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Larry L. Olmsted
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CONTENTS

PREFACE

The Freshwater Larval Fish Symposium was held in Charlotte, North Carolina, on February 24-25, 1977. The symposium was sponsored by the Southeastern Electric Exchange (a non-profit, non-political organization representing investor-owned electric utility companies serving the 12 Southeastern states) and hosted by Duke Power Company.

The National Environmental Policy Act of 1969 sparked new interest in the study of larval fishes. This legislation, along with other federal and state regulations, required detailed environmental investigations at many proposed and existing facilities. An integral aspect of most aquatic studies is the delineation of factors influencing the abundance and distribution of larval fishes. A major limitation in larval fish studies is the paucity of written information concerning sampling techniques, taxonomy, and data management and interpretation. As a result, concurrent studies are often performed by individual agencies using vastly different gear and sampling strategies, making data essentially non-comparable. The lack of taxonomic references results in many identifications going only to family or some other higher level. Finally, inadequate and/or inconsistent data analysis and presentation has severely limited the applicability of many studies. With these concerns in mind, the Freshwater Larval Fish Symposium was scheduled with the following objectives:

1) to assess and document the state-of-the-art of various aspects (sampling, taxonomy, etc.) of larval fish studies;
2) to provide a forum for sharing ideas, techniques, and methodologies;
3) to initiate actions leading to standardization of techniques; and
4) to make much of this information available to interested parties in the form of printed proceedings.

These objectives were achieved with various degrees of success. The entire symposium was approached in a pragmatic but informal manner. Likewise, primary emphasis on papers in these proceedings has been placed on technical accuracy and utility; with little emphasis placed on style and format. Thus, individual authors approached their subjects in what they considered to be the most practicable manner.

The coordinating efforts of Lou Davis (Southeastern Electric Exchange) were instrumental in establishing an atmosphere of cooperation and professionalism which prevailed at the symposium. Attendees (a list of names and addresses appears at the back of this volume) agreed that the symposium was highly valuable and recommended another be held in the near future. The second symposium was sponsored by TVA and held during February 1978. Proceedings of the second symposium will be available within the year (1978).

Subordinate Taxa of the Genus *Notropis*: A Preliminary Comparative Survey of Their Developmental Traits

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ABSTRACT

This paper addresses the problem of larval identification in the genus Notropis from a taxonomic standpoint. Characteristics of eggs, larvae, and juveniles of species representing each of twelve subgenera and species groups are described and compared. Data from personal observations as well as published sources are used. Spawning substrate, egg diameter and character, larval size and morphology, and total vertebral number (as an indicator of myomere number) are among the traits considered.

Information gaps were found most serious among Notropis species which lack strong subgeneric affiliations. Total vertebrae, and hence myomeres, were of limited value as subgeneric characters. Strong differences in morphology and/or pigment pattern among group representatives were occasionally found during certain phases of development but seldom throughout the embryonic or larval periods. Determination of reliable characters for identification purposes will require additional studies.

INTRODUCTION

Although new information on the early life histories of some American cyprinid fishes has developed subsequent to the general works of Fish (1932), Mansueti and Hardy (1967), Lippson and Moran (1974) and others (cf. Werner, 1976), data exist for few species. We believe that these data could be put to best use if they were eventually organized taxonomically, as closely related species are expected to exhibit similar developmental traits. Developmental parallelism between unrelated species is well known. Balon (1975) and Kryzhanovsky (1948) provide numerous examples of that phenomenon. But, on the whole, their data and that of Nakamura (1969) indicate that developmental characters are taxonomically useful.

The purpose of this paper is to consider larval development within the subordinate taxa of the genus Notropis. The genus is distributed throughout North American waters tributary to the Atlantic Ocean with few species occurring in Pacific drainages in Mexico (Gilbert, 1976). This genus is comprised primarily of small, omnivorous or carnivorous, non-barbeled, often laterally compressed "shiners." Herbivorous and barbeled species have been added to the genus. Results of recent investigations indicate that current nomenclature in the subfamily leuciscinae is untenable and that it is difficult to define differences among genera such as Pimephales, Hybopsis, Clinostomus, Hybognathus, Dionda, and Notropis (cf. Contrearas, 1975; Jenkins and Lachner, 1971; Clemmer, 1971; Gilbert and Bailey, 1972; Swift, 1970; and Snelson, 1971). It is therefore presumptuous to assume at the outset that development in Notropis is different from that of these other genera. We believe that developmental differences among genera can be understood only if variation within each genus

is known. With that in mind, we made a literature survey and cursory examination of reared specimens in order to assess the usefulness for indentification of available information from taxonomic studies and from discriptions of eggs and larvae, and to look for productive directions for future investigation.

The bibliography compiled by Kernehan (1976) is an extremely useful source of reference material. He includes many additional papers loosely related to tpics discussed here, such as those dealing with fecundity, breeding behavior, and spawning season.

METHODS

The following subgenera are included in the present study: Cyprinella, Notropis, Luxilus, Hydrophlox, Lythrurus, Opsopoedus, Pteronotropis, Chriope, and Alburnops. Other taxa to be considered include the N. procne species group, N. girardi, and N. hudsonius. We will consider each of these taxa individually. An asterisk indicates that development has been described and/or that specimens are available for study at the Academy of Natural Sciences of Philadelphia. In the comments section we indicate information gaps and problems associated with identification including the potential use of myomere counts.

Terms used here are defined by Mansueti and Hardy (1967) except for those describing developmental phases, which are defined by Snyder (1976).

One urostylar and four Weberian vertebrae are included in vertebral counts. Data from authors who did not follow this practice (e.g. Scott and Crossman, 1973) are adjusted accordingly.

Methods for counting preanal myomeres have not been standardized. In this paper all myomeres completely anterior to the anus are included. This is the procedure followed by Snyder et al. (1977) and Fish (1932).

Literature citations in the discussion section are indicated by superscript numbers which refer to the sources listed in the reference section of each subgeneric account. Standard presentation of cited literature is found at the end of this paper. Data in following sections deal primarily with individual species; this information is summarized subgenerically in Tables 1 to 3.

DISCUSSIONS

Subgenus: Cyprinella[1,2,3,4,5] (Fig. 1)

In his phylogram of Cyprinella Gibbs indicated six main groups of related species.[1] Species comprising each group are listed in separate columns below:

1	2	3
xaenurus	callistius	trichroistius
pyrrhomelas	leedsi*	
	callitaenia	
	callisema	
	niveus*	

4	5	6
camurus	whipplei	caeruleus
galacturus	analostanus*	venustus
	chloristius	lutrensis*-ornatus group
		spilopterus*

Notropis gibbsi was described later. It is most closely related to N. trichroistius.[6] N. formosa was resurrected from N. lutrensis,[7,8] but Contrearas did not concur.[9] He also argues that the N. ornatus complex, comprising one species, it not closely related to N. lutrensis. Apparently N. ornatus is similar to Pimephales species in morphology and breeding habits.

Pflieger[10,11] and others[12,13,14,15] found that many Cyprinella species lay clumps of eggs in cracks (e.g. under loose bark) or on the underside of

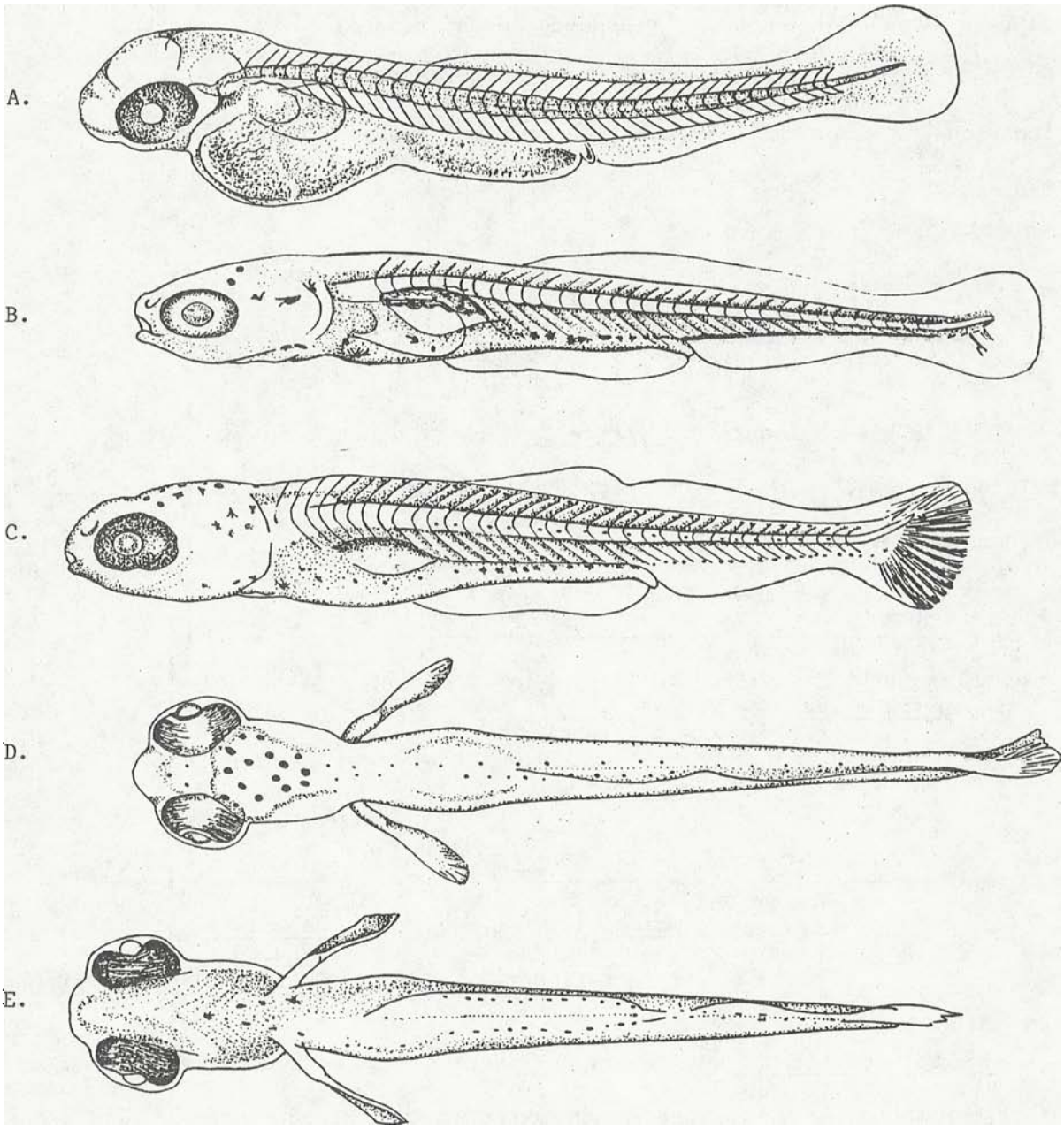

Figure 1. Notropis (Cyprinella) species. A. N. spilopterus, newly hatched, 4.8 mm TL. B. N. spilopterus, protolarva, 7.0 mm TL. C-E. N. analostanus, mesolarva, 6.7 mm TL: C. lateral view, D. dorsal view, E. ventral view.

objects. These representatives include all species in groups 4 and 5 plus N. caeruleus, N. venustus and N. spilopterus.

N. analostanus and N. spilopterus eggs are approximately 1.2 to 1.5 mm in diameter.[12,13,16] Mature ova of the former are about 1.0 mm in diameter and the micropyle is funnel shaped.[12] In newly hatched larvae of these two species,[12,16] total length is approximately 4 to 5 mm; the eye is pigmented; there is a moderate amount of yolk; and pectorals are prominent. No cement glands are present. In the mesolarval phase[12,16] there are two dorsal rows of melanophores. Another (lateral) row extends internally on the horizontal myoseptum. Two ventro-lateral rows of melanophores are found on the abdomen; a dense patch of melanophores lies over the gas bladder; and there is a sparse patch on top of the head. There are some melanophores on the opercle and otoliths and a row along the ventral aspect of preanal and postanal myomeres. This pigment pattern is referred to hereafter as type 1. In the representative (*) Cyprinella species the dorsal pigmentation is pale compared to that of upland species of Lythrurus, Hydrophlox, and Luxilus. There is often a prominent V-shaped pattern in the heart region of Cyprinella which opens posteriorly. Also in this phase of development the mouth is terminal; the head is dorso-ventrally compressed; and eyes are slightly longer than deep. In the metalarval phase the origin of the dorsal fin is over the pelvic fin buds and, depending on the species, there are usually eight or nine incipient principal anal fin rays.

We do not have eggs of N. leedsi or N. niveus available but cursory examination of mixed collections of mesolarvae and metalarvae of these species, some of which were reared to identifiable size, indicate they are similar to each other and to the species described above. Like N. spilopterus in the same phase they congregate in shallow water under direct sunlight during the heat of the day.

Mature ova from the ovaries of N. galacturus are approximately 1.6 mm in diameter. Newly hatched larvae are 5.2 to 5.5 mm TL.[14]

Pflieger[10] has observed that N. lutrensis eggs may be laid over gravel in riffle areas, over aquatic vegetation, or in nests of Lepomis cyanellus or L. humilis. Eggs, approximately 1.2 mm in diameter, average smaller than those of N. spilopterus and N. analostanus.[17] Like N. spilopterus and N. analostanus the eggs are rather opaque and adhesive. Blood pigment forms before hatching; this is not so in species with semi-pelagic eggs such as N. atherinoides. This condition is predicted by Balon.[18] Larvae appear similar to those described above.

Total number of vertebrae among some Cyprinella species are as follows:

Species	Range	Mode	Reference
N. gibbsi	37-40	38	6
N. trichroistius	38-40	39	6
N. spilopterus			
(Canada)	38-40	--	19
(Kansas)	35-38	--	20
N. lutrensis	34-36	--	20
N. camurus			
(Kansas)	37-38	--	20

Howell and Williams[6] are the only authors to include data on precaudal and caudal vertebrae; they indicate the former are those above and in front of the first interhaemal spine. Their data are summarized below.

	Precaudal		Caudal	
	Range	Mode	Range	Mode
N. gibbsi	18-20	19	19-21	20
N. trichroistius	18-20	19	18-21	19

Total numbers of myomeres in N. spilopterus counted by Snyder and Snyder[16] agree closely with reported numbers of vertebrae. Myomere numbers for this species do not appear dependent on developmental phase; modal values are 36 to 37 (range: 35-38). The mean number of postanal myomeres reported is 15 (range: 14-16). N. analostanus has 20 preanal and 12-14 postanal myomeres[12] and N. lutrensis has 19-20 and 14, respectively.[17]

References

1. Gibbs, R. H., Jr. 1957a:185-195.
2. Gibbs, R. H., Jr. 1957b:186-211.
3. Gibbs, R. H., Jr. 1957c:175-203.
4. Gibbs, R. H., Jr. 1961:337-354.
5. Gibbs, R. H., Jr. 1963:511-528.
6. Howell, W. M., and J. D. Williams. 1971:55-64.
7. Koster, W. J. 1957:67.
8. Moore, G. A. 1968:83.
9. Contrearas-Balderas, S. 1975:56-57.
10. Pflieger, W. L. 1975:156-160.
11. Pflieger, W. L. 1965:1-8.
12. Stone, U. B. 1940:44-69.
13. Hankinson, T. L. 1930:73-74.
14. Outten, L. M. 1958:122-134.
15. Gale, W. F., and C. A. Gale. 1976:1906-1913.
16. Snyder, D. E., and M. B. M. Snyder. ms.
17. Saksena, V. P. 1962:539-544.
18. Balon, E. K. 1975:821-864.
19. Scott, W. B., and E. J. Crossman. 1973:466.
20. Cross, F. B. 1967:121-126.

Subgenus: Notropis[1,2,3,4,5]
(Figs. 2 and 3)

This taxon is composed of a central group of closely related species, termed the N. atherinoides series, and a group of less closely related forms.[1] Another group of possibly affiliated species is not considered part of the subgenus at present but will be treated in this section. The species in each group are listed below:

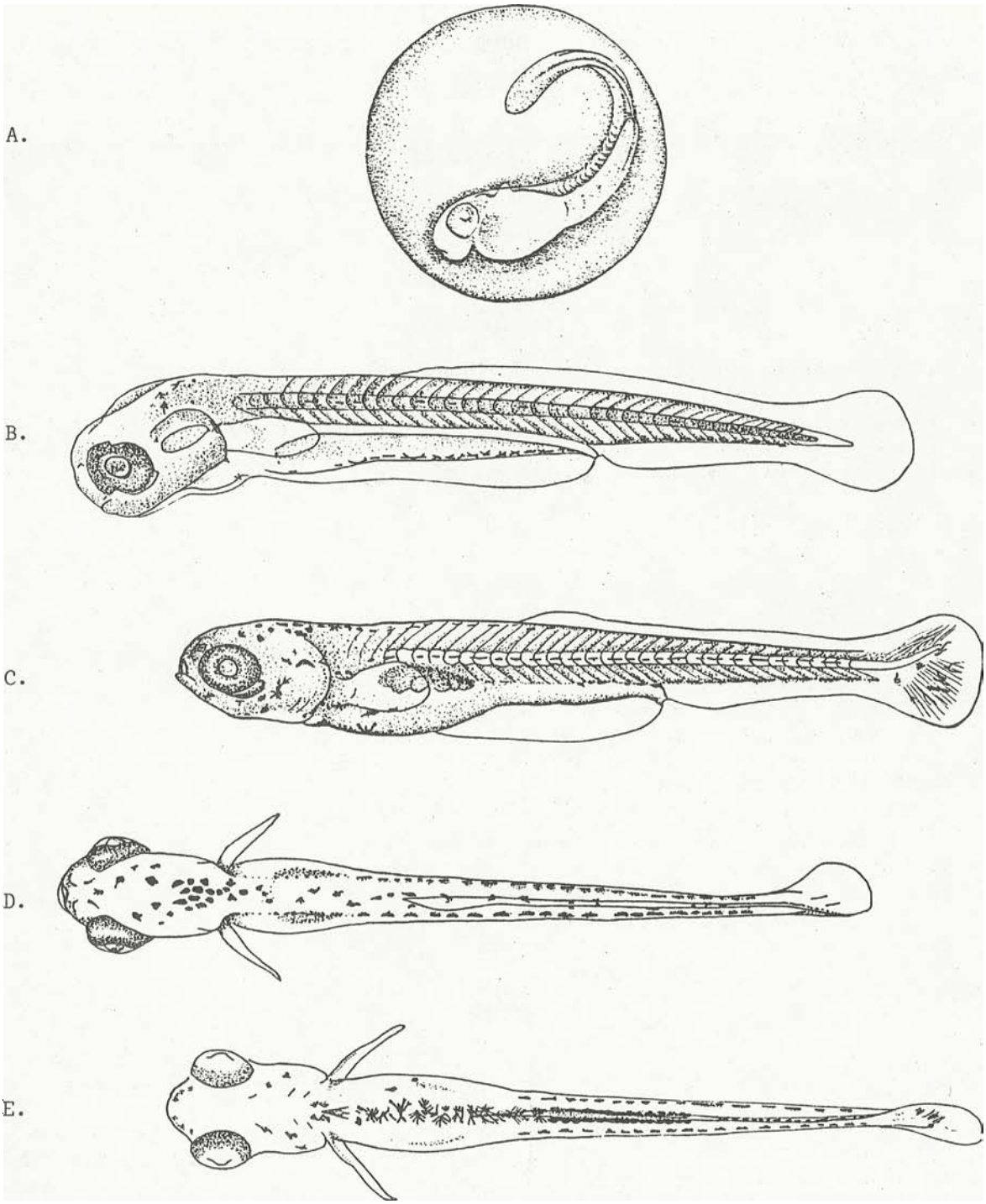

Figure 2. Notropis (N.) amoenus. A. egg, 3.2 mm in diameter. B. newly hatched larva, 4.9 mm TL. C-E. mesolarva, 6.2 mm TL: C. lateral view, D. dorsal view, E. ventral view.

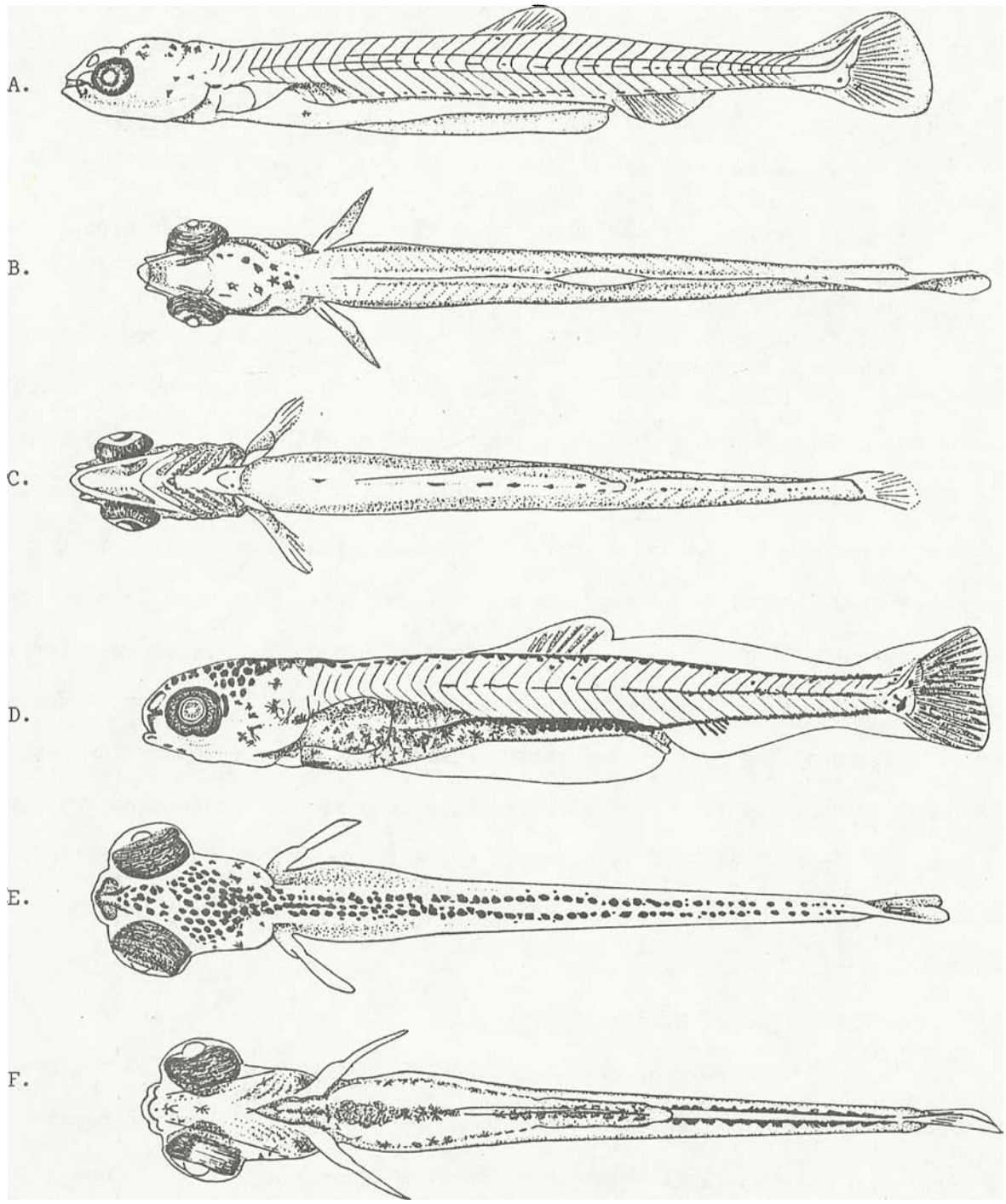

Figure 3. Notropis (N.) species and reported possible relative. A-C. N. N. atherinoides, mesolarva, 9.6 mm TL: A. lateral view, B. dorsal view, C. ventral view. D-F. N. telescopus, mesolarva, 9.0 mm TL: D. lateral view, E. dorsal view, F. ventral view.

atherinoides series	others	possible relatives
atherinoides*	photogenis	ariommus
percobromus	scepticus	telescopus*
amoenus*	semperasper	amabilis
oxyrhnychus	stilbius	perpallidus
jemezanus		

Evidence was given casting doubt on the validity of the species status ascribed to N. percobromus.[2]

The larval development of N. atherinoides is one of the most thoroughly described of any Notropis (sensu lato) species.[6,7] (One should read the original descriptions for details.) The expanded egg membrane is about 3.0 to 3.2 mm in diameter and only about 20 to 25 microns thick. The large perivitelline space is about one-third of the egg diameter. The micropyle is stellate. Yolk and embryo are colorless. After rapid hatching in an estimated 24 to 36 hour period, larvae (approximately 4.0 mm TL) lack pectoral fin buds and retinal pigmentation. A relatively large amount of yolk is present. The mouth is distinctly terminal before the end of the protolarval phase. Mesolarvae are more elongate than other Notropis (s.l.) larvae studied. They are only slightly pigmented and superficially resemble clupeiform larvae. In the metalarval phase the origin of the dorsal fin is well behind the base of the pelvic fin buds. The anal fin usually has 11 incipient rays.

In newly hatched N. atherinoides not all of the myomeres are formed; they total only 32 or 33. After the pectoral buds form there are 23 preanal and 13 postanal myomeres.[6] In mesolarvae the number of preanal myomeres remains the same while the postanal myomeres increase to approximately 16. Counts are similar in metalarvae to those of mesolarvae.[7] The totals in the last two phases agree with available vertebral data for adults.

The egg of N. amoenus is similar to that of N. atherinoides but the embryo hatches much later, after pectoral buds and retinal pigmentation have

developed and much of the yolk is absorbed. Mesolarvae are not relatively filiform and they have a type 2 pigment pattern. The type 2 pattern is similar to type 1 except that there is a single mid-ventral row of melanophores between the heart region and the vent. The two ventro-lateral rows are absent. Metalarvae are similar to those of N. atherinoides.

The mesolarvae of N. telescopus are similar to those of Luxilus species and to N. (Hydrophlox) luciodus and N. (H.) lutipinnis. N. telescopus metalarvae have more incipient principal anal fin rays (usually 11).

A larva described and illustrated by Moore,[8] which he thought might be N. percobromus, is not similar to the reportedly conspecific N. atherinoides. It is not nearly as filiform as N. atherinoides in the same developmental phase.

Published total vertebral data follow:

Species	Range	Mode	Reference
N. atherinoides			
(Mississippi River basin)	37-42	38-40	2
(Atlantic Slope)	39-41	40	1
(Great Lakes region)	38-42	40-41	6
(Canada)	40-41	--	9
N. percobromus			
(Kansas)	36-40	--	10
(Arkansas)	37-40	38-39	2
N. amoenus	37-42	39	1
N. semperasper	37-39	37	4
N. ariomus	36-39	37	5
N. telescopus	37-39	39	5
N. perpallidus	34-36	35	11

References

1. Snelson, F. F. 1968:776-802.
2. Bailey, R. M., and M. O. Allum. 1962:56-60.
3. Gilbert, C. R. 1961:450-456.
4. Jenkins, R. E., and N. M. Burkhead. 1975:178-191.
5. Gilbert, C. R. 1969:474-492.

6. Flittner, G. A. 1964:58-94.
7. Fish, M. P. 1932:335-338.
8. Moore, G. A. 1944:213.
9. Scott, W. B., and E. J. Crossman. 1973:440.
10. Cross, F. B. 1967:103.
11. Snelson, F. F., Jr., and R. E. Jenkins. 1973:294.

Subgenus: *Luxilus*[1]
(Fig. 4)

Gilbert[1] divided this taxon into three species groups. Members of each are listed in separate columns below:

*cornutus**	*coccogenis*	*zonatus*
*cerasinus**	*zonistius*	*pilsbryi*
albeolus		
*crysocephalus**		

Most or all of these species spawn over nests of other minnows when they are available.[1,2,3,4,5] *N. cornutus* is also reported to spawn over nests of smallmouth bass.[6] In the three species indicated (*) eggs are usually 1.7 to 1.9 mm in diameter. The diameter of *N. cornutus* eggs is approximately 1.7 to 1.8 mm; that of the yolk is approximately 1.3 mm. Their eggs are clumped sometimes. Mature ova of *N. chrysocephalus* are similar in weight to those of *N. cornutus*.[7] Mature ova of *N. coccogenis* are about 1.5 mm in diameter.[3]

In newly hatched larvae of indicated species (*), approximately 5.0 mm TL, eyes are unpigmented; there is a large amount of yolk; pectorals are not prominent and cement glands are absent. In the mesolarvae of these species a type 1 pigment pattern develops. A mid-ventral row of melanophores may or may not be present in different populations of *N. cornutus*. There tends to be a concentration of pigment around the urostyle which helps to distinguish indicated species from *Hydrophlox* larvae at the same phase of development. The mouth is terminal. In the metalarval phase the origin of the dorsal fin is over the posterior margin of the pelvic fin bud base. The anal fin usually has eight or nine incipient principal rays.

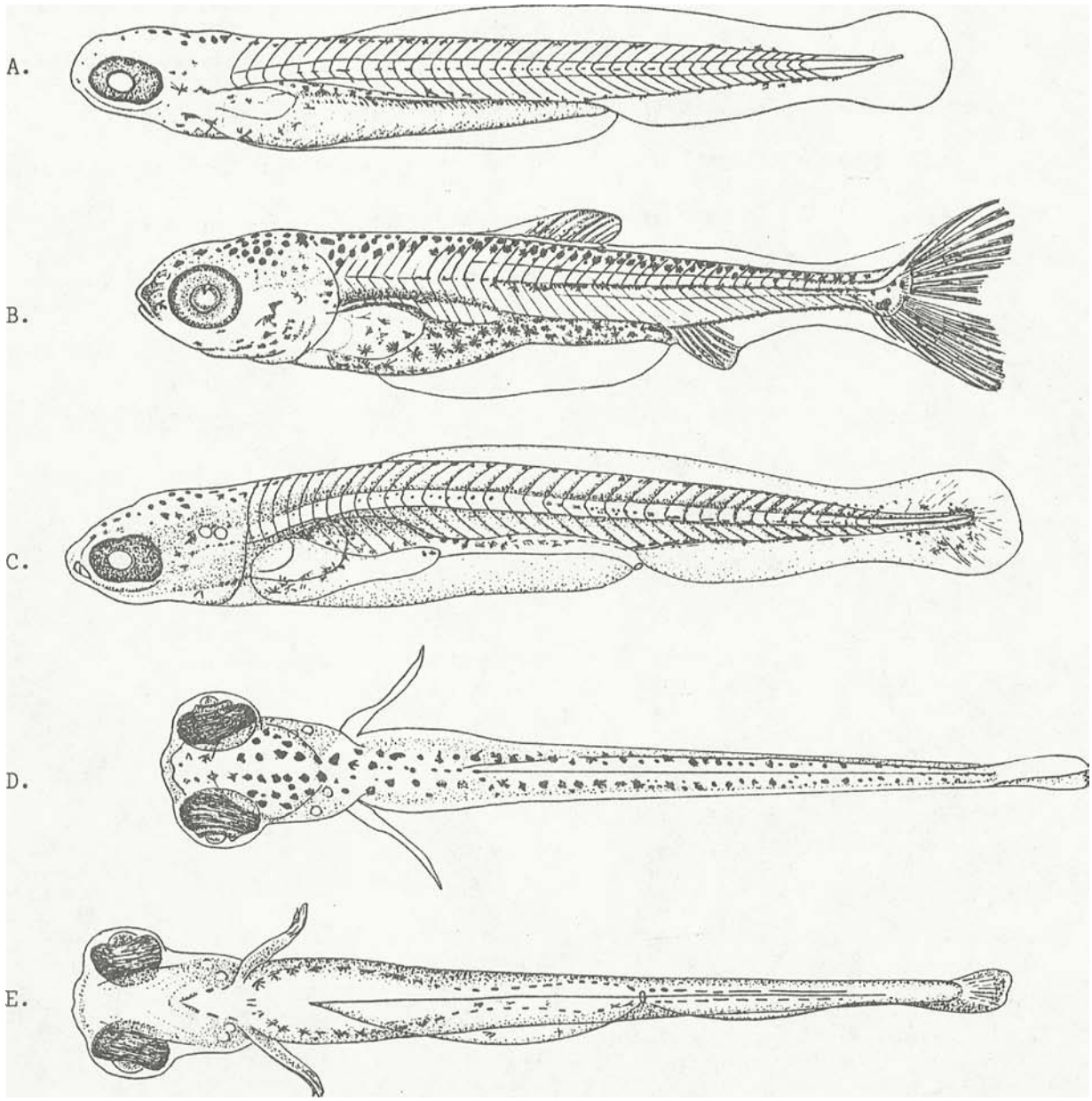

Figure 4. Notropis (Luxilus) species. A. N. cornutus, protolarva, 7.2 mm TL. B. N. cornutus, mesolarva, darkly pigmented specimen, 10.0 TL. C-E. N. cerasinus, mesolarva, 7.1 mm TL: C. lateral view, D. dorsal view, E. ventral view.

Eggs and newly hatched larvae of N. chrysocephalus, which were illustrated by Fish,[8] were incorrectly identified. We did not find a large oil globule in either eggs or newly hatched larvae as she indicated. Two metalarval specimens, also illustrated and described by Fish, were correctly identified, in our estimation. The number of myomeres for these two specimens were 36+ to 38. The number of preanal myomeres was 21 in each case.[8]

The data on total number of vertebrae come primarily from Gilbert's review.[1]

Species	Range	Mode	Reference
N. cornutus	36-42	40	1
(Kansas)	38-41	--	9
(Canada)	39-44	40-41	10
N. chrysocephalus	38-42	39	1
N. cerasinus	38-40	39	1
N. zonatus	39-41	40	1
N. pilsbryi	39-41	40	1
(Kansas)	39-41	40	9
N. coccogenis	40-42	41	1
N. zonistius	38-40	39	1

References

1. Gilbert, C. R. 1964:474-492.
2. Pflieger, W. L. 1975:147-150.
3. Outten, L. M. 1957:63-84.
4. Raney, E. C. 1940:1-13.
5. Raney, E. C. 1947:125-132.
6. Latta, W. C. 1957:26-27.
7. Horwitz, R. J. 1976:171.
8. Fish, M. P. 1932:339-342.
9. Cross, F. B. 1967:111.
10. Scott, W. B., and E. J. Crossman. 1973:448-449.

Subgenus: Hydrophlox[1,2]
(Figs. 5, 6, 7)

Swift[1] divided this taxon into three species groups whose members are listed in separate columns below.

rubellus*	rubricroceus	leuciodus*
	chiliticus	nubila
	chlorocephalus	chrosomus
	lutipinnis*	
	baileyi	

Pflieger retained nubila in the genus Dionda.[3]

Many of these species are known to spawn over chub nests when available,[3,4,5,6] but nests and redds of other species (including non-cyprinoids) may be substituted.[3] Eggs of indicated (*) species are approximately 1.5 to 2.5 mm in diameter. Reed found N. rubellus with mature ova that were 1.2 mm in diameter, while fertilized eggs were approximately 1.5 mm in diameter.[7] In N. leuciodus the pervitelline space is larger than in the other two indicated species and the egg membrane is thin and fragile. Its eggs are clumped which is not the case for N. rubellus and N. lutipinnis. Mature ova of N. baileyi are modally 1.2 mm in diameter,[8] while the corresponding measure for N. rubricroceus ova is 1.6 mm.[9]

In newly hatched larvae of indicated species (*) eyes are unpigmented; there is a large amount of yolk; pectorals are not prominent; and cement glands are absent. Total length at this stage is approximately 4.4 to 5.1 mm TL. Reed found a mean of 5.1 mm TL for N. rubellus.[7] N. lutipinnis and N. leuciodus develop a type 1 pigment pattern with a patch of melanophores on the breast while N. rubellus develops type 2. In all three the mouth is terminal in the mesolarval phase. In the metalarva the origin of the dorsal fin is variable with respect to its placement over the pelvic fin buds. The anal fin typically contains 11 incipient principal rays in N. rubellus and 9 such rays in the other two species. A metalarval N. rubellus specimen was described and illustrated by

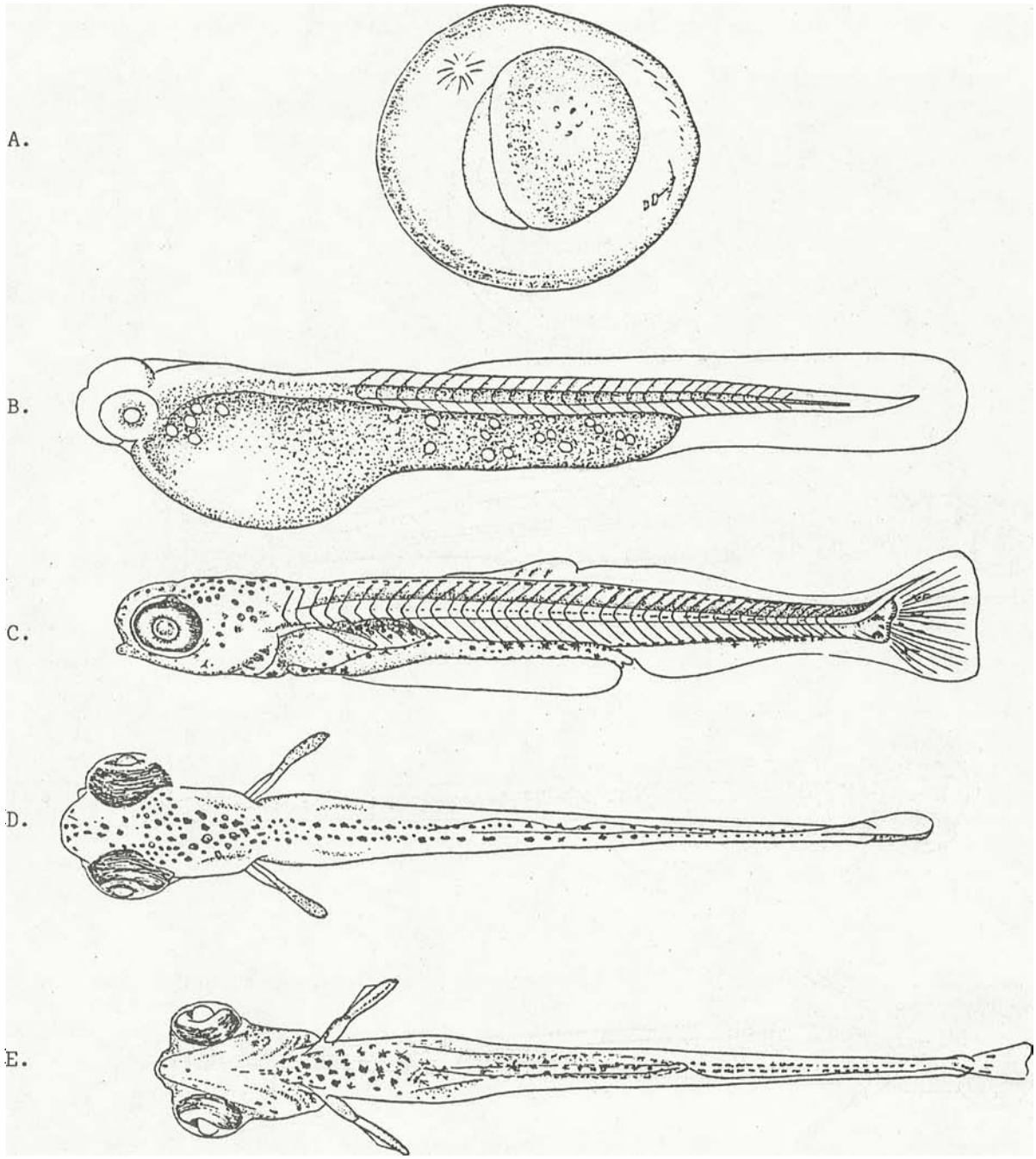

Figure 5. Notropis (Hydrophlox) leuciodus, leuciodus species group representative. A. egg, 2.5 mm in diameter. B. newly hatched larva, 5.4 mm TL. C-E. mesolarva, 8.5 mm TL: D. lateral view, E. dorsal view, F. ventral view.

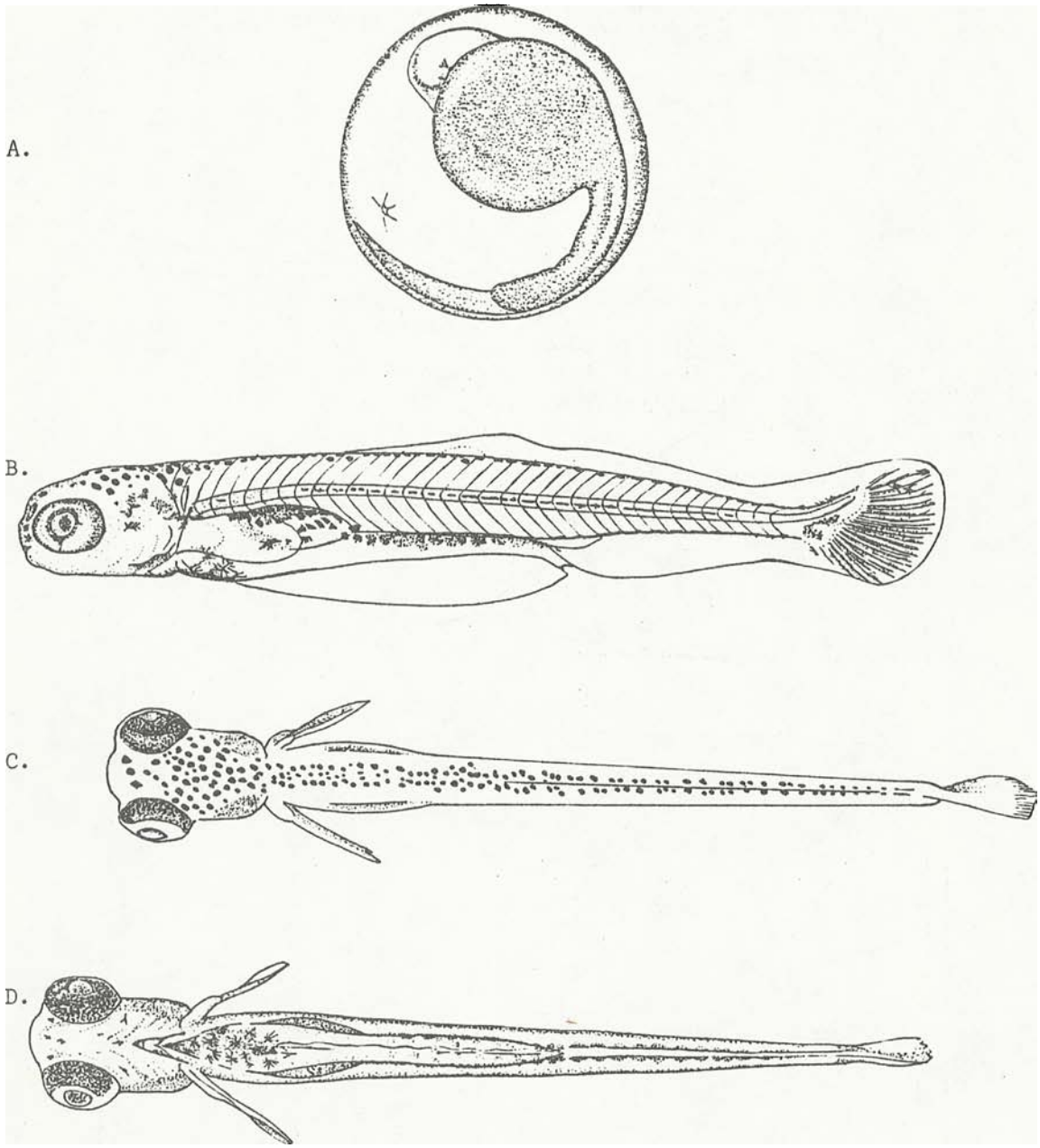

Figure 6. Notropis (Hydrophlox) lutipinnis, rubricroceus species group representative. A. egg, 2.3 mm in diameter. B-D. mesolarva 7.3 mm TL: B. lateral view, C. dorsal view, D. ventral view.

