.13	-1.00
1M	-1.00	-1.00	-1.00	NF	-1.00	0.00	0.86	-0.14	-1.00
2C	-0.78	0.67	0.66	-1.00	-0.60	NP	0.57	-0.16	-1.00
2M	0.92	0.87	-1.00	-1.00	0.27	-1.00	0.47	-0.74	-1.00
3C	0.00	0.80	0.05	-1.00	-0.33	NP	0.55	-0.27	-1.00
3M	-1.00	0.88	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
4C	-1.00	0.43	-1.00	-1.00	0.00	NP	0.45	0.00	-1.00
4M	-0.67	0.80	-1.00	-1.00	-1.00	-1.00	0.72	-0.14	-1.00
5C	-0.85	0.67	-0.54	-1.00	1.00	-1.00	0.36	0.50	-1.00
5M	-0.67	0.67	NF	-1.00	1.00	NF	0.67	0.60	NF

Table 5. Electivity indicies for rotifers consumed by 4 to 25 mm <u>Dorosoma</u> spp. in Center Hill Reservoir, 1978. Stations are coded by sampling region (see Fig. 1) and a cove (C) or mainstream (M) designation. NP indicates that the organism was absent from the environment and the diet. NF indicates that no fish containing food were collected.

Station	Keratella			Polyarthra			Trichocerca		
	May	June	July	May	June	July	May	June	July
1C	-1.00	-0.79	-1.00	-0.39	-0.78	-1.00	0.00	1.00	1.00
1M	-0.60	-0.49	-0.60	-0.82	-1.00	-1.00	1.00	NP	0.54
2C	-1.00	0.75	-1.00	-0.73	-0.95	-1.00	NP	0.73	-1.00
2M	-1.00	-0.89	0.52	-1.00	-1.00	-1.00	NP	-1.00	-1.00
3C	-0.70	0.14	-1.00	-1.00	-1.00	-1.00	1.00	0.89	-1.00
3M	-1.00	0.08	0.02	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
4C	-0.93	0.77	0.56	0.67	-0.98	-1.00	NP	0.96	0.97
4M	-1.00	-0.69	0.28	-0.89	-1.00	-1.00	1.00	NP	1.00
5C	-1.00	0.66	-0.39	0.49	-0.94	-1.00	1.00	0.97	0.99
5M	-1.00	0.67	NF	-0.38	-1.00	NF	NP	0.97	NF

median length of the shad was 17 mm. <u>Keratella</u> was also numerically important, but it was not strongly selected for. The high diversity of the diet during June probably resulted from the broad length range of larvae in the sample (Fig. 2). <u>Bosmina</u>, <u>Trichocerca</u>, and <u>Keratella</u> were numerically important components of the diet during July, when median length of the larvae was 23 mm. As in the June sample, <u>Bosmina</u> and <u>Trichocerca</u> were preferred while <u>Keratella</u> was consumed nearly in proportion to its abundance.

DISCUSSION

The predominance of zooplankton in the diet of 4 to 25 mm shad in Center Hill Reservoir is consistent with the conclusions of other investigators. Miller (1960), Kutkuhn (1957), and Bodola (1966) stated that shad shorter than 25 to 30 mm consumed zooplankton while larger fish switched to phytoplankton. Cramer and Marzolf (1970) reported that gizzard shad shorter than 20 mm in Tuttle Creek Reservoir, Kansas, primarily ingested crustacean zooplankton (<u>Cyclops</u>, <u>Bosmina</u>, and <u>Daphnia</u>) and that 20 to 35 mm fish consumed an increasing amount of phytoplankton. Although rotifers, including <u>Keratella</u>, <u>Polyarthra</u>, and others, were present and often abundant in Tuttle Creek Reservoir, they were unimportant components of the shad diet. In our study, rotifers were numerically more important than cladocerans or copepods during June and July.

Table 6. Relative prey density, percent composition, electivity indicies, and confidence intervals (in parentheses) for zooplankton consumed by 4 to 25 mm Dorosoma spp. in Center Hill Reservoir, 1978. Relative sizes of prey are indicated as large (L), intermediate (I), or small (S). An asterisk indicates that confidence intervals could not be calculated.

Prey item and size	Relative prey density (1000's/tow)			Percent of all zooplankton			Electivity index and confidence interval		
	May	June	July	May	June	July	May	June	July
COPEPODS									
Cyclops-L	40.1	11.4	44.6	6.3	1.2	1.8	-0.73 (-0.74,-0.71)	0.74 (0.62,0.86)	-0.29 (-0.46,-0.11)
Diaptomus-L	13.0	13.7	4.7	2.1	1.5	0.7	-1.00*	-0.20 (-0.27,-0.13)	-0.56 (-0.78,-0.33)
Nauplii-S	81.3	63.2	47.2	12.8	6.7	7.1	0.60 (0.53,0.68)	-0.14 (-0.18,-0.11)	-1.00*
CLADOCERANS									
Daphnia-L	10.7	5.5	4.4	1.7	0.6	0.7	-0.26 (-0.40,-0.12)	0.74 (0.69,0.79)	-0.56 (-0.78,-0.33)
Bosmina-I	16.0	11.2	12.9	2.5	1.2	1.9	-0.79 (-0.81,-0.76)	0.86 (0.77,0.95)	0.62 (0.31,0.92)
Diaphanosoma-I	0.1	1.6	4.4	<0.1	0.2	0.7	0.96 (0.00,1.92)	0.94 (0.79,1.10)	0.18 (-0.30,0.65)
ROTIFERS									
Keratella-S	147.9	273.4	230.3	23.4	29.2	34.7	-0.92 (-0.92,-0.92)	0.09 (0.04,0.14)	-0.03 (-0.08,0.03)
Polyarthra-S	293.3	159.0	113.0	46.3	17.0	17.0	-0.54 (-0.56,-0.52)	-0.85 (-0.86,-0.84)	-1.00*
Trichocerca-S	0.4	3.3	3.2	<0.1	0.3	0.5	0.51 (0.11,0.91)	0.96 (0.84,1.07)	0.98 (0.82,1.13)
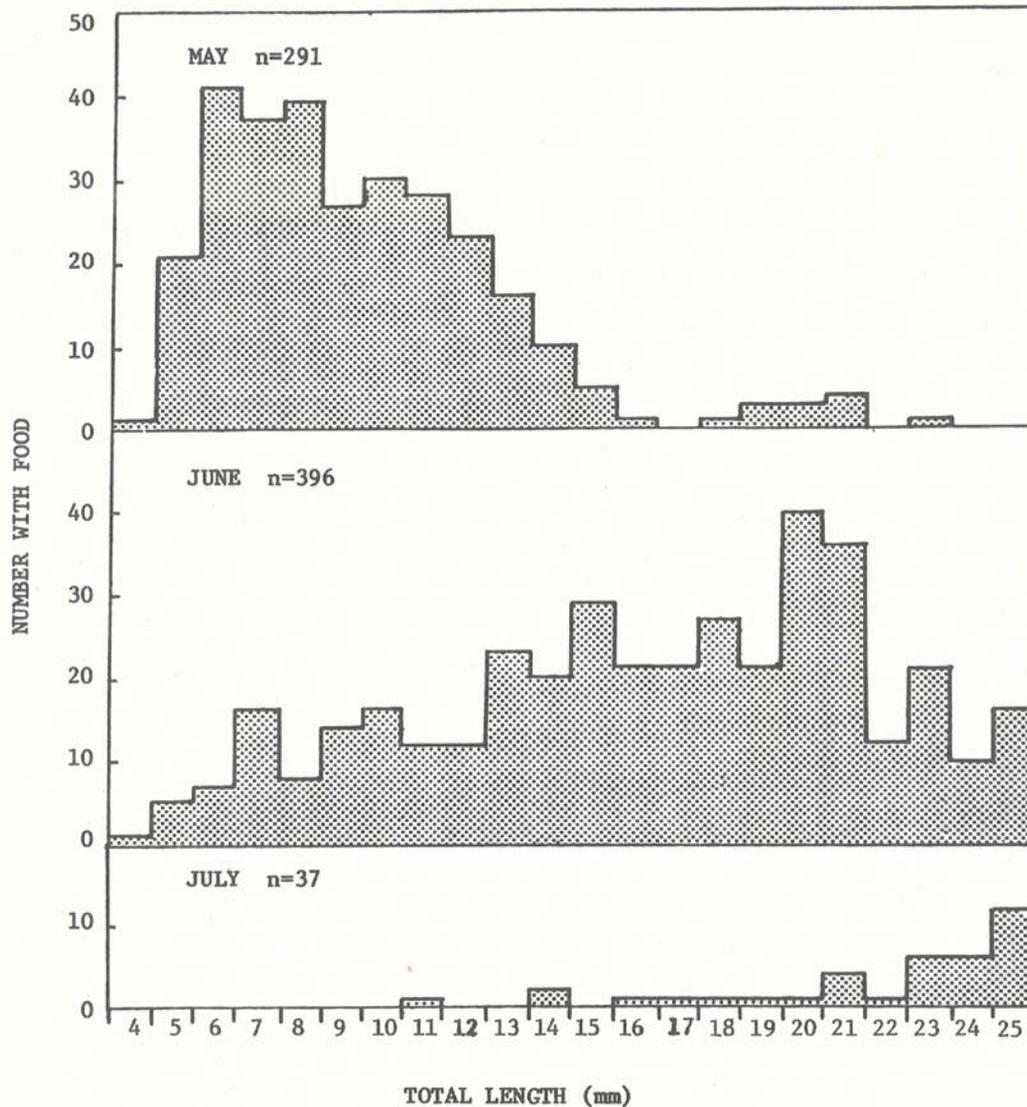
Figure 2. Length distribution of larval Dorosoma spp. for May, June, and July, 1978.

Authors have not consistently agreed as to whether shad feed selectively or randomly. Tiffany (1920) and Bodola (1966) believed shad to be filter feeders, ingesting whatever items were retained by the gill rakers. Kutkuhn (1957), however, reported that 24 to 82 mm gizzard shad selected blue-green algae, and Cramer and Marzolf (1970) concluded that gizzard shad shorter than 60 mm selected against some zooplankton while others were consumed at or slightly above their percentage of occurrence. We found that 4 to 25 mm shad exhibited definite prey selectivity during the 3 months sampled.

Many prey characteristics could influence food selection by fishes. Brooks and Dodson (1965) suggested that zooplankton size, abundance, and ability to avoid predation were important in determining whether they were selected or avoided by the alewife (Alosa pseudoharengus). Cramer and Marzolf

(1970) reported that food selection by young gizzard shad was significantly influenced by prey species, predator size, sample date, and sample time (day versus night). Preferred prey included Bosmina, Cyclops, and Daphnia, while rotifers, Diaptomus, and Diaphanosoma were strongly selected against. In Center Hill Reservoir, Bosmina, Cyclops, and Daphnia were selected against during May and either selected for or eaten in proportion to their abundance during June and July. Our results for the rotifers Keratella and Polyarthra and for Diaptomus were consistent with Cramer and Marzolf, but one genus of rotifers (Trichocerca) and Diaphanosoma were consistently selected for. Although the effects of time and shad size were somewhat confounded in our analysis, we believe that shad growth was primarily responsible for the variations of electivity between sample periods.