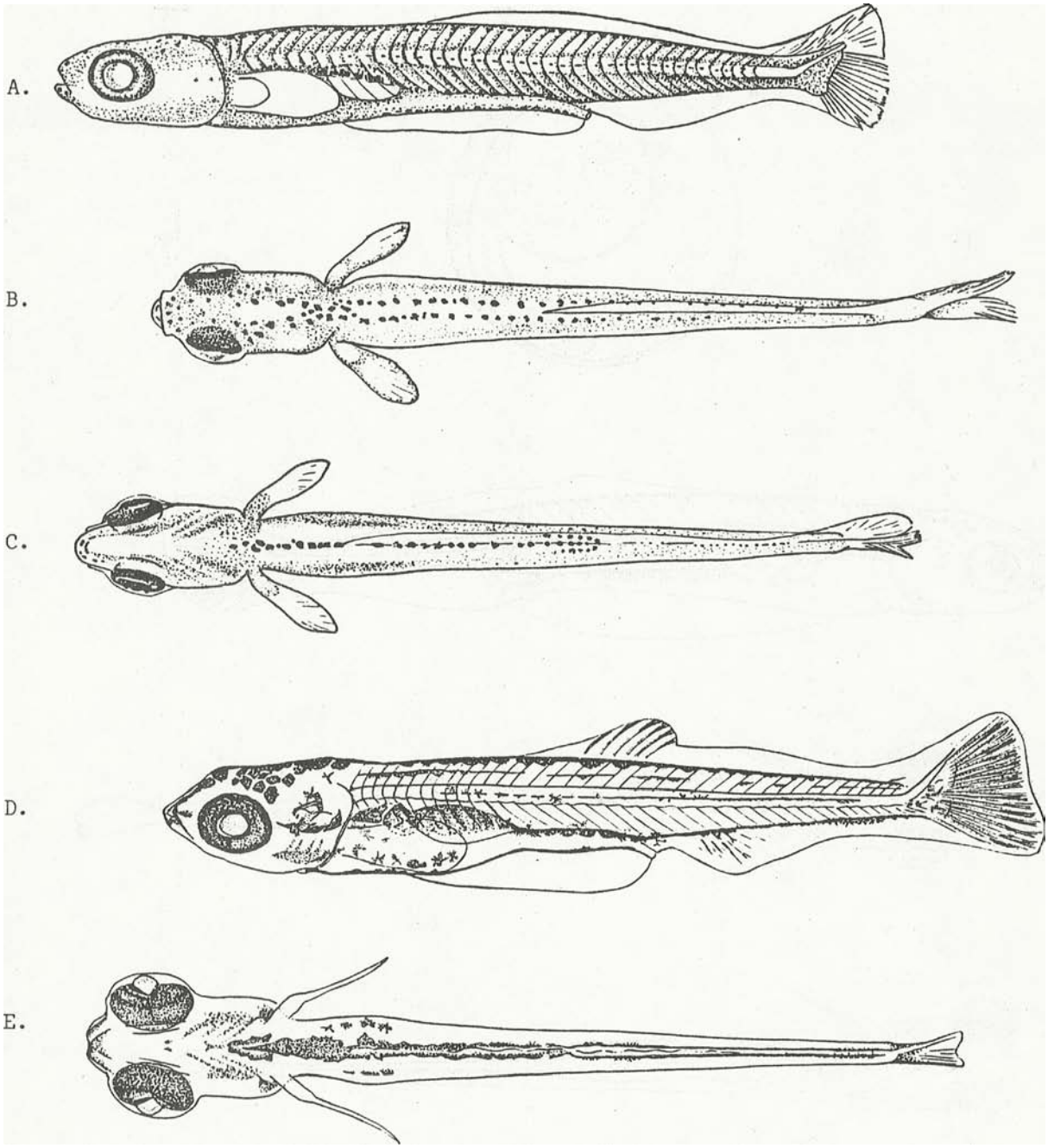

Figure 7. Similar species in subgenera Hydrophlox and Lythrurus. A-C. Notropis (H.) rubellus, mesolarva 8.8 mm TL: A. lateral view, B. dorsal view, C. ventral view. D-E. Notropis (L.) ardens, mesolarva, 8.3 mm TL: D. lateral view, E. ventral view.

Fish;[10] she indicated 22 preanal and 17 postanal myomeres. Pfeiffer's[5] observations seem to correspond, though they are sketchy.

The following vertebral data were gathered primarily by Swift.[1]

Species	Range	Mode	Reference
N. rubellus	38-40	40	1
(Canada)	38-42	40	11
(Kansas)	38-41	--	12
(Atlantic Slope)	39-42	41	13
R. rubricroceus	39-40	39-40	1
N. lutipinnis	38-40	38-39	1
N. leuciodus	37-41	39-40	1
"N." nubila	37-39	38	1
(Kansas)	36-39	--	11

References

1. Swift, C. C. 1970:43-101, 281-288.
2. Suttkus, R. D., and E. C. Raney. 1955a:71-86.
3. Pflieger, W. L. 1975:143-144.
4. Reighard, J. 1943:397-423.
5. Pfeiffer, R. A. 1955:95-104.
6. Lachner, E. A. 1952:433-466.
7. Reed, R. J. 1958:325-327.
8. Outten, L. M. 1958:124.
9. Mathur, D., and J. S. Ramsey. 1974:92.
10. Fish, M. P. 1932:138-139.
11. Scott, W. B., and E. J. Crossman. 1973:463.
12. Cross, F. B. 1967:104.
13. Snelson, F. F. 1968:794.

Subgenus: Lythrurus[1,2,3]
(Fig. 7)

Four species groups have been described for this subgenus. The members of each are listed in separate columns below.

fumeus	umbratilis	ardens*	bellus
		lirus	roseipinnis
			atrapiculus

Eggs of N. ardens are laid over Nocomis nests[4] when available. In all phases of embryonic and larval development this species is similar to N. (Hydrophlox) rubellus, which can be seen by comparing illustrations of mesolarval phases.

It is quite probable that development in the ardens species group is different from that of the others. N. bellus[1] and N. umbratilis[5] spawn over sunfish nests; the former also spawns over sand and gravel bottoms.[6] These species probably have small clear eggs typical of other cyprinids that utilize these spawning substrates. The weight of mature ova of N. umbratilis also indicates relatively small size.[7] Mature ova of N. roseipinnis average only 0.77 mm in diameter.[8]

The number of vertebrae reported by Snelson[1] are:

Species	Total		Precaudal		Caudal	
	Range	Mode	Range	Mode	Range	Mode
N. fumeus	35-38	36	16-18	17	18-21	19
N. umbratilis	35-38	37	17-19	18	18-20	19
N. bellus	34-38	36	16-19	17-18	17-20	19
N. atrapiculus	35-38	36	17-18	17	18-20	19
N. roseipinnis	35-38	36-37	16-18	17-18	17-20	18-19
N. ardens	37-41	39	18-20	19	18-21	20
N. lirus	37-39	38	18-19	19	18-21	19

In Canada, N. umbratilis has 36 to 37 vertebrae[6] and in Kansas 35 to 38.[9]

References

1. Snelson, F. F., Jr. 1972:776-802.
2. Snelson, F. F., Jr. 1973:166-191.
3. Snelson, F. F., Jr., and W. L. Pflieger. 1975:231-249.
4. Raney, E. C. 1947:125-132.
5. Hunter, J. R., and A. D. Hasler. 1965:265-281.

6. Scott, W. B., and E. J. Crossman. 1973:472.
7. Horwitz, R. J. 1976:171.
8. Heins, D. C., and G. I. Bresnick. 1975:521.
9. Cross, F. B. 1967:109.

Subgenus: Opsopoeodus[1]

N. emilae is the only species in the subgenus. Little is known about its early life history. As it prefers quite weedy areas,[1] it possibly spawns there. Mature ova are approximately 1.0 mm in diameters.[2] This species is one of only two congeneric species with nine principal dorsal rays; the other species is undescribed.[1] These rays are enumerable during the metalarval phase and therefore are useful as an identifying character for the species. Number of vertebrae in N. emilae range from 36 to 39 with a mode of 38;[1] in Canada the range is 38 to 39.[3]

References

1. Gilbert, C. R., and R. M. Bailey. 1972:1-35.
2. Mclane, W. M. 1955:80.
3. Scott, W. B., and E. J. Crossman. 1973:453.

Subgenus: Pteronotropis[1,2]

There are three species in Pteronotropis: N. hypselopterus, N. euryzonus, and N. signipinnis. Little is known of the early life history of any of these. Since all three species prefer quite weedy areas, they possibly spawn in such habitats. Mature ova of N. hypselopterus are 0.50 to 0.75 mm in diameter.[3] The following vertebral data have been published.[1,2]

Species	Range	Mode
N. euryzonus	34-38	36-37
N. signipinnis	35-37	36

In N. signipinnis there are 17 precaudal vertebrae.[1]

References

1. Bailey, R. M., and R. D. Suttkus. 1952:1-15.
2. Suttkus, R. D. 1955:85-100.
3. Mclane, W. M. 1955:95.

Subgenus: Chriope

As this subgenus has not been treated by modern ichthyologists, its validity and limits are not clear.[1] The following are species listed for the subgenus by Jordan and Evermann.[2]

bifrenatus
heterodon
maculatus
anogenus

Species of *Chriope* are often found in weedy areas and probably spawn there. The early life history of *N. bifrenatus* was described by Harrington.[3,4] The adhesive eggs (1.5 mm in diameter; 1.0 mm before water hardening) are laid over vegetation. Harrington thought they might fall through the vegetation without adhering, because he was unable to find them. It seems unlikely to us that a *Notropis* species would deposit eggs on a substrate of silt or organic debris that is commonly found under such aquatic vegetation. Further investigation into this aspect of their biology is needed. In newly hatched larvae (approximately 4.1 mm TL) the eye is pigmented; there is a moderate amount of yolk; and pectoral fin buds are minute or absent. Cement glands are apparently present. As far as we can determine this is the only congeneric species in which the ability of larvae to adhere to plants has been documented in a publication, though a species in another group reared by workers at the University of Guelph also has cement glands (Balon, personal communication). Balon[5] predicted that this ability will be found in other species that lay eggs in weedy areas. We have found cement glands present in larvae of *Notemigonus crysoleucas*, also one of Balon's phytophils. Mesolarvae and metalarvae of *N. bifrenatus* were not studied in detail.

N. maculatus is known to spawn over bass nests.[6] Mature ova are approximately 1.0 mm in diameter.[7] In metalarvae we identified there is an intense caudal spot and pale type 2 pigmentation.

Vertebral data[8] for members of this subgenus were adjusted to include the urostylar vertebrae:

Species	Range
N. anogenus	32-36
N. bifrenatus	34-36
N. heterodon	35-36

References

1. Swift, C. C. 1975:122-123.
2. Jordan, D.S., and B. W. Evermann. 1896:258-261.
3. Harrington, R. W., Jr. 1947a:97-102.
4. Harrington, R. W., Jr. 1947b:186-192.
5. Balon, E. K. 1975:834.
6. Chew, R. L. 1974:39.
7. Mclane, W. M. 1955:83.
8. Scott, W. B., and E. J. Crossman. 1973:438, 444, 454.

Subgenus Alburnops[1,2,3,4]

The limits of this taxon are not clear.[5] N. blennius is the type species. Swift[1] and Snelson[6] suggested the inclusion of N. bairdi, N. longirostris, and the N. texanus species group into Alburnops. N. edwardraneyi is closely related to N. blennius.[4]

Members of the N. texanus group include: texanus, petersoni, hypsilepis, asperifrons and chalybaeus*.

The early life history of N. chalybaeus has been described[7] but eggs are not included in existing descriptions. Mature ova are approximately 0.9 to 1.0 mm in diameter.[7,8] We have not examined eggs, which are commonly laid in sandy pools. In newly hatched larvae, approximately 2.3 mm TL, eyes are unpigmented; pectoral buds are absent; and there is a large amount of yolk. A

discussion of larval behavior[7] indicates that cement glands are absent. The mouth is terminal in the mesolarval phase and there is a dense band of dorsal body melanophores which is not divided into two rows. A dense band of melanophores occurs between the heart region and the vent. An intense spot on the caudal rays is present immediately below the upturned urostyle.[7] Some preliminary observations indicate that larvae of at least one other species in the group are not similarly pigmented.

Mature ova of N. petersoni are approximately 1.0 mm in diameter.[8] Newly hatched larvae are 4.0 to 4.2 mm TL and yolk is quickly absorbed within 48 hours.[9]

N. longirostris also spawns over sand[10] and observations of ripe N. edwardraneyi in sandy areas is suggestive of the same habit.[4]

The following vertebral data (total counts) are available.

Species	Range	Mode	Reference
N. texanus	34-38	36	1
N. petersoni	34-38	36	1
N. chalybaeus	33-37	35	1
N. hypsilepsis	35-37	36	1
N. asperifrons	36-39	37-38	1
N. blennius			
(Alabama)	34-38	36-37	4
(Kansas)	34-37	37	11
(Canada)	37-38	--	12
N. edwardraneyi	34-36	35	4

Also:[2]

	Trunk		Caudal		Total	
	Range	Mode	Range	Mode	Range	Mode
N. petersoni	17-19	18	17-19	17	34-37	36
N. asperifrons	18-20	19	17-19	18	36-38	36

References

1. Swift, C. C. 1970:102-280, 288-303.
2. Suttkus, R. D., and E. C. Raney. 1955b:161-170.
3. Suttkus, R. D., and E. C. Raney. 1955c:3-33.
4. Suttkus, R. D., and G. H. Clemmer. 1968:18-39.
5. Swift, C. C. 1975:122-123.
6. Snelson, F. F. 1971:461.
7. Marshall, N. 1947:163-188.
8. Mclane, W. M. 1955:86; 90.
9. Cowell, B. C., and B. S. Barnett. 1974:286.
10. Hubbs, C. L., and B. W. Walker. 1942:101-104.
11. Cross, F. B. 1967:117.
12. Scott, W. B., and E. J. Crossman. 1973:446.

Species not Assigned to a Subgenus

N. procne Species Group[1,2,3]
(Figs. 8 and 9)

The following species are tentatively included in this group: N. alborus, N. heterolepsis, N. mekistocholas, N. procne*, N. stramineus*, N. uranoscopus and a presently undescribed species.[1]

N. procne eggs are clear and approximately 1.2 mm in diameter. In newly hatched larvae (4.6 mm TL) the retinae are pigmented; there is a small amount of yolk; pectoral buds are evident and cement glands are absent. Mesolarvae develop a type 1 pigment pattern similar to that of Cyprinella species. The head does not become dorso-ventrally flattened. Mesolarvae are similar to N. hudsonius but they develop chevron shaped markings along the notochord which are absent in N. hudsonius. In metalarvae, the origin of the dorsal fin is over the pelvic fin buds, and the anal fin has seven incipient principal rays.

Mature ova of N. stramineus are apparently relatively small.[4] Cursory observation of metalarvae, collected as such and reared to identifiable size, closely correspond to Fish's[5] description and illustration. Since she had a large series to work from, it is probable that smaller larvae were also identified correctly. She found specimens as small as 4.7 mm with pigmented eyes. Mesolarvae are lightly pigmented in a type 1 pattern. In the metalarval

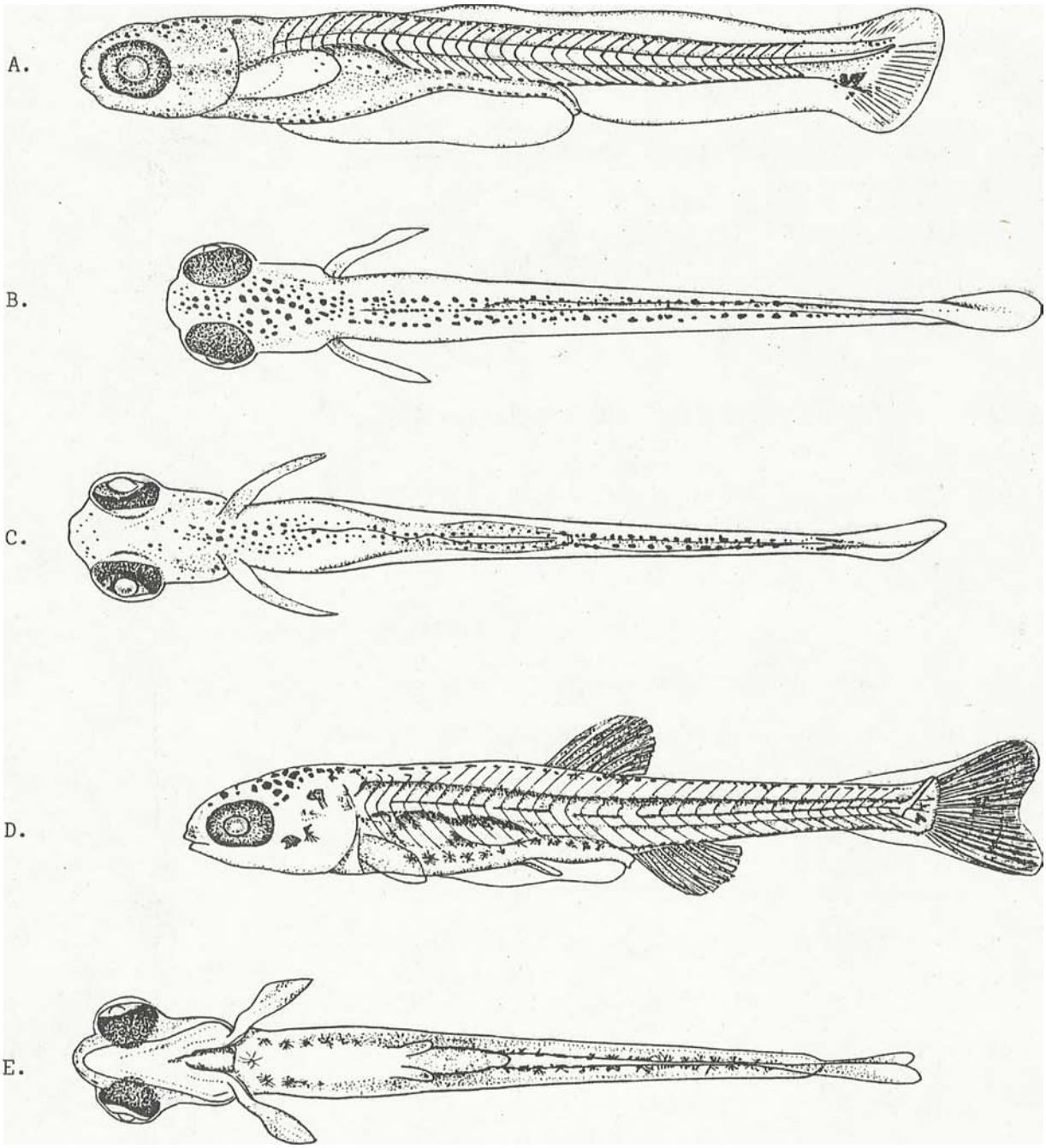

Figure 8. Notropis texanus and N. procne species group representatives. A-C. N. chalybaeus, mesolarva, 7.0 mm TL: A. lateral view, B. dorsal view, C. ventral view. D-E. N. stramineus, metalarva, 9.6 mm TL: D. lateral view, E. ventral view.

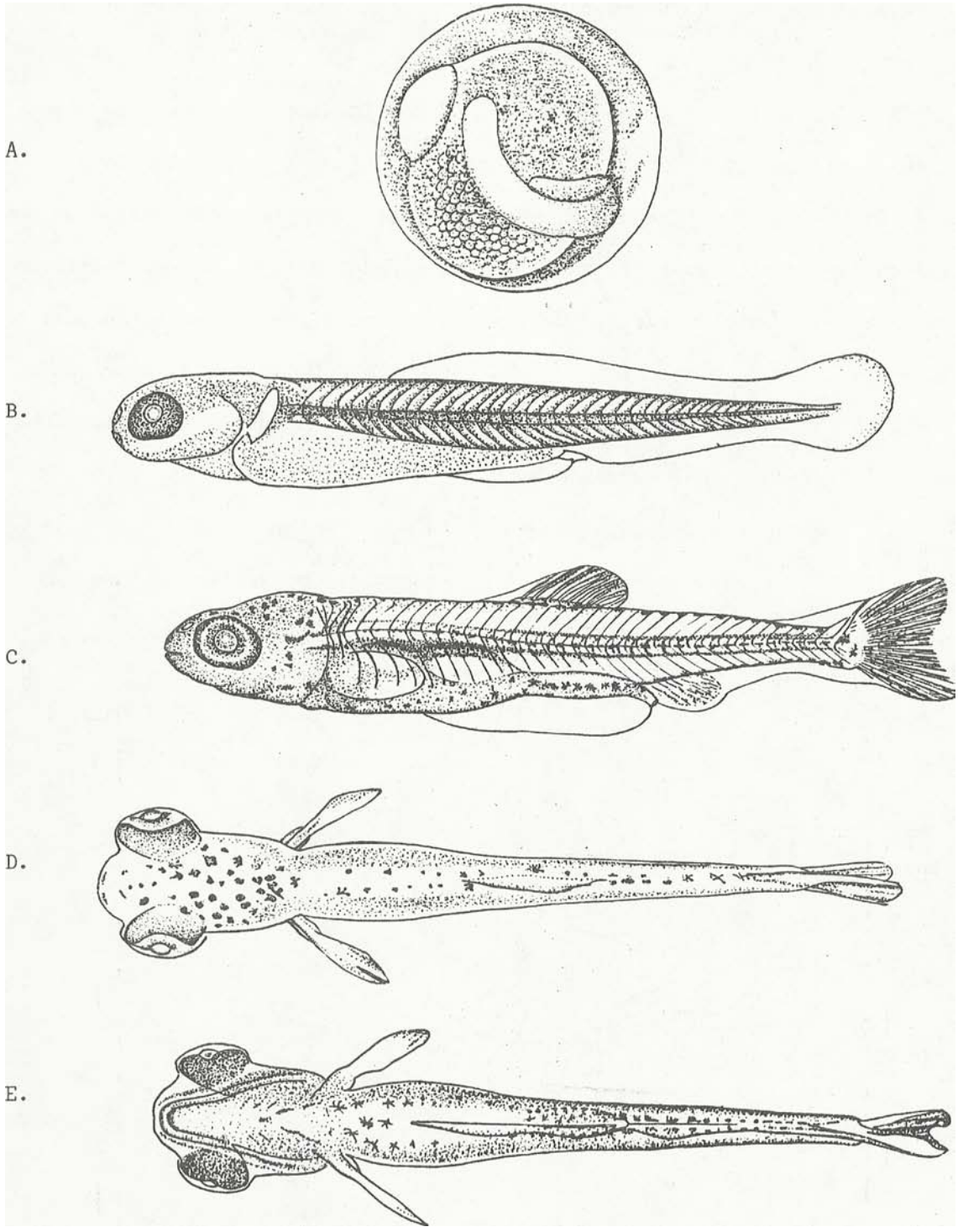

Figure 9. Notropis procne. A. egg, 1.2 mm in diameter. B. newly hatched larva, 4.6 mm TL. C-E. mesolarva, 9.0 mm TL: C. lateral view, D. dorsal view, E. ventral view.

phase, the most reliably identified in her series, she found 19 preanal and 17 postanal myomeres. N. stramineus and N. procne appear to be similar in development.

Fish[5] described a young (20 mm) specimen identified as N. heterolepsis, and noted that it differed from N. bifrenatus and N. heterodon (subgenus Chriope) in having an unpigmented lower lip. All Notropis (sensu lato) we have studied which exhibit lower-lip pigmentation as adults (e.g. Notropis [sensu stricto], Hydrophlox, Lythrurus, Luxilus) have such pigmentation throughout the metalarval phase. Many species in the N. procne group lack this pigmentation, but it is well developed in N. mekistocholas.[1] In N. heterolepsis, Fish found 19 preanal and 15 postanal myomeres.

The lower number of total myomeres in N. stramineus and N. heterolepsis (36 and 34, respectively) correspond with low numbers of vertebrae reported for this group.

Species	Range	Mode	Reference
N. alborus (N. Carolina)	34-36	35	1
N. heterolepsis			
(Canada)	35-37	--	6
(Kansas)	36-38	--	7
N. mekistocholas	36-37	36	1
N. procne (N. Carolina)	34-36	35	1
N. stramineus			
(Canada)	34-37	--	6
(Kansas)	33-36	--	7
(S. Dakota)	34-37	35-36	8
N. uranoscopus	35-38	36	2

References

1. Snelson, F. F., Jr. 1971:449-462.
2. Suttkus, R. D. 1959:7-11.
3. Hubbs, C. L., and E. C. Raney. 1947:1-25.
4. Horwitz, R. J. 1976:171.

5. Fish, M. P. 1932:331-333.
6. Scott, W. B., and E. J. Crossman. 1973:457, 470.
7. Cross, F. B. 1967:134, 141.
8. Bailey, R. M., and M. O. Allum, 1962:64-65.

N. girardi

The authors of the original descriptions of N. bairdi and N. girardi considered them closely related.[1] Both can mature at a small size when only a year old and both are summer spawners.[1] N. buccula is also closely related.[2,3]

Eggs and larvae of N. girardi were not studied by us but were described by Moore.[4] Eggs of this species (and possibly those of related species) are suspended in river currents (i.e. semipelagic) and are surrounded by a gelatinous egg membrane apparently unique among Notropis (sensu lato) species. Eggs of many Asiatic cyprinids have similar semipelagic eggs with such membranes.[5] Eggs of other American freshwater fishes such as gar, yellow perch, and pigmy sunfishes[6,7] have gelatinous egg capsules but their eggs are clumped and adhesive which is not the case with N. girardi eggs. Egg diameter, excluding the envelope, is slightly more than 1 mm; the entire egg diameter, estimated from a drawing, is approximately 3.2 mm. The micropyle is stellate. Hatching is estimated to occur in slightly more than 24 hours. Newly hatched larvae are evidently poorly developed but are not described. In mesolarvae, the mouth is terminal and a type 1 pigment pattern is developed. Metalarvae are not described.

In Kansas, N. girardi has 34 to 36 vertebrae.[8]

References

1. Hubbs, C. L., and A. I. Ortenburger. 1929:29-33.
2. Cross, F. B. 1953:252-259.
3. Swift, C. C. 1970:298.
4. Moore, G. A. 1944:209-214.
5. Kranzanovsky, S. G. 1974 translation:62-65.
6. Lippson, A. J., and R. L. Moran. 1974:27; 203.
7. Mettee, M. F. 1974:49-57.
8. Cross, F. B. 1967:136.

N. hudsonius*
(Fig. 10)

The phylogenetic relationships of this species are not clear. Although females have been observed depositing eggs among the alga Cladophora,[1] we have found that spawning occurs more frequently in gravel of riffles. Eggs are approximately 1.3 mm in diameter. Prior to spawning ripe ovaries contain eggs averaging .03 inches (.76 mm) in diameter.[2] In newly hatched larvae, approximately 4.7 mm TL; eyes are unpigmented; there is a moderate amount of yolk; pectoral buds are not prominent; and cement glands are absent. In mesolarvae light dorsal body pigmentation is composed of two rows of small melanophores in single file. Numerous scattered melanophores are found on the ventral body surface between the heart area and the vent.[3] Otherwise, the pattern is basically type 1. In the metalarval phase the origin of the dorsal fin is over the base of the pelvic fin buds and there are usually eight incipient principal anal fin rays.

Observations during development indicated that no large oil globules were present in eggs or newly hatched larvae. In fact, no large oil globules were found in any reared cyprinids. For this reason we conclude that the protolarva with an oil globule described and illustrated by Fish was misidentified. In an apparently correctly identified metalarval specimen, she found 21 or 22 preanal myomeres and 16 postanal myomeres. The total of 37 or 38 myomeres agrees with the number of vertebrae reported below.

We found that larvae of N. dorsalis and N. hudsonius also have numerous scattered ventral melanophores and have similar body shapes in the metalarval phase. The weight of mature ova indicates they are relatively small.[4]

In Canada,[5] the number of vertebrae in N. hudsonius ranges from 37 to 40 with a mode of 37 or 38, while for N. dorsalis the range is from 35 to 38

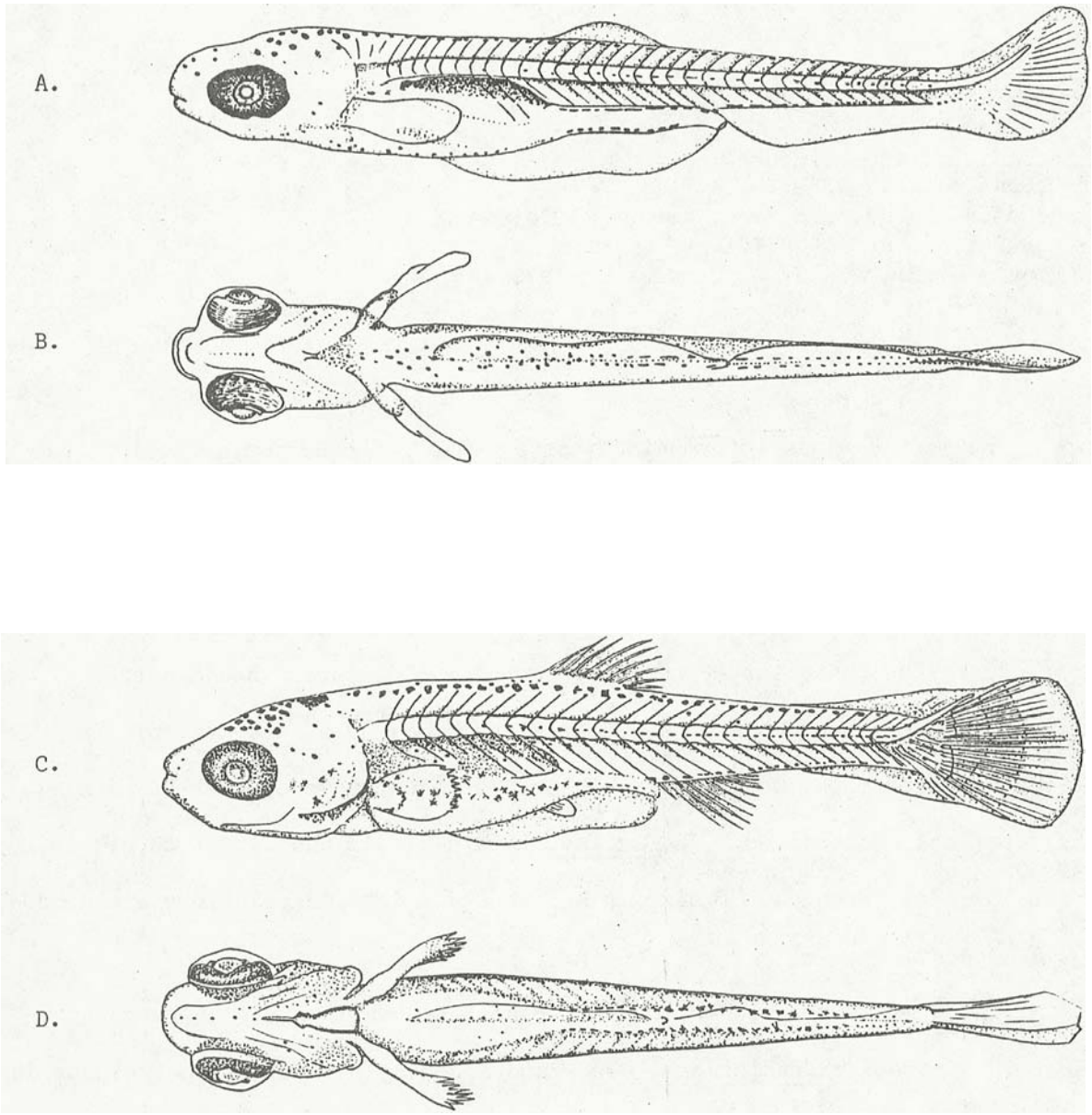

Figure 10. Notropis hudsonius and Notropis dorsalis. A-B. N. hudsonius, mesolarva, 7.9 mm TL: A. lateral view, B. ventral view. C-D. N. dorsalis, mesolarva, 10.0 mm TL: C. lateral view, D. ventral view.

with a mode of 35. In Kansas, the number of vertebrae for N. dorsalis ranges from 34 to 36.

References

1. Wells, L., and R. House. 1974:9.
2. McCann, J. A. 1959:341.
3. Lippson, A. J., and R. L. Moran. 1974:89-90.
4. Horwitz, R. J. 1976:171.
5. Scott, W. B., and E. J. Crossman. 1973:453, 460.

COMMENTS

The most serious information gaps are among the Notropis species that lack evident subgeneric affiliations. Most of these are more or less non-descript shiners often found in turbid waters, whose reproductive behaviors are little known. Appropriate data are also missing for Pteronotropis and Opsopoeodus. For these latter species, corrective measures should not be difficult. In no groups can we say that we have adequate information. In Lythrurus, for example, we know of only one representative of four species groups that has been reared. In Luxilus, this ratio is one out of three; in Cyprinella it is three out of six. Also, more detailed descriptions are needed for all species.

In a summary of data on several teleost fishes including a representative of the subfamily Leuciscinae, Gadow and Abbott (1895) state that except in the posterior half of the tail where in many fishes a great amount of stunting, fusion and shortening takes place, the number of vertebral centra agrees with that of the complete segments, neuro-myomeres. Several examples cited here indicate a rough correspondence in the numbers of myomeres and vertebrae for the genus Notropis. In this taxa, most published accounts indicate little or no increase in the number of myomeres during mesolarval and metalarval delopment.

Myomeres are easier to count than vertebrae in larval fishes and are therefore more useful identifying characters. While there are insufficient

data to allow subgeneric comparisons of numbers of myomeres in the genus Notropis, there is a large body of data on numbers of vertebrae in juvenile and adult specimens. These data, which should allow one to predict the usefulness of myomere counts, were obtained from a brief literature survey of review papers and general studies cited in the individual subgeneric and species group accounts of this paper. The results of this survey are reported in Table 1. There is a high degree of overlapping among Notropis subgenera. In fact, no two taxa have mutually exclusive ranges. Modal vertebral numbers are less than 37 in Pteronotropis, Chriope, Alburnops (particularly the N. texanus species group), N. girardi, and the N. procne species group. All other groups have modal vertebral numbers above 37. Lower counts among Lythrurus represent lowland species. On this basis, vertebral/myomere counts appear to be of limited value for subgeneric identifications within the genus as a whole. But, in most geographic areas there are only one or two representatives from each of the subgenera and species groups previously discussed. It may be found that the species present in such an area do have discontinuous ranges of vertebral/myomere numbers. In such cases the applicability of this meristic character will be enhanced.

There are usually distinct differences in portions of the larval development of representatives of each subgenus. But such differences are not found throughout the embryonic and larval periods (Tables 2 and 3). For example, the eggs of N. rubellus and N. amoenus are quite different from one another yet their mesolarvae and metalarvae are similar. Conversely, the eggs and protolarvae of Luxilus species and N. (Lythrurus) ardens are similar but their mesolarvae and metalarvae are not. In one case, representatives of different subgenera are similar throughout their development, i.e. N. (Hydrophlox) rubellus and N. ardens.

Table 1. Distribution of total vertebrae within subgenera and species groups of the genus Notropis. Data represent the number of species of a given taxon whose range of vertebral counts includes the respective total.

Taxon	Total Vertebrae													Species included here
	32	33	34	35	36	37	38	39	40	41	42	43	44	
Cyprinella			1	2	2	3	4	3	3					5
Notropis			1	1	3	6	6	6	3	2	2			7
Luxilus					1	1	4	6	7	5	3	1	1	7
Hydrophlox					1	2	4	5	4	2	1			5
Lythrurus			1	5	5	7	7	2	1	1				7
Opsopoeodus					1	1	1	1						1
Pteronotropis			1	2	2	2	1							2
Chriope	1	1	2	3	3									3
Alburnops		1	5	6	7	6	4	1						7
N. procne sp. group		1	3	4	5	3	1							6
N. girardi			1	1	1									1
N. hudsonius						1	1	1	1					1
N. dorsalis			1	1	1	1	1							1

Table 2. Subgeneric summary of available information on spawning sites and egg characteristics.*

Subgenus: Species Group	Spawning Site	Eggs in Clumps	Modal Diameters (mm)		Eggs Adhesive
			Mature ova** and/or yolk	Fertilized Eggs	
Cyprinella	Crevices; under side of objects	Yes	1.0-1.6	1.2->1.6	Yes
Notropis	Open water: over completed cyprinid nests and probably elsewhere	No	Ca 1.0	Ca 3.0	No
Luxilus	In its own nests or in those of other cyprinids and centrarchids	Sometimes	1.3-1.5	Ca 1.7-1.8	Yes
Hydrophlox	In cyprinid nests and elsewhere	Sometimes	1.2-1.6	1.5-2.5	Yes
Lythrurus:					
umbratitis group	Sand and gravel; riffles and centrarchid nests	Probably not	Relatively small		Probably
ardens group	Cyprinid nests	No	Roughly 1.2	Roughly 1.5-1.7	Yes
roseipinnis group	Probably centrarchid nests	Probably not	Ca 0.8		Probably
Pteronotropis	Possibly vegetation	Probably not	Ca. 0.5-0.75		Probably
Opsopoedus	Possibly vegetation	Probably not	Ca 1.0		Probably
Chriope	Centrarchid nests; possibly vegetation	No	Ca. 1.0	Ca. 1.5	Yes

Table 2.--Continued

Subgenus: Species Group	Spawning Site	Eggs in Clumps	Modal Diameters (mm)		Eggs Adhesive
			Mature ova and/or yolk	Fertilized Eggs	
Alburnops:					
texanus group	Sand and gravel	Probably not	Ca 0.9		Yes
Non-aligned Groups:					
procne group	Sand and gravel; centrarchid nests	No	Ca 1.0	Ca 1.2	Yes
girardi group	Open water	No	Ca 1.2	Ca 3.2	No
Others:					
N. hudsonius	Sand and gravel	No	Ca 0.8	Ca 1.4	Yes
N. dorsalis	Sand and gravel	Probably not	Relatively small		Probably

*See discussions of subgenera for sources of data and species to which data refer. Subject to revision as more information becomes available.

**Data on the size of eggs after water hardening is less readily available than that for mature ova. The latter is useful for identification because the ova diameter approximately equals yolk diameter.

Table 3. Subgeneric summary of available information on characteristics of larvae.*

Subgenus: Species Group	Newly Hatched Larvae: Eye Pigmentation	Newly Hatched Larvae: Amount of Yolk	Newly Hatched Larvae: Pectorals Prominent	Protolarvae: Cement Glands	Mesolarvae: Abdominal Melanophores
Cyprinella	Dark	Moderate**	Yes**	No	In ventro-lateral rows
Notropis	Absent or dark	Small to large	Variable	No	Few midventral melanophores; or midventral row
Luxilus:					
cornutus group	Absent to pale	Large***	No***	No	In ventro-lateral rows and/or midventral row
Hydrophlox	Absent to pale	Large	No	No	In blotch on breast or in midventral row
Lythrurus:					
ardens group	Absent to pale	Large	No	No	In midventral row
Chriope	Dark	Moderate	No	Yes	
Alburnops:					
texanus group	Absent	Large	No	No	Probably variable
Non-aligned group:					
procne group	Dark	Small****	Yes	No	In ventro-lateral rows
Other:					
N. hudsonius	Absent to pale	Moderate	No	No	Numerous; scattered

*See discussions of subgenera for sources of data and species to which data refer. Subject to revision as more information becomes available.

**This condition illustrated in Fig. 1.

***This condition illustrated in Fig. 6.

****This condition illustrated in Fig. 9.

This pattern of similarities and differences is interesting from the standpoint of taxonomy and evolutionary biology, but it makes accurate identification of preserved material difficult or impossible in many cases. However, if one has a large series of specimens with each developmental phase well represented, it is often possible to use characters more subtle than the ones described here. One may then work from developmental phases where differences are best developed to phases where they are least developed. We recommend caution because such characters may be liable to change due to environmental effects and local population differences. The early works of Hubbs (1922 and 1927) pointed out the importance of ecological factors, such as temperature and parasite infestation, as causes of variability in young fishes.

We hope that the information presented here will be of aid to workers faced with identification problems. More substantial assistance will have to await completion of more detailed studies.

Good luck!

LITERATURE CITED

Bailey, R. M., and M. O. Allum. 1962. Fishes of South Dakota. Misc. Publ. Mus. Zool., Univ. Mich. No. 119. 131 p.

_____, and R. D. Suttkus. 1952. Notropis signipinnis, a new cyprinid fish from southeastern United States. Occ. Pap. Mus. Zool., Univ. Mich. No. 542:1-15.

Balon, E. K. 1975. Reproductive guilds of fishes: a proposal and definitions. J. Fish. Res. Board Can. 32(6):821-864.

Chew, R. L. 1974. Early life history of the Florida largemouth bass. Fish. Bull. Game and Freshwater Fish Comm. No. 7. 76 p.

Clemmer, G. H. 1971. The systematics and biology of the Hybopsis amblops complex. Ph.D. Thesis, Tulane Univ., New Orleans. 155 p.

Contreas-Balderas, S. 1975. Zoogeography and evolution of Notropis lutrensis and "Notropis" ornatus in the Rio Grande basin and range, Mexico and United States (Pisces: Cyprinidae). Ph.D. Thesis, Tulane Univ., New Orleans. 156 p.

Cowell, B. C., and B. S. Barnett. 1974. Life history of the taillight shiner, Notropis maculatus, in central Florida. Am. Midl. Nat. 91(2):282-293.

Cross, F. B. 1953. A new minnow, Notropis bairdi buccula from the Brazos River, Texas. Tex. J. Sci. 5(2):252-259.

_____. 1967. Handbook of fishes of Kansas. University of Kansas, Misc. Publ. Mus. of Nat. Hist. No. 45. 357 p.

Fish, M. P. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U.S. Bur. Fish. 47:293-398.

Flittner, G. A. 1964. Morphometry and life history of the emerald shiner, Notropis atherinoides, Rafinesque. Ph.D. Thesis, Univ. Mich. 239 p.

Gadow, H., and E. C. Abbott. 1895. On the evolution of the vertebral column of fishes. Philosophical Trans. Royal Soc. London. 186(4):163-221.

Gale, W. F., and C. A. Gale. 1976. Selection of artificial spawning sites by the spotfin shiner (Notropis spilopterus). J. Fish. Res. Board Can. 33(9):1906-1913.

Gibbs, R. H. Jr. 1957a. Cyprinid fishes of the subgenus Cyprinella of Notropis. I. Systematic status of the subgenus Cyprinella with a key to the species exclusive of the lutrensis-ornatus complex. Copeia 1957(3):185-195.

_____. 1957b. Cyprinid fishes of the subgenus Cyprinella of Notropis. II. Distribution and variation of Notropis spilopterus, with the description of a new subspecies. Lloydia 20(3):186-211.

_____. 1957c. Cyprinid fishes of the subgenus Cyprinella of Notropis. III. Variation and subspecies of Notropis venustus (Girard). Tulane Stud. Zool. 5(8):175-203.

_____. 1961. Cyprinid fishes of the subgenus Cyprinella of Notropis. IV. The Notropis galacturus-camurus complex. Am. Midl. Nat. 66(2):337-354.

_____. 1963. Cyprinid fishes of the subgenus Cyprinella of Notropis. The Notropis whipplei-analostanus-chloristus complex. Copeia 1963(3):511-528.

Gilbert, C. R. 1961. Notropis semperasper, a new cyprinid fish from the upper James River system, Virginia. Copeia 1961(4):450-456.

_____. 1964. The American cyprinid fishes of the subgenus Luxilus (genus Notropis). Bull. Florida State Mus. 8(2):95-194.

_____. 1969. Systematics and distribution of the American cyprinid fishes Notropis ariommus and Notropis telescopus. Copeia 1969(3): 474-492.

_____. 1976. Composition and derivation of the North American freshwater fish fauna. Florida Scientist 39(2):104-111.

_____, and R. M. Bailey. 1972. Systematics and zoography of the American cyprinid fish Notropis (Opsopoeodus) emiliae. Occ. Pap. Mus. Zool., Univ. Mich. 664:1-35.

Hankinson, T. L. 1930. Breeding behavior of the silverfin minnow, Notropis whipplii spilopterus (Cope). Copeia 1930(3):73-74.

Harrington, R. W. Jr. 1947a. The breeding behavior of the bridled shiner, Notropis bifrenatus. Copeia 1947(2):186-192.

_____. 1947b. The early life history of the bridled shiner, Notropis bifrenatus (Cope). Copeia 1947(2):97-102.

Heins, D. C., and G. I. Bresnick. 1975. The ecological life history of the cherryfin shiner, Notropis roseipinnis. Trans. Am. Fish. Soc. 104(3): 516-523.

Horwitz, R. J. The distribution of fishes in streams. Ph.D. Thesis, University of Chicago.

Howell, W. M., and J. D. Williams. 1971. Notropis gibbsi, a new cyprinid fish from the Tallapoosa River system in Alabama and Georgia. Copeia 1971(1):55-64.

Hubbs, C. L. 1922. Variations in the number of vertebrae and other meristic characters of fishes correlated with the temperature of water during development. Am. Midl. Nat. 56:360-372.

_____. 1927. The related effects of a parasite on a fish. J. Parasitol. 14(2):75-84.

_____, and A. I. Ortenburger. 1929. Further notes on the fishes of Oklahoma with descriptions of new species of Cyprinidae. Publ. Univ. Okla. Biol. Survey 1(2):17-43.

_____, and E. C. Raney. 1947. Notropis alborus, a new cyprinid fish from North Carolina and Virginia. Occ. Pap. Mus. Zool., Univ. Mich. 535:1-25.

_____, and B. W. Walker. 1942. Habitat and breeding behavior of the American cyprinid fish Notropis longirostris. Copeia 1942(2):101-104.

Hunter, J. R., and A. D. Hasler. 1965. Spawning association of the redfin shiner, Notropis umbratilis, and the green sunfish, Lepomis cyanellus. Copeia 1965(3):265-285.

Jenkins, R. E., and N. M. Burkhead. 1975. Distribution and aspects of life history and morphology of the cyprinid fish Notropis semperasper endemic to the upper James River drainage, Virginia. Ches. Sci. 16(3):178-191.

_____, and E. A. Lachner. 1971. Criteria for analysis and interpretation of the American fish genera Nocomis Girard and Hybopsis Agassiz. Smithsonian Contr. Zool. 90:1-15.

Jordan, D. S., and B. W. Evermann. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. Bull. U.S. Nat. Mus. 47(1): x + 1240 p.