Cramer and Marzolf (1970) attributed most of their between-prey species variations of electivity to the sizes of individual zooplankton, and found that intermediate-sized organisms were weakly selected for while large ones were moderately selected against and small forms were strongly avoided. We did not measure prey size, but information presented by Wetzel and Likens (1979) and Cramer and Marzolf (1970) allowed us to classify the prey as relatively small, intermediate, or large (Table 6). Preferred prey during May and July were either small or intermediate forms, but electivity indices were not related to prey size in June. Although it might be expected that the longer larvae collected in July would have utilized larger prey, 77% of the diet was small zooplankton. Shad apparently select for progressively smaller prey as they approach the length at which phytoplankton are utilized almost exclusively. Cramer and Marzolf (1970) reported that gizzard shad shorter than 20 mm selected large zooplankton while 35 to 60 mm specimens selected against all zooplankton, presumably in favor of phytoplankton.

Several factors could have biased and/or contributed to the variability of our electivity indices. Since zooplankton were collected during the day and larvae were collected at night, diel variations in patchiness or position of the prey and larvae, as well as diel feeding periodicity, could have affected the validity of the computations. Gizzard and threadfin shad occur in Center Hill Reservoir, but the larvae from both species were combined in our analyses. Differences of feeding habits and selection between species may have been important sources of variation within and between time periods.

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HISTOLOGICAL AND MORPHOMETRIC CRITERIA FOR ASSESSING NUTRITIONAL STATE OF LARVAL STRIPED BASS, MORONE SAXATILIS[1]

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Abstract.- Starvation in the larval stages of striped bass (Morone saxatilis) is hypothesized as a major cause of mortality. Establishing criteria for assessing this starvation would aid greatly in predicting year class strength. Larvae were subjected to 5 different feeding regimes for 6 days and samples were preserved during this sequence. Four tissues proved to be sensitive to starvation and a fifth needs to be examined further. These tissues, in sequence of deterioration, are: abdominal body wall, epaxial musculature, gut epithelium, and liver. Retinal tissue may be the most sensitive tissue but further studies are necessary. Morphometric analysis followed by stepwise discriminant analysis found three parameters to be diagnostic. These were head depth, body depth at the pectoral fin, and body depth at the anus divided by head depth. The histological analysis can identify starvation unambiguously. The morphometric analysis is accurate when classifying laboratory reared specimens but further work is needed to relate this to the field.

Principal spawning areas of striped bass, Morone saxatilis (Walbaum), within its natural range are the tributaries of Chesapeake Bay. As much as 90% of stocks entering Atlantic coastal fisheries originate within the Chesapeake Bay system (Berggren and Lieberman 1978). Within the Chesapeake Bay system the Potomac River contributes about 22% of the total Chesapeake fishable stocks (Jones et al. 1977). On this basis it would seem especially important to understand the factors influencing year class strength from Chesapeake Bay and the Potomac River.

Hjort (1914, 1926) and Hunter (1976), among many others, have pointed out that larval stock survival may be the most important factor influencing ultimate adult recruitment. Ulanowicz and Polgar (1980) and Boynton et al. (in press) have found that striped bass year class strength is predictable based on stock size of early juvenile stages indicating that the critical determining events have already occurred at that point. Unpublished preliminary data from Chesapeake Biological Laboratory indicate that lack of larval food results in poor year classes between 1974 and 1977 within the Potomac estuary. Despite poor cohort strength of early juvenile stages, eggs and larvae were abundant in collections during those years.

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[1]Chesapeake Biological Laboratory Contribution Number 977.

We hypothesize that starvation was a principal cause of mortality for these poor year classes. We expect that some criteria for assessing starvation, such as those developed by O'Connell (1976) and Theilacker (1978) for northern anchovies and jack mackerel, respectively, could be used to indicate the magnitude of starvation in larval striped bass. The goal of these preliminary studies was to adapt these criteria to larval striped bass. Such studies are prerequisites before our hypothesis of larval food limitation in estuary nursery areas can be tested.

MATERIALS AND METHODS

Approximately 5,000 late yolk-sac stage larvae were obtained on 4 June, 1979, from the Virginia Commission of Game and Inland Fisheries Hatchery, Brookneal, Virginia. They were transported to Chesapeake Biological Laboratory, Solomons, Maryland, and placed in 38-1 standard aquaria with 10 1 of 1.2 ppt salinity water (obtained by diluting filtered Patuxent River water, salinity 12 ppt, with Solomons well water in a 1 to 9 ratio). Water was held at a modal temperature of 22 C with a range of 20 to 24 C. The experiment was reduced to 5 aquaria containing approximately 100 larvae each because of high mortality on the first day in the laboratory. Although this mortality was unexplainable, the survivors were apparently healthy and mortality in the control group for the entire experiment was minimal.

FEEDING

Larvae were subjected to five different feeding regimes. Group I was fed daily for 6 days at a level of 1,000 Artemia nauplii per liter. Groups II, III, and IV were starved for 2, 3, and 4 days, respectively, then provided with the same concentrations of Artemia as Group I. Group V was never fed. Houde (1975) found similar concentrations of copepod nauplii to be adequate in feeding sea bream, Archosargus rhomboidalis.