Kernehan, R. J. 1976. A bibliography of early life stages of fishes. Bull. Ichthyological Associates, Inc. 14: ii + 190 p.

Koster, W. J. 1957. Guide to the fishes of New Mexico. The Univ. of N.M. Press, Albuquerque. vii + 116 p.

Kryzhanovsky, S. G. 1948. Part II. Ecological groups of fishes. Pages 219-297. Transl. from Russian by Fish. Res. Board Can. 1974. Transl. Ser. No. 2945:1-132.

Lachner, E. A. 1952. Studies of the biology of the cyprinid fishes of the chub genus Nocomis of northeastern United States. Am. Midl. Nat. 48(2):433-466.

Latta, W. C. 1957. The ecology of the smallmouth bass, Micropterus d. dolomieui Lacepede, at Waugoshance Point, Lake Michigan. Ph.D. thesis. Univ. of Michigan. x + 144 p.

Lippson, A. J., and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River estuary. Martin Marietta Corp. Spec. Publ. PPSP-MP-13. 282 p.

Mansueti, A. J.,and J. D. Hardy. 1967. Development of fishes of the Chesapeake Bay region. An atlas of egg, larval and juvenile stages. Pt. 1. University of Maryland, Baltimore. 202 p.

Marshall, N. 1947. Studies on the life history and ecology of Notropis chalybaeus (Cope). Quart. J. Florida Acad. Sci. 9(3/4):163-188.

Mathur, D., and J. S. Ramsey. 1974. Reproductive biology of the rough shiner, Notropis baileyi, in Halawakee Creek, Alabama. Trans. Am. Fish. Soc. 103(1):88-93.

McCann, J. A. 1959. Life history studies of the spottail shiner of Clear Lake, Iowa, with particular reference to some sampling problems. Trans. Am. Fish. Soc. 88(4):336-343.

Mclane, W. M. 1955. The fishes of the St. Johns River system. Ph.D. Thesis. Univ. of Florida, Gainesville. 361 p.

Mettee, M. F. Jr. 1974. A study of the reproductive behavior, embryology and larval development of the pigmy sunfishes of the genus, Elassoma. Ph.D. Thesis. Univ. of Alabama. 35 p.

Moore, G. A. 1944. Notes on the early life history of Notropis girardi. Copeia 1944(4):209-214.

_____. 1968. Fishes. Pages 21-165, In: A. P. Blair, P. Brodkorb, F. R. Cagle, and G. A. Moore. Vertebrates of the United States. McGraw-Hill Book Co., Inc., New York. 616 p.

Nakamura, M. 1969. English summary. Pages 326-336, In: Cyprinid fishes of Japan - studies on the life history of cyprinid fishes of Japan. Res. Inst. Nat. Resour. Spec. Publ. 4:ii-455.

Outten, L. M. 1957. A study of the life history of the cyprinid fish Notropis coccogenis. J. Elisha Mitchill Sci. Soc. 73(1):68-84.

_____. 1958. Studies on the life history of cyprinid fishes Notropis galacturus and rubricroceus. J. Elisha Mitchill Sci. Soc. 74(2):122-134.

Pfeiffer, R. A. 1955. Studies on the life history of the rosyface shiner, Notropis rubellus. Copeia 1955(2):95-104.

Pflieger, W. L. 1965. Reproductive behavior of the minnows, Notropis spilopterus and Notropis whipplii. Copeia 1965(1):1-8.

_____. 1975. The fishes of Missouri. Missouri Dep. of Conserv. 343 p.

Raney, E. C. 1940. The breeding behavior of the common shiner, Notropis cornutus (Mitchill). Zoologica 25(1):1-14.

_____. 1947. Nocomis nests used by other breeding cyprinid fishes in Virginia. Zoologica 32(3):125-132.

Reed, R. J. 1958. The early life history of two cyprinids, Notropis rubellus and Compostoma anomalum pullum. Copeia 1958(4):325-327.

Reighard, J. 1943. The breeding habits of the river chub, Nocomis micropogon (Cope). Pap. Mich. Acad. Sci., Arts and Letters 28:397-423.

Saksena, V. P. 1962. The posthatching stages of the red shiner, Notropis lutrensis. Copeia 1962(3):539-544.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Bd. Can. No. 184. 966 p.

Snelson, F. F., Jr. 1968. Systematics of the cyprinid fish Notropis amoenus, with comments on the subgenus Notropis. Copeia 1968(4): 776-802.

_____. 1971. Notropis mekistocholas, a new herbivorous cyprinid fish endemic to the Cape Fear River basin, North Carolina. Copeia 1971(3):449-462.

_____. 1972. Systematics of the subgenus Lythrurus, genus Notropis (Pisces: Cyprinidae). Bull. Florida State Mus. 17(1):1-92.

_____. 1973. Systematics and distribution of the ribbon shiner, Notropis fumeus (Cyprinidae), from the central United States. Am. Midl. Nat. 89(1):166-191.

_____, and R. E. Jenkins. 1973. Notropis perpallidus, a cyprinid fish from south-central United States: description, distribution and life history aspects. Southwestern Naturalist 18(3):291-304.

_____, and W. L. Pflieger. 1975. Redescription of the redfin shiner, Notropis umbratilis, and its subspecies in the central Mississippi River basin. Copeia 1975(2):231-249.

Snyder, D. E. 1976. Terminologies for intervals of larval fish development. In: J. Boreman, ed. Great Lakes fish egg and larvae identification. Office of Biological Services, U.S. Fish and Wildl. Serv. FWS/OBS-76/23. 220 p.

Snyder, D. E., M. B. M. Snyder, and S. C. Douglas. 1977. Identification of golden shiner, Notemigonus crysoleucas, spotfin shiner, Notropis spilopterus, and fathead minnow, Pimephales promelas, larvae. J. Fish. Res. Board Can. 34(9):1397-1409.

Stone, U. B. 1940. Studies on the biology of the satinfin minnows, Notropis analostanus and Notropis spilopterus. Ph.D. Thesis. Cornell University. vii + 98 p.

Suttkus, R. D. 1955. Notropis euryzonus, a new cyprinid fish from the Chattahoochee River system of Georgia and Alabama. Tulane Stud. Zool. 3(5):85-100.

_____. 1959. Notropis uranoscopus, a new cyprinid fish from the Alabama River system. Copeia 1959(1):7-11.

_____, and G. H. Clemmer. 1968. Notropis edwardraneyi, a new cyprinid fish from the Alabama and Tombigbee River systems and a discussion of related species. Tulane Stud. Zool. Bot. 15(1):18-39.

_____, and E. C. Raney. 1955a. Notropis baileyi, a new cyprinid fish from the Pascagoula and Mobile Bay drainages of Mississippi and Alabama. Tulane Stud. Zool. 2(5):71-86.

_____, and _____. 1955b. Notropis hypsilepsis, a new cyprinid fish from the Apalachicola River system of Georgia and Alabama. Tulane Stud. Zool. 2(7):161-170.

_____, and _____. 1955c. Notropis asperifrons, a new cyprinid fish from the Mobile Bay drainage of Alabama and Georgia, with studies of related species. Tulane Stud. Zool. 3(1):3-33.

Swift, C. C. 1970. A review of the eastern North American cyprinid fishes of the Notropis texanus species group (subgenus Alburnops), with a definition of the subgenus Hydrophlox, and materials for a revision of the subgenus Alburnops. Ph.D. Thesis. Florida State University, Tallahasses. 476 p.

_____. 1975. Classification of the American cyprinid fish genus Notropis, and application of graph cluster analysis to an exemplar group. Am. Soc. Ichthyologists and Herpetologists, Abstracts of Papers, 55 Ann. Meeting: 122-123.

Wells, L., and R. House. 1974. Life history of the spottail shiner (Notropis hudsonius) in southeastern Lake Michigan, the Kalamazoo River, and western Lake Erie. U.S.D.I., Bur. Sport Fish. Wildl., Res. Rep. 78:1-10.

Werner, R. G. 1976. A preliminary annotated bibliography of the literature relevant to descriptions of eggs and larval stages of fishes of the Great Lakes. In: J. Boreman, ed. Great Lakes fish egg and larvae identification. Office of Biological Services, U.S. Fish Wildl. Serv. FWS/OBS-76/23. 220 p.

Completion of a
"Preliminary Guide to the Identification of
Larval Fishes in the Tennessee River"

by

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Completion of a "Preliminary Guide to the Identification of Larval Fishes in the Tennessee River"

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The stimulus for the Tennessee Valley Authority's (TVA) work in larval fish biology was generated by an awareness of our need for knowledge of young fish ecology and the concern regarding potential impacts of entrainment of larvae in the condenser cooling systems of steam-electric power plants. From the beginning of TVA's work in larval fish biology (1970), we recognized that the identification of larvae was one of the principal problems to be solved. Literature was sparse, especially descriptions and keys, and much of what was available was not applicable. Thus, in 1972, efforts were begun to develop a key that would facilitate the identification of larval fishes collected in the Tennessee Valley.

The "Preliminary Guide to the Identification of Larval Fishes in the Tennessee River" (TVA Technical Note B19, December 1976), coauthored by Jacob J. Hogue, Jr., Robert Wallus, and Larry K. Kay, is the first document representing our efforts in larval fish taxonomy.

The guide provides keys, detailed descriptions, and photographic plates to aid in the identification of individual taxa representing 18 families common to the southeast. Positive identification to the species level is possible for some larvae; in other cases, identification of only generic or even family groups is possible. Table 1 provides a summary of taxa that can be identified using the guide.

Due to the dynamic nature of larval fish taxonomy, this work must certainly be viewed as preliminary. It forms a base upon which we hope to build further as our knowledge improves. As such, it will hopefully be an evolving document with

subsequent revisions reflecting greater knowledge of the larval fauna. The guide is being disseminated at this time in the hope that it will help to foster broader communication and active interchange among larval fish taxonomists.

Constructive criticism by the users of this guide will be welcomed by the authors. The guide is available upon request from the Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority, Norris, Tennessee 37828.

TABLE 1: Taxa that can be identified with keys included in "Preliminary Guide to the Identification of Larval Fishes in the Tennessee River."

Family	Taxa in Keys
Polyodontidae	Polyodon spathula
Lepisosteidae	Lepisosteus spp.
Amiidae	Amia calva
Clupeidae	Prolarvae (larvae equal to or less than 6 mm TL) Alosa chrysochloris Dorosoma spp. Postlarvae (larvae greater than 6 mm TL and less than 20 mm TL) No identifications below Clupeidae Postlarvae (larvae greater than or equal to 20 mm TL) Alosa chrysochloris Dorosoma cepedianum Dorosoma petenense
Hiodontidae	Hiodon alosoides Hiodon tergisus
Esocidae	Esox spp.
Cyprinidae	Campostoma anomalum Clinostomus funduloides Cyprinus carpio Notemigonus crysoleucas Notropis atherinoides Notropis spilopterus Pimephales promelas (Additional descriptions provided for several distinctive groups of unclassified cyprinids.)
Catostomidae	Minytrema melanops (Additional descriptions provided for several distinctive groups of unclassified catostomids.)

TABLE 1 (continued)

Family	Taxa in Keys
Ictaluridae	Ictalurus furcatus I. punctatus I. melas I. natalis I. nebulosus Pylodictis olivaris
Aphredoderidae	Aphredoderus sayanus
Cyprinodontidae	Fundulus spp.
Poeciliidae	Gambusia affinis
Atherinidae	Labidesthes sicculus
Percichthyidae	Prolarvae: Morone spp. Morone saxatilis Postlarvae: No identifications possible below Morone spp.
Centrarchidae	Ambloplites rupestris Micropterus dolomieui Lepomis spp. Micropterus spp. Pomoxis spp.
Percidae	Perca flavescens Stizostedion spp. (Additional descriptions provided for several distinctive groups of unclassified percids.)
Sciaenidae	Aplodinotus grunniens
Cottidae	Cottus carolinae

SELECTIVITY OF LARVAL FISH GEAR AND SOME NEW TECHNIQUES FOR ENTRAINMENT AND OPEN WATER LARVAL FISH SAMPLING

BY

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SELECTIVITY OF LARVAL FISH GEAR AND SOME NEW TECHNIQUES FOR ENTRAINMENT AND OPEN WATER LARVAL FISH SAMPLING

Gear Selectivity

Bias resulting from gear selectivity is a recognized constraint in fisheries work with adult fishes. This constraint is also a problem when sampling larval fish. Aron and Collard (1969) demonstrated that length frequency distributions of larval catches were dependent on net speed for some species but independent of net speed for other species. A theory of larval fish sampler selectivity (Barkley 1972) recognizing net speed and net mouth diameter as dependent variables in determining vulnerability of a particular species and size of larvae has been developed and successfully tested. Fleminger and Clutter (1965) have shown that smaller plankton nets are more effectively avoided and that avoidance is species dependent.

Avoidance capability of larval fish in terms of sustained or burst swimming speed has been determined for few species. Houde (1969) found that yellow perch (Perca flavescens) larvae larger than 9.5 mm could sustain speeds of 3.8 cm/s for at least one hour. Larimore and Douver (1968) found larval smallmouth bass (Micropterus dolomieui) 20 to 25 mm in length capable of sustained speeds of 20 to 25 cm/s for over three minutes. Burst speeds are likely to be much higher for these species. Short duration (0.1 to 0.2 seconds) burst speeds for larval anchovy (Engraulis mordax) as high as 11.7 cm/s for 4.2 mm larvae and 30.2 cm/s for 12.1 mm larvae have been observed by Hunter (1972). The maximum duration of such a burst has not been determined. Murphy and Clutter (1972) projected that it would be reasonable that 7.5 mm anchovy larvae could detect a meter

net 200-400 cm away and begin to take meaningful evasive action. From this information it would seem likely that even some very small larvae may be capable of swimming speeds sufficient to effectively avoid a larval net. Specific information on the selective characteristics of the various larval fish sampling gear is needed to assure more accurate interpretation of larval fish density and length-frequency distributions. Few larval fish gear comparisons have been described in the literature.

Murphy and Clutter (1972) evaluated the sampling efficiency of a larval purse seine (5.6 m x 35.5 m) with that of a 1 m conical net on anchovy larvae (Stolephorus purpurus) catches. During the day the purse seine was "at least an order of magnitude more efficient for larvae over 5.5mm in length" (Fig. 1). Maximum length of larvae (day samples) from the meter net was 14.5 mm and from the purse seine was 29.5 mm. Similar results were reported for the night samples with the exception that both gear caught larger fish; maximum length from the meter net was 22 mm while the purse seine collected fish as long as 45.5 mm. These results agree with Ahlstrom's (1954) contention that some larvae are capable of avoiding nets during night as well as day. Noble (1970) found that catches of yellow perch larvae (Perca flavescens) with the Miller high-speed sampler tended to increase progressively with speeds increasing above 3.6 m/s; however, further tests indicated that avoidance of the sampler was occurring even at 4.9 m/s. Walker (1975) presented data on 0.5 m and 1 m conical net tows. The divergence in mean length of clupeid catches begins at about 8 to 9 mm (Fig. 2), after which length the 1 m net, with one exception, caught larger fish (Fig. 3).

Given this information on avoidance capabilities of larval fish relative to net size and fishing speed, we will discuss some of the special problems of commonly used larval fish gear.

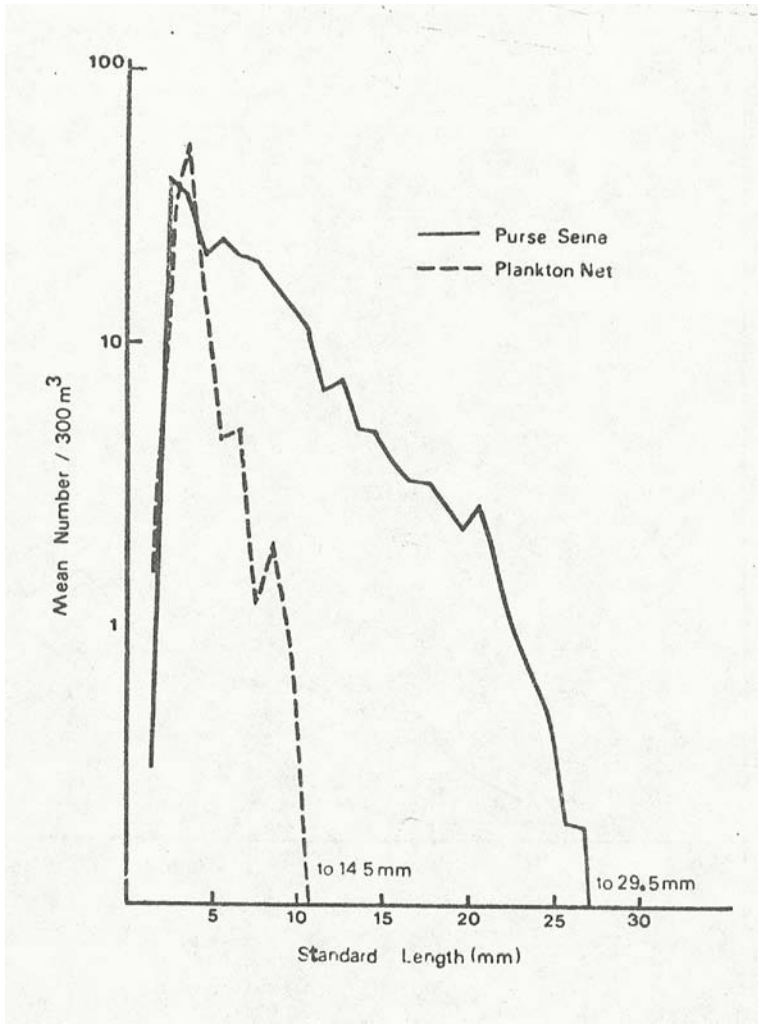

Figure 1. Densities of larval fish catches taken during the day using a purse seine or a 1 m conical plankton net. From Murphy and Clutter (1972).

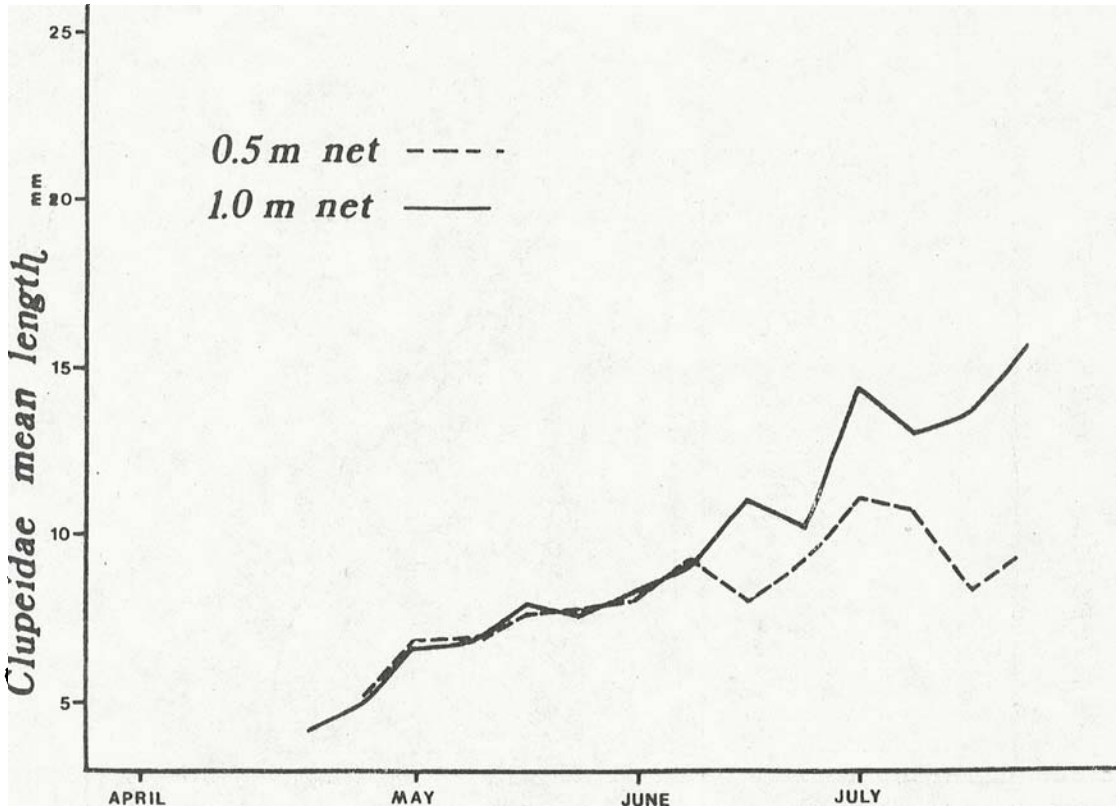

Figure 2, Mean length of larval Clupeidae taken with a 1 m or 1/2 m conical net. Data from tables presented by Walker (1975).

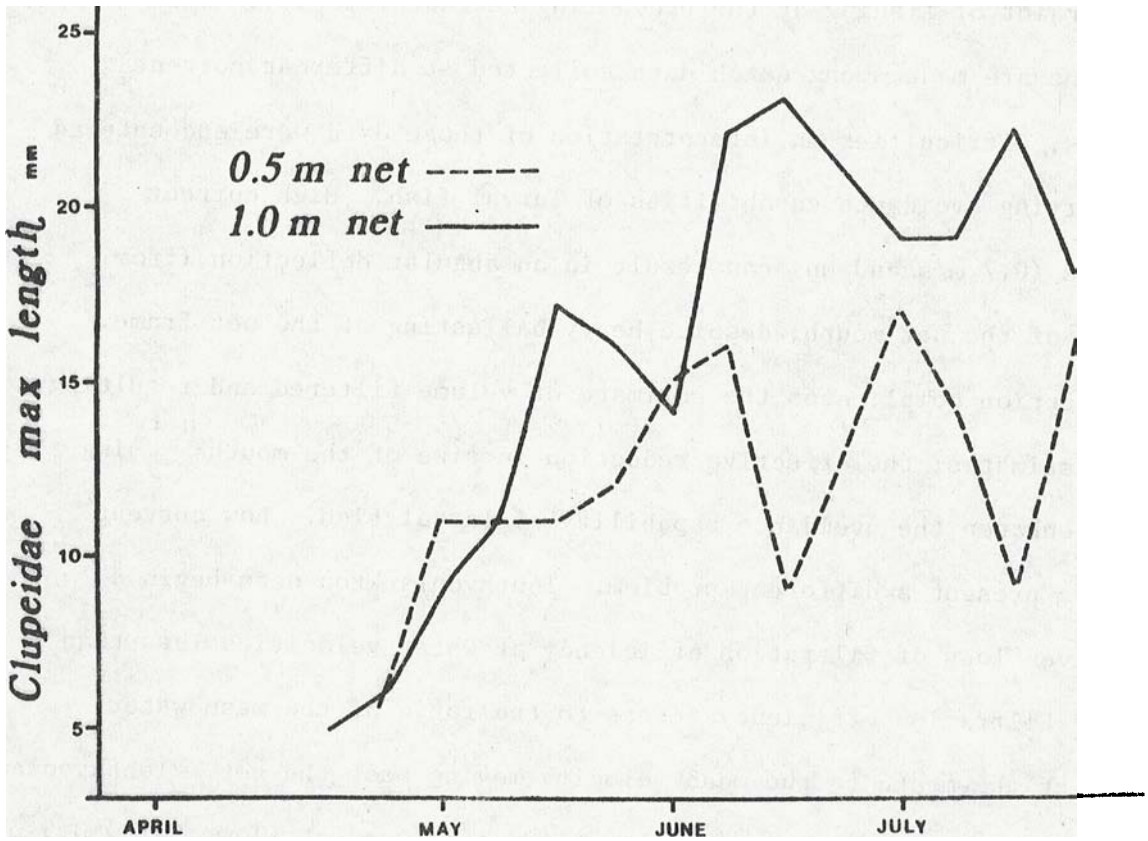

Figure 3. Maximum length of larval Clupeidae taken with a 1 m or 1/2 m conical net. From tables presented by Walker (1975).

Entrainment Sampling

Stationary netting in the current of power plant intake channels is one of the methods commonly used to estimate larval fish densities. The most obvious problem with stationary netting of ichthyoplankton is the constraint of fishing at the prevailing current velocity. When comparisons are made among catch data collected at different current velocities, difficulties in interpretation of those data were encountered due to varying avoidance capabilities of larval fish. High current velocities (0.7 m/s and up) can result in an angular deflection (from vertical) of the net mouth, despite heavy ballasting of the net frame. This deflection complicates the estimate of volume filtered and resulting density estimates; the effective reduction in size of the mouth opening may also enhance the avoidance capability of larval fish. Low current velocities present a different problem. Ichthyoplankton nets begin a progressive loss of filtration efficiency at water velocities less than 1.0 m/s. Filtration efficiency refers to the ratio of the mean water velocity at the mouth to the mean velocity moving past the net. Ichthyoplankton nets show a dramatic decrease in filtration efficiency at flows below 0.5 m/s (Fig. 4). This phenomenon has been substantiated both mathematically (Svein Vigander, Tennessee Valley Authority, Water System Development Branch, personal communication, 1976) and empirically (Tranter and Heron 1967). The further reduction in effective filtering rate owing to a loss in filtration efficiency at low flows would further increase the avoidance capability of larval fish.

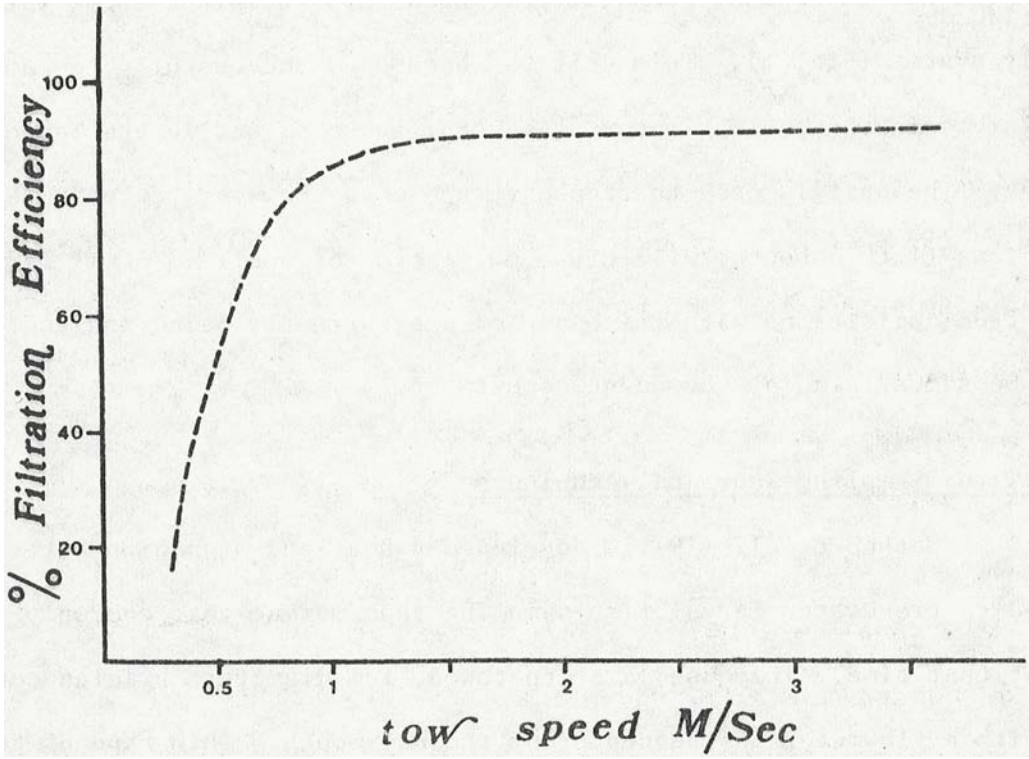

Figure 4. Filtration efficiency of a typical conical larval fish net* (Svein Vigander, Tennessee Valley Authority, Water System Development Branch, 1976).

*The inflection point of the curve and axis dimensions of this figure will vary among nets of various types because the filtration efficiency of a particular net is a function of mouth area, mesh area, type and size of mesh material and water filtration velocity. However, the general trend of the curve holds true for all larval fish nets.

During 1976, two alternative methods for measuring concentrations of larval fish entrained were developed by TVA. The first was a series of fine-mesh screens superimposed over the traveling trash screens of the plant intake. Details of this technique and the data collected are found in another section of these proceedings (Tomljanovich, 1977). The second technique was an inplant fish filter fitted into the plant's raw water supply system (Fig. 5). This unit has been used successfully to sample the larvae in the cooling water at several steam plants in the Tennessee Valley. The unit is easy to transport and use. However, extended sample durations (1 to 4 hours) will cause mutilation of small (3-6 mm) larvae. Data from collections with this sampler are currently being analyzed and will be summarized in subsequent reports.

Open Water Sampling Gear and Techniques

Netsch et al. (1971) developed a boat and stanchion better suited to freshwater larval fish sampling than marine gear commonly in use at that time. They used a stern-towed, 1 m diameter, bridled conical net with a flowmeter in the center of the net mouth. This type of towed larval fish net is commonly used for open water sampling, Several limitations in this gear are apparent. There is the unknown effect of propeller wash on larval fish distribution and flowmeter operation. There is also contamination of the sample from undesired depths as the net is deployed and retrieved while underway. Tranter and Heron (1967) indicated that turbulence created by the net bridle on a towed net can result in flowmeter readings 10 to 20 percent lower than the actual volume of water filtered through the net, resulting in overestimates of larval fish density.

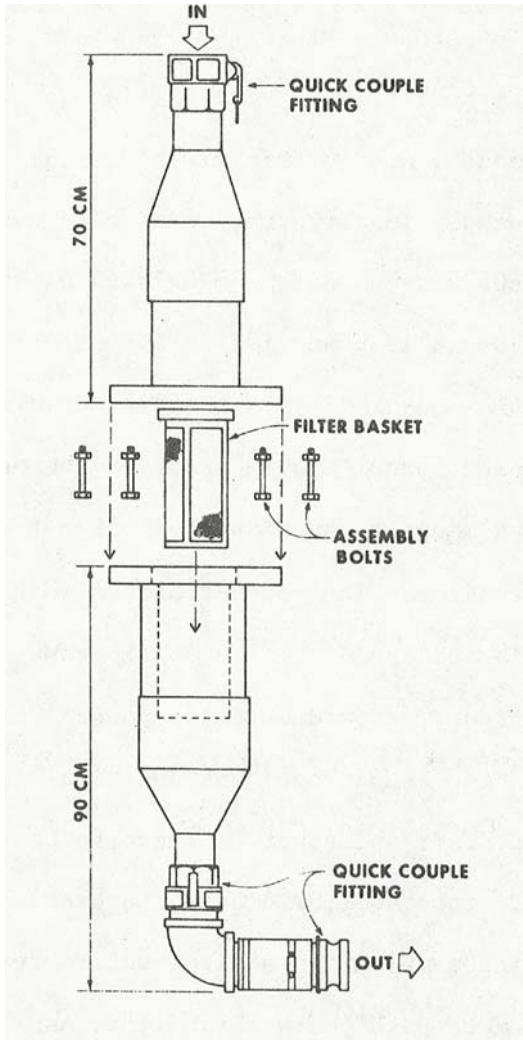

Figure 5. Inplant fish filter as used by TVA during the 1976 larval fish season.

There could be an avoidance reaction due to the turbulence created by the bridle and depressor warp, both of which travel in advance of the net mouth.

During the 1976 larval sampling season, TVA developed a new towed net and sampling procedure to achieve the objectives of (1) moving the towed net out of the propeller wash, (2) eliminating the net bridle from in front of the net mouth, and (3) minimizing contamination from strata other than the chosen sampling stratum. A side-towed beam net (0.5 m square; 1.8 m long; 505 micron nitex mesh) was utilized for obtaining ichthyoplankton samples in 1976 and 1977. The net frame (Fig. 6) allows attachment of the cable and bridle at points removed from the area of the net mouth, thus reducing turbulence in front of the net mouth and flowmeter; this arrangement helps minimize avoidance of the net by larvae and provides more accurate flow readings. The counterbalance weight (21 kg) keeps the net mouth perpendicular to the direction of the tow.

Twenty-one foot, inboard/outdrive powered boats (Fig. 7) are generally used by TVA for deeper overbank and open water larval fish sampling. Their deep draft and power winches are best suited to open water tows. "Push" boats (18-foot shallow draft john boats, Fig. 8) are better adapted for larval fish sampling in shallow water areas (0.5 m). Hand crank winches are used on push boats which limit maximum sampling depths to less than 10 m.

Oblique tows are made through a given stratum by a "stairstep" retrieval of the net (Fig. 7). The net is raised in equal increments at minute-point intervals during a 10-minute tow. Lift frequency is altered to suit a specific station or sampling objective. The boat is stopped with respect to the waterflow at the start and finish of a tow before the

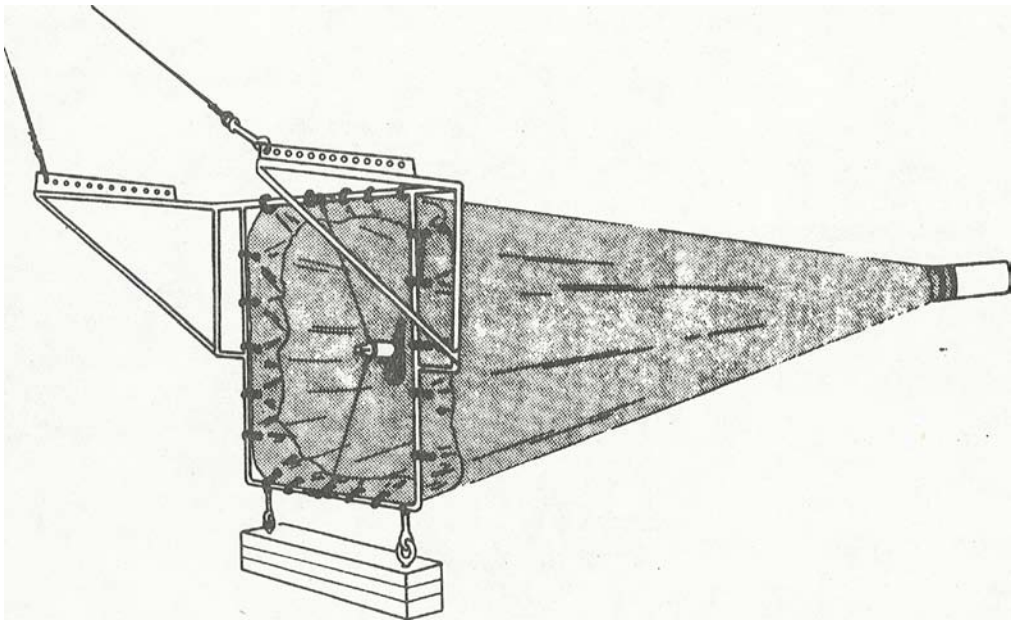

Figure 6. Net and frame of the side-towed larval fish sampler used by TVA in 1976-1977.

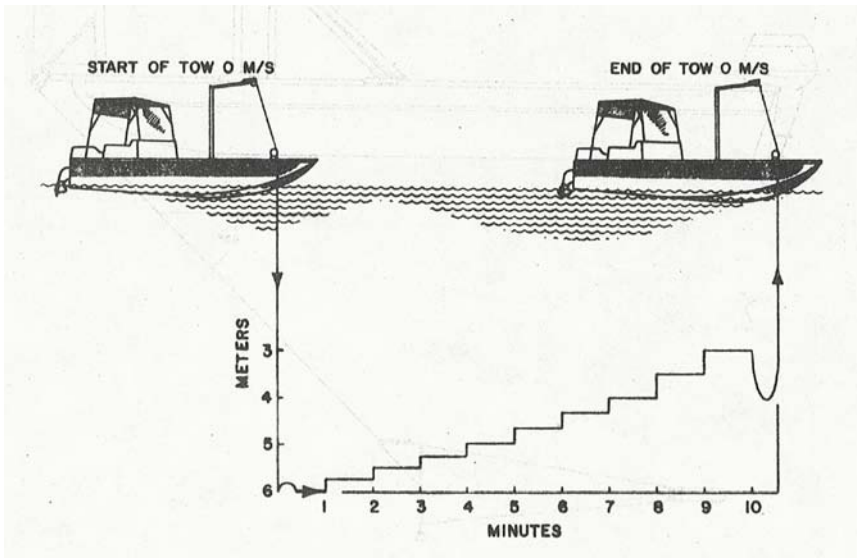

Figure 7. Open-water sampling boat and the "stairstep" retrieval pattern for stratified sampling.

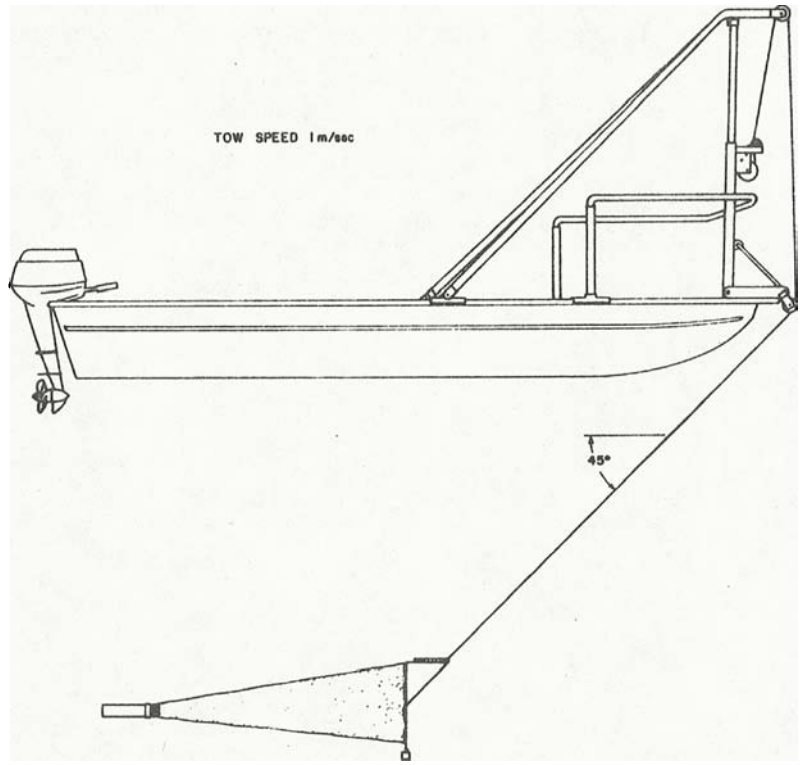

Figure 8. "Push" boat used by TVA in 1977 for larval fish sampling in shallow water (0.5 m) areas.
NOTE: This boat and gear are suited to a maximum sampling depth of approximately 10 m.

net is lowered or raised, thus the net moves through a "stationary" water mass and contamination from undesired strata is minimized.

This gear has been used successfully for two years of larval fish sampling. It has proved durable and easy to use in the field. Paired samples (1 m conical towed net and 1/2 m side-towed beam net) were taken during 1977; the data are currently being analyzed.

Literature Cited

Ahlstrom, E.H. 1954. Distribution and abundance of egg and larval populations of the Pacific sardine. Fish. Bull. 56:83-140.

Aron, W. and S. Collard. 1969. A study of the influence of net speed on catch. Limnol. Oceanog. 14:242-249.

Barkley, R.A. 1972. Selectivity of towed-net samplers. Fish. Bull. 70:799-820.

Fleminger, A. and R. I. Clutter. 1965. Avoidance of towed nets by zooplankton. Limnol. Oceanog. 10:96-104.

Houde, E. D. 1969. Sustained swimming ability of larvae of walleye (Stizostedion vitreum vitreum) and yellow perch (Perca flavescens). J. Fish. Res. Bd. Canada 26:1647-1659.

Hunter, J. R. 1972. Swimming and feeding behavior of larval anchovy, Engraulis mordax. Fish. Bull. 70:821-838.

Larimore, W. R. and M. J. Douver. 1968. The effects of temperature acclimation on swimming ability of smallmouth bass fry. Trans. Amer. Fish. Soc. 97:175-184.

Murphy, G. I. and R. I. Clutter. 1972. Sampling anchovy larvae with a plankton purse seine. Fish. Bull. 70:789-798.

Netsch, Norval F., A. Houser, and L. E. Vogele. 1971. Sampling gear for larval reservoir fishes. Prog. Fish-Cult. 33:175-179.

Noble, R. L. 1970. Evaluation of the Miller high-speed sampler for sampling yellow perch and walleye fry. J. Fish. Res. Bd. Canada 27:1033-1044.

Tomljanovich, D. A. 1977. Results of a feasibility study for protecting larval fish at power plant intakes with fine mesh screening. Proceedings of the 1977 Freshwater Larval Fish Symposium, Southeastern Electric Exchange, February 1977.

Tranter, D. J. and A. C. Heron. 1967. Experiments on filtration in plankton nets. Aust. J. Mar. Freshwat. Res., 18:89-111.

Walker, R. B. 1975. A study of fish eggs and larvae in Nickajack Reservoir, Tennessee, during 1973 and 1974. M.S. Thesis, Tennessee Technological University.

EVALUATION OF POTENTIAL ENTRAINMENT AT CHEROKEE NUCLEAR STATION, SOUTH CAROLINA

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ABSTRACT

Ichthyoplankton sampling to evaluate potential entrainment at the proposed Cherokee Nuclear Station was conducted during the 1976 spawning season (April through September) on the Broad River and Ninety-Nine Islands Impoundment in Cherokee County, South Carolina. The mainstream stations had lower ichthyoplankton densities than the backwater station. The mainstream stations were dominated by shad, minnows, and catfish, whereas the backwater station was dominated by shad, sunfish, and crappie. Under worst case (4-pump) conditions, 8.869×10^6 total larvae, representing 5.4% of the drift past the river intake, were potentially entrained during the 1976 spawning season. In order to evaluate the significance of entrainment as a mortality factor, entrainment estimates of shad were compared to production estimates. Calculations showed that 0.2% of the 2.608×10^9 larval shad hatched in the water flowing past the Cherokee intake site during the 1976 spawning season were potentially entrained under 4-pump operation.

INTRODUCTION

Ichthyoplankton were sampled during the 1976 spawning season on the Broad River and Ninety-Nine Islands Impoundment in Cherokee County, South Carolina as part of the preoperational environmental monitoring program for Cherokee Nuclear Station (CNS). The first unit of CNS is scheduled to start commercial operation in 1984. The station will employ three identical pressurized water reactors with a combined net output of 3840 MWe. The exhaust system will be cooled in a closed-cycle system incorporating nine (three for each unit) circular mechanical draft wet cooling towers utilizing makeup water from the Broad River. Blowdown from the condenser cooling water system will be discharged into the Broad River just downstream from Ninety-Nine Islands Dam.

The objectives of this study were: (1) to determine species composition and density of the ichthyoplankton community in order to calculate potential entrainment (Entrainment estimates based on operating characteristics, river discharge, and ichthyoplankton densities in 1976 will be referred to as potential entrainment.), (2) to calculate production estimates of shad larvae in order to evaluate the significance of entrainment as a mortality factor, and (3) to assess factors regarding operating mode and design which may influence entrainment losses.

STUDY AREA

Stations were located on the mainstream of the Broad River and the west backwater of Ninety-Nine Islands Impoundment (Fig. 1). The Broad River in the study area was a typically turbid Piedmont stream. The mainstream stations (459.2, 460.0, 460.1, and 460.2) were lotic with a mean annual flow of 2577 cfs (73.0 cms) and 7 Q_{10} flow (lowest seven-day average flow in a ten-year period) of 490 cfs (13.9 cms). Station 459.2 (intake site) was approximately 200 m upstream from

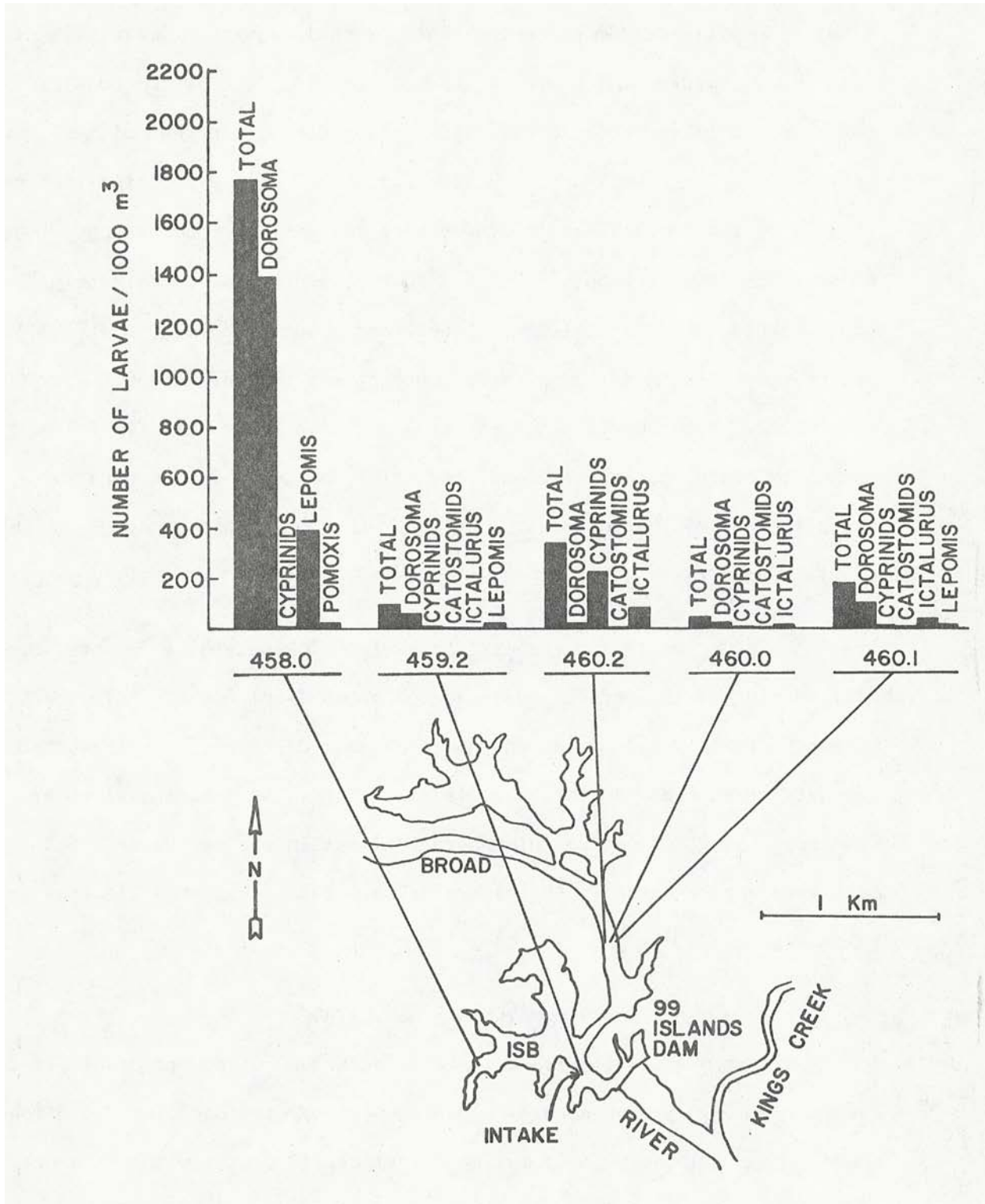

Figure 1. Map showing collection stations and average density of larval fish at each station during 1976.