SAMPLING

Five to 15 larvae, depending on availability, were removed daily from each group and preserved in 4% formaldehyde buffered with calcium carbonate. Only live larvae were preserved so that starvation effects would not be confused with postmortem lysing. After a minimum fixation of 1 week to allow major shrinkage to end, each specimen was measured for notochord length, head depth, body depth at the pectoral fin, body depth at the anus, and eye diameter and the following ratios computed: head depth/notochord length; body depth at the pectoral fin/notochord length; body depth at the anus/notochord length; eye diameter/notochord length; body depth at the pectoral fin/head depth; body depth at the anus/head depth; and eye diameter/head depth.

MORPHOMETRIC ANALYSIS

Morphometric analysis followed Theilacker (in press). The best set of variables (body measurements) that differentiated between known groups of larvae was determined through stepwise discriminant analysis. Our purposes for using stepwise discriminant analysis were:

1) to find the best set of variables in which predetermined groups differed,

2) to assess the power of the technique to properly classify individual larvae by comparing stepwise discriminant analysis classification with histological assessment of condition,

3) to use discriminant functions derived by this technique to classify larvae of unknown nutritional history.

HISTOLOGICAL ANALYSIS

After measurements were made, preserved larvae were carefully oriented in agar gel to allow for easy handling during dehydration and embedding in Paraplast(R). Serial sections (8 micrometers) were stained with Heidenhaen's iron hematoxylin and counterstained with triosin. Histological analysis consisted of observing seven target tissues: nerve cord, notochord, liver, gut, epaxial muscle tissues of the body wall, and as analysis progressed, the retina. Each larva was scored for as many target tissues as were observable. Tissues were arbitrarily ranked according to the following scheme: 1, for healthy tissue; 2, for an intermediately deteriorated tissue; and 3, for a clearly deteriorated tissue.

All of the above procedures were also undertaken on 50 striped bass larvae captured in plankton tows at 2 different stations on the Potomac River in May 1975. These two stations differed greatly in the proportions of larvae with food in their digestive tract. They were selected to provide a valid test for histological and morphological analysis.

RESULTS

GROWTH

Growth of all five groups reflected their feeding regime. Group I, which was fed daily, increased its mean standard length from 5.79 mm to 7.35 mm in a 1 week period. Mean body depth at the pectoral fin increased from 0.9 to 1.37 mm. Group V, which was not fed, had an initial standard length of 5.52 mm and only increased its mean length by 0.19 mm. Mean body depth at the pectoral fin decreased by 0.2 mm. This situation was also reflected in the histological analysis by a deteriorating body wall. Groups II, III, and IV were delayed feedings for 2, 3, and 4 days, respectively. All three groups increased their body proportions intermediately to Groups I and V (Table 1).

HISTOLOGICAL CONDITION

Day One of Starvation

After 1 day of starvation 28% of larvae from the starved control group (Group V) showed an intermediate deterioration in tissues of the body wall. Tissues of larvae from Group I (fed daily) appeared normal.

Table 1. Mean daily growth of laboratory reared striped bass larvae.

Group	N	Day	Notochord length		Head depth		Eye diameter		Body depth at pectoral		Body depth at anus	
			X̄	s	X̄	s	X̄	s	X̄	s	X̄	s
I	6	1	5.94	0.09	0.95	0.15	0.40	0	0.82	0.10	0.85	0.08
	10	2	6.36	0.28	1.04	0.08	0.48	0.04	0.91	0.34	1.10	0.15
	11	3	6.80	0.24	1.12	0.08	0.50	0	1.13	0.06	1.25	0.07
	12	4	6.91	0.25	1.24	0.13	0.53	0.05	1.23	0.09	1.32	0.13
	10	5	7.32	0.39	1.31	0.11	0.54	0.05	1.31	0.12	1.47	0.12
	14	6	7.35	0.56	1.34	0.06	0.50	0.06	1.40	0.22	1.56	0.21
II	5	2	6.00	0.14	0.88	0.05	0.40	0	0.78	0.05	0.78	0.05
	11	3	6.26	0.23	1.02	0.10	0.43	0.05	0.96	0.07	1.11	0.11
	5	4	6.36	0.36	0.84	0.15	0.42	0.05	0.86	0.09	0.90	0.17
	5	5	6.40	0.26	1.14	0.10	0.49	0	1.09	0.08	1.24	0.08
	9	6	6.40	0.35	1.01	0.08	0.48	0.04	1.03	0.07	1.17	0.07
III	11	3	6.26	0.23	1.02	0.10	0.43	0.05	0.96	0.07	1.11	0.11
	12	4	6.18	0.23	1.01	0.07	0.43	0.05	0.96	0.09	1.07	0.12
	12	5	6.48	0.34	1.14	0.08	0.49	0.03	1.10	0.09	1.32	0.13
	10	6	6.38	0.39	0.97	0.08	0.49	0.03	1.19	0.09	1.20	0.20
IV	9	4	6.02	0.16	0.89	0.03	0.40	0	0.84	0.07	0.98	0.06
	3	5	6.40	0.23	1.00	0	0.50	0	0.96	0.15	1.06	0.15
	6	6	6.53	0.47	0.98	0.10	0.48	0.04	0.97	0.10	1.10	0.11
V	9	1	5.51	0.46	0.90	0.12	0.36	0.05	0.90	0.35	0.69	0.16
	9	2	6.02	0.07	0.89	0.08	0.40	0	0.91	0.11	0.96	0.14
	11	3	5.80	0.29	0.85	0.07	0.39	0.03	0.78	0.06	0.82	0.08
	9	4	5.84	0.24	0.91	0.06	0.40	0	0.78	0.08	0.92	0.04
	8	5	5.80	0.19	0.90	0	0.40	0	0.76	0.07	0.81	0.04
	28	6	5.70	0.36	0.85	0.07	0.40	0.04	0.77	0.10	0.80	0.15

Day Two of Starvation

Groups II and V were starved for 2 days, so data were lumped. Of all samples taken 46% showed signs of intermediate body wall deterioration and 38% showed severe deterioration. Thirty percent had epaxial muscles showing signs of deterioration.