Ninety-Nine Islands Dam where the river channel was approximately 75 m wide with a maximum depth of 5 m. Because of scouring, the bottom consisted of hard compact clay. Location 460 (Stations 460.0 at mid-channel, 460.1 on the left bank facing downstream, and 460.2 on the right) was located in the main channel of the Broad River in Ninety-Nine Islands Impoundment approximately 0.9 km upstream from Station 459.2. The channel width was approximately 80 m. Depth ranged from 0.5 to 1.0 m at 460.2 and about 1.0 to 2.0 m at 460.1. The bottom consisted of shifting sand. Current was swifter at 460.0 and 460.1 than 460.2. Numerous fallen trees provided cover for adult fish. The fish community of the mainstream consisted mainly of cyprinids, centrarchids (mostly bluegill, Lepomis macrochirus), percids (darters), and ictalurids (Cloutman and Edwards, In press).

Station 458.0, located in the west backwater of Ninety-Nine Islands Impoundment, will be part of the intake sedimentation basin (ISB) for CNS. The backwater was approximately 150 m wide and had a maximum depth of 5 m. The bottom consisted of soft, silty mud. Brush and fallen trees provided substantial cover. Clupeids (Dorosoma spp.) and centrarchids were dominant in the backwater. Total fish densities were greater in the backwater than the mainstream (Cloutman and Edwards, In press).

MATERIALS AND METHODS

Ichthyoplankton was collected with Nitex nets (560 µm square mesh) attached to square frames (0.5 m on each side) which were mounted on poles 2.6 m long. The square shape allowed equal sampling effort at all depths within the nets. A frame designed to hold three nets simultaneously was mounted to the bow of a (4.9 m) aluminum boat. Duplicate and triplicate push samples were taken at Stations 458.0 and 459.2, respectively. Because of shallow water, drift samples were taken at Stations 460.0, 460.1, and 460.2. The boat was held stationary

in the current by attaching to a rope strung across the river and secured on each bank. A General Oceanics flowmeter suspended across the net mouth allowed calculation of the volume of water filtered in each sample. All samples were preserved in the field in 10% formalin and rose bengal dye was added to facilitate sorting of specimens. Sampling began on 7 April 1976, and thereafter was conducted on an approximately weekly basis from 22 April through 2 August 1976. From 2 August through 21 September 1976, samples were taken biweekly. All samples were taken at the surface. Sampling time was 5 min for each sample, and all of the above samples were taken at night (starting just after dark).

A diel study was conducted at Stations 459.2, 460.0, 460.1, and 460.2 on 13 May 1976 to determine differences in larval fish densities among times of day. Samples were taken at 0300, 0900, 1500, and 2100 hr EST. Low water caused by hydroelectric generation at Ninety-Nine Islands Dam during night samples eliminated Station 460.2 from the analysis. Six 5-min replicate samples were taken at each station during each time period.

At the laboratory, formalin and excess dye were rinsed out of each sample jar through a piece of 560 µm mesh Nitex net inserted in a jar lid. The samples were sorted in white enamel pans, identified, and preserved in 40% isopropanol. Larval fish densities were extrapolated to number per 1000 m^3 based on the volume of water filtered in each sample.

Friedman's randomized block analysis of variance by ranks was used to determine if significant differences in larval fish densities occurred among the different mainstream stations throughout the spawning season and times of day in the diel sample. Differences among stations were not significant but differences among times of day were significant. A nonparametric Student-Newman-Keuls (SNK) multiple

range test (Zar 1974) was performed to determine at which times the densities were significantly different.

Annual production estimates of shad were calculated by (1) integration of a polynomial curve of interpolated daily production, (2) summation of interpolated daily production, and (3) trapezoidal integration of weekly production.

For estimating potential entrainment, larval fish densities (larvae per 1000 m^3) on days between samples were considered to be the same as the densities recorded in the previous sample. Daily river discharge rates (USGS data from the Boiling Springs, North Carolina gauge x 1.79 to compensate for added drainage area downstream from the gauge) were averaged for each sampling interval based on 1976 flow data and converted to cubic meters per sampling interval. Although current velocity is greatest in the mid-channel area of streams (Beaumont 1975), this factor was not important in the potential entrainment calculations because densities of larval fish were not significantly different between mid-channel and shoreline areas of the Broad River. From the above data, the number of larvae passing the intake during each sampling interval was calculated. Potential entrainment during each sample interval was estimated by calculating the number of larvae of each taxonomic group passing the intake and multiplying it by the percent of water potentially entrained through the intake pumps. Calculations were made for constant 2, 3, and 4-pump operation. Summation of potential entrainment for each sample interval gave potential annual entrainment for 1976.

RESULTS AND DISCUSSION

SPECIES COMPOSITION AND SPATIAL-TEMPORAL DISTRIBUTION OF ICHTHYOPLANKTON

The mainstream samples (Stations 459.2, 460.0, 460.1, and 460.2) had fewer total larvae than the backwater samples (Station 458.0) (Table 1, Fig. 1), but there were no significant differences among the mainstream stations

Table 1. Ichthyoplankton densities (larvae per 1000 m^3) and average number of adults per 100 m of shoreline shocked during the 1976 spawning season in the Broad River (mainstream stations 459.2, 460.0, 460.1, and 460.2 combined) and Ninety-Nine Islands Impoundment (backwater station 458.0). Seasonal average densities of ichthyoplankton were based on individual seasons for each taxon. The season was considered to begin for each taxon when it was first encountered in the samples and end after being absent for three consecutive weeks.

		Ichthyoplankton Densities (1976)																		Average Number of Adults/100 m Shoreline Shocke
		22 Apr	5 May	13 May	24 May	1 Jun	7 Jun	14 Jun	21 Jun	30 Jun	7 Jul	15 Jul	19 Jul	26 Jul	2 Aug	16 Aug	24 Aug	7 Sep	Seasonal Average	
Dorosoma spp. (Shad)	Backwater	793.0	1712.8	2036.0	2904.4	2827.5	1326.5	684.0	2958.6	4514.9	1010.0	1101.4	958.4	410.6	160.9	115.9	79.2	35.5	1390.0	2.0
	Mainstream	67.1	90.0	399.5	0.0	25.3	102.6	137.0	5.0	91.9	58.0	--	48.0	14.0	8.3	0.0	1.9	2.6	52.9	0.2
Cyprinids (Minnows) (Excluding carp)	Backwater	0.0	0.0	7.9	0.0	0.0	0.0	5.8	16.2	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0
	Mainstream	5.0	11.7	25.9	0.0	1.6	3.1	10.6	0.0	0.0	3.1	--	13.8	14.7	335.9	139.5	2.9	0.0	35.5	1.7
Cyprinus carpio (Carp)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
	Mainstream	19.8	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0.0	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.4
Catostomids (Suckers)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mainstream	59.4	5.9	10.5	1.6	0.0	0.0	1.3	0.0	1.8	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
Ictalurus spp. (Catfish)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	Mainstream	0.0	0.0	0.0	0.0	1.4	0.0	0.0	5.0	59.0	81.5	--	3.6	12.8	0.0	0.0	0.0	0.0	14.8	0.1
Lepomis spp. (Sunfish)	Backwater	0.0	0.0	0.0	0.0	74.1	39.5	172.4	248.4	0.0	219.8	16.9	2558.6	1331.5	186.6	6.4	0.0	0.0	373.4	20.8
	Mainstream	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	25.3	--	29.1	10.9	4.8	1.4	0.0	0.0	6.5	2.0
Micropterus salmoides (Largemouth bass)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
	Mainstream	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.1
Pomoxis spp. (Crappie)	Backwater	31.7	14.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	0.8
	Mainstream	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Percina crassa (Piedmont darter)	Backwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mainstream	4.3	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0
Total Fish	Backwater	824.7	1727.2	2043.9	2904.4	2901.6	1366.0	862.2	3223.2	4520.1	1229.8	1118.3	3517.0	1742.1	347.5	122.3	79.2	35.5	1776.1	27.0
	Mainstream	155.6	112.0	435.9	1.6	28.3	105.7	158.2	10.0	152.7	167.9	--	94.5	52.4	349.0	140.9	4.8	2.6	123.3	4.6

-- Sample Not Collected

($\chi^2_r = 3.73$, $v = 3$, $\alpha = 0.05$). Similar results were obtained by Hess and Winger (In press) who found significantly higher concentrations of larval fish in the Dixon Creek backwater than in the mainstream of the Cumberland River in Tennessee. These differences were related to population densities and spawning behavior of the adults, and behavior and habitat selection of the larvae. The samples from the mainstream of the Broad River were dominated by shad, minnows, and catfish, with minor occurrences of sunfish, suckers, carp, largemouth bass, and Piedmont darters. The backwater samples were dominated by shad, sunfish, and crappie. Small numbers of unknown cyprinids and carp were also present.

Johnson and Edwards (In press) also reported generally low densities of larval fish in the Yadkin River, a Piedmont stream in North Carolina. Although the taxa found in the Broad and Yadkin Rivers were similar, some differences in relative abundance of larvae could be noted. Higher densities of catostomids were reported from the Yadkin River, probably because more spawning riffles were present. Higher densities of shad and presence of Lepomis larvae in the Broad River were probably due to the close proximity of Ninety-Nine Islands Impoundment in the study area.

Results of a Friedman's test of diel data taken during 13 May 1976 from mainstream stations indicated that ichthyoplankton densities varied significantly with time of day ($\chi^2_r = 23.81$, $v = 3$, $\alpha = 0.05$). An SNK test ($\alpha = 0.05$) indicated that total larval fish densities at 1500 hr and 2100 hr did not differ significantly from each other, although mean densities were greater at 2100 hr. Densities at 1500 and 2100 hr were significantly higher than densities at 0300 hr and 0900 hr. Densities did not differ significantly between 0300 hr and 0900 hr samples. Based on the above analysis, it appears that fish larvae in the Broad River are

more susceptible to collection in drift samples during the afternoon and evening than during the morning, however this is not necessarily true for all rivers or taxa. For instance, Johnson and Edwards (In press) noted highest catostomid densities during the morning in the Yadkin River whereas Geen et al. (1966) found that catostomid larvae drifted more at night in Frye Creek, British Columbia.

Shad were the most abundant larvae in backwater and mainstream samples, with average densities of 1390.0 and 52.9 per 1000 m^3, respectively (Table 1). Generally high densities of larval shad, especially at the backwater station, were attributed to several characteristics of the species in the study area. Densities of adult shad were much higher at the backwater station than the mainstream stations (Table 1). High densities of shad larvae would be expected because the fecundities of the two species involved (gizzard shad, Dorosoma cepedianum, and threadfin shad, D. petenense) are normally very high (Baglin 1968; Kilambi and Baglin 1969). Furthermore, larval shad are generally limnetic, and thus very susceptible to collection by the gear used in this study.

SHAD PRODUCTION ESTIMATES

A knowledge of the number of larvae produced during the spawning season is important in understanding population dynamics and potential effects of entrainment. Shad are especially important species to study since they are forage fishes and are highly susceptible to entrainment because of their limnetic habits (48.9% of the fishes potentially entrained were shad). Production estimates for the 1976 spawning season were calculated for the backwater station and the combined mainstream stations. In order to determine the total number of shad per 1000 m^3 produced (hatched) during the spawning season, the density of recently hatched shad (those less than 24 hr old) was plotted as a function of time (Fig. 2). Three assumptions were made:

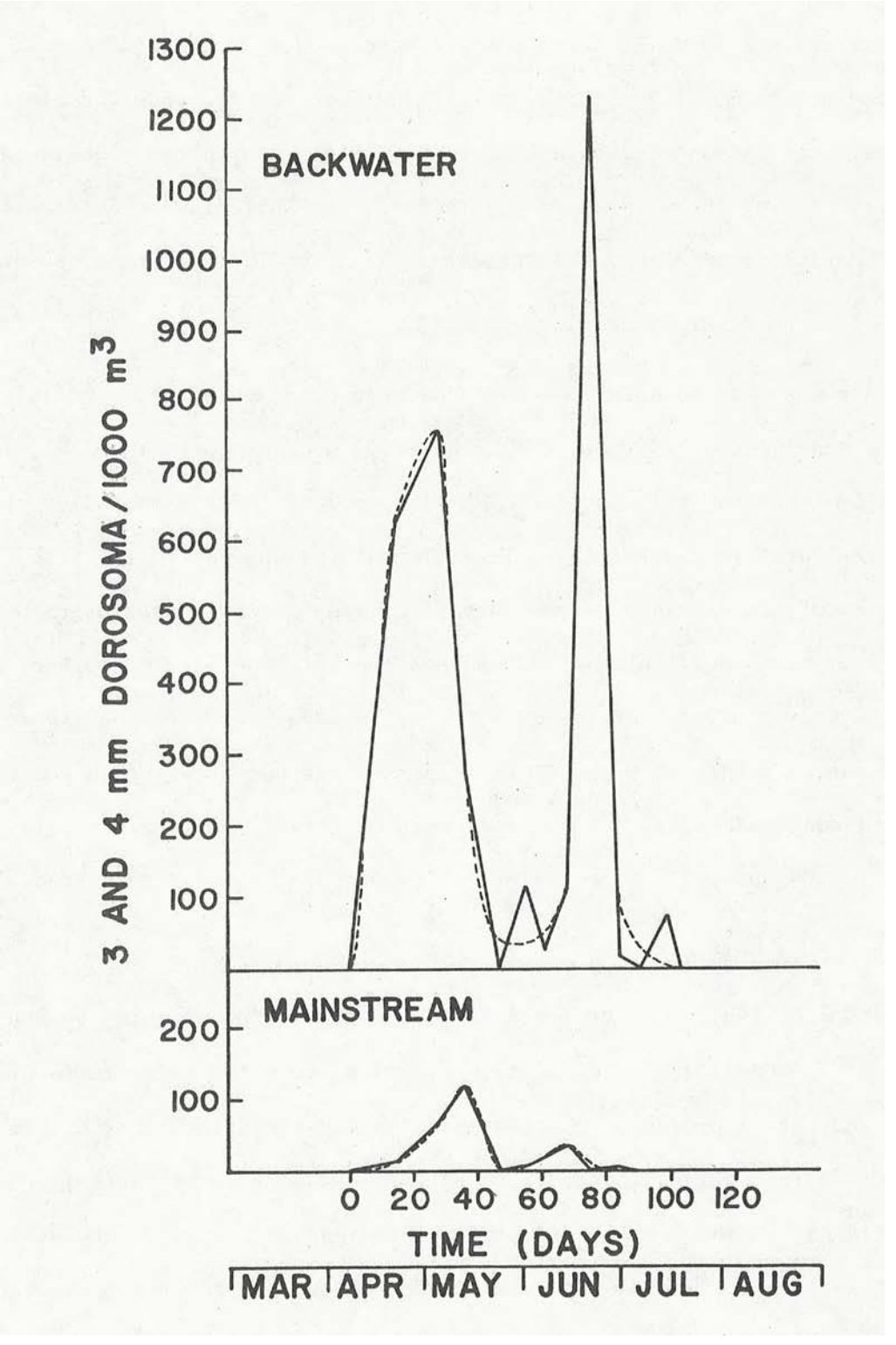

Figure 2. Seasonal densities of 3 and 4 mm larval shad (Dorosoma spp.) used to calculate 1976 production in backwater (Station 458.0) and mainstream (Stations 459.2, 460.0, 460.1, and 460.2 combined) areas of the Broad River and Ninety-Nine Islands Impoundment. The straight solid lines connect actual data points. The curved dashed lines represent the sixth order polynomial equations used to express mathematically the daily production curves.

Assumption 1. Larvae in the 3 and 4 mm size groups were hatched within 24 hr prior to being sampled and entered the 5 mm size group at the end of their first day (24 hr). Although the exact growth rate for the first 24 hr is unknown, and probably varies with environmental factors such as temperature, the rough estimate that shad surpass the 4 mm size group after 24 hr is realistic. Mansueti and Hardy (1967) reported that D. cepedianum averaged 3.25 mm at hatching and 3-day-old larvae were 5.5 to 6.5 mm long.

Assumption 2. Larvae in the 3 and 4 mm size groups were sampled adequately (sample densities were accurate representations of the actual population densities). Length frequency data indicated that the number of 3 and 4 mm larvae were underestimated. The 5 mm larvae were usually more numerous than the 3 and 4 mm fish combined. This was probably due partially to to the spawning characteristics of the fish. The eggs are usually scattered over the bottom in the littoral area and adhere to submerged or floating objects (Jester and Jensen 1972). Therefore, newly hatched larvae would be most numerous near the bottom in shallow areas and not susceptible to capture by the collection methods employed. Also, the mesh (560 µm) may have been large enough for some of the small shad to pass through the net.

Assumption 3. No mortality occurred between hatching and 5 mm. This assumption would cause an under estimation of production, since it is certain that some unknown amount of mortality exists between hatching and 5 mm.

Based on the above assumptions, production was estimated by calculating the area under the curves generated by connecting the data points of 3 and 4 mm shad per 1000 m^3 for each date of collection (Fig. 2). Mathematical expressions of the curves were derived and then integrated to calculate the area under the curves. In order to derive accurate mathematical expressions of the curves, curved lines were superimposed by hand on the straight lines connecting the actual data points (Fig. 2), and daily production was interpolated by estimating the number where the line intersected each day. Step-up polynomial fit procedure calculated sixth order polynomial equations to represent the curves. The curve for the backwater station was:

$$(1)\quad N_b = f_1(t) = 28.8709 - 17.8237t + 10.1363t^2 - 0.573537t^3 + 0.0122681t^4 - 0.00011347t^5 + 0.000000381689t^6$$

and the curve for the mainstream stations combined was:

$$(2)\quad N_m = f_2(t) = 28.8489 - 14.9135t + 1.67347t^2 - 0.0616935t^3 + 0.00101862t^4 - 0.00000781962t^5 + 0.00000022709t^6$$

where N_b and N_m were the number of 3 and 4 mm shad per 1000 m^3 in backwater and mainstream areas, respectively, and t was time (number of days). To determine the total number of shad per 1000 m^3 produced in 1976, equations (1) and (2) were integrated:

$$(3)\quad \text{Backwater Production} = \int_{t=0}^{t=105} f_1(t)dt = 31832 \text{ shad per } 1000 \text{ m}^3$$

$$(4)\quad \text{Mainstream Production} = \int_{t=0}^{t=92} f_2(t)dt = 2427 \text{ shad per } 1000 \text{ m}^3$$

Instead of integrating equations (1) and (2), as shown in equations (3) and (4), the area under the curves could have been calculated by adding the daily interpolated production values. By doing this, production estimates for 1976 were 31522 and 2451 shad per 1000 m^3 for backwater and mainstream stations, respectively. Since these values are similar to the values derived from

integration of the equations, it appears that the equations generated from the step-up polynomial procedure were reasonably accurate. However, the shortcoming of the step-up polynomial procedure is that either interpolation or very frequent sampling (more often than once per week) is necessary to calculate accurate polynomial equations.

In order to eliminate complicated mathematical procedures and the need for interpolation or frequent ichthyoplankton collections, the areas under the lines connecting the actual data points were calculated by trapezoidal integration or summation (Hackney In Press). Using this method, annual production of 31430 and 2514 shad per 1000 m^3 was estimated for the backwater and mainstream stations, respectively (Fig. 3). A comparison of this method and the method using equations (3) and (4) showed a difference of 1.3% and 3.6% in the production estimates for the backwater and mainstream areas, respectively. Since these estimates were reasonably close, it would generally be more prudent to use the trapezoidal integration technique because of its simplicity and less stringent requirements for frequent collections or interpolation.

Most of the shad production at the backwater station occurred during two peaks, one in early May and the other in late June (Figs. 2 and 3). The peak in early May was probably the result of gizzard shad spawning and the late June peak was probably mainly threadfin shad. Most of the production in the mainstream areas occurred during early May and was probably gizzard shad. These results indicate that lentic backwaters such as those in Ninety-Nine Islands Impoundment are more important habitats for shad production than lotic habitats such as the mainstream of the Broad River (31430 shad produced per 1000 m^3 at the backwater station compared to 2514 per 1000 m^3 at the mainstream stations).

The above production estimates are a preliminary effort, and are only rough

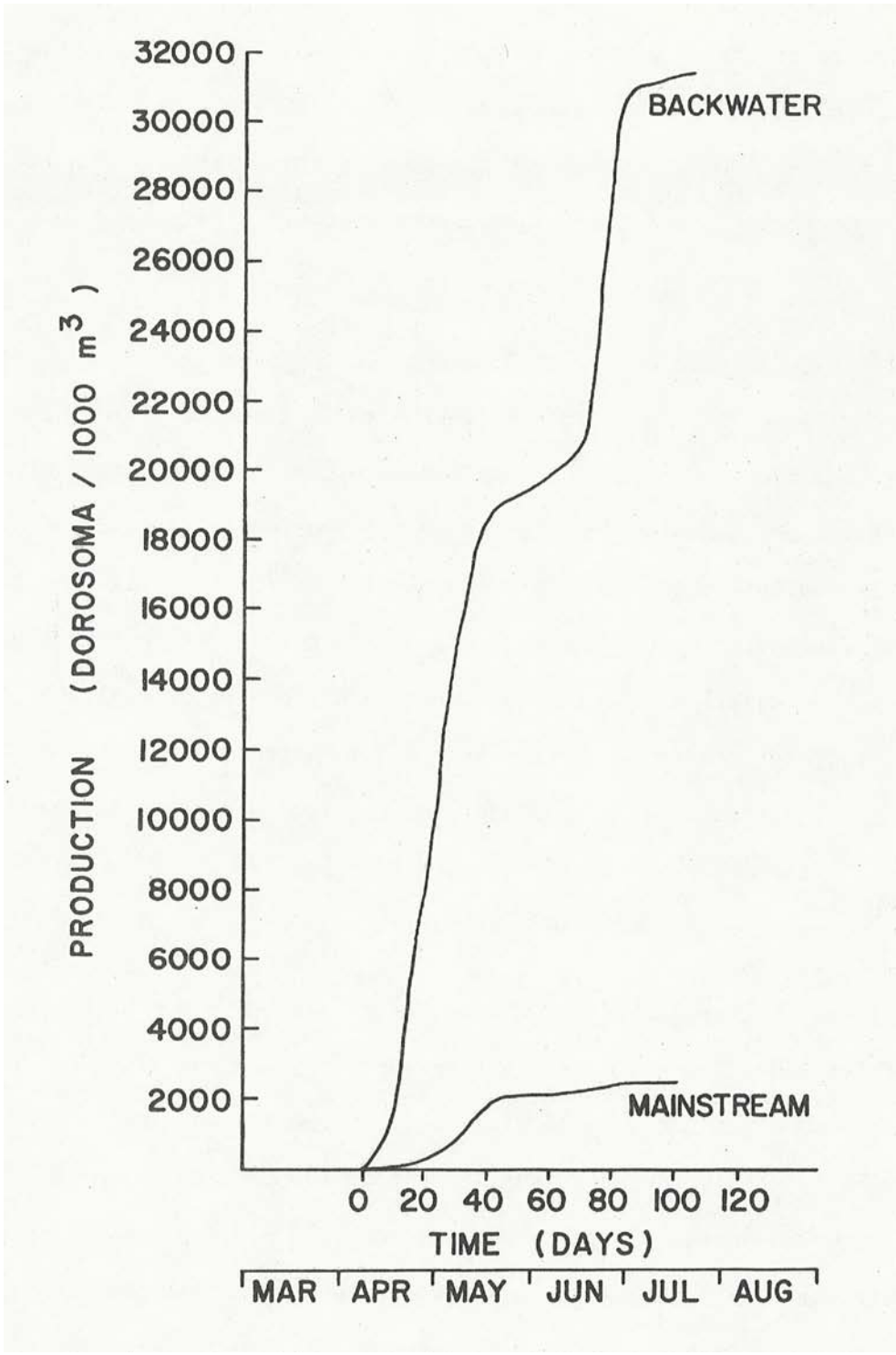

Figure 3. Cummulative production curve for larval shad (Dorosoma spp.) in backwater (Station 458.0) and mainstream (Stations 459.2, 460.0, 460.1, and 460.2 combined) areas of the Broad River and Ninety-Nine Islands Impoundment during 1976.

estimates. Work needs to be done toward meeting or improving the three assumptions outlined above. Growth rates of newly hatched larvae and environmental effects on growth rate need to be determined, sampling methods for newly hatched larvae need to be improved, and mortality rates of newly hatched larvae need to be determined.

POTENTIAL ICHTHYOPLANKTON ENTRAINMENT

Make-up water for the cooling towers at CNS will be taken from the ISB, which will obtain its water through an intake located at Station 459.2 (Fig. 1). Make-up water will require an average of 85 cfs (2.4 cms) and a maximum of 138 cfs (3.9 cms) to be withdrawn from the Broad River. Four pumps, each with a capacity of approximately 43 cfs (1.2 cms), will draw water through the intake. Under average load and meteorological conditions, the ISB can generally be kept full by alternating two-pump (86 cfs or 2.4 cms) and three-pump (129 cfs or 3.7 cms) operation. Normally, the fourth pump will serve a standby or reserve function; however, under maximum load and extreme meteorological conditions, it will operate intermittently to maintain the ISB level. The pumps will be modulated by the ISB level, and operate in a predetermined sequence as level drops. When all four pumps are operating, approximately 172 cfs (4.9 cms) will be entrained. As the ISB fills, each pump will shut off in sequence.

Entrainment losses will vary with plant operation, river flow, and density of larval fishes. Under average flow (2577 cfs or 73.0 cms), the entrainment percentages are 1.7, 3.3, 5.0, and 6.7% for 1, 2, 3, and 4-pump operation, respectively. During $7Q_{10}$ flow (490 cfs or 13.3 cms), the entrainment percentages are 9.1, 18.3, 27.4, and 36.6% for 1, 2, 3, and 4-pump operation, respectively. Since lowest flows normally occur in September, after the spawning season, it is doubtful that entrainment will be significant during $7Q_{10}$ flows.

In order to calculate potential entrainment, the following factors were considered: spatial and temporal distribution of larvae, river discharge, location and design of the intake, and number of pumps in operation. With these factors in mind, potential entrainment at Cherokee Nuclear Station for 1976 was estimated using the ichthyoplankton and river discharge data recorded in 1976 (Table 2, Fig. 4). The estimates were based on night samples (2100 hr) which generally contained higher densities of larvae than morning samples. Depth distribution was not a factor in this particular analysis because the Broad River was quite shallow (0.5 - 2.0 m). Friedman's test as discussed earlier, revealed no significant differences of total ichthyoplankton densities among the various mainstream stations, so it was assumed that larvae were randomly distributed in the river. The estimates assumed continuous operation (24 hr per day) throughout the spawning season. Therefore, the 4-pump entrainment estimates (Table 2) are worst case values which are extreme and unlikely.

Under worst case (4-pump) entrainment, 8.869×10^6 total larvae representing 5.4% of the ichthyoplankton drift were potentially entrained during the 1976 spawning season. However, since the ISB normally will be kept full by alternating two-pump and three-pump operation and the plant will probably not be continuously operated, the estimates for 2 and 3-pump operation are more realistic. The 5.4% potential entrainment at 4-pump operation in 1976 was less than the 7.0% potential entrainment under average annual flow (2577 cfs or 73.0 cms). This was due to the fact that the highest ichthyoplankton densities occurred in May and June when river discharge was higher than the average annual flow, causing a lower entrainment percent. This phenomenon was illustrated in the larval shad data. Larval shad comprised 64.4% of the total

Table 2. Potential annual ichthyoplankton entrainment at Cherokee Nuclear Station, 1976.

	Number of Larvae in Drift	Number of Larvae Entrained			Percent of Larvae Entrained			Species Composition (%)	
		2 Pumps	3 Pumps	4 Pumps	2 Pumps	3 Pumps	4 Pumps	Drift	Entrained
Dorosoma spp.	1.051×10^{8}	2.171×10^{6}	3.256×10^{6}	4.341×10^{6}	2.1	3.1	4.2	64.4	48.9
Cyprinids (excluding carp)	3.272×10^{7}	1.438×10^{6}	2.158×10^{6}	2.877×10^{6}	4.4	6.6	8.8	20.0	32.4
Cyprinus carpio	1.149×10^{6}	3.790×10^{4}	5.685×10^{4}	7.581×10^{4}	3.3	5.0	6.6	0.7	0.9
Catostomids	6.283×10^{6}	1.718×10^{5}	2.577×10^{5}	3.436×10^{5}	2.7	4.1	5.4	3.8	3.9
Ictalurus spp.	1.234×10^{7}	3.764×10^{5}	5.646×10^{5}	7.527×10^{5}	3.1	4.6	6.2	7.5	8.5
Lepomis spp.	5.117×10^{6}	2.078×10^{5}	3.117×10^{5}	4.156×10^{5}	4.1	6.1	8.2	3.1	4.7
Micropterus salmoides	2.340×10^{5}	4.913×10^{3}	7.370×10^{3}	9.826×10^{3}	2.1	3.2	4.2	0.1	0.1
Percina crassa	8.060×10^{5}	2.660×10^{4}	3.990×10^{4}	5.319×10^{4}	3.3	5.0	6.6	0.5	0.6
Total	1.637×10^{8}	4.435×10^{6}	6.653×10^{6}	8.869×10^{6}	2.7	4.1	5.4	100.1	100.0

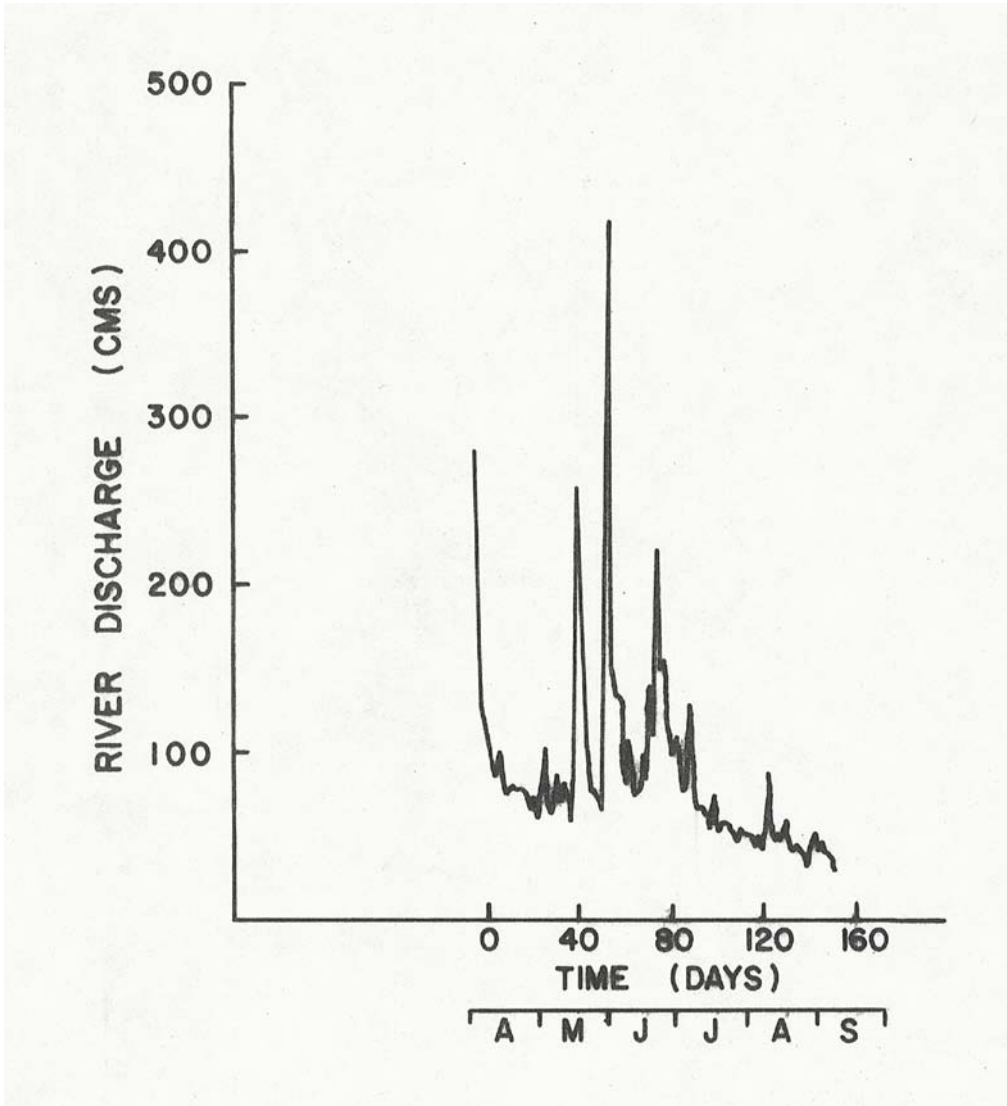

Figure 4. Daily discharge (cms) of the Broad River during the 1976 spawning season at the Cherokee Nuclear Station intake (Station 459.2).

larval drift (Table 2), but because they were most abundant during May and June (Table 1) when river discharge was above normal (Fig. 4), they comprised only 48.9% of the larvae potentially entrained. Opposite results were noted for cyprinids. Cyrpinids comprised only 20.0% of the total ichthyoplankton drift (Table 2), but because they were most abundant during August (Table 1) when river discharge was below normal (Fig. 4), they comprised 32.4% of the larvae potentially entrained.

In order to evaluate the significance of entrainment as a mortality factor, the entrainment estimates of shad were compared to the production estimates. Based on an annual production estimate of 2514 shad larvae per 1000 m^3 for the mainstream stations, a total of 2.608×10^9 larval shad was hatched in the water that passed the Cherokee Nuclear Station intake during the 1976 spawning season. Of this 2.608×10^9 larvae, only 1.051×10^8 (4.0%) drifted past the intake because of mortality or failure of the larger larvae to become incorporated into the drift. Under four-pump operation, 4.341×10^6 (0.2% of the production) were potentially entrained. Since only 0.2% of the 2.608×10^9 larvae hatched were potentially entrained, it does not appear that entrainment will be a significant mortality factor.

In further evaluating the ecological significance of entrainment losses at CNS, it is noted that water passing the intake site quickly passes through the hydro unit at Ninety-Nine Islands Dam. Thus, most ichthyoplankton are lost from the aquatic environment above the dam after they pass the intake site. The entrainment of ichthyoplankton by CNS will have little additional impact on the fish community in the impoundment and the river above the dam. The aquatic community that potentially would be adversely affected would be the Broad River below the dam; however, it is unlikely that the fish community

in this portion of the river is reliant upon recruitment of larvae from above the dam because reproducing populations exist below the dam.

The proposed intake will be located on a point where the main flow of the river occurs. In addition, the intake will be flush with the bank to avoid slackwater areas where larvae could concentrate. These factors will also play an important role in reducing entrainment of ichthyoplankton.

ACKNOWLEDGMENTS

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LITERATURE CITED

Baglin, R. E., Jr. 1968. Fecundity of the gizzard shad, Dorosoma cepedianum (LeSueur), and the threadfin shad, Dorosoma petenense (Gunther), in Beaver and Bull Shoals Reservoirs. M.S. Thesis, Univ. of Arkansas, Fayetteville. 131 pp.

Beaumont, P. 1975. Hydrology. Pages 1-38 in B. A. Whitton, ed. River ecology. Univ. of California Press, Berkeley.

Cloutman, D. G. and T. J. Edwards. In press. Chapter 6 in Baseline environmental summary report on the Broad River in the vicinity of the Cherokee Nuclear Station. Duke Power Co. 101 pp.

Geen, G. H., T. G. Northcote, G. F. Hartman, and C. C. Lindsey. 1966. Life histories of two species of catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Board Can. 23(11):1761-1788.

Hackney, P. A. In press. Methods for calculating natural mortality rate, biomass production, and proportion entrained of lacustrine ichthyoplankton. Proc. Symp. Freshwater Larval Fishes. Southeastern Electric Exchange, Charlotte, NC.

Hess, T. B. and P. V. Winger. In press. The occurrence and distribution of larval fish in the Cumberland River. Proc. 30th Ann. Conf. S. E. Assoc. Game Fish Comm.

Jester, D. B. and B. L. Jensen. 1972. Life history and ecology of the gizzard shad, Dorosoma cepedianum (LeSueur) with reference to Elephant Butte Lake. New Mexico State University Agricultural Exp. Sta. Res. Rep. 218. 56 pp.

Johnson, S. R. and T. J. Edwards. In press. Ichthyoplankton in the Yadkin River and potential entrainment at Perkins Nuclear Station. Proc. Symp. Freshwater Larval Fishes. Southeastern Electric Exchange, Charlotte, NC.

Kilambi, R. V. and R. E. Baglin, Jr. 1969. Fecundity of the gizzard shad, Dorosoma cepedianum (LeSueur), in Beaver and Bull Shoals Reservoirs. Am. Mid. Nat. 82(2):444-449.

Mansueti, A. J. and J. D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay Region. Part 1. Nat. Res. Inst. Univ. Maryland. Port City Press, Baltimore, MD. 202 pp.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ. 620 pp.

ENTRAINMENT OF ICHTHYOPLANKTON AT HATCH NUCLEAR PLANT

by

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ABSTRACT

Entrainment of Altamaha River ichthyoplankton was monitored weekly during the 1975 and 1976 spawning seasons. Dominant ichthyoplankton species collected included Minytrema melanops, Carpiodes spp., Hybognathus nuchalis, Notropis hudsonius, Notemigonus crysoleucas, Lepomis auritus, L. macrochirus, Pomoxis nigromaculatus and Elassoma spp. Estimated rates of entrainment of total fish larvae ranged from 0 to 16,468/day. Estimated rates of entrainment of total fish eggs ranged from 0 to 4592/day. Maximum entrainment of ichthyoplankton into the cooling water intake remained less than one percent of the total community and did not constitute a significant reduction in the ichthyoplankton near Hatch Nuclear Plant. Predicted time-temperature histories indicated that exposure of ichthyoplankton to the heated discharge was not harmful.

INTRODUCTION

In 1975 and 1976 Georgia Power Company sampled ichthyoplankton drift in the Altamaha River to monitor entrainment at Hatch Nuclear Plant (Unit 1), and to provide preoperational data for Unit 2. Unit 1 began operating in 1975 with a nameplate rating of 810 mw. Unit 2, now under construction, is scheduled to begin operating in April, 1979 with a nameplate rating of 820 mw.

Hatch Nuclear Plant has a shoreline intake structure with 1 cm mesh vertical traveling screens. The intake structure is located on the south bank of the Altamaha River in relatively shallow water (3 m).

The main channel of the river in the vicinity of the plant is near the opposite (north) bank. There are four pumps for Unit 1, each with 32.17 m^3/min (8,500 gpm) capacity. Under normal operating conditions three pumps are used for a combined intake capacity of 95.52 m^3/min (25,500 gpm). During conditions of minimum river flow, river elevation is 19 m above msl and river depth near the intake structure is 2 m. Under minimum flow conditions with screens operating 100% trash free, the average through-screen velocity is 56 cm/sec.

Hatch Nuclear Plant has a circulating cooling water system with three mechanical draft cooling towers for each unit. Due to pressure and shear stresses encountered from pumps, strainers, and mechanical draft cooling towers, 100 % mortality of entrained organisms is assumed.

Hatch Nuclear Plant is located in Appling County, in the Middle Coastal Plain province of Georgia, approximately 32 km below the confluence of the Ocmulgee and Oconee Rivers and 187 km from the Atlantic Coast. The river at the plant site drains an area of 30,303 km^2. The average river elevation is 21 m above msl and ranged during the period of study from 20.5 to 25.3 m. above msl. The average river depth is 3 m and ranged from 1 to 7 m. The width of the river in the vicinity of the plant is 180 m, but during flooding often exceeds 2 km in low areas. The average river discharge is 340 m^3/sec and ranged during the period of study from 156 to 2500 m^3/sec. Average surface velocity is 46 cm/sec and ranged from 30 to 90 cm/sec.

The Altamaha River at the plant site is essentially unpolluted and unregulated. It supports an abundant and diverse community of macroinvertebrates (Georgia Power Company 1974), and is a spawning area for several anadromous fish including Alosa sapidissima, A. mediocris, and A. aestivalis which are of commercial importance in the area (Adams 1970).

MATERIALS AND METHODS

Drift surveys were conducted weekly February through May and less frequently, in June (1975 and 1976) and July (1976). Each survey consisted of a day and a night sampling period. Transects were established across the river in three locations (Fig. 1). Transect A was located 171 m above the intake structure. Transect B was located 190 m below the discharge structure. In 1976 an alternate transect (C) was established

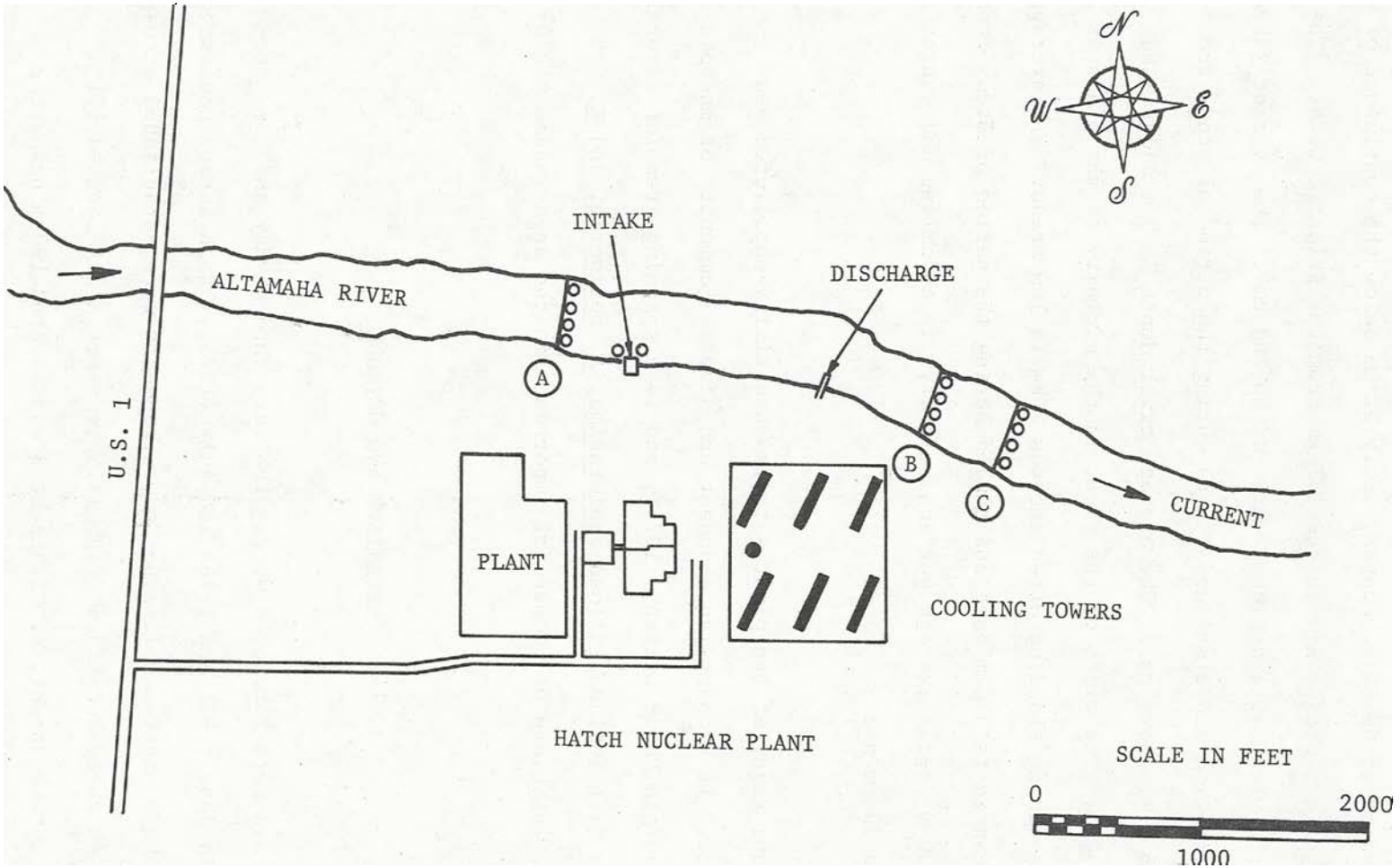

Figure 1. Hatch Nuclear Plant area map showing transect locations for sampling ichthyoplankton.