Day Three of Starvation

Groups III and V larvae showed either severe or intermediate deterioration in five of the seven target tissues. Thirty-five percent of the larvae had body walls with cells severely separating and with a reduction in cell number. Sixty-five percent showed intermediate conditions. Epaxial muscles showed signs of intermediate deterioration with muscle groups clearly separated in 57%; this condition was severe in 28%. Digestive tract epithelium of 28% of those sampled showed severe separation of cells while 64% were at an intermediate stage. Eye tissue cells were also separating but there is no reliable percentage. A number of these pertinent sections were destroyed before we realized that eye tissue was an appropriate target tissue.

Group II (after feeding 1 day) appeared normal in all tissues except the body wall. Body wall cells were separating severely in 55% of the larvae sampled and 22% were intermediately deteriorated. The control, Group I, appeared normal (Table 2).

Day Four of Starvation

Group IV and V larvae indicated critical deterioration. Only 14% of the sampled larvae showed an intermediate condition in any tissues. The remaining 86% showed a uniform, severe deterioration in all tissues. Group III (after feeding 1 day) showed 33% of sampled larvae with severe gut epithelium deterioration and 33% showed intermediate deterioration. In 14% of Group III larvae the epaxial musculature was severely deteriorated while 57% showed intermediate deterioration. Cells of the body wall were all mildly separated but increasing in number (Table 2).

Day Five of Starvation

Group V showed severe deterioration in all tissues. This included separation and condensing of the cells creating cavities around them. The liver appeared heavily nucleated but with a lack of obvious cell walls.

Group IV (after feeding 1 day) looked identical to Group V samples. Groups II (after 3 days feeding) and III (2 days feeding) showed intermediate signs of deterioration. In both groups the only tissue that was deteriorated in all samples was the eye (Table 2).

Day Six of Starvation

Group I, the control, showed signs of slight separation, and decreased size, of body wall cells in 33% of the samples. This was the only indication of malnutrition in the control. Group II (4 days feeding) showed a state of intermediate deterioration in 50% of the gut, muscles, and body wall samples and 16% showed severe deterioration in the body wall and epaxial musculature samples. Remaining tissues were normal except for the eye which showed severe deterioration in the available samples. Group II (3 days feeding) showed intermediate deterioration of all tissues from 20% of the larvae sampled. Groups IV (2 days feeding) and V (starved) were severely deteriorated in 100% of the samples (Table 2).

Table 2. Summary of histological data. Data are percentages of samples (H, I, and S represent healthy, intermediate, and starved individuals, respectively).

Day		3			4			5			6		
Condition	Group	H	I	S	H	I	S	H	I	S	H	I	S
Body wall	I	100			100			100			66	33	
	II	23	22	55							34	50	16
	III					100		56	42		80	20	
	IV									100			100
	V		65	35		7	93			100			100
Digestive tract epithelium	I	100			100			100			100		
	II	23	66	11							50	50	
	III				33	33	33	44	42	14	80	20	
	IV									100			100
	V		40	60		14	86			100			100
Liver	I	100			100			100			100		
	II	45	55								84	16	
	III				75	25		86	14		80	20	
	IV									100			100
	V	79	7	14		14	86			100			100
Epaxial musculature	I	100			100			100			100		
	II	12	66	22								50	16
	III				29	57	14	72	28		80	20	
	IV									100			100
	V	15	57	28		14	86			100			100

Histological analysis of wild striped bass larvae was performed identically to that of laboratory reared specimens. Larvae had a mean size of 6.99 mm in Group A and 6.77 mm in Group B. The general histological state of Group A was: 22% mildly starved, 18% intermediately starved but approaching severe starvation, and 4% were severely starved. Group B showed signs of severe starvation in 43% of the samples, 8% intermediate, and the remainder were healthy.

MORPHOMETRIC ANALYSIS

Stepwise discriminant analysis of morphometric data selected three variables for classification functions: head depth, body depth at the pectoral fin, and the body depth at the anus to head depth ratio. Using these criteria

Table 3. Percent correct classification for stepwise discriminant analysis of laboratory reared larvae.

Group	% Correct	Number classified into group				
		I	II	III	IV	V
I	73.8	45	9	1	5	1
II	40.5	9	17	0	9	7
III	6.4	2	16	3	15	11
IV	54.2	1	2	1	13	7
V	78.3	0	2	0	11	47

stepwise discriminant analysis correctly classified 73.8% of the fully fed larvae. Seventy-eight percent of the starved larvae were correctly classified. Intermediate groups also indicated reliable prediction. Forty percent of Group II larvae were classified correctly and 54% of Group IV larvae were correctly classified (Table 3). The 6% correct prediction of Group III indicates that Groups II and III and Groups III and IV are closely related and that Groups II and IV are distinctly separate. Group III had very poor percentage correct classification because these larvae were placed in Groups II and IV (Table 3).

Coefficients and constants derived by the analysis (Table 4) were then applied to the wild larvae. This classified all wild larvae in Group V.