514 m below the discharge due to the development of a sand bar on the south bank at transect B. Four stations were sampled at each transect in approximately south bank, south center, north center and north bank locations. At each station a 15 minute sample was collected using a stationary plankton net (760 μ aperture) set approximately 25 cm from the river bottom (Fig. 2). A propeller type pigmy flow meter was attached to the net opening to measure current velocity. At the end of the 15 min. period, the net was retrieved with a winch. Material captured was washed into a quart jar attached to the end of the net. Samples were preserved in 10% formalin.

At the laboratory samples were washed in a #30 standard seive. Ichthyoplankton was sorted from detritus with the aid of an illuminated magnifier. Samples were often stained with rose-bengal solution to facilitate picking. Identifications were made using a stereo zoom microscope. For analyses, the data were grouped by family with the exception of Alosa sapidissima eggs and Alosa spp. larvae.

RESULTS AND DISCUSSION

Altamaha River Discharge and Temperature

United States Geological Survey data for mean daily discharge and temperature of the Altamaha River for sampling periods in 1975 and 1976 are presented in Fig. 3. In 1975, total river discharge for February through June was 11 x 10^9 m^3 and ranged from 400 to 2500 m^3/sec. Temperature ranged from 10 to 28 C. In 1976, total river discharge for February through June

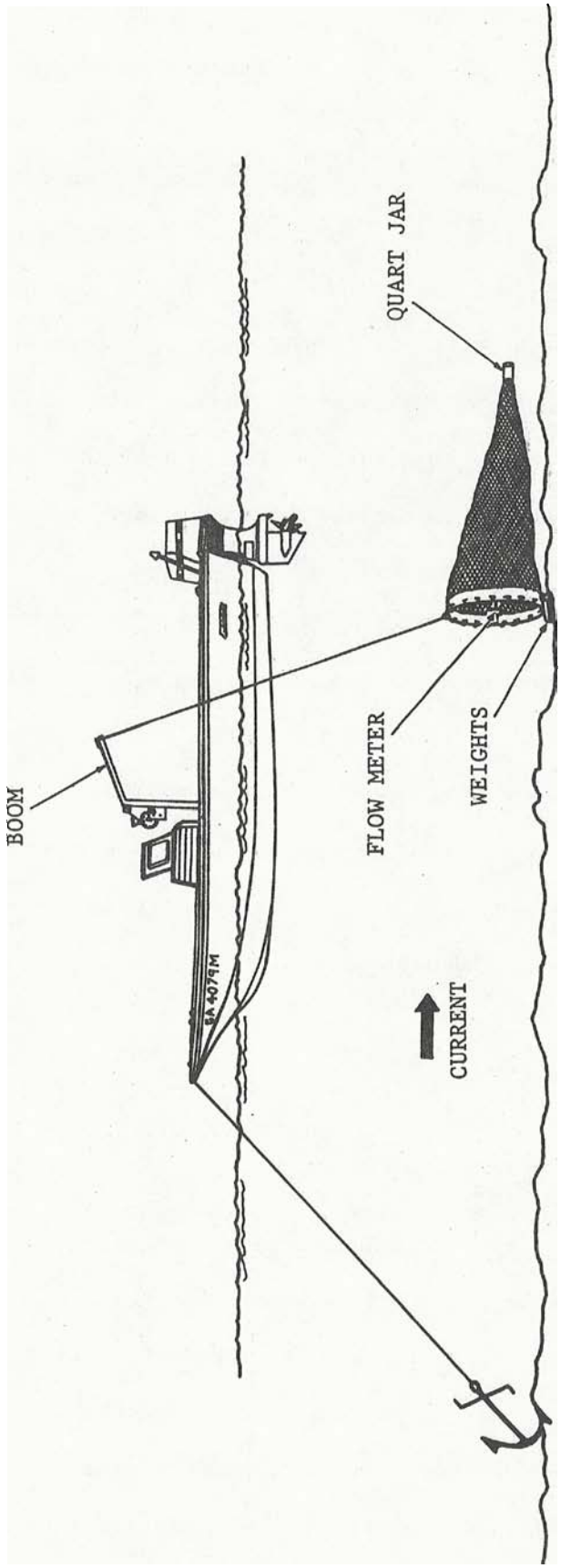

Figure 2. Diagram of ichthyoplankton sampling gear.

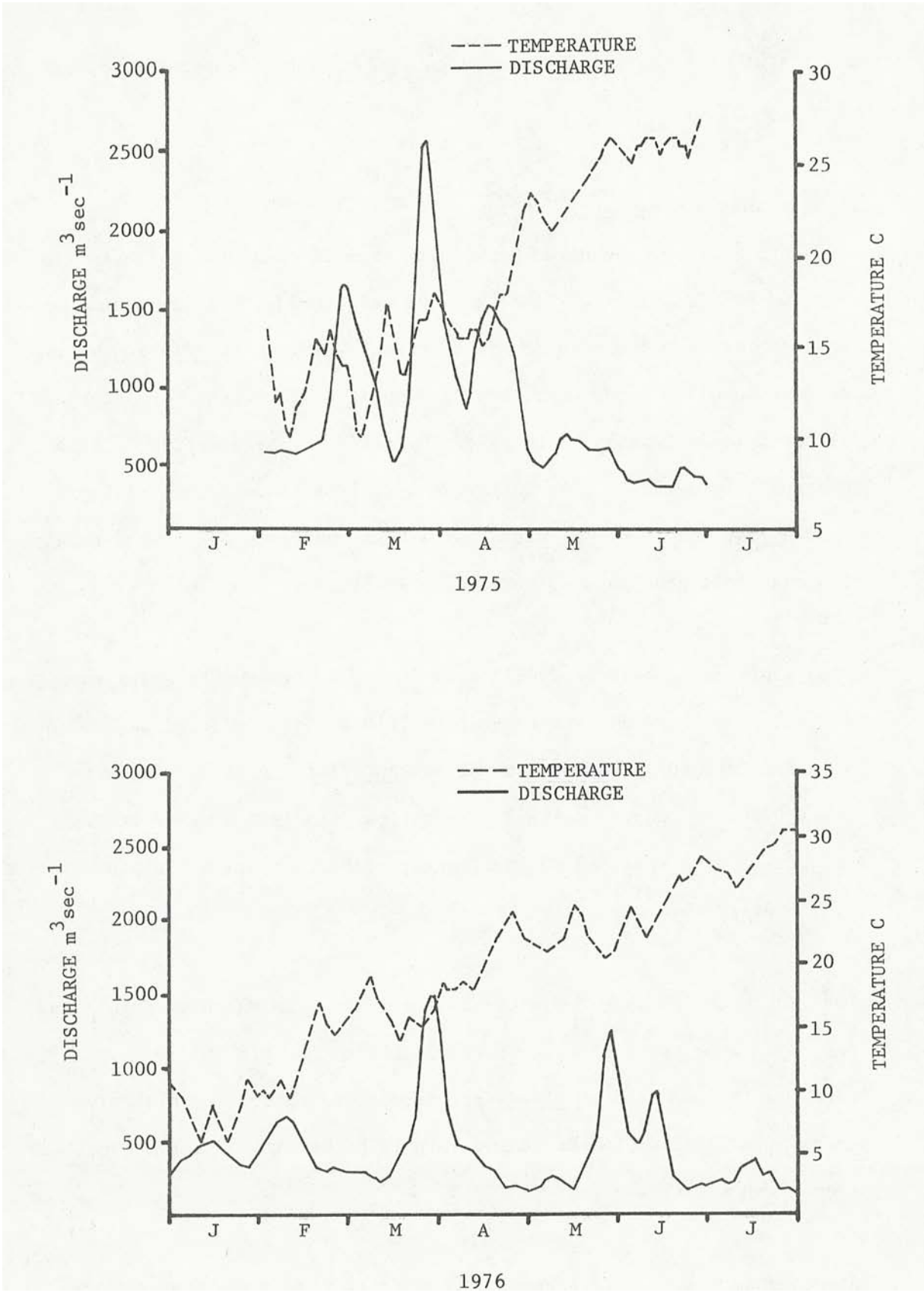

Figure 3. Altamaha River discharge and temperature (USGS data) for 1975 and 1976.

was 6 x 10^9 m^3 and ranged from 156 to 1487 m^3/sec. Temperature ranged from 6 to 31 C.

Icthyoplankton Abundance

Fish eggs, larvae, juveniles and adults from 56 taxa were collected in 1975 and 1976 (Table 1). In both years catostomids, cyprinids and centrarchids were the most abundant larvae, while A. sapidissima were the most abundant eggs. Catostomids comprised 12% of the total larvae collected in 1975, and 56% in 1976. Cyprinid larvae comprised 37% in 1975 and 14% in 1976. Clupeid larvae were less abundant comprising 2.5% in both 1975 and 1976. A. sapidissima eggs comprised 53% of the total fish eggs collected in 1975 and 86% in 1976.

Alosa sapidissima eggs were collected in the drift from Feburary through May (Fig. 4). Maximum density reached 7/1000 m^3 in 1975 and 34/1000 m^3 in 1976. In both years, density of A. sapidissima eggs decreased to almost 0/1000 m^3 during peaks in river flow. In 1975 density of A. sapidissima eggs remained low during repeated fluctuations in discharge from Feburary through April.

Alosa spp. larvae were collected in the drift from March through June (Fig. 5). Density of larvae reached 3/1000 m^3 in 1975 and 15/1000 m^3 in 1976. In 1975 density of Alosa spp. larvae was reduced by high river discharge until late in the season. In 1976, density of larvae was less affected by river discharge.

Catostomidae larvae were present in the drift from March through June

TABLE 1

Altamaha River drift species list. Letters following scientific names denote eggs, larvae, juveniles or adult specimens collected.

Acipenseridae	
Acipenser spp. (LJ)	Sturgeon
Lepisosteidae	
Lepisosteus spp. (LJ)	Gar
Anguillidae	
Anguilla rostrata (J)	American eel
Clupeidae	
Alosa spp. (ELJ)	
Alosa aestivalis (ELJ)	Blueback herring
Alosa mediocris (EJ)	Hickory shad
Alosa sapidissima (ELJ)	American shad
Dorosoma cepedianum (J)	Gizzard shad
Dorosoma petenense JA)	Threadfin shad
Umbridae	
Umbra pygmaea (J)	Eastern mudminnow
Esocidae	
Esox spp. (LJ)	
Esox americanus (J)	Redfin pickeral
Cyprinidae	
Cyprinus carpio	Carp
Hybognathus nuchalis (LJA)	Silvery minnow
Notropis spp. (L)	
Notropis callisema (A)	Ocmulgee shiner
Notropis hudsonius (LJA)	Spottail shiner
Notropis longirostris (LJ)	Longnose shiner
Notropis petersoni (JA)	Coastal shiner
Notemigonus crysoleucas (LA)	Golden shiner
Catostomidae	
Carpiodes spp. (L)	
Erimyzon spp. (L)	
Erimyzon oblongus (L)	Creek chubsucker
Minytrema melanops (ELJ)	Spotted sucker
Moxostoma anisurum (LJ)	Silver redhorse
Ictaluridae	
Ictalurus spp.	
Ictalurus catus (J)	White catfish
Ictalurus nebulosus (LJ)	Brown bullhead
Ictalurus platycephalus (J)	Flat bullhead
Ictalurus punctatus (LJA)	Channel catfish
Noturus gyrinus (J)	Tadpole madtom
Noturus leptacanthus (LJ)	Mottled madtom
Aphredoderidae	
Aphrododerus sayanus (LJA)	Pirate perch
Cyprinodontidae	
unidentified spp. (L)	
Poeciliidae	
Gambusia affinis (JA)	Mosquito fish
Atherinidae	
Labidesthes sicculus (EL)	Brook silverside
Percichthyidae	
unidentified spp. (L)	
Centrarchidae	
Acantharchus pomotis (JA)	Mud sunfish
Centrarchus macropterus (J)	Flier
Elassoma spp. (L)	
Elassoma evergladei (J)	Everglades pygmy sunfish
Elassoma zonatum (JA)	Banded pygmy sunfish
Lepomis spp. (LJ)	
Lepomis auritus (LJ)	Redbreast sunfish
Lepomis gulosus (JA)	Warmouth
Lepomis macrochirus (LJ)	Bluegill
Lepomis microlophus (L)	Redear sunfish
Lepomis punctatus (L)	Spotted sunfish
Micropterus salmoides (LJ)	Largemouth bass
Pomoxis nigromaculatus (LJ)	Black crappie
Percidae	
Etheostoma spp. (L)	
Etheostoma hopkinsi (J)	Christmas darter
Etheostoma olmstedi (LJ)	Tessellated darter
Perca flavescens (LLJ)	Yellow perch
Percina nigrofasciata (JA)	Blackbanded darter
Soleidae	
Trinectes maculatus (JA)	Hogchoker

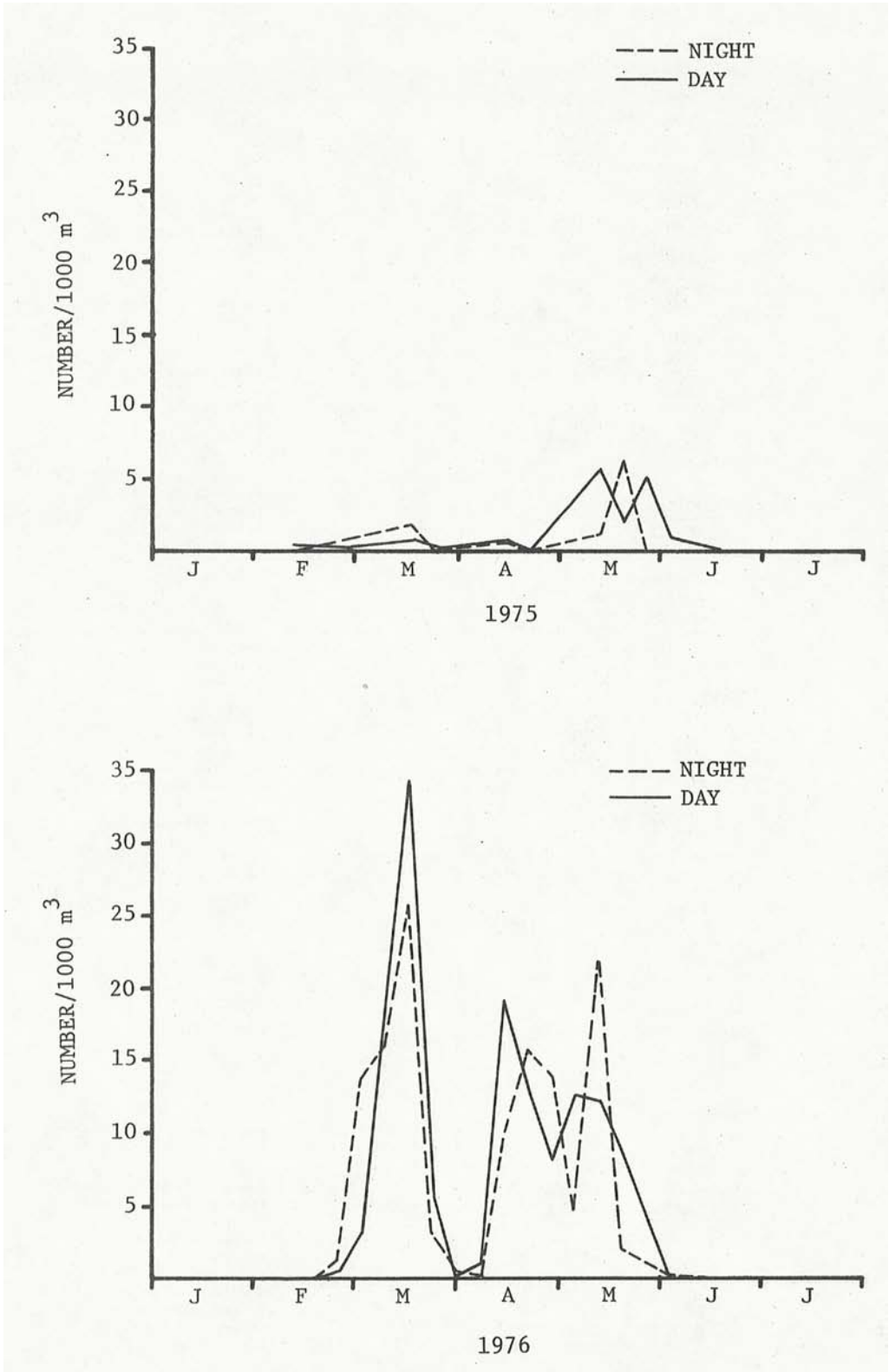

Figure 4. Density of Alosa sapidissima eggs in day and night drift for 1975 and 1976.

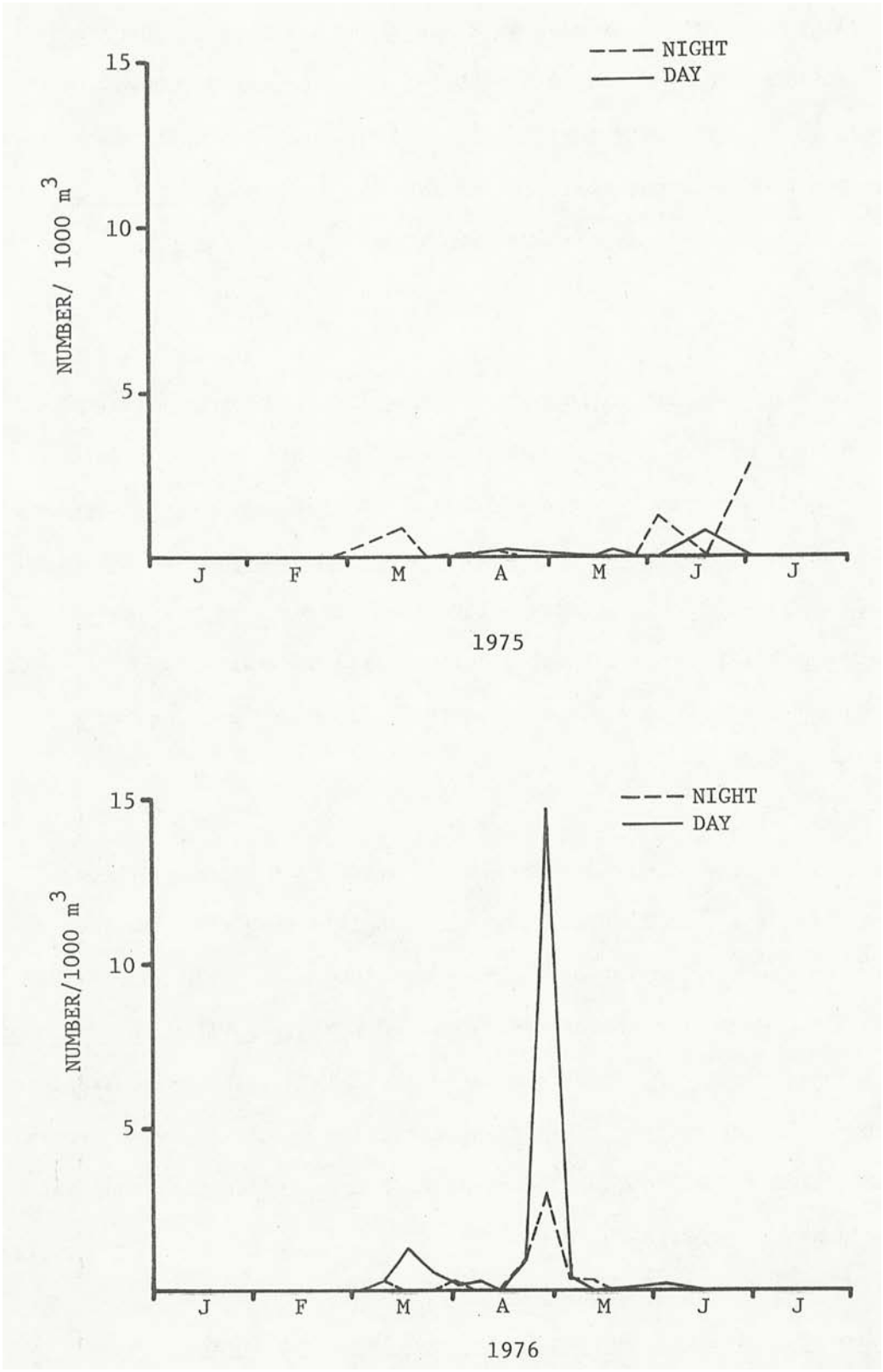

Figure 5. Density of Alosa spp. larvae in day and night drift for 1975 and 1976.

(Fig 6). Dominant catostomids were Minytrema melanops and Carpiodes spp. Maximum density reached 57/1000 m^3 in 1976 and 70/1000 m^3 in 1976. In 1976 most of the catostomids collected in March and April were Minytrema melanops, whereas those collected in late May were mostly Carpiodes spp. Density of catostomid larvae was also affected by high discharge in 1975.

Cyprinidae larvae were collected February through June in 1975 and March through July in 1976 (Fig. 7). Maximum density of catostomid larvae reached 26/1000 m^3 in 1975 and 42/1000 m^3 in 1976. Dominant cyprinids collected were Hybognathus nuchalis, Notropis hudsonius, and Notemigonus crysoleucas. In 1976 cyprinids collected in March were mostly Notemigonus crysoleucas. Cyprinids collected during April and early May were mostly Hybognathus nuchalis and those collected in late May and June were Notropis spp.

Centrarchidae larvae were present in the drift from February through June in 1975 and from March through July in 1976 (Fig. 8). Maximum density of centrarchid larvae reached 38.5/1000 m^3 in 1975 and 17/1000 m^3 in 1976. Dominant centrarchids included Lepomis auritus, L. macrochirus, Pomoxis nigromaculatus, and Elassoma spp. In 1976 peaks in centrarchid density could not be attributed to a particular species as with cyprinids and catostomids. All dominant centrarchids appeared equally abundant during peaks in density in 1976.

Entrainment of Ichthyoplankton in the Cooling Water Intake

Estimates of numbers of abundant icthyoplankton entrained per 24 hour

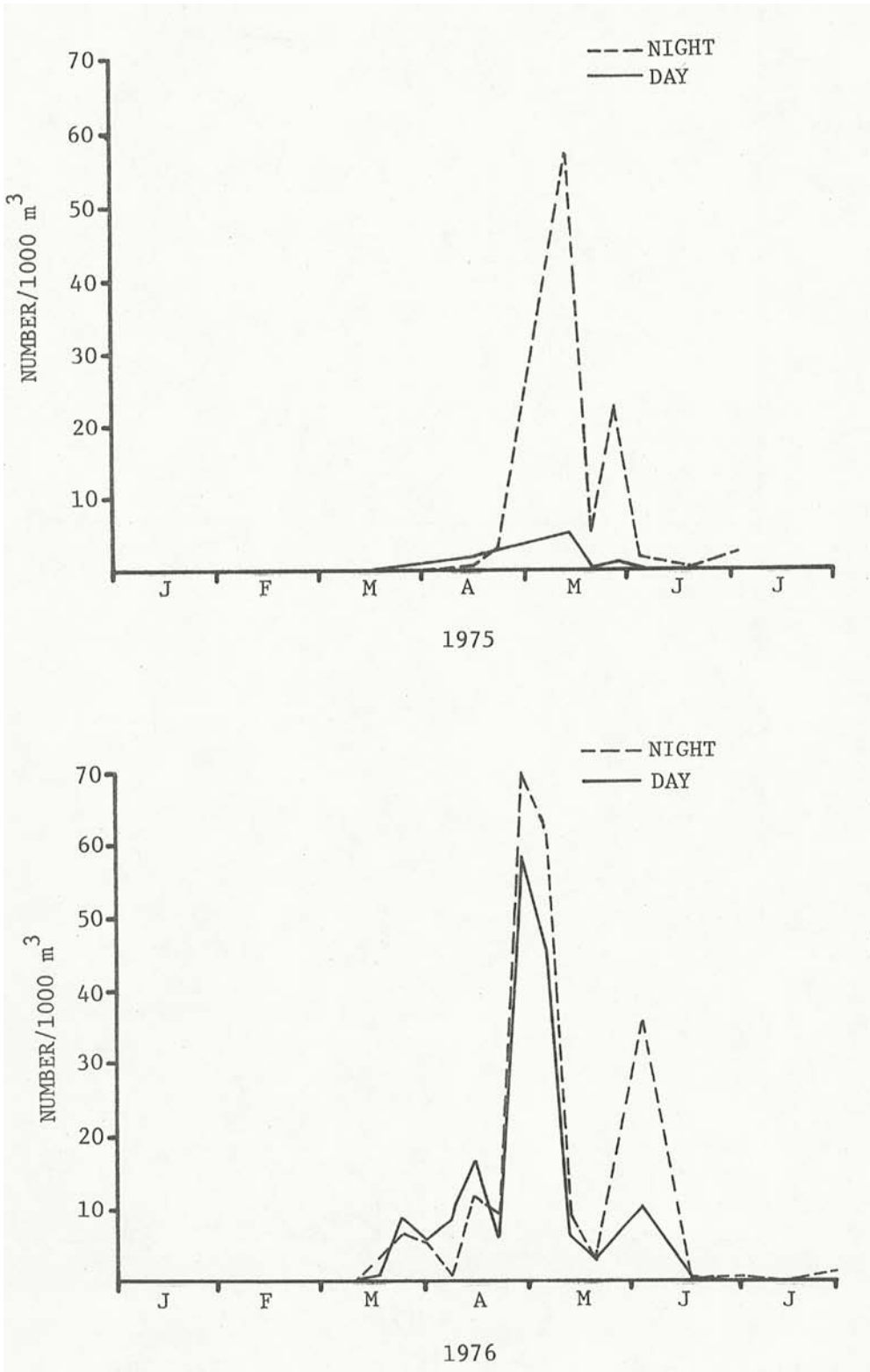

Figure 6. Density of Catostomidae larvae in day and night drift for 1975 and 1976.

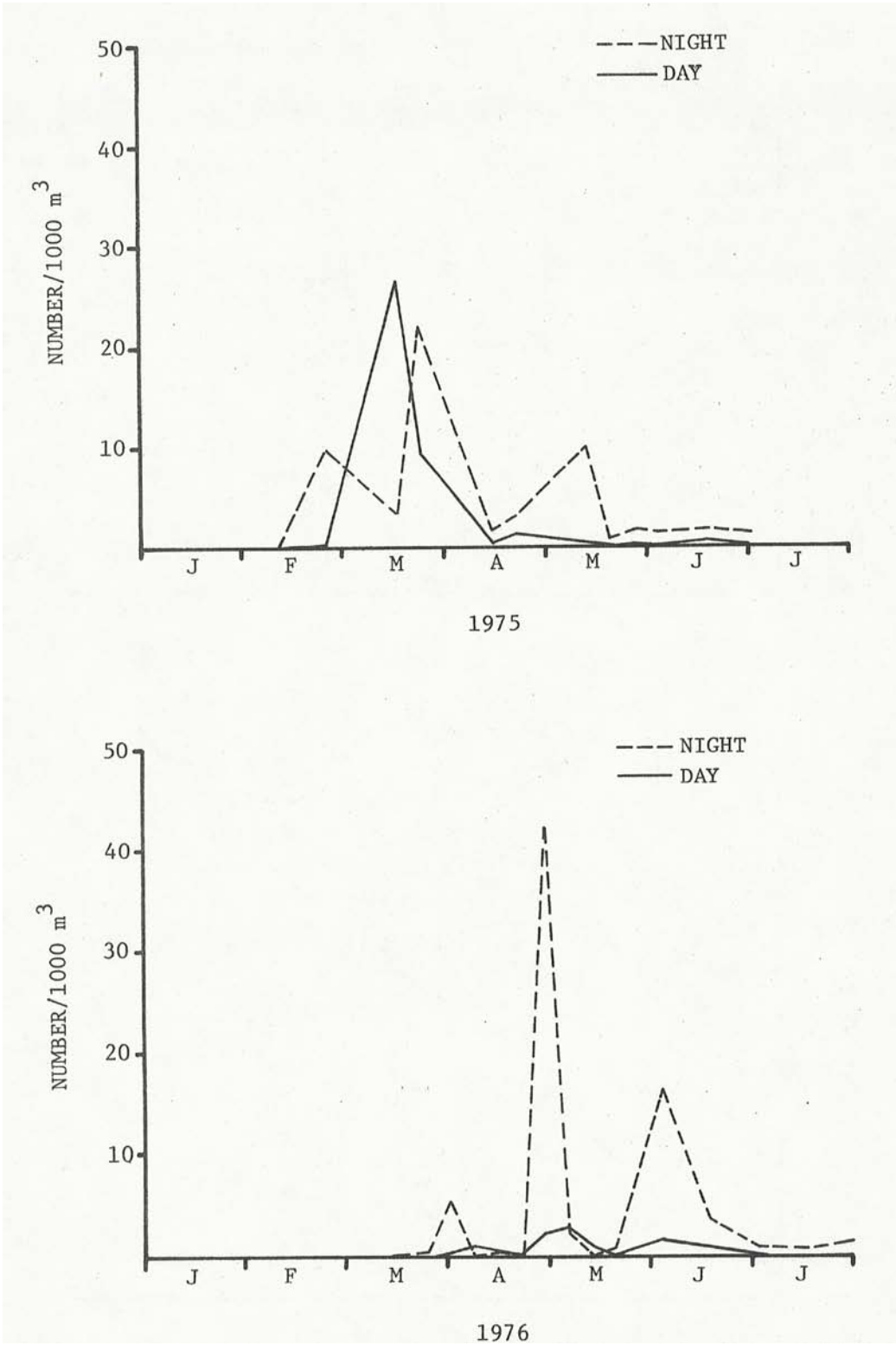

Figure 7. Density of Cyprinidae larvae in day and night drift for 1975 and 1976.

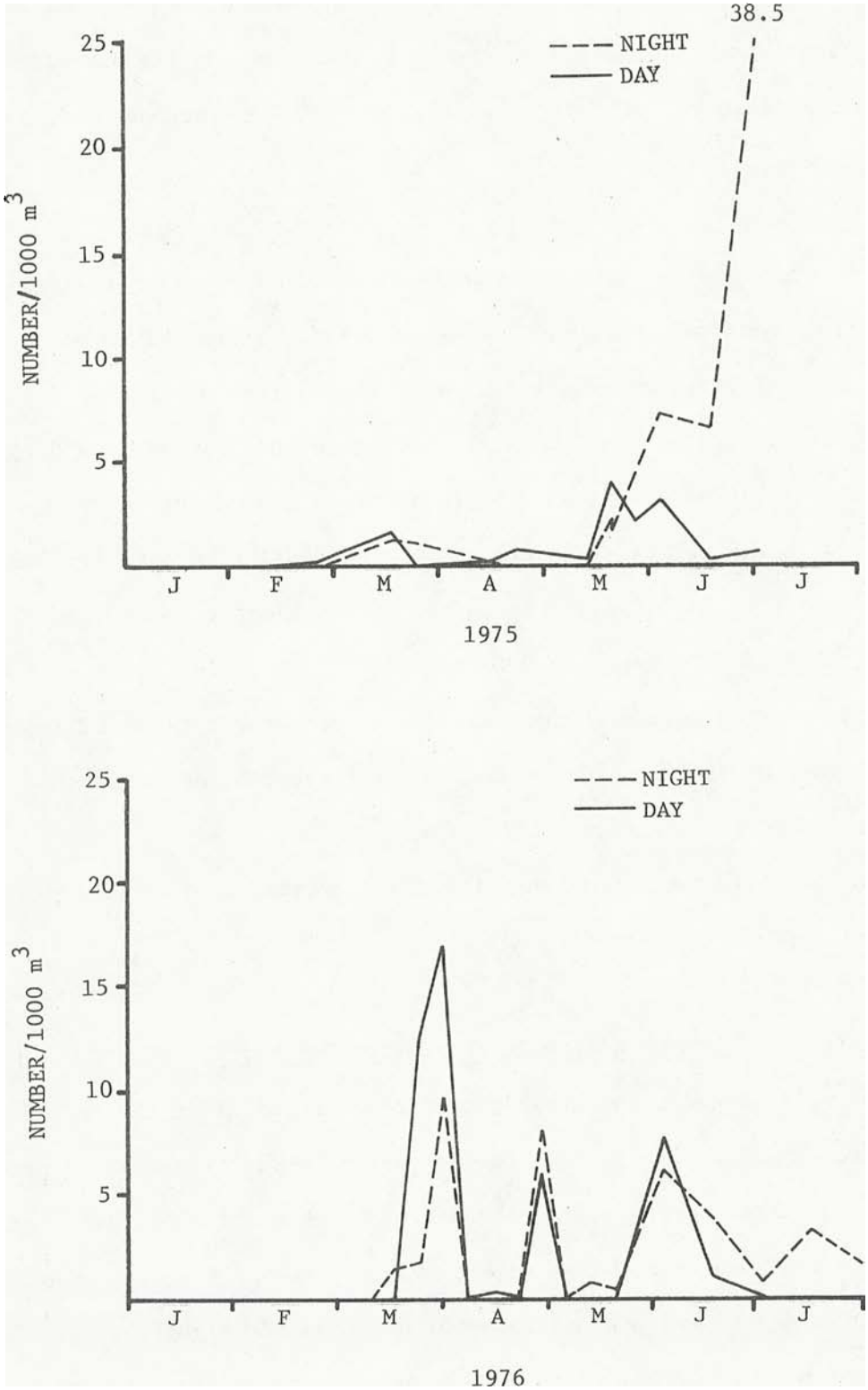

Figure 8. Density of Centrarchidae larvae in day and night drift for 1975 and 1976.

period were derived by multiplying mean densities in weekly night and day collections by intake volume for a 12 hour day and 12 hour night period. Entrainment estimates for 1975 and 1976 are presented in Tables 2 and 3.

In 1975 during the extended high water season, the fraction of total river flow entrained ranged from 0.10 to 0.41%. Estimated rates of entrainment of total fish larvae in 1975 ranged from 99 to 5930/day. Estimates of entrainment of total fish eggs in 1975 ranged from 0 to 1584/day. In 1976 the fraction of total river flow entrained ranged form 0.12 to 0.91%. Rates of entrainment of total fish larvae in 1976 ranged from 0 to 16,468/day. Estimates of entrainment rate of total fish eggs in 1976 ranged from 0 to 4592/day. Total river discharge for the period February through June was about twice the total discharge for the same period in 1976. Generally, lower river discharge in 1976 resulted in greater ichthyoplankton densities in the river, a larger fraction of total river flow entrained, and greater numbers of entrained ichthyoplankton than in 1975.

Entrainment of Ichthyoplankton in the Heated Discharge

In order to assess the potential impact of entrainment in the heated discharge plume, a computerized two dimensional model was used to predict the maximum time and temperature exposure of ichthyoplankton drifting in the thermal plume (Motz and Benedict, 1970). Figures 9 and 10 show the predicted time-temperature histories of organisms drifting through the centerline of the thermal plume during average and extreme summer and winter conditions. For average summer conditions the predicted maximum

TABLE 2

Rate of ichthyoplankton entrainment (number/day) for 1975 data.

Survey Week Beginning	Percent River Flow Entrained	LARVAE					EGGS	
		Alosa spp.	Catostom-idae	Cyprin-idae	Centrarch-idae	Total Larvae	Alosa Sapidissima	Total Eggs
Feb. 2	0.27	0	0	0	0	0	0	0
Feb. 9	0.25	0	0	0	0	35	0	0
Feb. 16	0.45	0	0	0	0	0	132	165
Feb. 23	0.51	0	0	0	0	0	1176	1176
Mar. 1	0.56	42	0	0	0	136	2438	2543
Mar. 8	0.63	91	288	41	103	774	4162	4592
Mar. 15	0.48	42	1088	28	977	2754	620	865
Mar. 22	0.21	38	778	396	1845	3369	52	194
Mar. 29	0.12	19	650	71	0	754	82	562
Apr. 5	0.34	0	1979	55	16	2400	2002	2081
Apr. 12	0.41	120	1059	0	0	1258	1969	2128
Apr. 19	0.64	1235	8918	3064	974	16468	1511	1543
Apr. 26	0.87	48	7484	352	0	8315	1195	1492
May 3	0.77	21	1093	0	56	1293	2317	2414
May 10	0.75	0	456	53	27	682	733	819
May 24	0.19	15	3220	1229	959	6160	13	13
Jun. 7	0.23	0	73	310	334	805	0	0
Jun. 21	0.91	0	55	57	57	168	0	0
Jul. 5	0.72	0	24	42	230	340	0	0
Jul. 19	0.57	0	120	98	117	335	0	30

TABLE 3

Rate of ichthyoplankton entrainment (number/day) for 1976 data.

Survey Week Beginning	Percent River Flow Entrained	LARVAE						
		Alosa spp.	Catostom-idae	Cyprin-idae	Centrarch-idae	Total Larvae	Alosa Sapidissima	Total Eggs
Feb. 3	0.28	0	0	16	0	99	26	52
Feb. 17	0.25	0	0	696	16	815	66	171
Mar. 10	0.20	61	30	2078	197	2575	187	284
Mar. 17	0.22	0	36	2187	75	2941	28	60
Apr. 7	0.17	29	184	149	29	590	96	364
Apr. 14	0.10	0	390	309	48	1200	0	28
May 5	0.31	0	4308	735	16	5930	489	754
May 12	0.24	14	393	54	424	1295	571	685
May 19	0.27	0	1651	135	257	4454	354	1584
May 26	0.30	83	141	121	721	2683	78	103
Jun. 9	0.41	53	19	155	476	2030	0	0
June 23	0.38	197	176	90	2726	4016	0	0

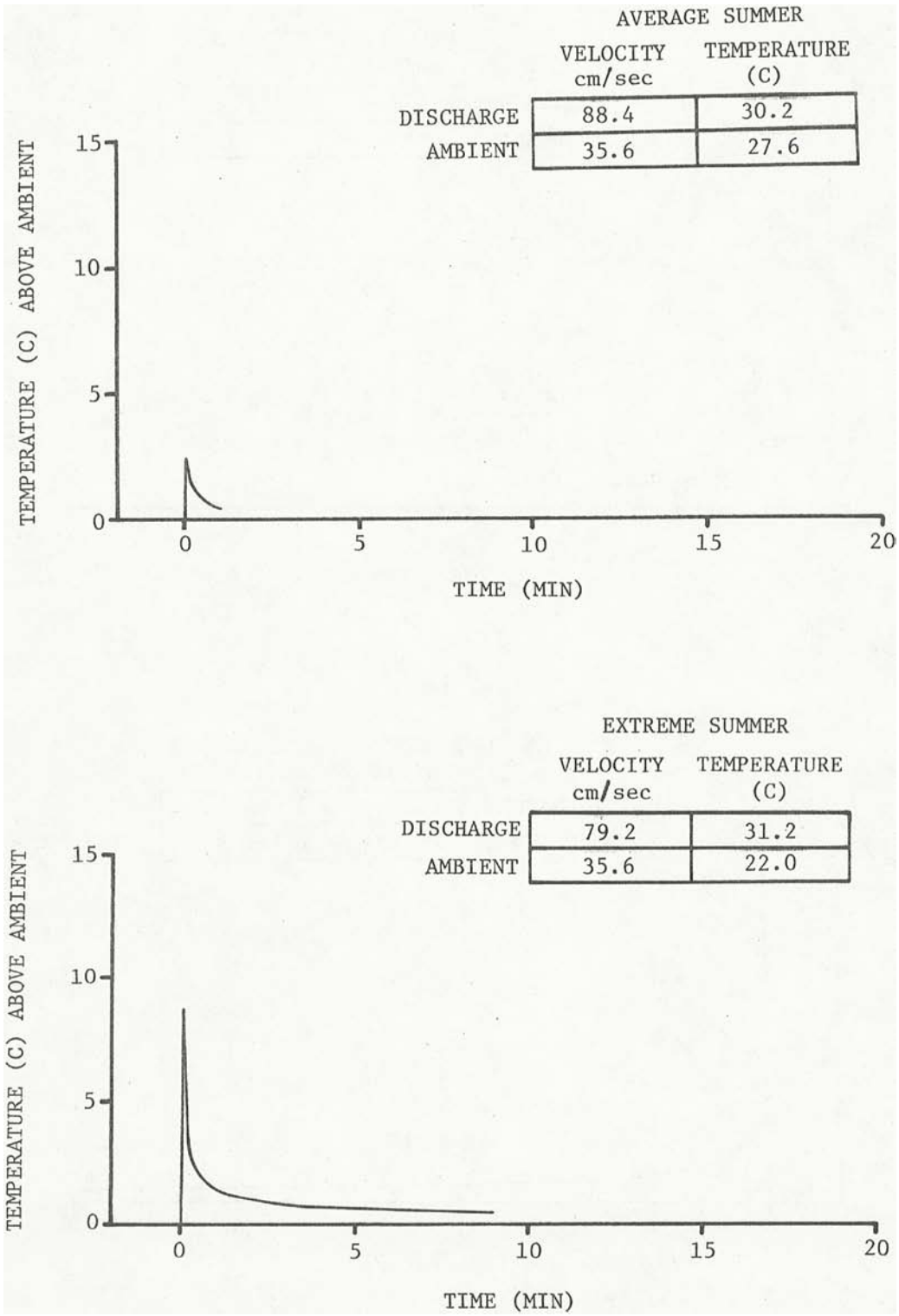

Figure 9. Predicted time-temperature exposure of ichthyoplankton drifting in heated discharge for average and extreme summer conditions.

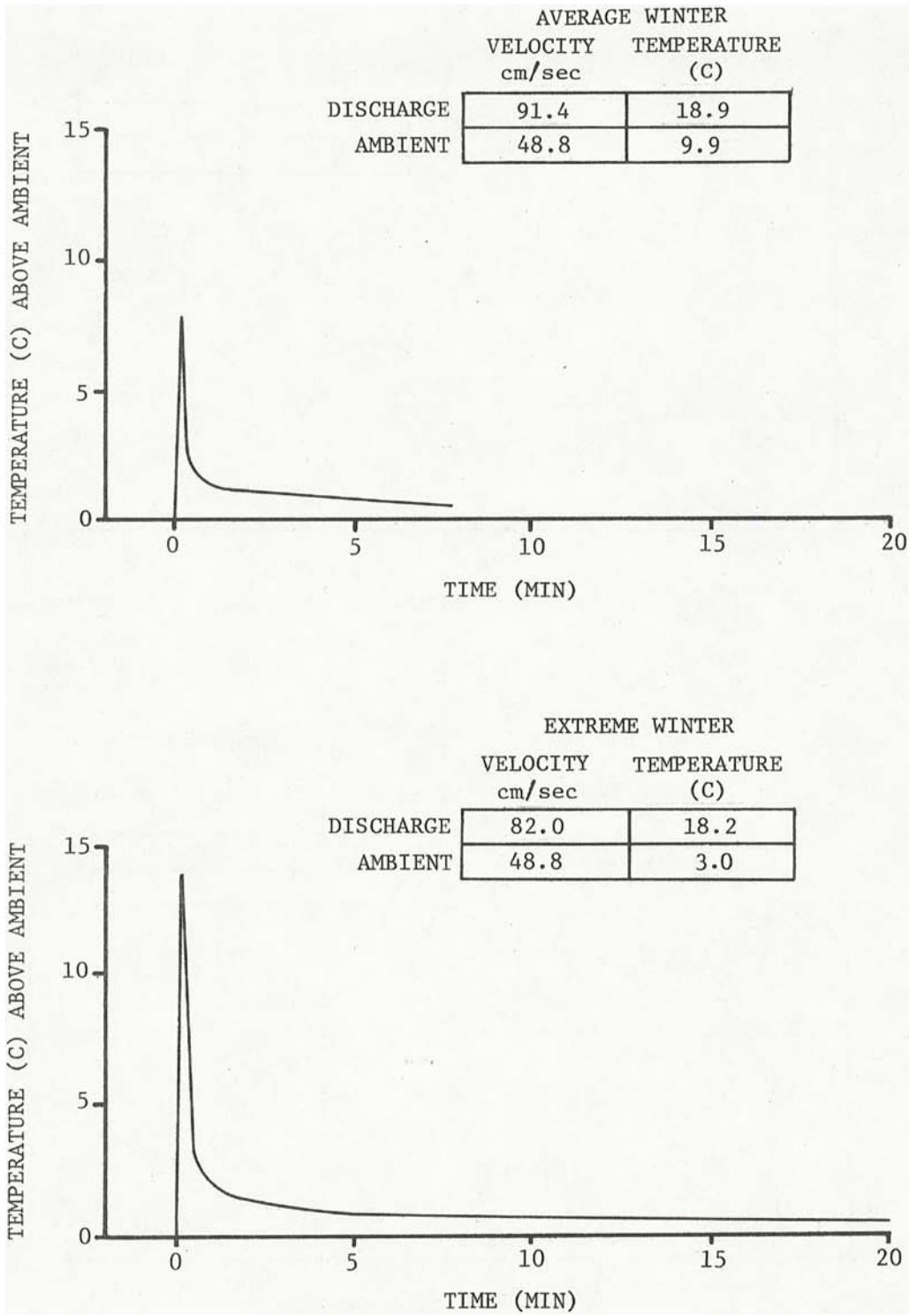

Figure 10. Predicted time-temperature exposure of icthyoplankton drifting in heated discharge for average and extreme summer conditions.

ΔT in the mixing zone was less than $3^{o}C$ above ambient. For extreme summer conditions maximum predicted ΔT in the mixing zone reached $9^{o}C$ above ambient but was $2^{o}C$ above ambient at one-minute exposure. For average and extreme winter conditions, the maximum predicted ΔT reached 8 and $14^{o}C$ above ambient respectively. Within one-minute exposure for both average and extreme winter conditions, the predicted ΔT was $2^{o}C$ above ambient. The exposure of drifting ichthyoplankton to heated water even under extreme conditions is of relatively short duration and not likely to be harmful. Studies by Schubel (1974), and Kedl and Coutant (1976) have suggested that exposure to time temperature regimes similar to those experienced at Hatch Nuclear Plant would not harm ichthyoplankton.

CONCLUSIONS

1. Catostomids, cyprinids and centrarchids were the dominant ichthyoplankton families collected. Abundant ichthyoplankton species were Minytrema melanops, Carpiodes spp., Notropis hudsonius, Notemigonus crysoleucas, Lepomis auritus, L. macrochirus, Pomoxis nigromaculatus, and Elassoma spp.

2. Estimated rates of entrainment of total fish larvae ranged from 99 to 5930/day in 1975 and from 0 to 16,468/day in 1976. Estimated rates of entrainment of total fish eggs ranged from 0 to 1584/day in 1975 and from 0 to 4592/day in 1976.

3. Maximum entrainment of ichthyoplankton into the cooling water intake remained less than one percent of the total community during two consecutive spawning seasons.

4. Predicted time-temperature histories indicated that exposure of ichthyoplankton to the heated discharge was not harmful.

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LITERATURE CITED

Adams, J. G. 1970. Clupeids in the Altamaha River, Georgia. Coastal Fisheries Division, Georgia Game and Fish Commission; Brunswick, Georgia. Contribution Series No. 20. 27pp.

Georgia Power Company. 1974. Edwin I. Hatch Nuclear Plant Unit No. 1. Preoperational Environmental Surveillance Report, Chapter 5 Biological Monitoring. 53pp.

Kedl, R. J. and C. C. Coutant. 1976. Survival of juvenile fishes receiving thermal and mechanical stresses in a simulated power-plant condenser. In Thermal Ecology II, G. W. Esch and R. W. McFarlane (Ed.) pp. 394-400. Technical Information Center, Engery Research and Development Administration, U. S. Department of Commerce, Springfield, Virginia.

Motz, L. M. and B. A. Benedict. 1970. Heated surface jet discharged into a flowing ambient stream. Department of Environmental and Water Resources Engineering, Vanderbilt University. Report No. 4. 207pp.

Schubel, J. R. 1974. Effects of exposure to time-excess temperature histories typically experienced at power plants on the hatching success of fish eggs. Chesapeake Bay Institute, Johns Hopkins University; Special Report No. 32. 37pp.

ICHTHYOPLANKTON IN THE YADKIN RIVER AND POTENTIAL ENTRAINMENT AT PERKINS NUCLEAR STATION

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Abstract

The Yadkin River was sampled for ichthyoplankton during spring and summer of 1976 to predict entrainment at a proposed nuclear power plant. Catostomids were the dominant family in the ichthyoplankton samples from the Yadkin River. Clupeids, cyprinids, ictalurids, centrarchids, and percichthyids were also present. Most of the larval fish drifting in the Yadkin River occurred during April and May, and tended to be located in mid-channel and deeper areas of the river. Total larval fish entrainment losses were predicted for the 133 day period from 21 April through 31 August 1976. Horizontal distribution of larval fish in the river was taken into account for calculating predicted entrainment. Maximum entrainment was predicted to be approximately 1.7×10^6 larval fish or 5.3% of the drifting component of the community. Catostomids incurred the highest numerical losses (up to 1.32×10^6 individuals); however, these losses only amounted to 4.9% of the total number of larval catostomids. Entrainment losses of clupeids, cyprinids, ictalurids, centrarchids, and percichthyids were predicted to be of little consequence.

INTRODUCTION

The ichthyoplankton community of the Yadkin River, North Carolina, was sampled during spring and summer 1976 as part of a preoperational baseline study for ecological evaluation of the effects of the proposed Perkins Nuclear Station (PNS). The objectives of the study were to: 1) determine the taxonomic composition of Yadkin River ichthyoplankton, 2) analyze spatial and temporal distribution and abundance of the major taxa, 3) predict total yearly entrainment by PNS.

Perkins Nuclear Station will employ three identical pressurized water reactors with a combined net output of 3840 MWe. The condensers will be cooled with Yadkin River water in a closed cycle cooling system with circular, mechanical draft, wet cooling towers. The four pump intake will be located flush with the river bank. Maximum intake volumes will be 4.87 cms with maximum intake velocities of 0.15 mps.

STUDY AREA

The study area is located in the Piedmont of North Carolina. In this area the Yadkin River, a typically turbid stream, averages 60 m wide with an average midstream depth of 2 to 3 m. Current velocities at midstream generally range from 0.2 to 1.7 mps. No impoundments are present in the study area. The nearest downstream (47 km) impoundment from the future plant site is High Rock Lake and the nearest upstream (31 km) blockage is Idols Hydroelectric Station (Duke Power Co. 1974). Flow in the Yadkin River is generally highest from February through May and lowest from July through November. Mean annual flow is 81 cms, with recorded maximum and minimum instantaneous flows of 2270 and 5 cms (Duke Power Co. 1974). The seven day lowest average flow with a recurrence interval of once in 10 years (7Q10) is 18 cms (Duke Power Co. 1974).

The Yadkin River was classified by the state of North Carolina as a carp (Cyprinus carpio), catfish (Ictaluridae), and sunfish (Centrarchidae) stream (Fish 1968). Johnson et al. (1978) indicated that carp, bluegill (Lepomis macrochirus), white catfish (Ictalurus catus), and channel catfish (I. punctatus) were the most common species in the river throughout the year. Gizzard shad (Dorosoma cepedianum) also occurred sporadically in adult fish samples and were most abundant during spring and summer. Seasonal changes in adult species composition occurred because of spawning migrations of fish from High Rock Lake, notably suckers (Catostomidae) and white bass (Morone chrysops). A total of 43 fish species was collected during adult sampling but only nine taxa of larval fish were collected during two spawning seasons (Johnson et al. 1978). The Yadkin River fish community has experienced recurring fish kills which have generally occurred in late summer and early fall when ichthyoplankton abundance was low (North Carolina Department of Natural and Economic Resources 1970, 1972, 1973a, 1973b, 1976).

Ichthyoplankton samples were collected at two locations in the Yadkin River during 1976. Location 444 was approximately 200 m upstream from the future PNS intake site. Location 436, approximately 3 km downstream, served as a reference area. At both locations the river was approximately 60 m wide and 2 to 3 m deep. At Location 444 the river bottom consisted of bedrock and sand, while the bottom at Location 436 was primarily sand. Shoreline areas of both stations consisted of sand and silt.

MATERIALS AND METHODS

FIELD SAMPLING

Ichthyoplankton was collected with Nitex nets (560 µm), attached to square frames (0.5 m on each side) which were mounted on poles approximately 2.6 m long. A frame designed to hold two nets simultaneously was mounted to the bow

of a 4.9 m aluminum boat. A rope secured to each bank held the boat stationary in the river. Nets were usually set for 5 min; however, during periods of high flows, sample times were decreased to prevent clogging and backwash. A General Oceanics flowmeter suspended across the net mouth allowed calculation of water volumes filtered for each sample. Samples were preserved with 10% formalin and stained with rose bengal (0.5 g/ℓ).

Ichthyoplankton sampling was conducted approximately weekly during daylight hours from mid-March through August. Locations were sampled at midchannel and right and left banks. Sampling at each point within a location consisted of duplicate surface and duplicate 1 m (or bottom) samples.

A diel study of larval fish density and distribution was conducted on 11 through 12 May at Location 444. Samples were taken at 1100, 1700, 2300, and 0500 hr EST. Five stations in the river were sampled, left bank (LB), left channel (LC), midchannel (MC), right channel (RC), and right bank (RB).

LABORATORY ANALYSES

Samples were washed in 30 mesh (250 μm) U. S. Standard Sieves to remove formalin and excess stain. Samples were sorted in white enamel pans; larval fish were removed, identified, and preserved in 40% isopropanol. Larval fish densities were expressed as number/1000 m^3 based on volume of water filtered in each sample.

Diel distribution data were tested for normality with the Kolmogorov-Smirnov test (Lillefors 1967) and for homogeneity of variances with Bartlett's test (Zar 1974). Transformed diel distribution data were analyzed with 3-way split plot ANOVA (Hicks 1973). Times of day were used as plots because randomization among sample times were restricted. Student-Newman-Keuls (SNK) multiple range

tests were used to determine which stations or times differed significantly. The significance of all analyses was judged at the 0.05 probability level.

POTENTIAL ENTRAINMENT ESTIMATES

Potential entrainment was defined as the number of larval fish that would have passed through the PNS condenser cooling system had the plant been operating during 1976. Potential entrainment estimates were made based on: 1) three modes of plant operation, 2) ichthyoplankton densities, and 3) mean daily discharge during each sampling period. The three levels of plant operation represented intake volumes at two-pump (2.43 m^3/sec), three-pump (3.65 m^3/sec), and four-pump (4.87 m^3/sec) operation. Mean daily discharge for the Yadkin River was partitioned into three groups representing mid-channel, right bank, and left bank of the river. Since current velocity is greatest in mid-channel areas of streams (Beaumont 1975), each shoreline area was assumed to carry 20% and the channel area 60% of the mean daily discharge. Larval fish drift was estimated for each of these partitions. Depth distributions of larval fish were not taken into account in the entrainment estimates since the intake screens would cover the entire depth of the river. Estimates of larval fish density were assumed to be representative of daily densities during each sampling interval. Eighty percent of the predicted intake volume was assumed to enter the plant from the right bank (intake side) and 20% from the mid-channel of the river. It was assumed that biotic entrainment equaled hydraulic entrainment. This is essentially the same method used by Marcy (1974) to calculate entrainment of Connecticut River larval fish. However, adjustments were made taking into account horizontal distribution of fishes within the river.

RESULTS AND DISCUSSION

RELATIVE TAXONOMIC COMPOSITION

Relatively few taxa occurred in the larval fish samples (Table 1). Catostomids

Table 1. Percent composition of larval fish collected in samples from the Yadkin River from April through August 1976.

Taxon	Percent
Clupeidae	
Dorosoma spp.	14.5
Cyprinidae	2.2
Catostomidae	75.5
Ictaluridae	0.9
Percichthyidae	
Morone chrysops	0.2
Centrarchidae	
Pomoxis spp.	0.2
Unidentified or damaged	6.4

predominated with shad being the next most abundant taxon of larval fish. Cyprinids, primarily carp and unidentifiable minnows, were at times abundant. White catfish and channel catfish were the most common ictalurids. Larval fish of other families were rare.

Larval fish densities in the Yadkin River were comparable to those in the mainstream of the Broad River but taxonomic composition was much different. Shad were the most abundant larval fish in the Broad River, South Carolina; however, this area was influenced by a small reservoir and backwater which provided excellent spawning areas for adult shad (Cloutman and Edwards, In press). Cloutman and Edwards (In press) also found that larval fish densities were much higher in backwater areas than in the mainstream of the Broad River; however, taxonomic composition remained relatively unchanged, with shad dominant. The dominance of catostomids in the Yadkin River was likely due to the presence of many riffle areas suitable for the spawning of adult catostomids.

SPATIAL-TEMPORAL DISTRIBUTION

Ichthyoplankton occurred in the Yadkin River from early April through August. Fish eggs were common in early April and larval fish were present during the 133 day period from 21 April to 31 August 1976.

Larval fish densities were highest during April and May, declined sharply in June, and remained low through August (Fig. 1). Larval fish densities generally followed the same seasonal trend at both locations. The peaks during April and May were due primarily to catostomid larvae. The peak at Station 436 during late May was due to high densities of shad larvae. The low densities of larval fish from June through August were comprised primarily of catostomids, ictalurids, and cyprinids.

Highest densities of larval fish usually occurred in mid-channel areas of the

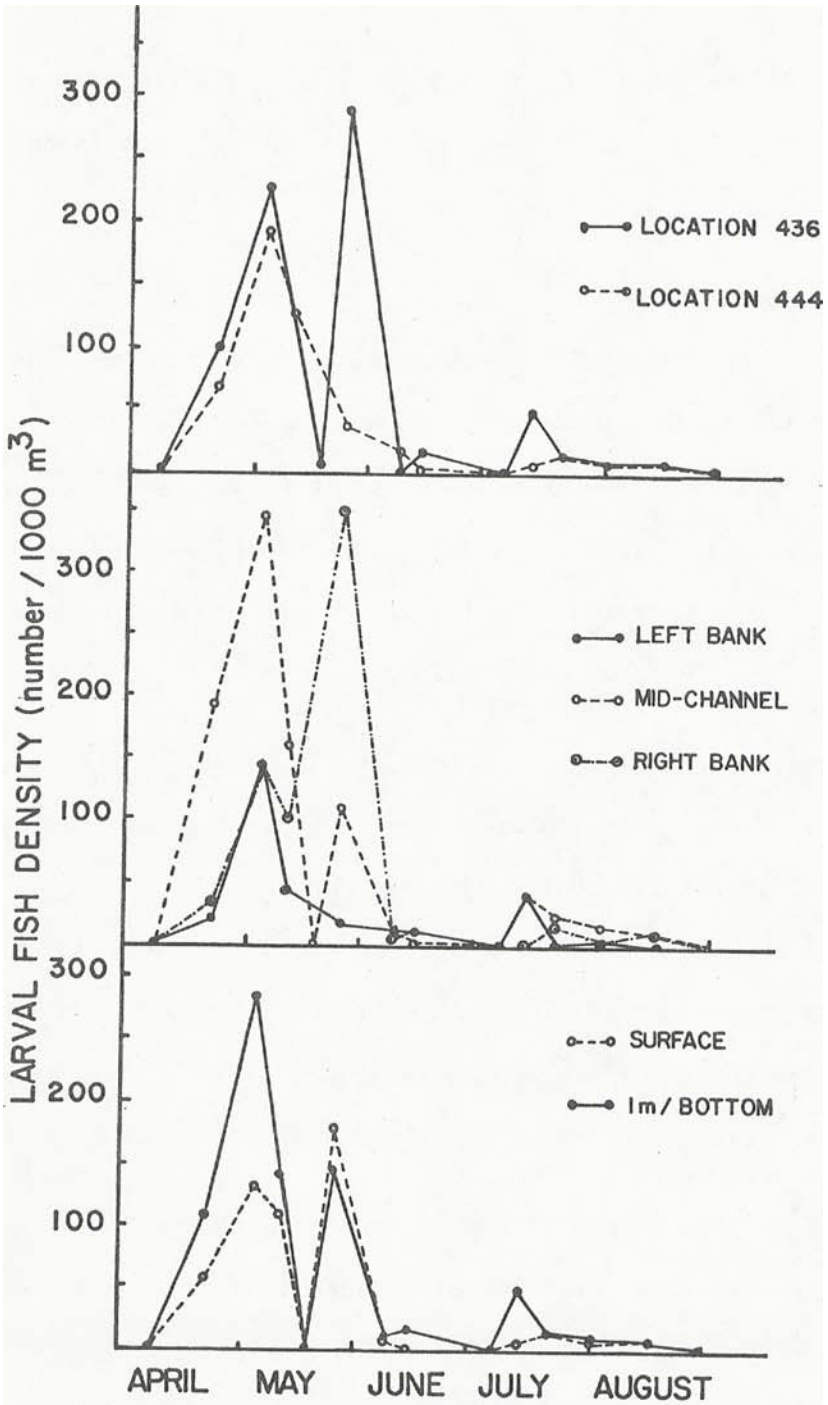

Figure 1. Mean density of larval fish from samples at two locations, three areas, and two depths in the Yadkin River, North Carolina during spring and summer 1976.

river during April and May (Fig. 1). These peaks were due to catostomid larvae which were most abundant during this period. The peak in late May for right shoreline samples was due to larval shad. After these initial peaks, there were only small horizontal differences from June through August (Fig. 1).

As with horizontal distribution, there was little difference in depth distribution after April and May. Larval fish densities were highest in deep samples during April and May (Fig. 1).

Suckers (Catostomidae)

Catostomid larvae dominated the ichthyoplankton community (Table 1, Fig. 2), even though adult catostomids were uncommon. The wide range of water temperatures at which catostomid larvae were collected (Fig. 2) suggested that more than one species of catostomid spawned in the Yadkin River, and that some of these species may have protracted spawning periods. Identification of larval catostomids below family level was not possible.

Larval catostomids ranging from 5 to 15 mm in length were collected during April through July in water temperatures ranging from 18 to 25 C (Fig. 2). High densities of larval catostomids occurred during early May (Fig. 3) and accounted for most of the ichthyoplankton collected during the period. A secondary peak occurred during July at Location 436. In general, mid-channel samples contained the highest densities of larval catostomids (Fig. 3). Deep samples contained consistently higher catostomid densities than surface samples (Fig. 3).

Catostomid densities from diel samples taken on 11 and 12 May at Station 444 (plant intake) exhibited distinct distribution patterns. Highest densities occurred in midday (1100 hr) samples and densities were generally highest in mid-river (Fig. 4).

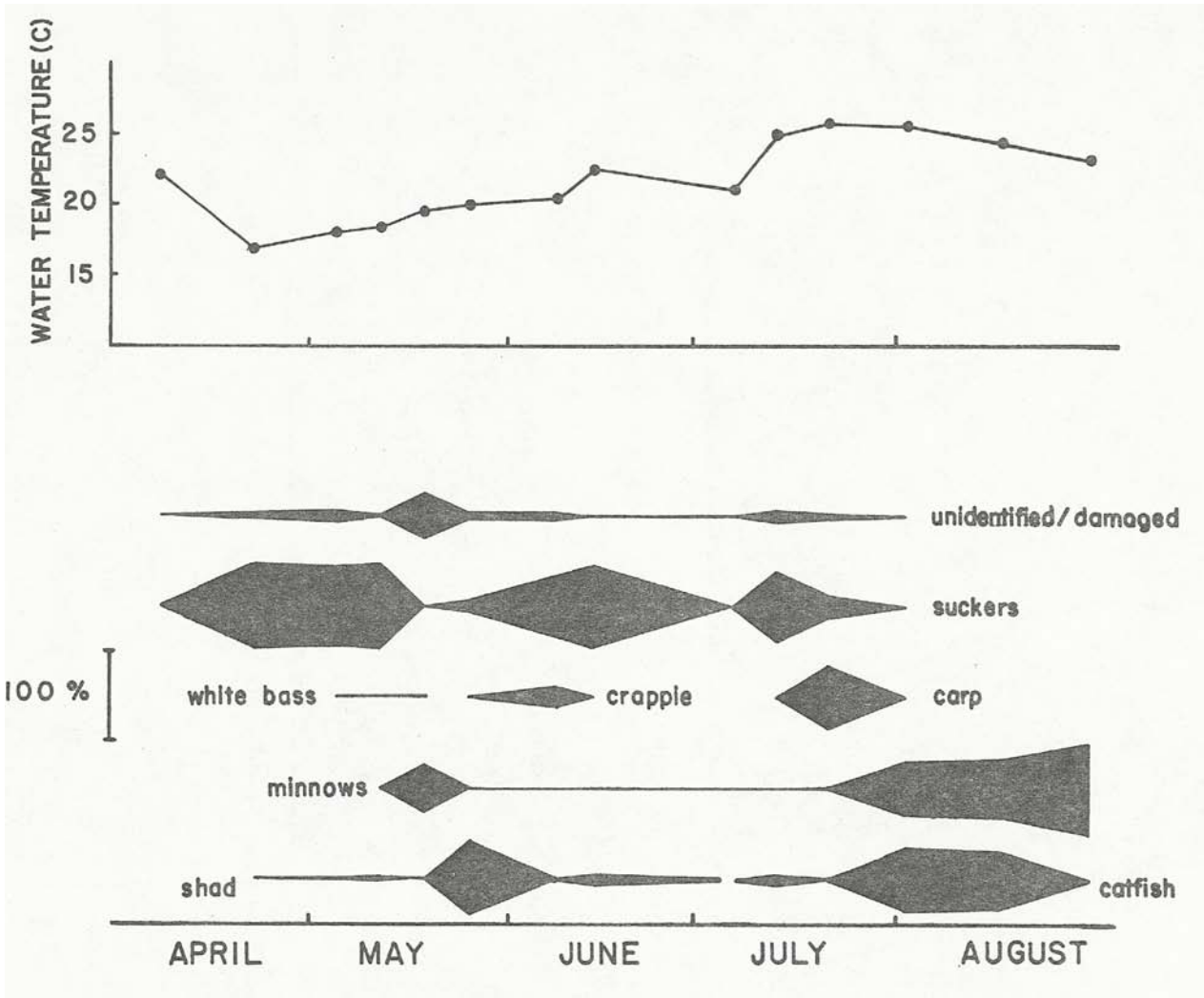

Figure 2. Relative taxonomic composition of larval fish collections and mean water temperature at four locations on the Yadkin River, North Carolina during spring and summer 1976.

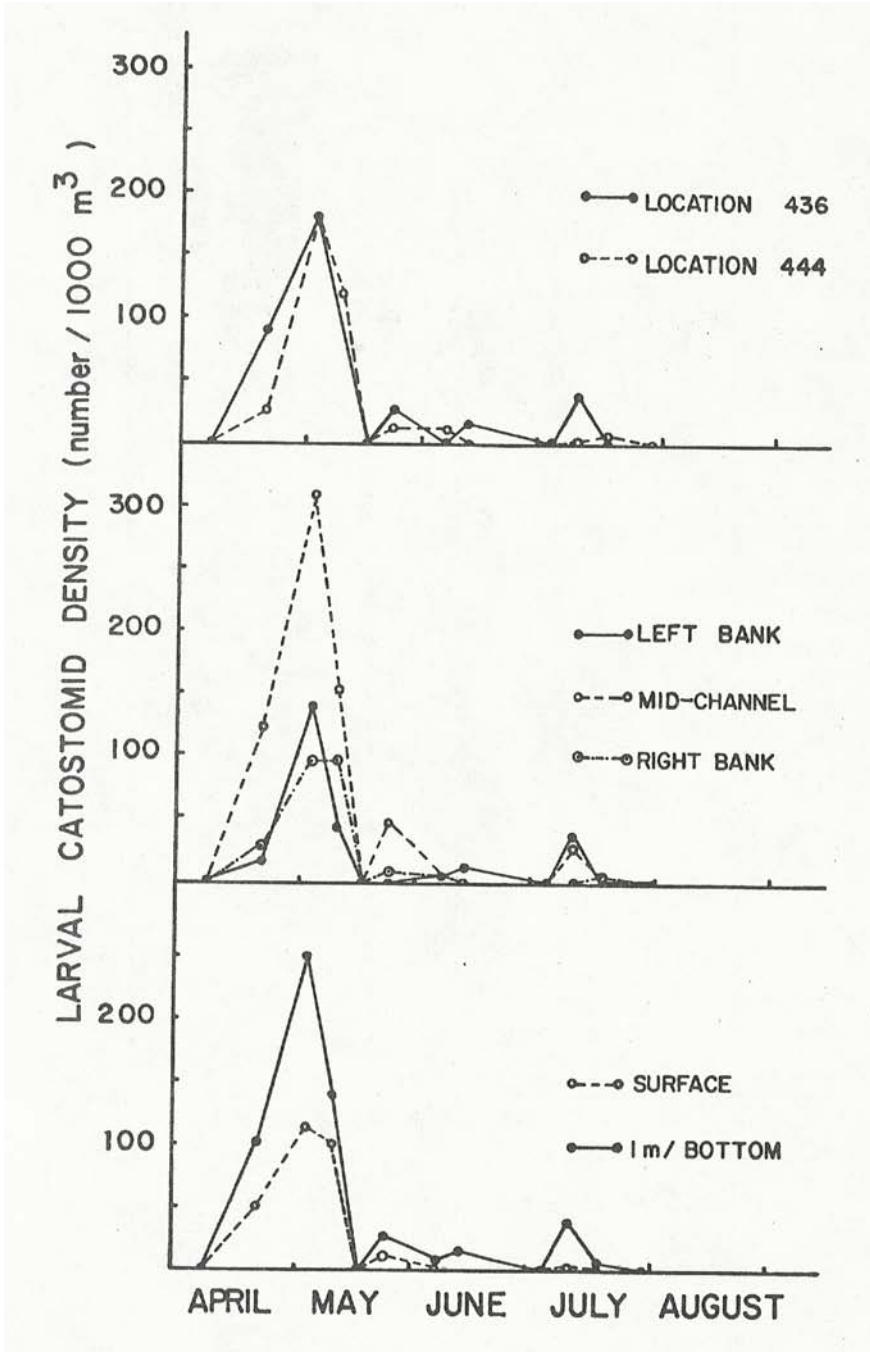

Figure 3. Mean density of larval catostomids from samples at two locations, three areas, and two depths in the Yadkin River, North Carolina during spring and summer 1976.

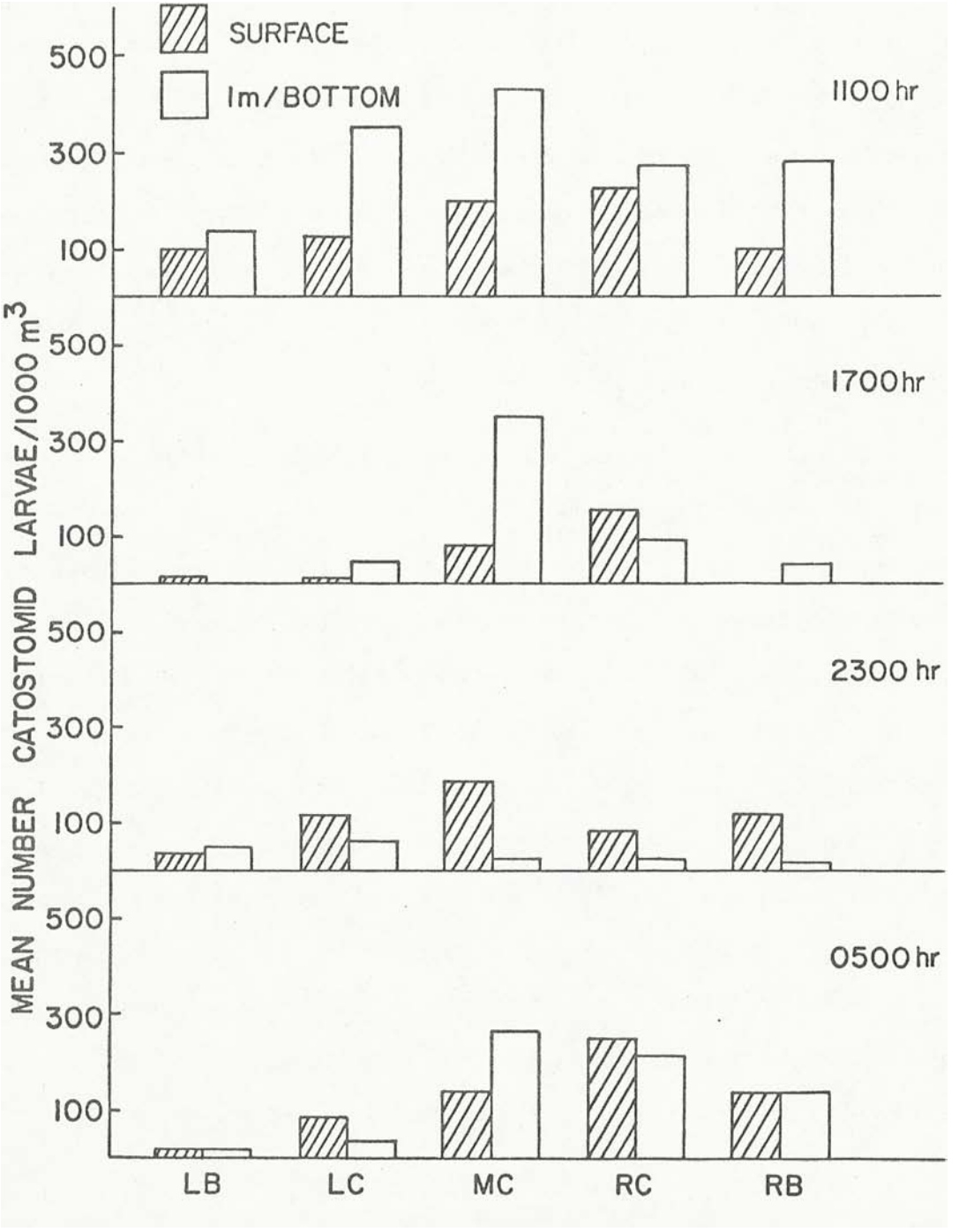

Figure 4. Mean densities of larval catostomids collected in the Yadkin River, North Carolina at Location 444 on 11 and 12 May 1976. Time of sample is in the upper right corner of each histogram. LB = left bank, LC = left of midchannel, MC = midchannel, RC = right of midchannel, and RB = right bank.

Three-way split plot ANOVA indicated that sample location, time of day, and depth-time interaction were highly significant (Table 2). Although there was some overlap of location means, an SNK multiple range test indicated that significantly less larvae drifted down the left bank of the Yadkin River (Table 2). Densities of catostomid larvae also tended to be higher in the mid-channel throughout the diel period (Fig. 4), but these were significantly higher than only the samples from the left channel and right and left bank locations (Table 2). These trends were indicated throughout April and May during the weekly sampling (Fig. 3). Means of times of day could not be separated because of the significant depth-time interaction.

In order to evaluate the depth-time interaction, two-way ANOVAS were performed for each sample period of the diel. Depth was the only significant term during the 1100 hr sample (Table 3). Since only two depths were sampled, this indicated significantly higher densities of catostomid larvae in deep samples. Depth and location were significant in the analysis of the 1700 hr sample. Densities of catostomid larvae were still higher in the deep samples during this period. Catostomid densities were also significantly higher in mid-channel and right-channel locations at 1700 hr (Table 4). At 2300 hr, depth was the only significant factor and significantly more larvae were drifting at the surface than at 1 m. By 0500 hr, distribution patterns had again changed, with location the only significant term in the ANOVA (Table 3). There was considerable overlap among location means in the multiple range test (Table 4); however, a trend for more larvae to drift in channel areas of the river was indicated.

Geen et al. (1966) found that more sucker larvae moved downstream at night in the turbid waters of a British Columbia stream. Apparently, at Station 444 more catostomid larvae drifted downstream during daylight and early morning hours

Table 2. Results of 3-way split plot analysis of variance of larval catostomid density (number/1000 m^3; square root transformed) and associated Student-Newman-Keuls multiple range test for horizontal location, at Station 444 on the Yadkin River, North Carolina on 11 and 12 May 1976. Means shown for the multiple range test are retransformed.

Analysis of Variance

Variable	DF	Mean Square	F
Times of Day	3	203.454	56.53 **
Replicates (Times)	4	3.599	
Location	4	147.707	10.08 **
Times X Locations	12	28.832	1.97
Times X Locations X Replicates	16	14.657	
Depth	1	34.904	2.36
Times X Depth	3	93.913	6.34 **
Location X Depth	4	11.340	0.77
Times X Location X Depth	12	17.008	1.15
Residual	20	14.807	

Student-Newman-Keuls Multiple Range Test[1]

Location	Mid-Channel (MC)	Right-Channel (RC)	Left-Channel (LC)	Right Bank (RB)	Left Bank (LB)
Mean	171.1	131.8	75.2	66.7	26.5

** Highly Significant ($p<0.01$)

[1] Means not connected by horizontal lines are significantly ($p=0.05$) different

Table 3. Results of 2-way analysis of variance of larval catostomid density (number/1000 m^3; square root transformed) with respect to horizontal location and sample depth for each sampling period at Station 444 on the Yadkin River, North Carolina, 11 and 12 May 1976.

Sampling Period	Variable	DF	Mean Square	F
1100	Depth	1	156.202	7.85 *
EST	Location	4	23.155	1.16
	Interaction	4	16.593	0.83
	Residual	10	19.898	
1700	Depth	1	64.237	7.88 *
EST	Location	4	110.989	13.61 **
	Interaction	4	19.948	2.45
	Residual	10	8.154	
2300	Depth	1	95.093	6.40 *
EST	Location	4	10.293	0.69
	Interaction	4	19.622	1.32
	Residual	10	14.866	
0500	Depth	1	1.112	0.10
EST	Location	4	89.766	7.75 **
	Interaction	4	6.200	0.54
	Residual	10	11.586	

* Significant ($0.01<p<0.05$)
** Highly Significant ($p<0.01$)

Table 4. Results of Student-Newman-Keuls multiple range test for differences in larval catostomid densities (number/1000 m^3; square root transformed) among horizontal locations for samples taken at 1700 hr and 0500 hr (EST) at Station 444 on the Yadkin River on 11 and 12 May 1976. Means not connected by lines are significantly (p=0.05) different.

Location	Mid-Channel (MC)	Right Channel (RC)	Left Channel (LC)	Right Bank (RB)	Left Bank (LB)
Mean	184.5	105.6	21.6	12.5	0.0

Location	Right channel (RC)	Mid-channel (MC)	Right Bank (RB)	Left Channel (LC)	Left Bank (LB)
Mean	224.5	171.1	109.8	49.9	9.7

(Fig. 4). Geen et al. (1966) further suggested that absence of light caused loss of the ability of catostomid larvae to maintain their position in the current, or that a negative phototactic response caused catostomid larvae to hide in gravel at the bottom of the stream during daytime. Highest densities of Yadkin River catostomids were nearer the bottom during daylight hours (Fig. 4; Table 2); however, the sandy bottom at Station 444 may have afforded catostomids much less protection from the current than a gravel bottom.

Stream morphology also affects catostomid distribution. Densities of catostomids were depressed just below a run-or-the-river reservoir at Idols Hydroelectric Station on the Yadkin River 31 km upstream from Location 444 (Johnson et al. 1978). The small reservoir above and the pool below the dam offered lentic refuge areas for larval fish. There were no such areas at Location 444 and catostomid larvae were more abundant.

Shad (Dorosoma spp.)

Larval shad were present in samples from early May through early July at water temperatures ranging from 17 to 23 C (Fig. 2). Shad larvae ranged from 2 to 16 mm. Shad densities were generally low at all stations (0 to 69/1000 m^3) except on one occasion during May at Station 436. At this time, most of the larval shad collected (669/1000 m^3) ranged from 2 to 6 mm. Shad spawning occurred in May, however, the majority of shad probably spawned downstream in the upper reaches of High Rock Lake.

Minnows (Cyprinidae)

Carp were collected during July at a water temperature of 26 C (Fig. 2). Carp probably spawn through spring and summer in the Yadkin River but the larvae may not drift. Larval carp have been reported to have anterior cement glands

which they used to maintain position within flowing waters by attaching to rocks or vegetation (Balon 1975). Other cyprinids, probably shiners (Notropis spp.) were collected during May and were predominant in larval samples during August (Fig. 2).

Catfish (Ictaluridae)

Ictalurid alevins and juveniles, primarily white catfish and channel catfish, were collected from mid-July through mid-August at water temperatures of 24 to 26 C (Fig. 2). Ictalurid juveniles generally ranged from 12 to 18 mm long, although eyed eggs were occasionally collected. Ictalurid densities at Locations 436 and 444 were so low (0 to 12/1000 m^3) and variable that no patterns of horizontal or depth distribution were indicated.

Others

Larvae of other taxa occurred in relatively low densities. Crappie (Pomoxis spp.) were the only larval centrarchids collected, occurring in June at a water temperature of 26 C (Fig. 2). One white bass larvae was collected in a sample from Location 444 during May (Fig. 2). Electrofishing samples indicated that the tailrace of Idols Hydroelectric Station (31 km upstream) may have been a spawning site of white bass. Numerous running ripe males were collected there during April and May; however, no mature females and one larval white bass were collected. Either white bass did not spawn successfully in the Yadkin River in 1976, were not subject to downstream drift in the areas sampled, or were not susceptible to the sampling gear.

PREDICTED EFFECTS

An estimated 3.3×10^7 larval fish drifted past the PNS intake site during the 133 day larval season in 1976. From 1.0×10^6 to 1.7×10^6 of the drifting larval fish would be entrained, for a maximum loss of approximately 3 to 5%

(Table 5). Depending on horizontal distribution within the river, some taxa would be more severely affected than others.

Catostomids, the most abundant taxon in the larval fish samples, had the highest potential entrainment in total number; however, the percentage entrained at the highest predicted level of plant operation was only 5% (Table 5). Catostomids ascend streams to spawn (Breder and Rosen 1966, Clifford 1972, Geen et al. 1966). Most catostomids spawn in riffles and deposit demersal eggs in the gravel (Breder and Rosen 1966). Catostomid larvae drift soon after hatching and are therefore more susceptible to entrainment than other taxa. Weekly sampling and the diel distribution study indicated that highest densities of catostomid larvae occurred in mid-channel during daylight hours (Figs. 3 and 4). Although horizontal distribution was taken into account in the entrainment estimates, diel periodicity was not incorporated, and the ensuing estimates were probably high.

Losses of shad larvae were predicted to the next highest (Table 5); however, the Yadkin River near the PNS site is probably not a major spawning area for shad. Although shad are known to spawn in feeder streams (Shelton 1972), most shad spawning in the Yadkin River probably occurred further downstream in upper High Rock Lake. In addition, the predicted maximum number of larvae lost (Table 5) is within the range of fecundity reported for one female shad (Carlander 1969) and the potential loss could be compensated by one spawning pair. The high densities of larval shad that occurred at Station 436 during late May (Fig. 1) were not reflected in the entrainment estimates. Shad may occasionally spawn as far upstream as the PNS intake and the estimates of shad entrainment may be conservative for other years.

Cyprinids, including carp, were predicted to be the group having the highest

Table 5. Estimates of total numbers of several taxa of larval fish drifting by Station 444 (Yadkin River, North Carolina), potential entrainment by Perkins Nuclear Station, and percent of the drift potentially entrained in 1976.

	Drift Estimate ($x10^6$)	Entrainment Estimate ($x10^6$)			Percent Entrainment		
		2 pump	3 pump	4 pump	2 pump	3 pump	4 pump
Catostomidae	26.709	0.784	1.176	1.320	2.9	4.4	4.9
Cyprinidae	1.400	0.087	0.130	0.174	6.2	9.3	12.4
Dorosoma spp.	1.242	0.055	0.082	0.109	4.4	6.6	8.8
Ictaluridae	0.567	0.009	0.014	0.019	1.6	2.5	3.4
Others	3.255	0.063	0.094	0.126	1.9	2.9	3.9
Total	33.172	0.998	1.496	1.747	3.0	4.5	5.3

percent total number entrained (6 to 12%), though total losses were relatively low (Table 5). Although cyprinids comprised a large proportion of the fish drifting in the river during August (Fig. 2), total larval fish densities were low during this period (Fig. 1). Entrainment losses of this group would be expected to be minimal since cyprinids were not a consistent component of drifting larval fishes.

Catfish were predicted to be the least affected taxon, losing from 1.6 to 3.4% of the drifting population (Table 5). The breeding habits of most ictalurids would preclude high susceptibility to drift (Breder and Rosen 1966) and a 3.4% maximum loss of drifting alevins and juveniles is considered to be negligible.

The other category (Table 5) included crappie, white bass, and damaged (i.e. unidentifiable) specimens. Centrarchids are generally nest builders (Breder and Rosen 1966) which may minimize drifting and consequently entrainment. Crappie were the only centrarchids collected although adult bluegill and redear sunfish (Lepomis microlophus) were common in the adult fish samples (Johnson et al. 1978). Any entrainment losses of centrarchids would be expected to be small or to occur during periods of increased flow. The consistently occurring number of damaged specimens (Fig. 2) indicated either that the sampling technique was causing damage to the larval fish, or that many drifting larval fish were dead or moribund when collected.

Potential entrainment by PNS in 1976 (Table 5) was probably overestimated for five reasons: 1) Perkins Nuclear Station is not expected to operate constantly at full power, 2) a considerable proportion of larvae drifting in the river are probably already dead or moribund, 3) the Yadkin River had relatively low discharge during spring and summer 1976 (73 cms) as compared to 20 year mean discharge values (85 cms), 4) discharge values used for predicting entrainment

are based on a gage 16 km upstream of the Perkins intake and percent hydraulic entrainment would actually be slightly less, and 5) biotic entrainment has been shown to be much less than hydraulic entrainment for some species (Lauer et al. 1974).

SUMMARY

Most ichthyoplankton drifting in the Yadkin River occurred from April through August. Several families occurred in the drift samples, including catostomids, clupeids, cyprinids, ictalurids, centrarchids, and percichthyids. Larval fish densities were highest in April and May, decreased in June, and were low through the remainder of the summer. Catostomids dominated the ichthyoplankton community and were present from April through July and accounted for the high densities in April and May.

Catostomid densities tended to be highest in mid-stream and deeper areas. A diel distribution study showed that larval catostomid densities varied significantly with time of day, sample depth, and horizontal location. Stream morphology probably played an important part in regulating density and horizontal distribution of catostomids.

Maximum total potential entrainment for PNS during 1976 was 5.3% of the ichthyoplankton community or approximately 1.7×10^6 larvae. Catostomids had the highest potential entrainment losses in numbers of individuals (7.8×10^5 to 1.3×10^6), but were intermediate in percentage lost (2.9 to 4.9%). By proportion, cyprinids were predicted to receive the highest entrainment losses (6.2 to 12.4%) and ictalurids the lowest (1.6 to 3.4%). These groups were present in very low densities and did not appear to be consistent components of the drift. Therefore, losses of these groups were expected to be minimal. Overall, potential entrainment estimates for PNS are likely inflated, primarily

because of overestimates of plant operation time and underestimates of discharge volumes at the plant site.

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References Cited

Balon, E. K. 1975. Reproductive guilds of fishes: a proposal and definition. J. Fish. Res. Board Can. 32(6):821-864.

Beaumont, P. 1975. Hydrology. pp. 1-38. In: River ecology. B. A. Whitton ed. University of California Press. Berkeley.

Breder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. T.F.H. Publications. Jersey City, NJ. 941 pp.

Carlander, K. D. 1969. Handbook of freshwater fishery biology volume one. Iowa State University Press, Ames, IA. 752 pp.

Clifford, H. F. 1972. Downstream movements of white sucker, Catostomus commersoni, fry in a brown water stream of Alberta. J. Fish Res. Board Can. 29(7):1091-1093.

Cloutman, D. G. and T. J. Edwards. In Press. Evaluation of potential entrainment at Cherokee Nuclear Station, South Carolina. Proc. Symp. Freshwater Larval Fishes. Southeast Electric Exchange., Charlotte, NC.

Duke Power Company. 1974. Environmental Report, Perkins Nuclear Station, Vol. 1, 2, and 3. Charlotte, NC.

Fish, F. F. 1968. A catalog of the inland fishing waters in North Carolina. North Carolina Federal Aid Project F-14-R (Final Report), North Carolina Wildlife Resources Commission. 312 pp.

Geen, G. H., T. G. Northcote, G. F. Hartman, and C. C. Lindsey. 1966. Life histories of two species of catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Board Can. 23(11):1761-1788.

Hicks, C. R. 1973. Fundamental concepts in the design of experiments. Holt, Rinehart, and Winston. New York, NY. 349 pp.

Johnson, S. R., D. A. Blakesley, and T. J. Edwards. In Press. Chapter 7. Baseline environmental summary report on the Yadkin River in the vicinity of Perkins Nuclear Station.

Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, D. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River organisms. pp. 37-82. In: L. D. Jensen ed. Proc. of the Sec. Workshop on Entrainment and Intake Screening. Electric Power Research Institute.

Lillefors, H. W. 1967. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. J. Amer. Stat. Assoc. (62):399-402.

Marcy, B. C., Jr. 1974. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. pp. 281-288. In: L. D. Jensen ed. Proc. of second workshop on entrainment and intake screening. Electric Power Research Institute.

North Carolina Department of Natural and Economic Resources. 1970. Final report of investigation fish kills Yadkin River and High Rock Lake. Raleigh, NC.