DISCUSSION

Using laboratory reared larvae to establish criteria for assessing starvation has many inherent problems. Laboratory conditions controlling area, temperature, and constant food availability do not correspond to field situations. Larvae that normally would not survive, runts, may do well along with average specimens achieving above average structural characteristics (Ehrlich, et al. 1976). Morphometric criteria are especially in need of being checked against field situations because laboratory conditions such as temperature and salinity regimes can affect body size and proportions (Kinne 1963, 1964; Kinne and Kinne 1962).

Since delayed feeding retards growth in striped bass larvae, both notochord length and body depth are affected. Predictive measurements are mostly related to body depth. This is considered to be an important indicator (Theilacker 1978). Head depth and body depth at the pectoral fin were used as selection functions by stepwise discriminant analysis along with the body depth at the anus to head depth ratio. None of these are the factors found most useful in discrimination by Theilacker (1978), O'Connell (1976), Nakai et al. (1969), or Ehrlich et al. (1976). Each species reported had different diagnostic parameters.

Table 4. Coefficients and constants of disrciminant analysis.

Variable	Group				
	I	II	III	IV	V
Head depth	8.32	7.53	7.03	6.59	7.29
Body depth at pectoral fin	1.06	0.50	0.62	0.77	−0.45
Body depth at anus: head depth	0.44	0.38	0.38	0.38	0.33
Constant	−83.76	−62.98	−58.29	−56.04	−46.69

Four tissues reliably indicated starvation in striped bass and a fifth needs to be studied further. The histological changes we noted are similar to changes reported for other species:

1) digestive tract cells (northern anchovy, O'Connell 1976; jack mackerel, Theilacker 1976; herring and plaice, Ehrlich et al. 1976),

2) separation of fibers of the musculature (O'Connell 1976; Theilacker 1978),

3) liver deterioration (O'Connell 1976; Theilacker 1978; plaice, Ehrlich as cited in Theilacker 1978).

Cells of the body wall proved to be an initial definitive tissue in striped bass. This corresponds with the decrease in body depth indicated by morphometric criteria. The retina may be an even more sensitive tissue to starvation, but more investigation is needed. Figure 11 of Ehrlich et al. (1976) shows some retinal deterioration in herring. If this is the case it opens an interesting area of research for starvation studies in larval visual feeders. Striped bass do not recover from retinal damage quickly and this may affect their feeding behavior.

Rogers and Westin (1979) reported that striped bass have no "point of no return" in starvation. If the "point of no return" is simply a physiological condition we agree with their assessment, but if the "point of no return" also involves altered feeding behavior as suggested by Ware (1974) and by our observations on retinal damage, then their data are inconclusive. They did not state precisely the concentrations of Artemia nauplii offered their larvae but the description that there were some left over between twice daily feedings suggests that concentrations were such that even a nearly moribund larva could obtain some food.

As exhibited in Tables 2 and 3, morphometric and histological techniques are effective for predicting the condition of laboratory samples. Histological analysis of wild specimens was also accurate. However, the

evidence of morphological differences in wild larvae makes a laboratory-to-field correlation difficult (Theilacker 1978). Morphometric analysis of wild larvae placed all larvae in Group V, the starved control. Larger studies are needed to establish the difference between laboratory and field, and the value of morphometric analysis to field specimens. The histological approach is currently the most reliable for analyzing the nutritional state of field samples.

ACKNOWLEDGEMENTS

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ABSTRACTS

Editor's note: Three presentations were made at the conference which do not appear among the technical papers of these proceedings. Titles of these papers, by Guillen and Landry, Tuberville, and Snyder, are listed in the Agenda which follows this section. Mr. Snyder wished to have a portion of his presentation included in the proceedings, and so, his abstract follows. The contents of this abstract and its manuscript have not undergone critical review and therefore cannot be considered a part of the technical papers section. Mr. Snyder's abstract is presented as an informational supplement to the proceedings and interested parties are urged to contact him for further details.

STANDARDIZED FORMAT, COUNTS, MEASURES, AND ILLUSTRATIONS FOR
A SERIES OF LARVAL FISH IDENTIFICATION CIRCULARS

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Abstract.- The Laboratory for the Identification and Study
of North America's Freshwater Larval Fishes, otherwise known
as the Larval Fish Laboratory, is planning the preparation
and publication of a major series of larval fish identifica-
tion circulars. The objective is to provide a standard
format of standardized information for species accounts that
con be utilized or prepared by any interested party. Since
the same species accounts can be used in any and all appro-
priate regional guides, duplication of effort in preparation
of larval descriptions will be minimized and the time and
effort to assemble guides will be ultimately much reduced.
As more species are covered, regional guides can be made
more complete with respect to species coverage and expanded
or combined for greater geographical coverage. Eventually,
this accumulative approach could result in a guide to the
freshwater fish larvae of North America and perhaps one or
more for our coastal fishes as well. The circulars are
designed for loose-leaf binding and intended to be updated
as sufficient additional information becomes available, an
activity in which all can participate.

The circulars consist of eight pages. Background
information including general distribution, habitat, and
reproduction is provided on the first page along with
drawings of the adult and an egg with late embryo. Pages
two and three provide brief descriptions by developmental
period or phase and emphasize diagnostic characters. Eight
sets of dorsal, lateral, and ventral view drawings, two for
each larval phase and the early juveniles, occupy pages four
and five. Page six consists of three tables of standardized
data: the means and ranges of selected morphometrics and
myomere counts summarized for each larval phase and the
early juvenile, selected adult meristics, and sizes at
apparent onset of selected developmental events. Morpho-
metric length data in terms of percent standard length are
graphed for a full range of individual specimens on trans-
parencies associated with page seven. The use of trans-
parencies allows data for one species to be lain over that
for another for quick and easy comparison. The final page
includes source citations, credits, acknowledgements, and
perhaps additional space for user notes.