_____. 1972. Report of fish kill investigation, Yadkin River at I-85, Upper High Rock Lake. Raleigh, NC.

_____. 1973a. Report of fish kill investigation, Upper High Rock Lake, Yadkin River at I-85. Raleigh, NC.

_____. 1973b. Report of fish kill investigation in Muddy Creek-Yadkin River, Yadkin-Pee Dee River Basin, Raleigh, NC.

_____. 1976. Report of investigation of Muddy Creek and Yadkin River fish kill Yadkin-Pee Dee river basin. Raleigh, NC.

Shelton, W. L. 1972. Comparative reproductive biology of the gizzard shad Dorosoma cepedianum (Lesueur), and the threadfin shad, D. petenense (Gunther), in Lake Texoma, Oklahoma. PhD Dissertation. University of Oklahoma. Norman. 232 pp.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ. 620 pp.

DENSITY AND DISTRIBUTION OF LARVAL SHAD (*DOROSOMA* SPP.) IN LAKE NORMAN, NORTH CAROLINA - ENTRAINMENT AT MCGUIRE NUCLEAR STATION

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INTRODUCTION

Proceedings of recent workshops edited by L. D. Jensen (1974, 1976) have focused attention on the entrainment of organisms in power plant cooling water systems. Some of the earlier work on this subject concentrated primarily on estimating mortality of entrained larvae (Marcy 1971, 1974). This paper concerns the distribution characteristics of larval shad (Dorosoma spp.) and the effect that distribution may have on entrainment at McGuire Nuclear Station (MNS).

The objectives of this paper are:

1) To describe the density and spatial and temporal distribution of larval shad (Dorosoma spp.) in the study area.
2) To describe how these factors may relate to entrainment when MNS begins operation.

Two species of Dorosoma occur in Lake Norman. Threadfin shad (D. petenense) were stocked after the reservoir was impounded to provide forage for largemouth bass (Micropterus salmoides) and striped bass (Morone saxatilis). Gizzard shad (D. cepedianum) originated from the pre-impoundment fish community.

STUDY AREA

Lake Norman, impounded on the Catawba River in 1963 by Duke Power Company, is the largest reservoir in North Carolina. It 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.

McGuire Nuclear Station, located just east of Cowan's Ford Dam, has two units with a combined output of 2,360 MWe. Unit one is scheduled to begin commerical operation in July 1979, unit two in March 1981. McGuire Nuclear Station will utilize two condenser cooling water intakes. The primary intake withdraws water

between 4.6 and 13.7 m below full pond. During summer a low level intake, 27.6 to 32.3 m below full pond, can be used to provide cooler hypolimnetic water (up to 44% of the total cooling water) to maintain a monthly average discharge temperature of no greater than 35 C.

The study area includes four sampling stations (Fig. 1). Station 1 is near the MNS intakes. The shoreline at Station 1 is steep rip-rap bank with no aquatic vegetation. Station 4 is located at the mouth of the discharge canal. The shoreline at Station 4 includes relatively steep banks of red clay hardpan with some overlying sand and mud. There is very little cover at Station 4 other than tree stumps below the water line. Station 6 is located at the north end of Ramsey Creek and is expected to be minimally affected by the thermal plume from MNS. The habitat at Station 6 is characterized by a shallow sandy bottom with gently sloping banks; there is some brush and aquatic macrophytes, primarily Eleocharis sp., in the back of the cove. Station 10, located 10.7 km upstream from Cowan's Ford Dam in the Davidson Creek arm of the reservoir, is a reference station and will not be influenced by the thermal plume from MNS. The habitat at Station 10 is similar to Station 6.

MATERIALS AND METHODS

Larval fish were collected using a nylon net 2.4 m long with a mouth opening of 0.91 m and a mesh size of 794 µm. A General Oceanics flowmeter suspended in the mouth of the net allowed calculation of the volume of water sampled. A 5.8 m aluminum utility boat powered by a 115 hp outboard motor was used to tow the net. In 1975 larval fish samples were collected weekly at Stations 1, 6, and 10 from 30 April through 23 September. Two replicate 5-min samples were taken at each substation (surface shoreline, surface channel and 5 m channel). Data collected at these stations are used to describe seasonal and spatial distribution

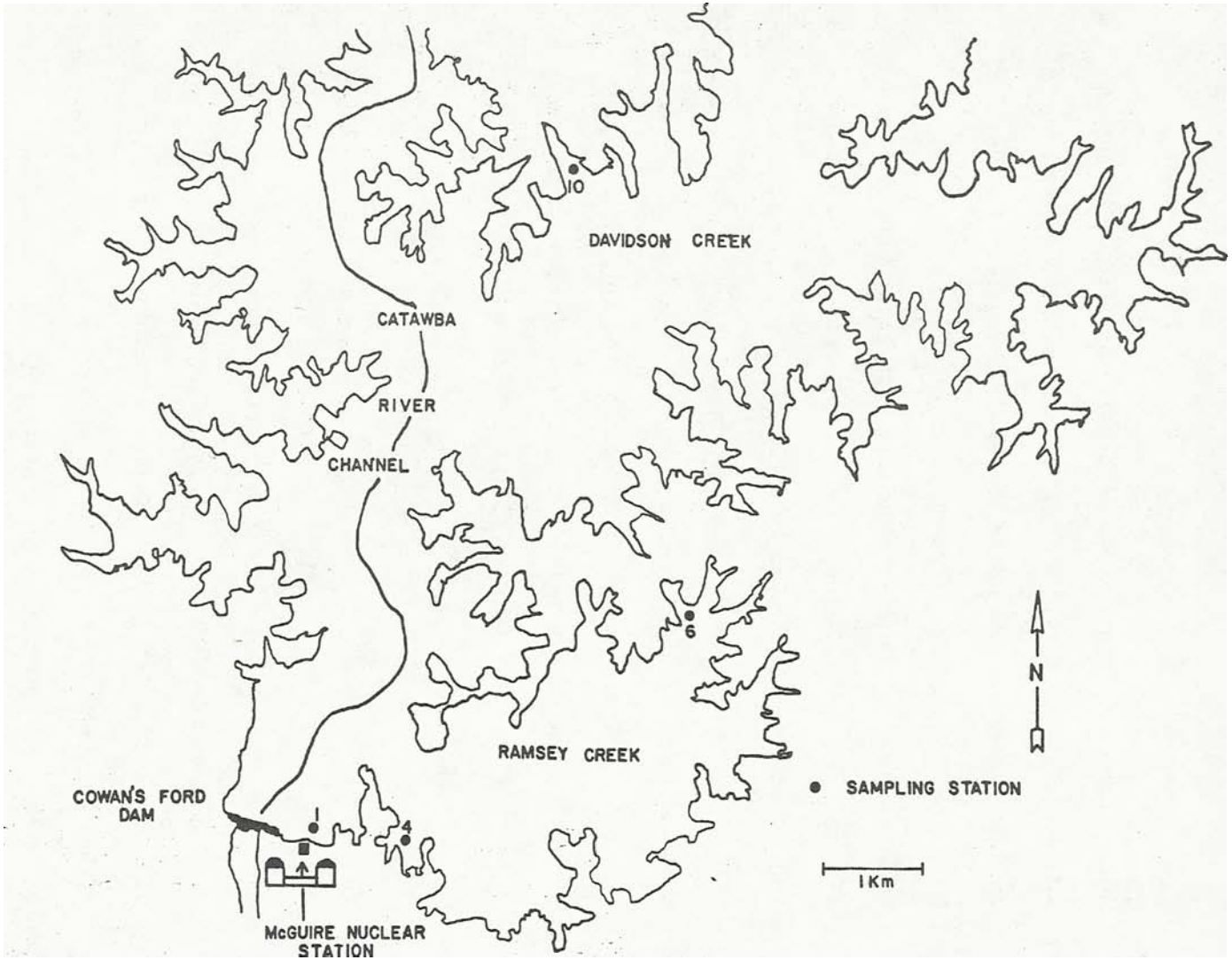

Figure 1. Map of the Lake Norman sampling area showing the location of Stations 1, 4, 6 and 10, McGuire Nuclear Station, and Cowan's Ford Dam.

within the study area. Data collected at Station 1 are used to describe both spatial and temporal distribution of larval shad near the MNS intake.

In addition to weekly samples, diel trawl samples were collected at Station 4 on 19 May 1975. Diel samples were collected in the channel at surface, 5, 10 and 15 m. Duplicate samples were collected at each substation at 0530, 1030, 1500, 2000 and 2400 EDST. Samples collected 0530, 1030 and 1500 were considered day samples; 2000 and 2400 were considered night. All samples were preserved in the field with 5% formalin.

In the laboratory, samples were sorted under a magnifying lamp. Larval fish were identified, measured to the nearest millimeter, counted and stored in 70% isopropyl alcohol. Since identification of Dorosoma spp. less than 20 mm is questionable and because, in the larval stage, the two Lake Norman species are similar ecologically, no effort was made to separate species of Dorosoma. Volumes for each sample were calculated and the number of larvae collected converted to number per 1000 m^3.

RESULTS

Weekly Distribution and Abundance

Weekly mean densities of larval shad at Stations 1, 6 and 10 (substations combined) are shown in Figure 2. Larval shad were common at all stations. Larval shad were first collected on 30 April at all stations when shoreline water temperatures were just above 18 C. Larval shad were most abundant during May and June, but by 3 September densities at the shoreline areas dropped to less than 10 larvae/1000 m^3. Densities showed distinct multiple peaks at each station. The highest density of larval shad (2,315/1000 m^3) occurred at Station 6 on 11 June. On 21 May maximum densities were reached at both Stations 1 and 10, 755 and 1,308 larval shad/1000 m^3, respectively.

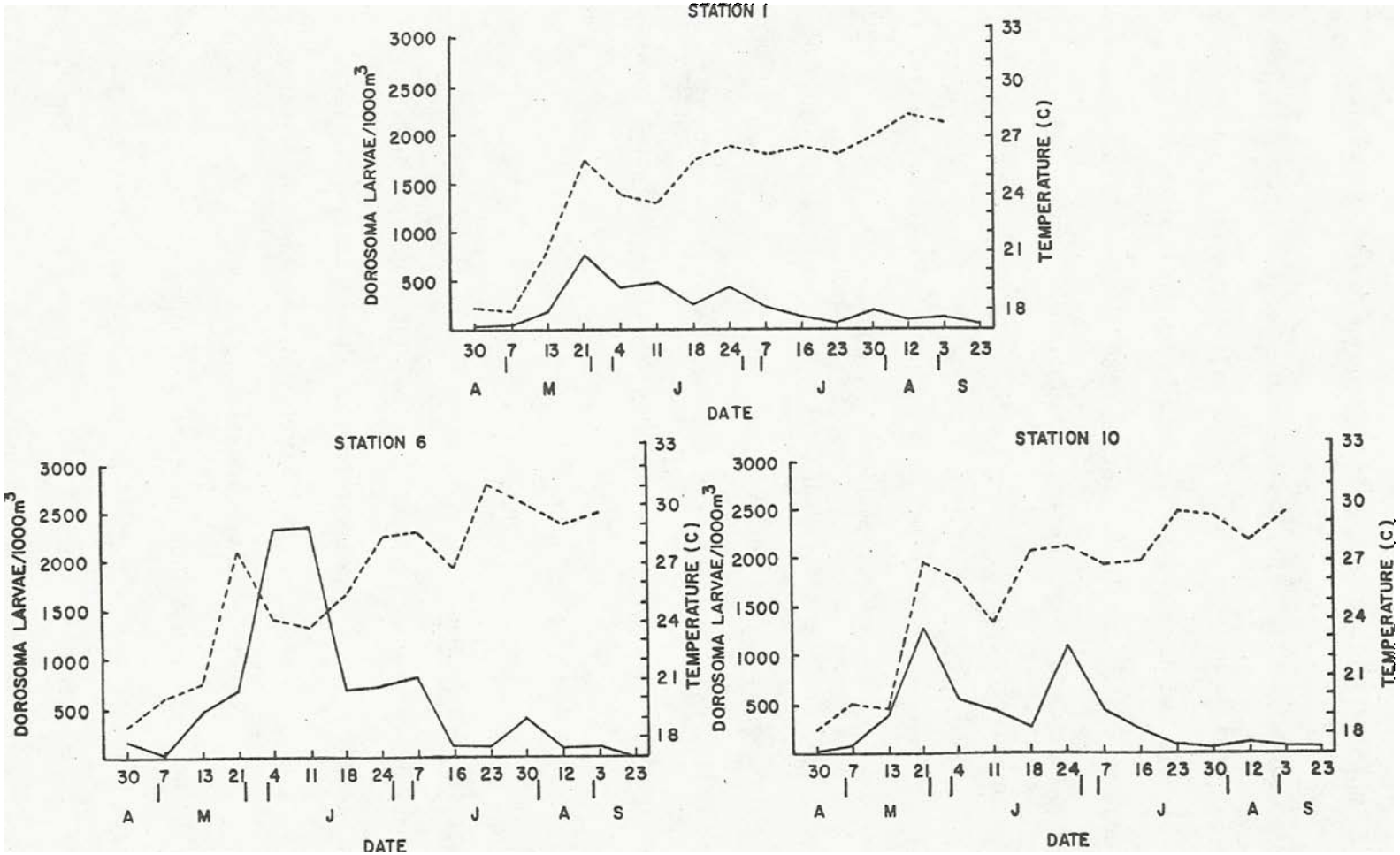

Figure 2. Densities of larval shad (Dorosoma spp.) and associated water temperatures (dashed line) on 15 sample dates during 1975 at Stations 1, 6 and 10 on Lake Norman. Values are mean densities from surface shoreline, surface channel and 5 m channel.

Intrastation distribution of larval shad (by 1-mm size class) at Station 1 is illustrated in Figures 3, 4, and 5. As the spawning season progressed, densities decreased at the surface shoreline and increased at the channel substations. All size classes (5 to 28 mm) were represented at each of the three substations at some time during the sampling period. Newly hatched larvae (4-6 mm) were not sampled efficiently; the smallest larvae collected efficiently were 7-9 mm in length. These were collected primarily from 13 May to 4 June and were most abundant at the surface shoreline substation. Larval shad greater than 20 mm were most common in the channel substations after 11 June.

Diel Distribution

Mean day and night densities at each depth are shown in Figure 6. Density of larval fish was highest at the surface during both day and night. Mean densities ranged from 613 larvae/1000 m^3 which occurred during night at the surface to 3 larvae/1000 m^3 which occurred during the day at 15 m.

During the day, the mean density of larvae collected at the surface was 115/1000 m^3. Day samples collected at 5 m were considerably lower in density (15 larvae/1000 m^3). Densities of larvae collected during the day were less than 5 larvae/1000 m^3 at both 10 m and 15 m depths.

The relationship of density to depth was similar during both day and night periods. Mean densities of larvae collected at the surface during night were higher than the corresponding day samples by more than a factor of 5. The mean density during night at 5 m (37 larvae/1000 m^3) was considerably lower than the density at the surface and, as was true for day samples, mean densities of larvae collected at 10 m and 15 m were less than 5/1000 m^3.

DISCUSSION

The collection of larval shad over a period of 15 weeks indicates that shad have an extended spawning season. The relatively high densities of larval shad

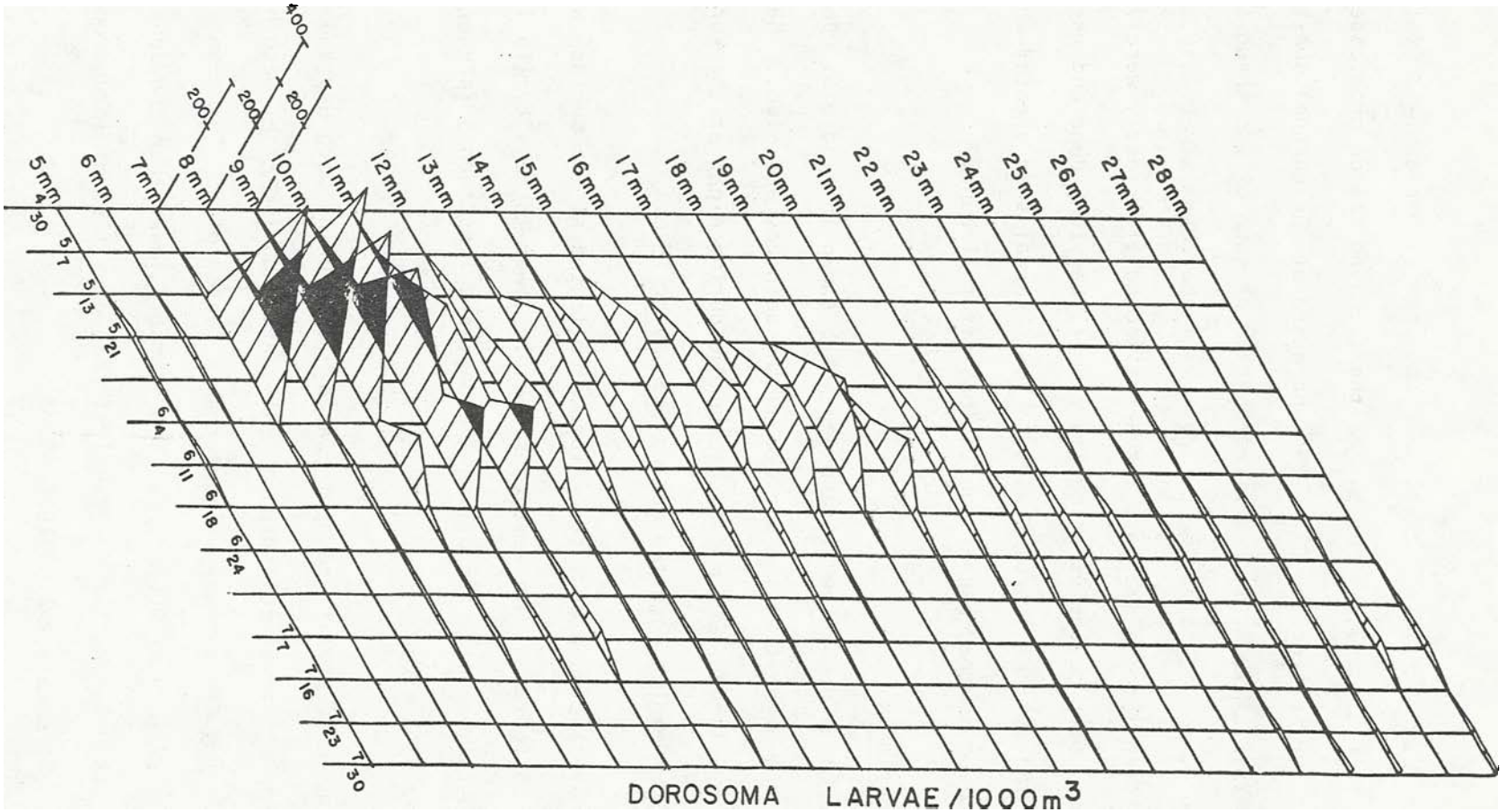

Figure 3. Densities of larval shad (Dorosoma spp.) on 12 sample dates during 1975 at Station 1, surface shoreline, Lake Norman. Values are means of duplicate samples collected on each date.

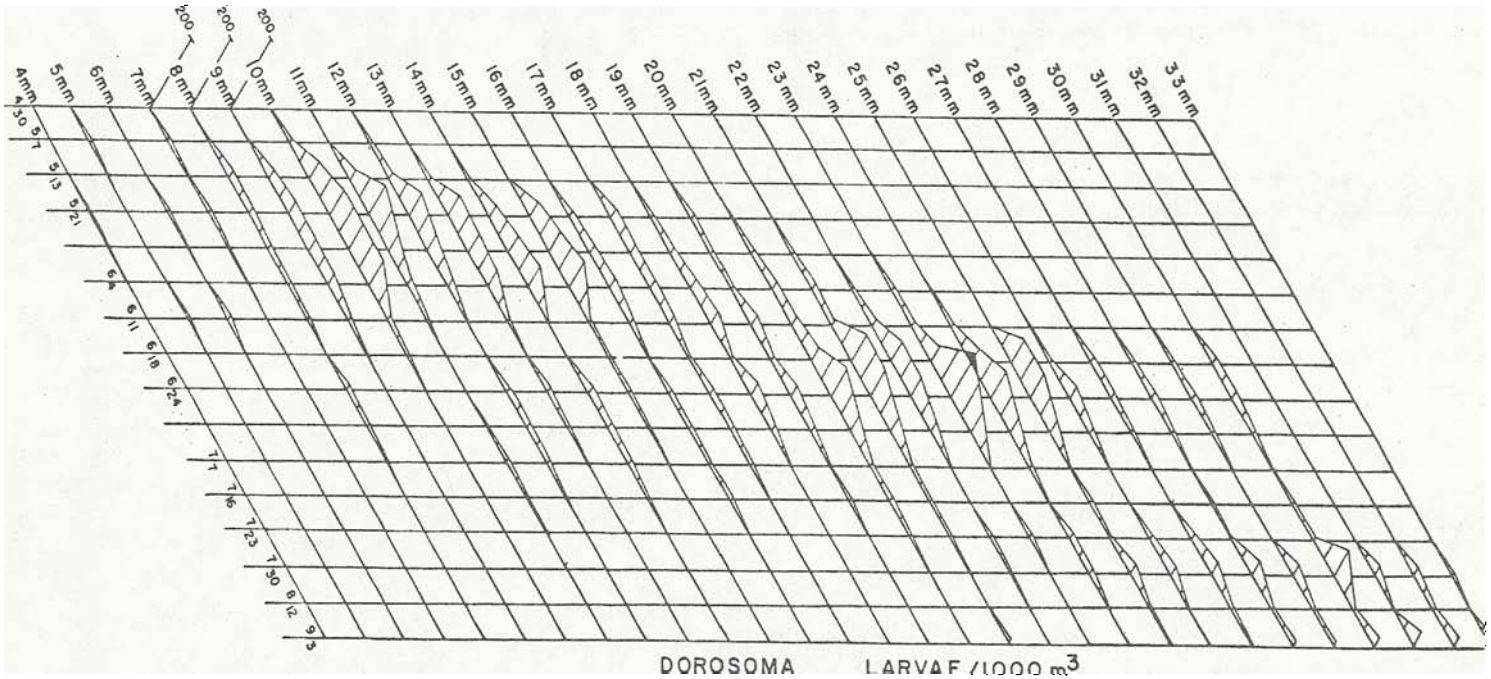

Figure 4. Densities of larval shad (Dorosoma spp.) on 14 sample dates during 1975 at Station 1, surface channel, Lake Norman. Values are means of duplicate samples collected on each date.

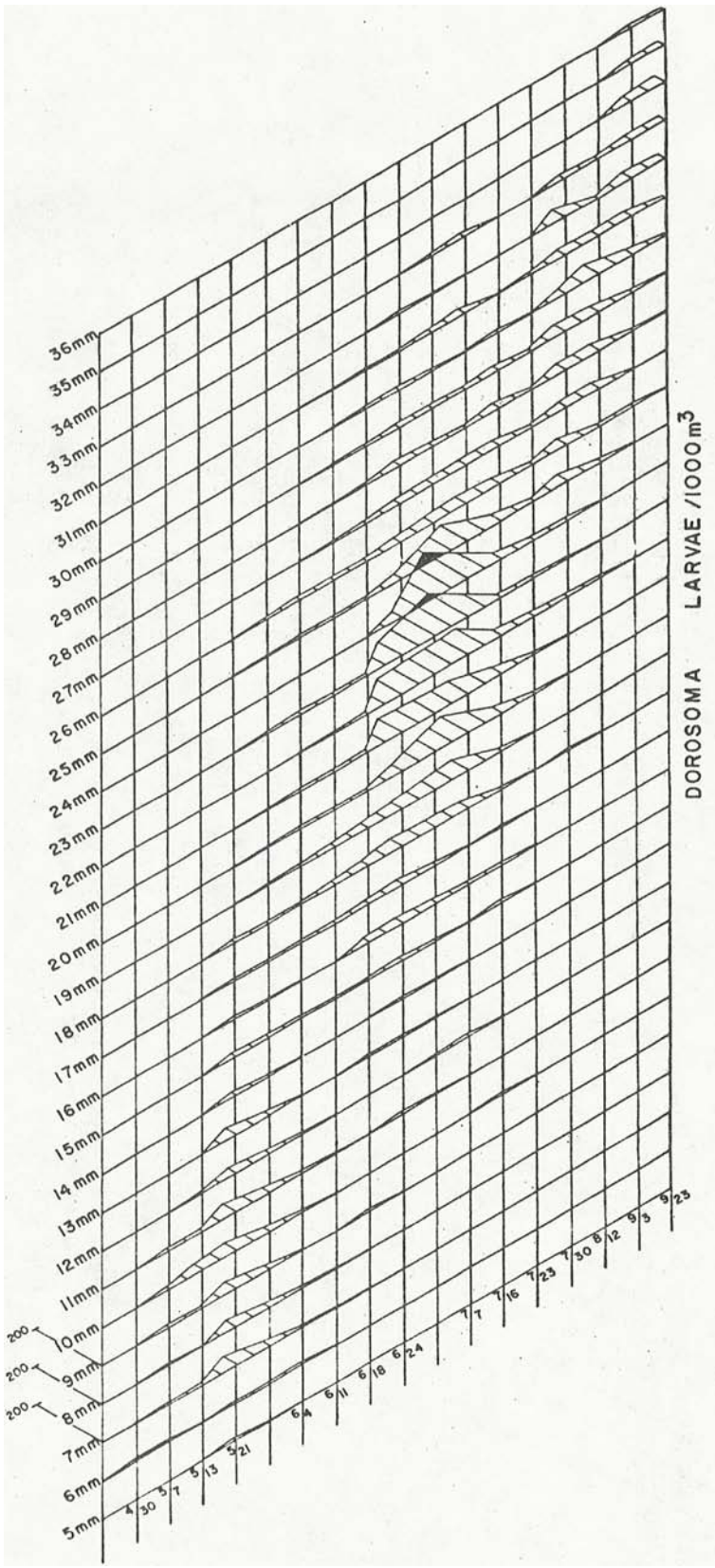

Figure 5. Densities of larval shad (Dorosoma spp.) on 15 sample dates during 1975 at Station 1, 5 m channel, Lake Norman. Values are means of duplicate samples collected on each date.

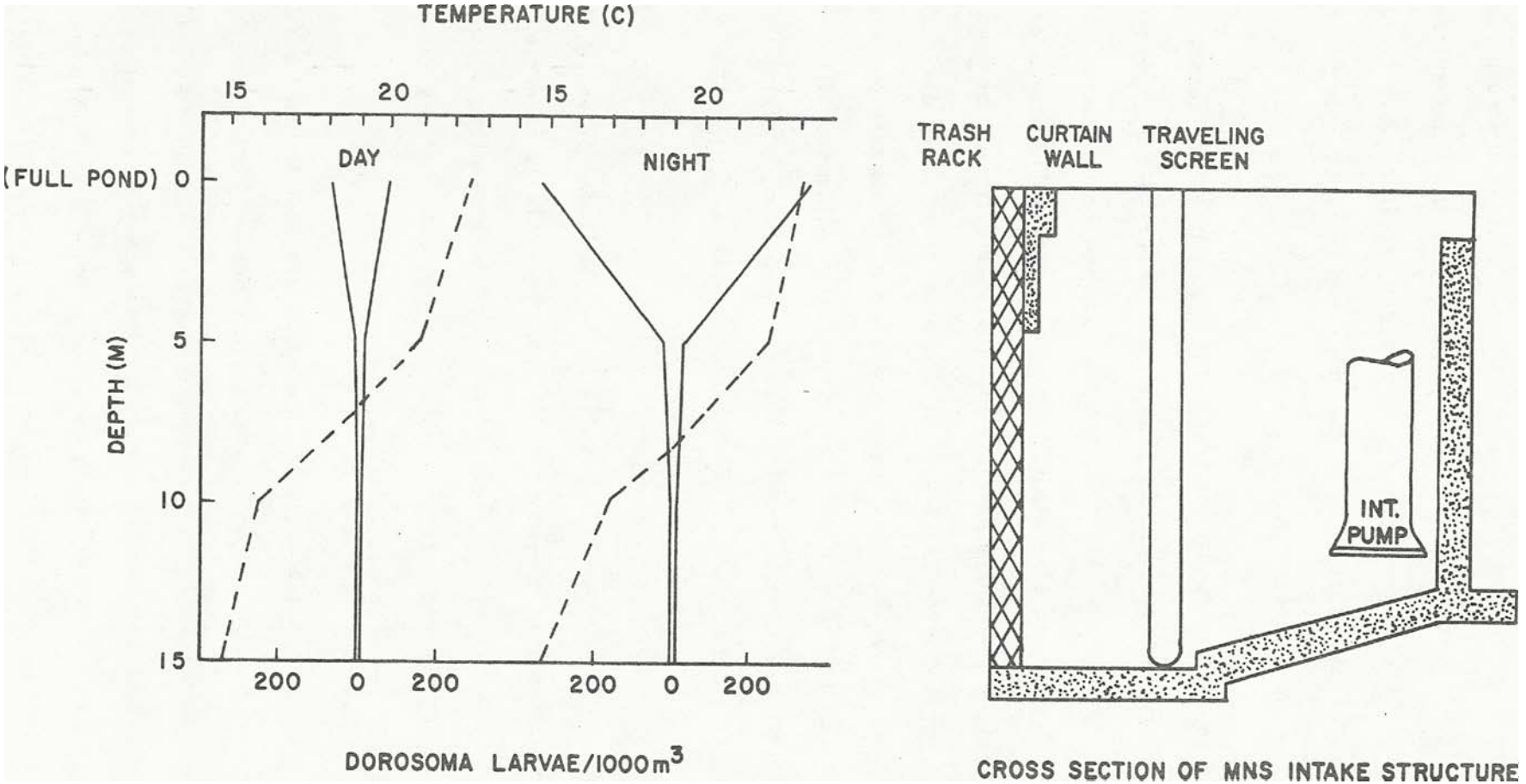

Figure 6. Day and night distribution of larval shad (Dorosoma spp.) and associated water temperatures (dashed line) on 19 May 1975 at Station 4, Lake Norman. Cross section of McGuire Nuclear Station intake structure shows relationship of intake opening to vertical distribution of larval shad.

collected at Stations 6 and 10 and the low densities at Station 1 were probably the result of habitat differences. Station 1 appears to be the least suitable for spawning of shad. The rip-rap banks are very steep providing very little shallow water. The station offers none of the preferred cover such as brush and aquatic vegetation as described by May (1968).

Newly hatched shad, approximately 4-6 mm in length, were rarely collected. Since newly hatched larvae must be abundant at some time during the spawning season, their absence in our samples indicates that our collection techniques were inefficient for the 4-6 mm size class. This may be partially explained with results reported by Shelton (1972). Shelton reported that although Dorosoma yolk sac larvae exhibit a negative geotactic and/or a positive phototactic response, when swimming activity ceases the larvae rotate 180 degrees and sink head downward because of the high specific gravity of the yolk mass. Therefore, the newly hatched larvae may tend to remain close to the bottom, becoming vulnerable to our sampling only after the yolk sac is absorbed and larvae begin swimming and feeding.

The relatively high densities of small larvae (7-10 mm) collected in the surface shoreline samples indicates that the majority of spawning activity occurred in the near shore areas. Low numbers of small larvae in channel samples suggests that some spawning occurs in open water. Similar spawning behavior has been reported for Dorosoma in Lake Texoma, Oklahoma (Shelton 1972).

As the spawning season progressed a segregation of size groups developed between shoreline, surface channel and 5 m channel areas. This not only emphasizes the need to include these habitat types in any study of larval shad populations but also suggests a migratory behavior of larval shad. Most spawning took place near shore; however, densities in near shore areas were low after 18 June when most larvae of the population exceeded 20 mm (Fig. 3). After 18 June, densities

of larvae greater than 20 mm increased at the channel substations (Figs. 4 and 5), indicating that as larvae approach and exceed 20 mm they migrate from shoreline to channel areas.

Diel data show that larval shad are most abundant from surface to 5 m deep during both day and night. Netsch et al. (1971) has also reported highest densities of larval shad from surface to 5 m in Beaver Reservoir, Arkansas. It has been pointed out by Netsch et al. that in their study 5 m coincided with the upper limit of the thermocline. This was true in Lake Norman when diel data were collected (Fig. 6), suggesting that the thermocline limits the vertical distribution of larval shad. The presence of larval shad reported at 10 m and 15 m can be partly attributed to contamination from shallower water as the net was put out and retrieved.

The relatively low densities of larvae in day samples from Lake Norman probably resulted from greater avoidance during daylight periods. Although swim speeds for threadfin and gizzard shad reported by Barnes (1977) are considerably less than the net speed used in this study, the avoidance reaction may have been in response to the towing cable, net bridle, boat or a combination of these factors.

Entrainment at McGuire Nuclear Station

Based on available data there appears to be several factors, both physical and biological, that may influence the magnitude of larval shad entrainment at MNS. The spawning of shad in Lake Norman is not a localized event. Therefore it would be impossible to locate an intake structure on Lake Norman that would not result in some entrainment of larval shad. However, because of differences in habitat, some areas are better suited as intake sites (from an entrainment standpoint) because densities of larval shad are relatively low throughout the spawning period. The MNS intake (Station 1) is located in an area of relatively low larval shad density. This factor will reduce the entrainment impact of larval shad.

The intake cove at MNS opens to the main channel of the reservoir and most cooling water will be drawn directly from the channel area. Thus, larvae in the channel area of Station 1 will be most directly associated with cooling water. Newly hatched larvae are not expected to be particularly vulnerable to entrainment. Newly hatched larvae (4-6 mm) probably sink to the bottom in near shore areas and are not generally present in the water column until a length of 7-10 mm is reached. Even at this stage larvae tend to remain inshore where they would not be highly susceptible to entrainment, except for those larvae in the immediate vicinity of the MNS intake structure.

Densities of small larvae (less than 20 mm) are relatively low in the channel, whereas larvae over 20 mm apparently migrate to channel areas. Thus, shad over 20 mm will be most directly affected by entrainment currents created by the condenser cooling water pumps. These larvae have greater swim speed capabilities than the smaller larvae and to some extent will be able to avoid the peripheral entrainment currents associated with the MNS intake. Larvae over 20 mm are not planktonic and are not expected to drift into the area of MNS influence from uplake. The effects of larval shad entrainment at MNS should be minimal and localized.

The physical design of the McGuire intake structure may also limit entrainment of larval shad. The cross section of the intake structure (Fig. 6) is shown relative to the vertical distribution of larval shad. We have assumed full pond elevation; although, lake level is dependent on rainfall and hydroelectric demand. It is clear that the curtain wall which extends 4.6 m below full pond elevation will provide a deterrent to entrainment of surface water and associated organisms. The effectiveness of the curtain wall in limiting the entrainment of shad larvae will be enhanced by high lake level and thermal stratification. In reality, both lake elevation and thermal characteristics will vary throughout

each spawning period and from one spawning period to the next. Nevertheless, the curtain wall may be an important limiting factor and one which deserves further attention at other sites.

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LITERATURE CITED

Barnes, J. M. 1977. The sustained swimming ability of larval and juvenile gizzard shad, Dorosoma cepedianum (Lesueur), and threadfin shad, D. petenense (Gunther), as related to entrainment and/or impingement by water intake structures of power stations. M. S. Thesis. University of Arkansas, Fayetteville, Arkansas. 141 pp.

Marcy, B. C. 1971. Survival of young fish in the discharge canal of a nuclear power plant. J. Fish. Res. Board Can. 28: 1057-1060.

_____. 1974. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. Pages 281-288 in L. D. Jensen, ed. Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Baltimore, Md.

May, B. 1968. Biology of the threadfin shad. Final Rept. North Carolina Wildl. Res. Comm. Div. Inland Fish. Job X-B, Proj. F-16-R. 13 pp.

Netsch, N. F., G. M. Kersh, Jr., A. Houser, and R. V. Kilambi. 1971. Distribution of young gizzard and threadfin shad in Beaver Reservoir. AFS Spec. Publ. No. 8: 95-105.

Second Workshop on Entrainment and Intake Screening. 1974. L. D. Jensen, ed. The Johns Hopkins University, Baltimore, Md. 347 pp.

Shelton, W. L. 1972. Comparative reproductive biology of the gizzard shad, Dorosoma cepedianum (Lesueur), and the threadfin shad, D. petenense (Gunther), in Lake Texoma, Oklahoma. PhD Dissertation. The University of Oklahoma. Norman, Oklahoma. 232 pp.

Third National Workshop on Entrainment and Impingement. 1976. L. D. Jensen, ed. Communications Division, Ecological Analysis, Inc. 425 pp.

ON THE USE OF PHYSICAL MODELS IN ENTRAINMENT RESEARCH[1,2]

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[2]Publication No. ____, Environmental Sciences Division, ORNL.

[3]Operated by Union Carbide Corporation for the Energy Research and Development Administration.

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ABSTRACT

An experimental program to evaluate the effects of entrainment on aquatic organisms is being conducted at ORNL. The damage to fish eggs and larvae during entrainment through condenser cooling water systems is one of the major environmental impacts of electric power plants. Studies at operating power plants have indicated that mortality rates can be excessive. These rates may vary among species and between plants. In order to assess the mortality associated with each component of the cooling system, a power plant simulator has been designed and is now under construction. The design of the apparatus is such that the internal hydraulics of an operating power plant condenser cooling system will be effectively reproduced. Experiments will be conducted using fresh water and marine fish species according to the experimental designs described herein. Rearing and holding facilities have been designed and assembled to assure a supply of specimens and allow assessment of delayed mortality. The identification of the factors which cause mortality during entrainment will provide a rational foundation for redesign of the components in cooling systems to minimize environmental impacts.

INTRODUCTION

Entrainment, the passage of non-screenable organisms through condenser cooling systems, is an environmental issue of some concern at the present time. Available evidence[1] suggests that many fragile fish eggs and larvae are physically damaged during entrainment through power station cooling circuits and that this damage either kills the organism directly, or greatly reduces later survival. In some power plant licensing cases,[2,3,4] this prospect has caused delay in the licensing procedures and alterations in siting and mode of operation. The mechanisms of biological damage have not been investigated carefully and the engineering criteria for minimizing or avoiding damage have not been obtained. The objective of entrainment research at ORNL is to define the biological and engineering parameters which cause mechanical damage to aquatic organisms entrained in power plant condenser cooling water, and the effects of these damages on organism survival, in order that cooling systems can be redesigned to minimize such damages.

The physical model approach has underlain entrainment research at ORNL. The use of a physical model (cooling system simulator) has several advantages. First, fish introduction and recovery points can be designed into the appratus so that individual components of the entrainment process can be examined. In operating power plants, internal sampling is usually impossible due to design or operation constraints. Second, a physical model can be designed to be adjustable, allowing controlled modification of the entrainment

stresses experienced by organisms. Also, a physical model allows the research to examine individual entrainment stresses and any synergistic effects that may occur. In addition, the approach produces data, useful for verifying mathematical models of entrainment effects, such as that developed by Ebey and Beauchamp (1977).*

Past entrainment research at ORNL has been carried out as a cooperative effort between the Engineering Technology and Environmental Sciences Divisions. As a result of this unique combination of engineering and biological knowledge, those studies[5,6] dealt with the problem of entrainment in a particularly penetrating way, examining the biological and the engineering aspects of the phenomenon, both to develop accurate definition of the mortality associated with parts of the entrainment process.

Entrainment research began at ORNL in 1973. At that time, an apparatus originally part of a nuclear reactor technology development program was modified to examine the effects of shear forces on small fish. It consisted initially of a pump, about 12 m of 5.08 cm diameter glass pipe and collecting gear, through which fish and water could be passed at a variety of flow rates. During these preliminary tests, pressure remained positive; vacuum conditions were not experienced by the fish. High speed motion pictures (11,000 frames per second) were used to examine the torsion experienced by young fish under these conditions. Those photographs showed the fish experiencing extreme

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*Ebey, S. F. and J. T. Beauchamp. 1977. Larval Fish, Power Plants, and Buffon's Needle Problem. American Mathematical Monthly, in press.

torsion, some being bent double by fluid forces. Carp subjected to these test conditions were found to be lethargic and unresponsive, although mortalities were low. It should be emphasized that although the water recirculated in the system, organisms did not pass through the pump. They were introduced into the loop downstream of the pump, and recovered upstream.

At the end of these preliminary experiments, the experimental loop was modified to include 12 m of 22 mm OD tubing. This size and length of tubing was typical of that found in Tennessee Valley Authority power plants, and made the loop a closer simulation of extant power plant conditions. Again, tests were run on carp larvae, using condenser-tube velocities of 2.1 and 4.6 m/sec. As with the preliminary experiments, mortalities were low, and lethargy was observed in entrained fish. Despite this obvious lethargy, they were not selectively eaten by bluegill (Lepomis macrochirus) predators. Additional experiments were run using tadpoles of the bullfrog, Rana catesbiana, the cladoceran, Daphnia magna, and juvenile silversides, Labidesthes sicculus at condenser tube velocities up to 6 m/sec. It was found that copper, used in the 22 mm tubing, poisoned the cladocerans, and the loop was refabricated to contain only glass, stainless steel and minor amounts of plastic. The conclusion reached as a result of these preliminary experiments was that shear forces associated with turbulent flow were probably not the cause of mortalities seen at power plants.[7]

The loop was then modified to allow partial vacuum ($\sim$1/2 atm) in the central portion of the condenser tubing. This configuration of the

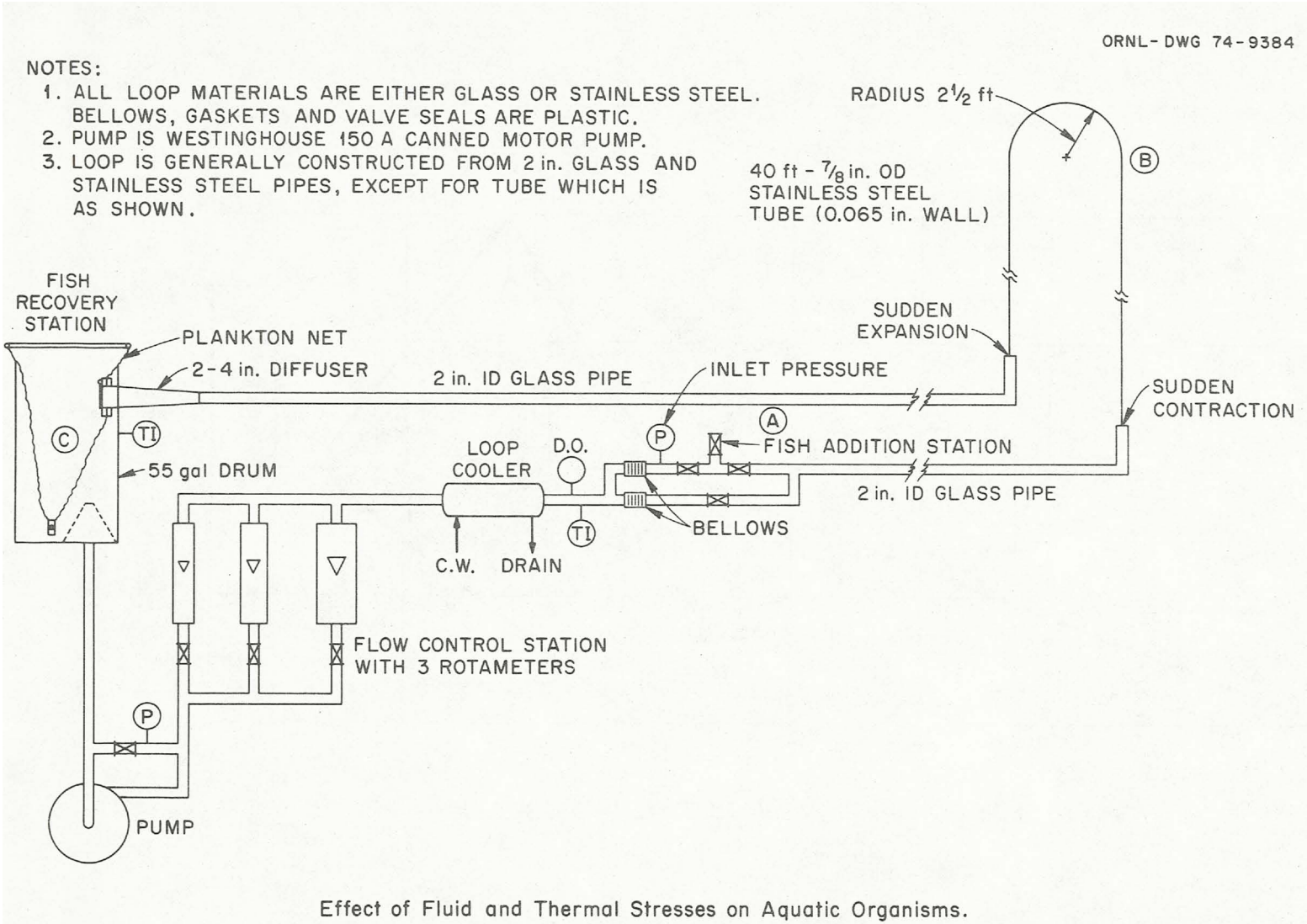
loop is shown schematically in Figure 1. Vacuum conditions were generated by the geometry of the system, (the U-shaped heat exchanger tube was mounted vertically) and partial vacuum was developed near the top of the inverted U. At a condenser tube velocity of 2.1 m/sec, about 0.5 atm vacuum was developed, (Figure 2) while at 5.8 m/sec, the pressure at the tube inlet was great enough to swamp out vacuum conditions.