SUMMARY OF THE FOURTH ANNUAL LARVAL FISH CONFERENCE

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The purpose of the conference was to present a forum for dissemination of information on the biology of larval fishes. There were 18 papers presented followed by an open discussion and a laboratory based specimen examination session. These papers fell into four major categories: taxonomy, distribution, feeding and growth, and methodology. This summary will attempt to identify the possible areas of future research as well as discuss the general findings of the conference.

TAXONOMY

The accurate identification of fish eggs and larvae is becoming increasingly important. Environmental perturbations may have a detrimental effect on populations of important commercial or sport fishes. Since the larval period is very susceptible to these perturbations, accurate identifications of fish eggs and larvae is of primary importance. Unfortunately, our knowledge of the developmental stages of most fishes is nil. Descriptions of the developmental stages of fishes is increasing, and we are now at the point of even being able to compare larvae of closely related species for systematic and other purposes.

Fish development is a continuum (although a recently proposed saltation theory disputes this) and is different for each taxon. Artificial divisions of this continuum have been made in order to allow better comparisons for identification purposes. Arguments and discussion concerning proper terminology and separation of these divisions has taken much of the energy away from the area of concern, namely description of development for these species. I hope that questions of whether to use yolk-sac larvae or protolarvae, for example, will be put aside until the time when we have enough information on these stages to begin to devise identification keys. These divisions are purely artificial and detract from the need to describe development as it occurs.

Fritzsche and Johnson have pioneered the use of osteological characters in identifying larval fishes. This technique appears to work well for separating problematical specimens that can be cleared and stained for cartilage and bone. Chatry and Conner presented data to the conference participants showing how this technique can be used for separating Pomoxis larvae. There appears to be a bright future for the use of osteological development as an identification tool. It must be pointed out that a strong background in fish osteology is absolutely necessary before this technique can be applied toward solving an identification problem.

Of particular interest was the paper by Conner, Gallagher, and Chatry. It is now apparent that the fears of most fishery biologists and ichthyologists have been realized. Larvae of the grass carp have been collected in the Mississippi River. Natural reproduction of this introduced fish is now occurring in the wild.

DISTRIBUTION

Studies of the distribution and abundance of fish larvae have increased. These studies have focused on areas that are impacted by man's activities, particularly by electric power plants. Discrete samples are now being made so that both horizontal and vertical distribution of larvae can be elucidated. Diel and seasonal components of the distribution of fish larvae is also of importance. The papers presented at this conference by Guillen and Landry (not in these proceedings); Van den Avyle and Fox; Cada, Loar, and Kumar; Lewis and Siler; Gallagher and Conner; and Hatch all touched on these aspects of larval fish distribution.

Future research on larval fish distributions should probably concentrate on the patchiness of distribution patterns with an eventual goal of being able to construct theoretical models. Refinement of theoretical models will allow prediction of changes in distribution following environmental perturbation.

FEEDING AND GROWTH

The papers presented by Barger and Kilambi and by Van den Avyle and Wilson dealt with the food of larval shad. These are phytoplankton feeders as adults. We now find that larvae select large zooplankters early in life and gradually adjust to smaller organisms as they grow.

Of particular interest was the paper by Martin and Malloy dealing with starvation in striped bass larvae. It has become apparent in recent years that simply measuring abundance of larvae does not provide the information necessary in predicting year class strength. The nutritional state of fish larvae must be analyzed in order to predict survivorship. Martin and Malloy have developed a histological technique for this purpose with striped bass.

METHODOLOGY

Recent advances in sampling gear used in freshwater impoundments by the Tennessee Valley Authority were discussed.

Snyder proposed the use of standardized larval fish circulars. These circulars would contain descriptions and illustrations of fish larvae. A loose leaf format would allow organization of the circulars into a guide to all freshwater fish larvae of North America or into smaller regional guides. The project is still in the developmental stages but such guides would be very useful to those actively working in the field.

OPEN DISCUSSION AND SPECIMEN EXAMINATION

During the informal discussion concern was expressed by many over the minor participation by marine oriented individuals. The status of the Great Lakes Regional Fish Larvae Collection was presented. Offers were made for hosting the conference for next year, 1982, and 1983. It was suggested that the laboratory session of the annual meeting be expanded to include subject matter other than specimen examination (for example, sampling gear, sampling design, and analysis techniques).

Many participants attended the specimen examination session which was held at the end of the second day of the meeting. Several people brought problem specimens with them and enlisted the help of other colleagues to identify them. A few others brought reference collections of fish larvae.

CONCLUSIONS

The annual larval fish conferences have come a long way in just four years. The content of the papers presented has been useful to those persons involved with ichthyoplankton research. The main problem area remains the lack of participation in these conferences by persons working with marine fish larvae. It is imperative that the two factions (freshwater and marine) communicate with each other. Both groups have much to offer and each would benefit from an exchange of information and ideas. It is hoped that future conferences will attract investigators from both groups.

Future meetings have been scheduled at least through the next three years. With such support, the outlook for a permanent annual conference looks bright.

This conference did provide a good forum for discussion of problems in ichthyoplankton research. Future meetings will probably evolve into providing even more information on current techniques used by researchers involved with ichthyoplankton. Thanks are due to all participants, the sponsoring organizations, and particularly to Mr. Bruce Bellande of the Division of Continuing Education, The University of Mississippi, for logistical organization and support.

AGENDA

WEDNESDAY, FEBRUARY 27, 1980

8:00 a.m.   REGISTRATION, Lobby, E. F. Yerby Center for Continuing Education

8:45 a.m.   WELCOME

Dr. Joseph Sam, Dean of the Graduate School
University of Mississippi

9:00 a.m.   Session I - Taxonomy

"Comparative developmental morphology of the crappies, Pomoxis
annularis Rafinesque and P. nigromaculatus (Lesueur)."
Mark F. Chatry and John V. Conner
Louisiana Cooperative Fishery Research Unit
Louisiana State University
Baton Rouge, Louisiana

"A description of larval Cottus bairdi and Cottus cognatus from
southeastern Lake Michigan."
George R. Heufelder and Nancy A. Auer
Great Lakes Research Division
University of Michigan
Ann Arbor, Michigan

"A comparison of larval stages of three Nocomis species."
Wayne A. Potter
Wayne A. Potter Environmental Consultants
LaPlata, Maryland

Jules J. Loos and Jeanne M. Potter
Potomac Electric Power Company
Washington, District of Columbia

10:00 a.m.   BREAK

10:20 a.m.   Session I (continued)

"Some diagnostic features of larval and postlarval rock bass,
Ambloplites rupestris (Rafinesque), in central Ontario."
P. M. Powles, D. R. Vandeloo, and B. Clancy
Trent University
Peterborough, Ontario, Canada

"Larval development of the banded killifish (Fundulus diaphanus)
with notes on the distribution in the Hudson River Estuary."
Gail G. Jones and Michael A. Tabery
Ecological Analysts, Inc.
Middleton, New York

11:00 a.m.   Session II - Distribution

"Species composition and abundance of larval fishes in beachfront
and tidal marsh environments."
George J. Guillen and Andre M. Landry, Jr.
Texas A & M University
Galveston, Texas

"Diel, vertical, and horizontal variations in abundance of larval
Dorosoma spp. in Center Hill Reservoir, Tennessee."
M. J. Van Den Avyle and D. D. Fox
Tennessee Cooperative Fishery Research Unit
Tennessee Technological University
Cookeville, Tennessee

"Larval evidence for natural reproduction of the grass carp
(Ctenopharyngodon idella) in the lower Mississippi River."
John V. Conner, Robert P. Gallagher, and Mark F. Chatry
School of Forestry and Wildlife Management
Louisiana State University
Baton Rouge, Louisiana

12:00   LUNCH

1:30 p.m.   Session II (continued)

"Diel patterns of ichthyoplankton length-density relationships in
upper Watts Bar Reservoir, Tennessee."
Glenn F. Cada, James M. Loar, and K. Deva Kumar
Oak Ridge National Laboratory
Oak Ridge, Tennessee

"Determination of the vertical distribution of ichthyoplankton in
Lake Norman, North Carolina, using a discrete-depth sampling
design."
Ronald E. Lewis and James R. Siler
Duke Power Environmental Sciences Unit
Huntersville, North Carolina

"Spatio-temporal distribution of ichthyoplankton in the lower
Mississippi River, Louisiana."
Robert P. Gallagher and John V. Conner
School of Forestry and Wildlife Management
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Baton Rouge, Louisiana

"Seasonal occurrence, distribution and power plant entrainment of
larval fishes in Presque Isle Harbor, Lake Superior."
Jay T. Hatch
Department of Ecology and Behavioral Biology
University of Minnesota
Minneapolis, Minnesota

3:00 p.m.   BREAK

3:20 p.m.   Session III - Feeding and Growth

              "Feeding ecology of larval shad (Dorosoma) in Beaver Reservoir,
              Arkansas."
              Lyman E. Barger and Raj V. Kilambi
              University of Arkansas
              Fayetteville, Arkansas

              "Food habits and feeding selectivity of larval Dorosoma spp. in
              Center Hill Reservoir."
              J. R. Wilson and M. J. Van Den Avyle
              Tennessee Cooperative Fishery Research Unit
              Tennessee Technological University
              Cookeville, Tennessee

              "Histologic and morphometric criteria for assessing nutritional
              state of larval striped bass, Morone saxatilis."
              F. Douglas Martin and Robert Malloy
              University of Maryland
              Chesapeake Biological Laboratory
              Solomons, Maryland

THURSDAY, FEBRUARY 28, 1980

8:30 a.m.   Session III (continued)

              "Observations on the early life of the golden shiner in Lac
              Heney, Quebéc."
              Daniel J. Faber
              National Museum of Natural Sciences
              National Museums of Canada
              Ottawa, Ontario, Canada

              Session IV - Methodology

              "Recent developments in TVA's larval fish sampling gear."
              Jack Tuberville
              Tennessee Valley Authority
              Norris, Tennessee

              "Standardized format, counts, measures and illustrations for a
              series of larval fish identification circulars."
              Darrel E. Snyder
              Colorado State University
              Fort Collins, Colorado

10:00 a.m.   BREAK

10:20 a.m.   OPEN DISCUSSION

12:00   LUNCH

1:30 p.m.   SPECIMEN EXAMINATION AND ADJOURNMENT

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PROCEEDINGS OF THE FOURTH ANNUAL LARVAL FISH CONFERENCE

PROCEEDINGS OF THE PREVIOUS ANNUAL LARVAL FISH CONFERENCES

Proceedings of the First Symposium on Freshwater Larval Fish.
Larry L. Olmsted, editor.

Address inquiries to: Larry L. Olmsted
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                        Route 4, Box 531
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Proceedings of a Workshop on Freshwater Larval Fishes.
Robert Wallus and Clyde W. Voigtlander, editors.

Copies available from: Robert Wallus
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Price: not available

Proceedings of the Third Symposium on Larval Fish.
Robert D. Hoyt, editor.

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Price: $5.00

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