Tests with bluegill and mosquitofish (Gambusia affinis) suggested that pressure changes might cause increased mortality and that fluid, pressure, and thermal stresses might act synergistically.[7,8] With the loop in a configuration that allowed examination of multiple stresses, more sophisticated experiments were begun.

From 90 to 95% of the fish were recovered from the loop in the experiments; computations of mortality were based on the number of fish recovered. Organisms were maintained at $\sim$ 20 C after the tests to observe latent mortalities.

With bluegill, there were no immediate mortalities (within 1 hr) after passage through the condenser at either test velocity. Assessment of latent mortality was obviated, however, by massive dieoffs attributed to inadequacy of the holding facilities.

The striped bass, (Morone saxatilis), when passed through the loop at 2.1 and 5.6 m/sec at nonlethal temperatures suffered less than 5% mortality within 1 hour. Both experimental and control fish died off at about the same rate (Figure 3) over the ensuing days, suggesting that delayed mortality associated with entrainment was of minimal consequence. When entrainment temperature was above tolerance thresholds,



Effect of Fluid and Thermal Stresses on Aquatic Organisms.

Figure 1. Schematic diagram of test loop. All loop materials are either glass or stainless steel. Bellows, gaskets, and valve seals are plastic, and a canned-motor pump is used (Kedl and Coutant, 1976).

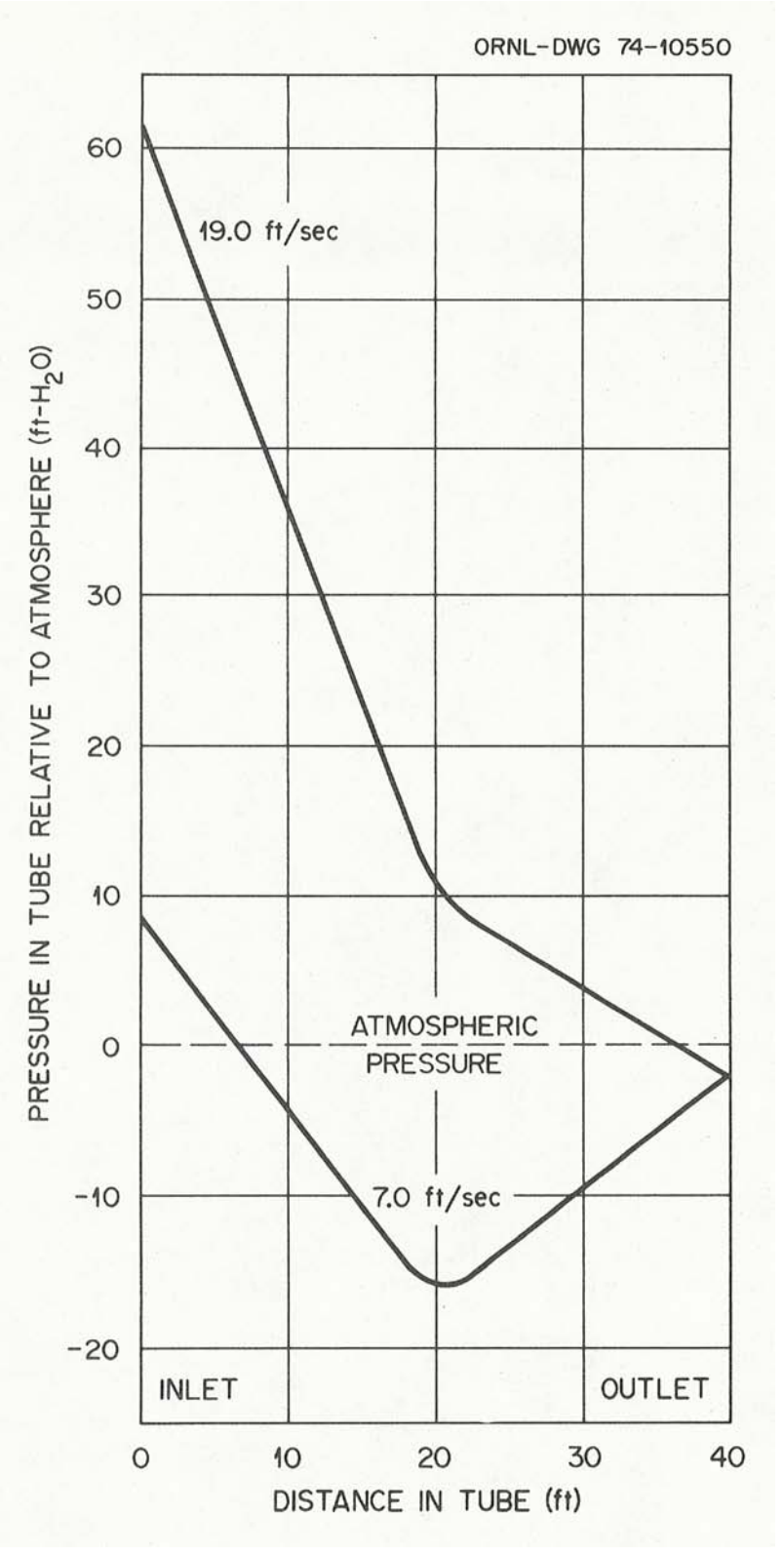


Figure 2. Pressure in tube relative to atmosphere (m H_2O) (Kedl and Coutant, 1976).

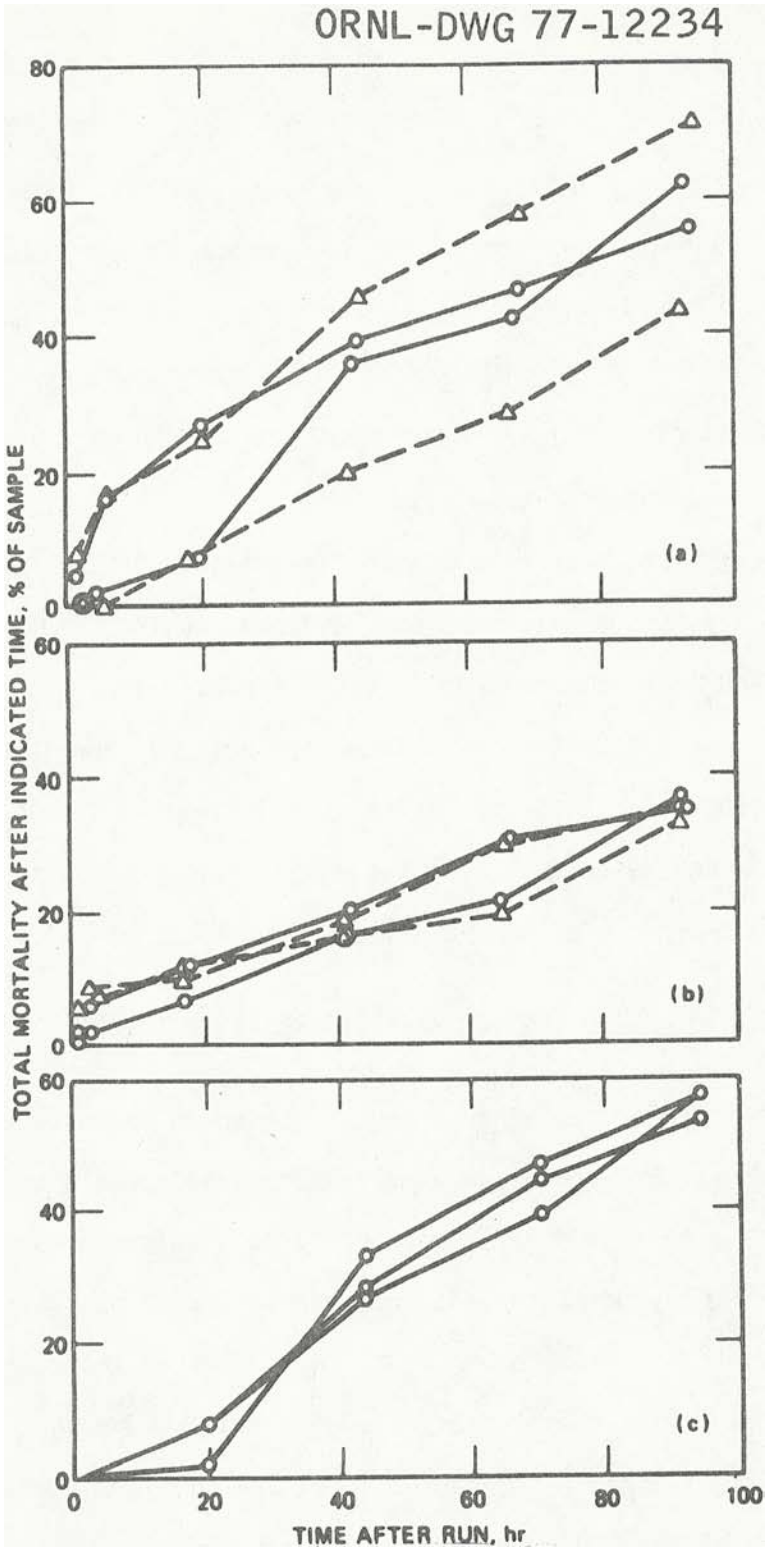


Figure 3. Percent mortality of larval striped bass tested at a non lethal temperature. (a) Loop velocity, 2.1 m/sec, low ΔT. o——o, tests 2 and 4. Δ--Δ, barrel control samples 3 and 5. (b) Loop velocity, 5.6 m/sec, low ΔT. o——o, 6 and 8. Δ--Δ, barrel control samples 7 and 9. (c) Absolute control samples 1, 2, and 3 (Kedl and Coutant, 1976). Note: "Barrel Controls" include handling stresses. Fish were added to the collecting barrel from a height of about 6" and were recovered with the plankton net. "Absolute Controls" were transferred gently from a transport bucket into a beaker of loop water. The only stresses to which these fish were subjected were those involved in living in a laboratory rather than their natural environment.

results were quite different. There was an initial substantial mortality, with subsequent dieoff rates which were similar in control and entrainment samples (Figure 4). While high control mortalities made precise analysis of the data difficult, these experiments lend strength to the hypothesis that condenser tube passage alone is not a major source of entrainment mortality.

Other factors need examination: cavitation by the pump, vacuum conditions (the vacuum conditions developed in the simulator were shorter and less extreme than is often the case in power plants) and the pump itself. Synergisms between factors are largely unknown, and may be important. These considerations led to the second major phase of entrainment research at ORNL, and the construction of a much more versatile experimental apparatus.

CURRENT ENTRAINMENT RESEARCH AT ORNL

Current research on entrainment is based on experience gained in the work described above. Planned experimental programs are based on the use of a new and more sophisticated cooling system simulator which more thoroughly models the internal hydraulics of operating power plant cooling systems. Previous work at ORNL suggested that condenser tube passage may not be the major source of mortality during entrainment. Accordingly, the new simulator was designed to allow examination of the stresses associated with pumps (cavitation, intense turbulence sudden changes in pressure, mechanical abrasion against the impeller blades), vacuum conditions, thermal effects and condenser tubing. Several objectives were delineated as the basis for the new work. Among these

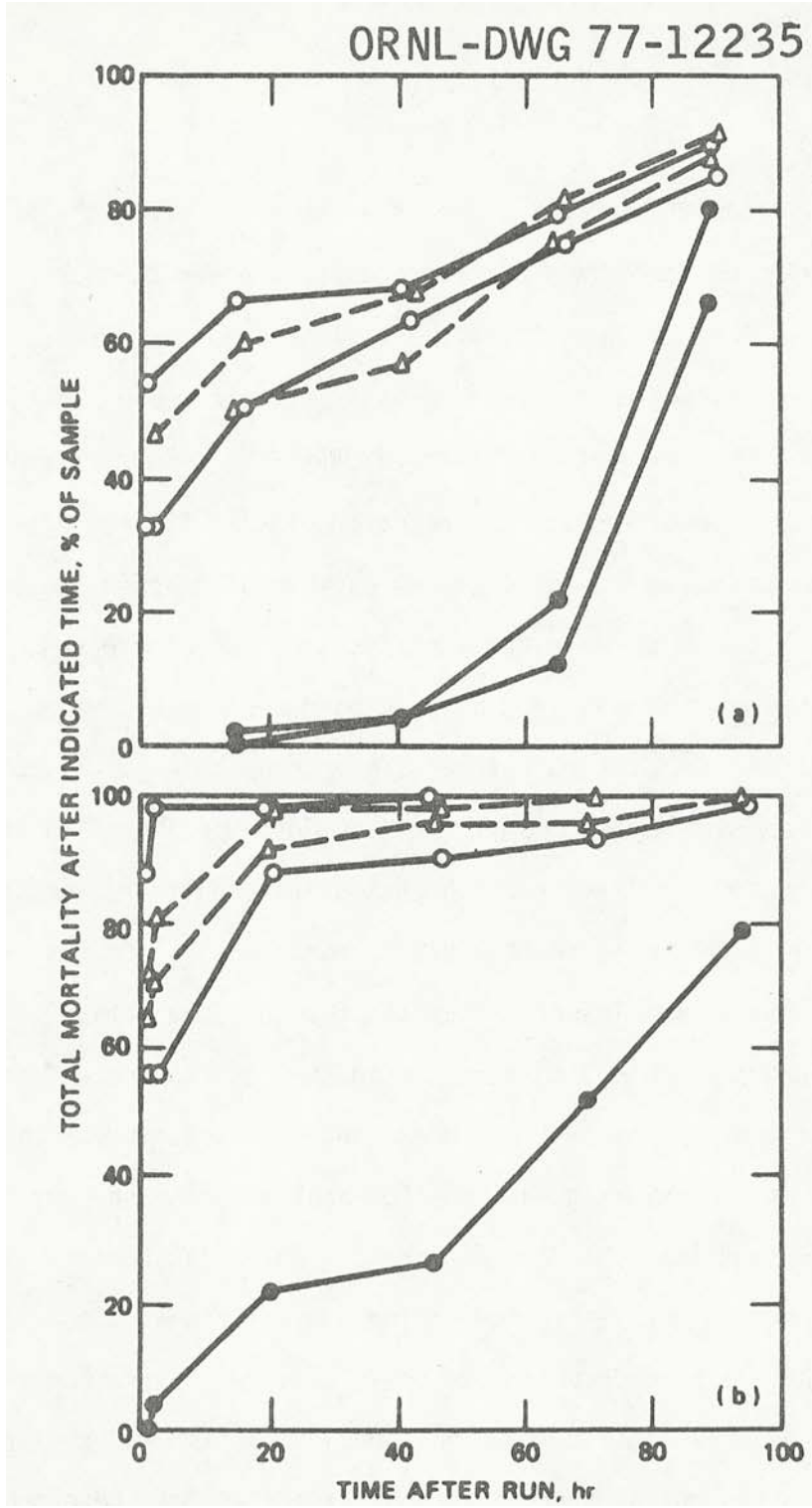


Figure 4. Percent mortality of larval striped bass tested at a lethal temperature and a loop velocity of 5.8 m/sec. (a) Loop temperature, 31.0 C. o--o, tests 8 and 10, high ΔT. Δ--Δ, barrel control samples 9 and 11, high ΔT. ●—●, absolute control samples 12 and 13, no ΔT. (b) Loop temperature, 31.9 C. o—o, tests 3 and 7, high ΔT. Δ--Δ, barrel control samples 4 and 6, high ΔT. ●—●, absolute control sample 5, no ΔT (Kedl and Coutant, 1976). Note: "Barrel Controls" include handling stresses. Fish were added to the collecting barrel from a height of about 6" and were recovered with the plankton net. "Absolute Controls" were transferred gently from a transport bucket into a beaker of loop water. The only stresses to which these fish were subjected were those involved in living in a laboratory rather than their natural environment.

were: (1) To estimate, through engineering evaluation, the mechanical and hydraulic characteristics of contemporary power stations that apparently contribute most to damage of fish eggs and larvae. This was necessary to provide an engineering basis for the design of the experimental apparatus, and was conducted at ORNL using design specifications from manufacturers and operating or planned TVA power stations (2) To provide an experimental system capable of exposing test fish to chosen stresses. The new experimental system was considered necessary because sampling difficulties and lack of experimental versatility at operating power stations make their use unacceptable (3) To obtain, spawn and rear sufficient fish for conduct of experiments, allowing large enough sample sizes for high statistical confidence in the results (4) To determine short and long term survival of fish eggs and larvae of several species after passage through a variety of hydraulically defined and controlled stresses in the test apparatus.

The scope of the project was broadened, to include determination of the impact of condenser passage on important plankton species at offshore power stations. One of the greatest potential sources of cooling water for power plants is in the marine coastal areas. Since these areas are highly productive and serve as nursery grounds for many economically and ecologically important species of fish and shellfish, mortality due to entrainment of various life stage of these organisms is of great concern. With minor design changes the test apparatus was modified to quantify mortality of entrained marine organisms.

The Cooling System Simulator

A highly simplified schematic drawing of the new simulator is shown in Figure 5. The apparatus is a closed loop, like the previous simulator built at ORNL.[9,10] Experimental organisms can be introduced into the system on either side of the pump, allowing evaluation of stresses associated solely with the pump. The adjustable elevation of the return piping will allow control of the vacuum to which the larval fish are exposed. The main tank is fabricated of 1/4" type 316 stainless steel. This particular alloy was chosen because it has very good resistance to saltwater corrosion. All the metal components of the simulator proper with the exception of the pump housing and impeller have been fabricated of #316 stainless steel. Thus, it can be used to examine entrainment effects on both marine and freshwater organisms.

The pump is an Ingersoll-Rand model 10 BPM (Figure 6) equipped with a Reeves Vari-Drive. A comparison of the hydraulic parameters of a typical power plant circulating water pump and the Ingersoll-Rand 10-BPM pump is shown in Table 1. Some explanation of the terms in Table 1 is in order that an evaluation of the 10-BPM pump as a simulation of power plant circulating pumps can be made. The less obvious parameters are listed below, with definitions.

a. Head. A measure of the pressure developed by a pump. Technically, it is the height of a vertical discharge above the pump at which design flow will be delivered. Twenty feet of head is equivalent to 8.7 psi.

b. Tip Speed. The velocity of an impeller blade tip at design RPM.

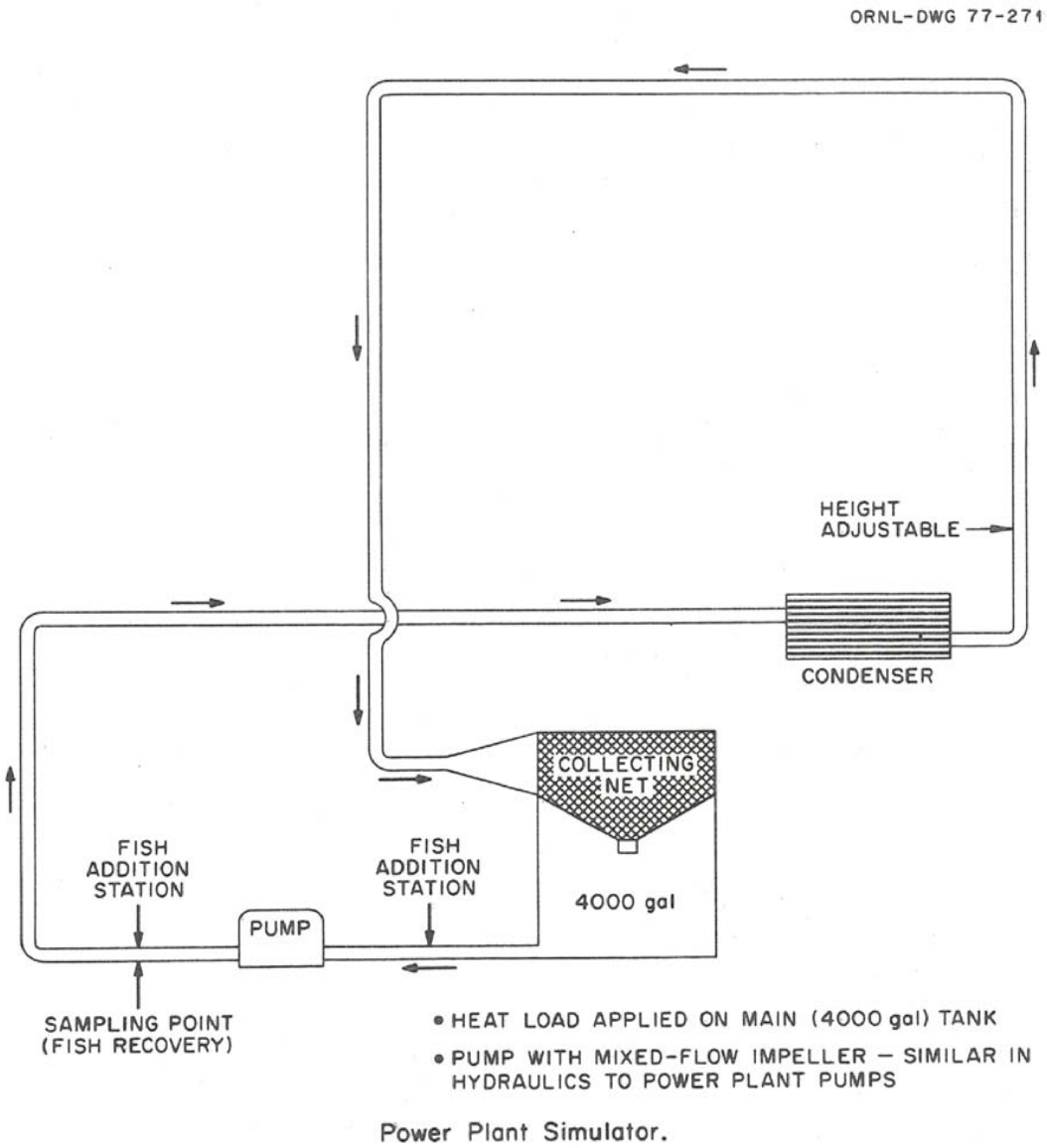


Figure 5. Schematic drawing of the cooling system simulator.

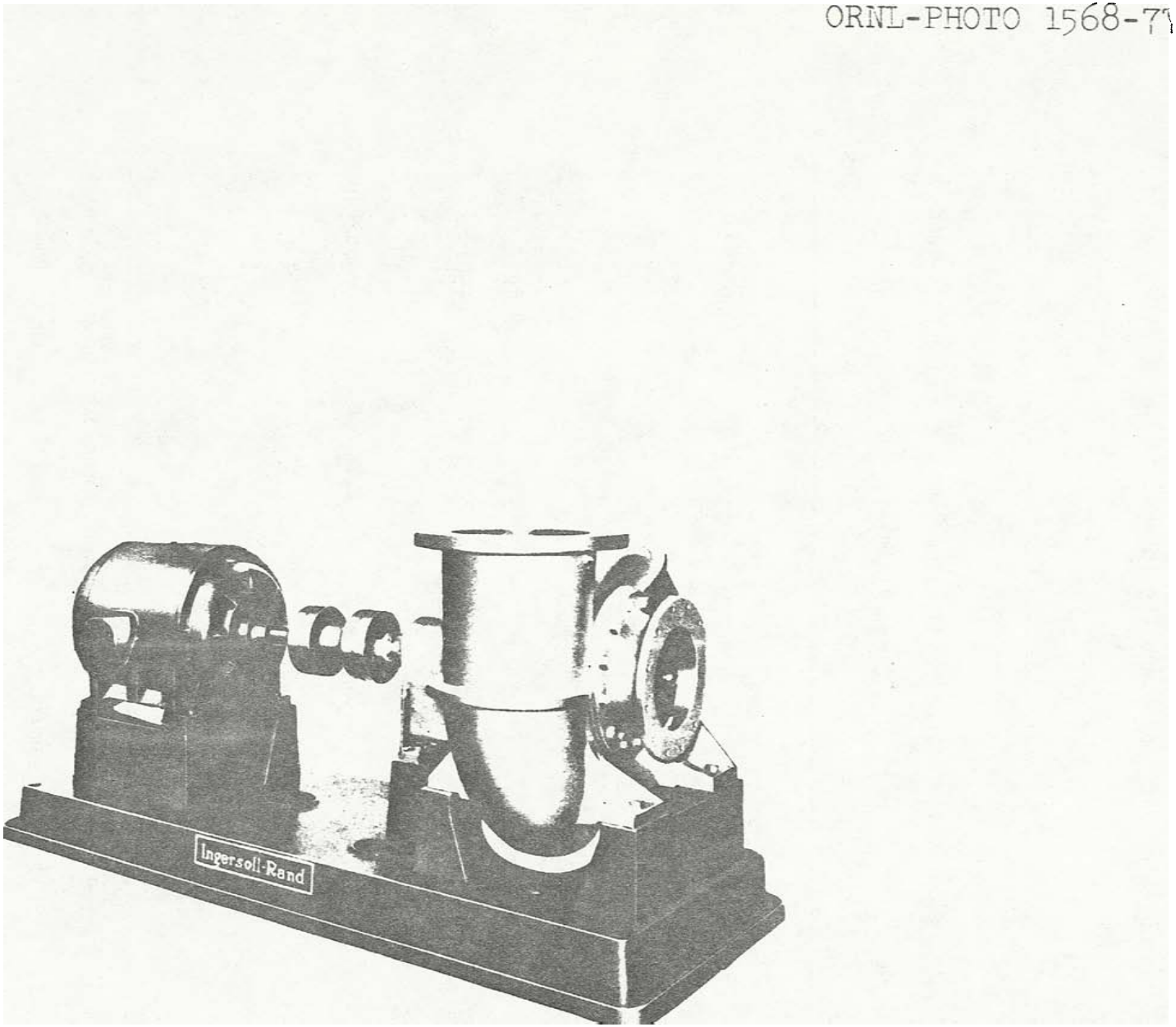


Figure 6. The Ingersoll-Rand 10 BPM Pump.

Table 1. Hydraulic parameter comparison between a typical power plant circulating water pump and the Ingersoll-Rand 10 BPM

Parameter	Typical circulating water pump (Bull Run Steam Plant)*	Ingersoll-Rand 10-BPM
Capacity	139,000 GPM	2000 GPM
Head	20 ft	22 ft
Tip speed	95 ft/sec	61 ft/sec
NPSH - Required	13 ft	13 ft
Maximum sphere size	Large	2 in
Specific speed	94600	5150
Impeller	Mixed-axial	Mixed
Suction	Wet Pit	Flanged Pipe
RPM	235	1170
Diffuser type	Axial diffuser vanes	Volute
Efficiency	90.5%	72%

*The values listed as typical for power plant pumps are those for the units at TVA's Bull Run steamplant, and are comparable to those for 8 other TVA plants examined as a basis for this comparison.

c. NPSH. Net positive suction head. This term refers to the decrease in pressure at the pump intake, which is the height above the surface of source water that the pump can run at design conditions without cavitation. (Cavitation is localized boiling caused by localized vacuum conditions).

d. Maximum Sphere Size. The size of a sphere that will just pass between adjacent impeller blades.

e. Specific Speed. This parameter is defined verbally as the speed in rpm at which a geometrically similar impeller would run if it were of a size to have 1-GPM capacity against a 1-ft head. Mathematically, it can be defined as:

$$N_S = \frac{rpm\sqrt{gpm}}{H^{3/4}},$$

where N_S is the specific speed and H is the head in feet for which the pump was designed, corresponding to its gpm capacity. Specific speed is a fundamental parameter in pump design and an index to the impeller type, with centrifugal pumps having specific speed values from 900 to around 3000, mixed flow pumps ranging from 3000 - 9500, and axial pumps having values above 9500. A discussion of the various impeller designs[11] and a detailed treatment of specific speed[12] are available.

f. Suction. The type of intake structure.

g. Diffuser type. The hydraulic component used to convert kinetic to potential energy and straighten out the flow.

h. Efficiency. Measures the conversion of energy by the pump. Inefficiency in pumps ends up as fluid turbulence and ultimately, as heat.

It is worthwhile to consider several of the parameters in detail. The head (20 ft) found in the TVA (see Table 1) pumps is closely approximated by the simulator pump. Occasionally, pumps with much greater head are installed in power stations. However, it was felt that a head value typical of the plants examined (19-27 ft) would be the most useful in the simulator.

The specific speeds of the pumps indicate that they are of mixed-flow design. Although the power plant circulating water pumps are at the upper end of that design class, the shape and geometry of the impellers are very similar. This similarity in impeller design is felt to be an important factor in the interaction of the pump with entrained organisms, and is one of the principal reasons for the selection of the 10 BPM pump.

The diffuser type is of considerable interest. In the power plant ciculating water pump, axial diffuser vanes (see Fig. 7) are used to convert kinetic to potential energy and straighten out flow, while in the simulator pump (see Figs. 8, 9) a curved volute is used to accomplish the same end.

Pump efficiency is much higher (90.5%) in the CW pump than in the simulator pump (72%). This is primarily due to design factors. The CW pump is custom-designed for its specific application, while the BPM

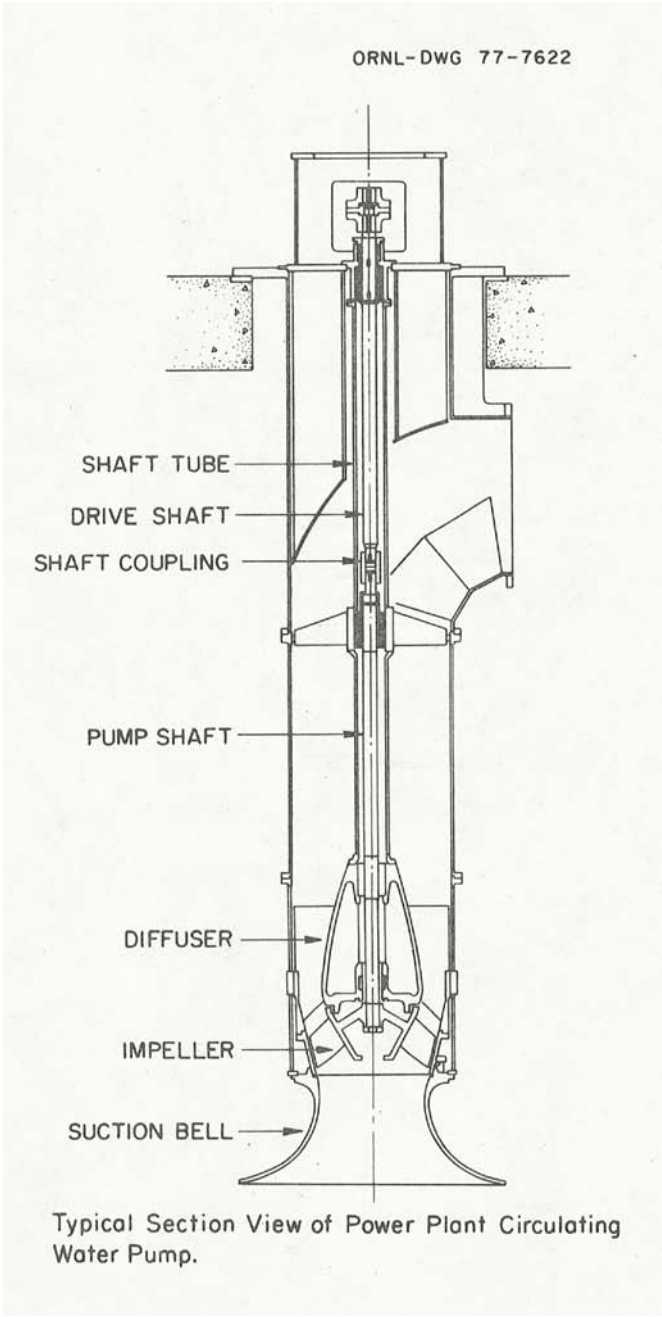


Figure 7. Section view of a power plant circulation water pump.

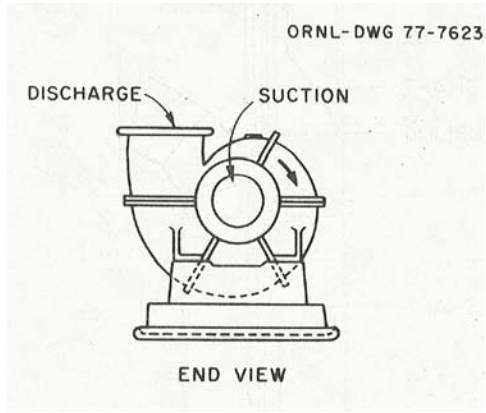


Figure 8. End view of a BPM pump.

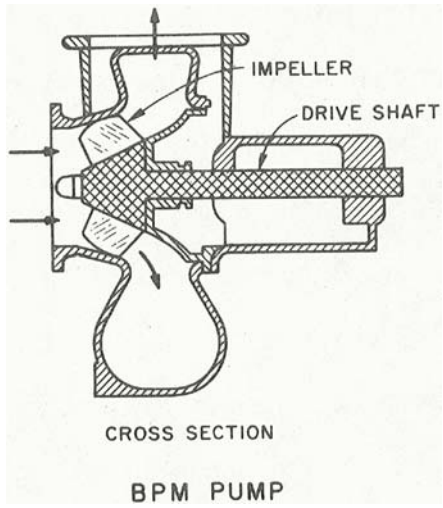


Figure 9. Cross section of a BPM pump.

pump is an off-the-shelf model, which contains several design compromises necessary to broadening its range of possible uses. Since the simulator pump is less efficient, and pump inefficiency is expressed initially as turbulence and ultimately as heat, the simulator will represent a worst case situation. This consideration coupled with the NPSH value for the unit (13 ft) and the Reeves vari-drive will allow examination of off-design (inefficient) pump operation. This is opportune, as it is felt at this time that pump efficiency may be strongly correllated with entrainment mortality.

The small sphere size of the simulator pump could be a problem if experimental organisms are large in comparison. However, with small test animals (length:1-2 cm), the problem will be minimized.

In selecting the pump for the power plant simulator, the parameters judged to be of prime importance are head and specific speed (impeller type). Other parameters were chosen as follows. Capacity should be as low as possible. It was recognized that it would be in the thousand GPM range. Maximum sphere size should be as large as possible, suction configuration was judged not to be of primary importance. In addition, it was judged that a piped suction would result in a cheaper and easier to operate loop. Diffuser design, while possibly important, was a factor over which we had little control. Tip speed and RPM were judged to be unimportant. Finally, the pump had to be commercially available and based on and existing design. In this framework then, the 10 BPM pump represents an effective simulation of a typical power plant circulating water pump.

The piping in the loop is fabricated of polyvinyl chloride (PVC). This material will allow easier adjustments in dimensions than would iron pipe. In addition, PVC is unaffected by salt water, an important consideration, since seawater will be used in experiments on marine organisms. Valves will be made of stainless steel to minimize corrosion problems.

The condenser was purchased from Manning and Lewis Engineering Company. Made of #316 stainless steel, it was designed to produce flow velocities typical of operating condensers. At design flow rates 126.2 liters/sec (~2000 gpm) condenser tube velocities will be 146.3 meters/min (8 fps). The device is made of seventy-three 3.18 cm (1 1/4") OD tubes with water boxes at each end. About 10 feet of head is lost across the condenser, again typical of the pressure changes in operating stations.

As shown in Figure 5 the height of the loop is adjustable. This is accomplished by using spool pieces in the vertical runs of pipe; adding and removing them to produce desired conditions in the top horizontal run of pipe. The main reason for this feature is to allow development of up to one atmosphere of vacuum. Vacuum conditions are often found in once-through cooling systems and merit a good deal of investigation. Sudden decompression in static test chambers has been examined and found it to be a significant mortality factor.[13] We suspect that vacuum may be one of the more critical components of the entrainment process and plan to look at several degrees of vacuum exposure.

At the discharge end of the loop, a diffuser has been installed to lower water velocity. This has been done to ensure survival of the

test organisms during retrieval. Work at power plants has repeatedly shown that larval fish suffer heavy net mortality at velocities greater than 3 fps. The retrieval system in the loop is designed to yield through-the-net velocities of around .25 fps, making net mortalities a minor consideration in experimental design. The retrieval net was fabricated by Wildlife Supply Co. to our specifications. It is 2 m in diameter, with 500 micrometer mesh and stainless steel fittings. The main tank is externally equipped with Heat Sheets which are supplied with hot and cold water as well as steam. This heating/cooling system will allow experimental temperatures from 4 C to about 40 C $\pm$ 0.1 C.

Support Facilities

In order to maintain experimental organisms before and after tests, maintenance facilities have been built (Figure 10). One hundred forty-four 5.5 litre aquaria have been fitted onto temperature controlled (4-40 C) water supply manifolds. Each aquarium has an independently controlled flow-through rate, and all are connected to a common drain system. The facility will allow maintenance of several experimental and control groups at the same time.

To allow experimentation with marine organisms, a sea water support system has been designed as an adjunct to the power plant simulator. Consisting of a 8000 gallon reserve tank, a biofilter and associated piping, it will permit experimentation and associated maintenance of several different species at the same time.

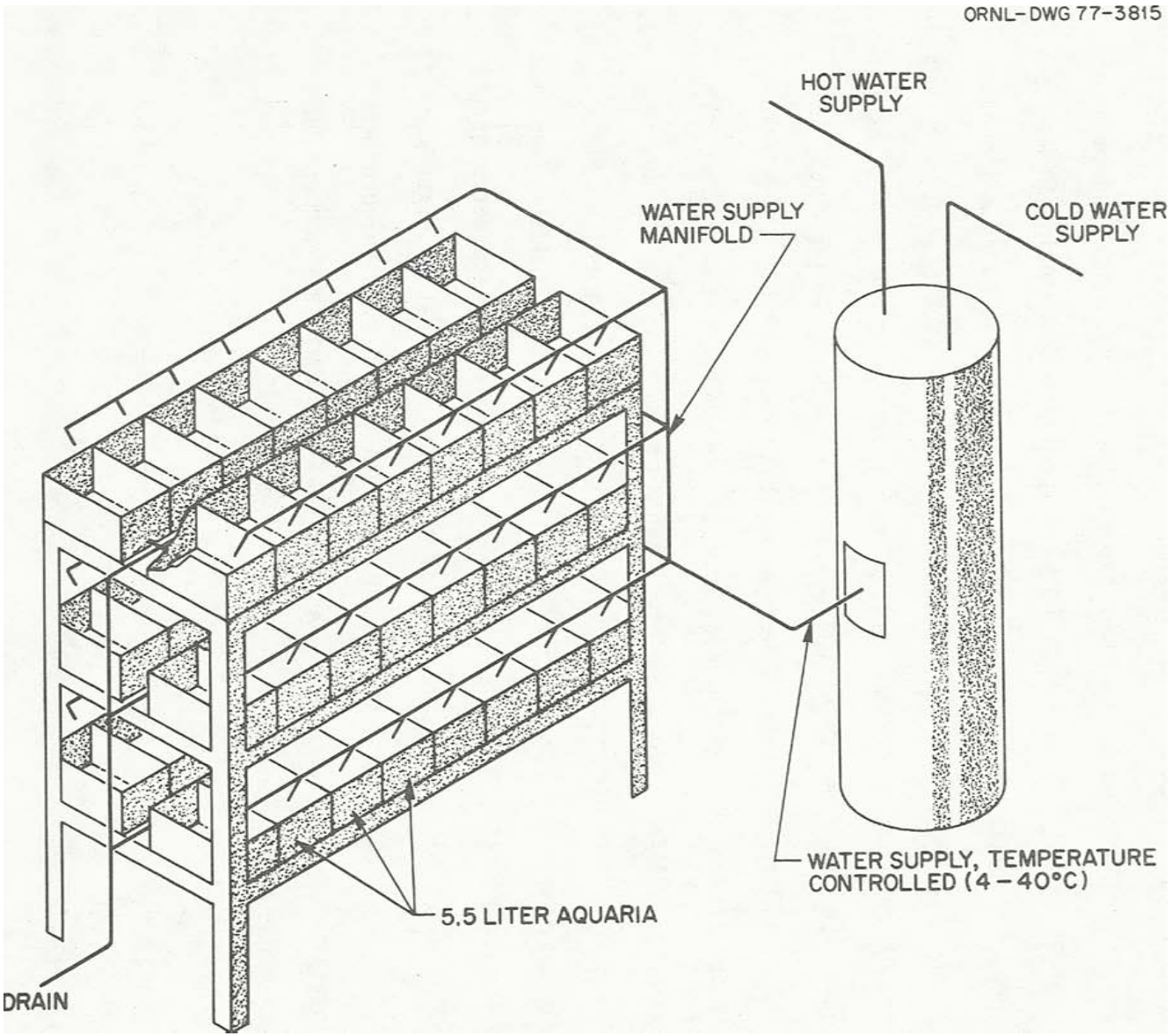


Figure 10. Test organism maintenance facility.

WORKSHOP

Prior to the construction of the cooling system simulator, a workshop was held at ORNL. Specific goals of the meeting were to evaluate the design of the apparatus and to assess the useability of ORNL's proposed research program.

Workshop attendees included representatives from pump and condenser manufacturers (Ingersoll-Rand Corp.), architect-engineering firms (Burns and Roe), the Tennessee Valley Authority, Southern California Edison Co., New York University, and New York State ERDA. A brief summary of the conclusions reached by the participants can be made as follows. The basic design of the simulator was judged to be sound. Several minor modifications were suggested, changes that would add flexibility to the experimental program and increase the accuracy of sampling. These suggestions have been incorporated into the design. It was felt that there is a high probability of our experimental results being used for redesign by the electric power industry and that the most effective avenue of communication between the research effort and industry was via the regulatory agencies. One rather surprising conclusion reached by industry representatives was that the projected budget for the ORNL project ($500,000) was too low; they encouraged a search for broader funding.

Planned Experiments

Test Species

In order to maximize the utility of experiments run on the simulator, careful selection of target species has been made. Entrained species have been identified from environmental monitoring programs during the early years of power plant operation. The most commonly entrained species were identified from data on two nuclear power plants, Surrey (an estuarine situation) and Peach Bottom (a freshwater situation). In addition, the Tennessee Valley Authority provided entrainment information from several plants in the Southeast. From these sources, a list of potential experimental organisms was developed for freshwater situations. The gizzard shad, Dorosoma cepedianum, threadfin shad, Dorosoma petenense, channel catfish, Ictalurus punctatus, the cyprinid , Cyprinus carpio, and the catostomids Carpiodes sp. and Catostomus commersoni, along with the bluegill, Lepomis macrochirus, yellow perch, Perca flavescens, and freshwater drum, Aplodinotus grunniens will be used in initial experiments. The striped bass, Morone saxatilis will be used in both fresh and salt water experiments. Other salt water test organisms will be the menhaden Brevoortia tyrannus, the spot, Leiostomus xanthurus the anchovy, Anchoa mitchilli and the naked goby, Gobiosoma basci. In addition to fish species, zooplankton, mostly cladocerans and copepods, will be used. Other organisms will be used when obtainable.

Experimental Sequence

The basic experimental approach will be to first examine pump-related mortality, as this factor is the least understood of all the components of the entrainment process. The effects of vacuum conditions will be evaluated next, as there is reason to believe this may be a significant mortality factor. The effects of these two stresses in combination will be examined, to see if there is any synergy between them. Upon completion of these basic studies, the effects of temperature and biocides in conjunction with other stresses will be evaluated. Experimentation will begin in June 1977. It is anticipated that 3-5 years of experimentation will be necessary to fully utilize the potential of this system.

Experimental Design

The basic design of the experiments is straightforward. A stock of larval fish will be divided into two groups, one of which will be used as a control, the other as a test. Treatment of control groups will be uniform. They will be handled in exactly the same manner as test groups, (i.e., poured into containers, moved about the laboratory, placed in maintenance aquaria,) but will not go through the simulator. In order to assess mortality associated with recovery from the system, a preliminary series of experiments will be performed with each species.

It is anticipated that mortality rates, even in controls, will be quite high, necessitating a rather sophisticated analytical procedure. This high mortality is common to many larval fishes.[14] Present plans are to use a categorical linear model (a categorical analog of analysis

of covariance.)[15,16] This analysis will compare control and test conditions by using a categorical covariance program LINCAT.[15]

Delayed mortality will be evaluated over a five-day period, a long enough interval to allow delayed mortality factors to manifest themselves. Tests also will be carried out to evaluate possible variations in susceptibility to predation that might be associated with entrainment. In these experiments, larval fish from both experimental and control groups will be subjected to predation by bluegill predators, using experimental techniques developed by the author.[17] Experiment will also be carried out to examine the relationship between feeding ability (prey selection and feeding efficiency), providing a broad scale trophic examination of the effects of entrainment.

MODEL DEVELOPMENT

In order to provide a basis for assessment of pump-related mortality, members of ORNL's Computer Sciences Division were asked to develop a model to assess the probability of larval fish being killed by an impeller blade of a pump in a power plant intake. The following assumptions were given as the basis of the problem:

1. The velocity of the water is such that the fish can be considered as floating in the stream, not swimming; and turbulence is so great that the spatial orientation of the fish can be assumed to be random.

2. The density of the fish is assumed to be the same as that of water; the distribution of the fish can, therefore, be considered random.

Using the basic arguments of Buffon's needle problem (where a needle of unit length is thrown at random onto a plane partitioned into strips of parallel unit width) Ebey and Beauchamp[18] developed two solutions; one where the pump blade was consiered to be a line of no thickness, and a second, where the pump blade was considered to have a finite thickness.

The first of these formulations is

$$P = 4\ nL/\pi^3\ (R + R_o), \text{ where}$$

P is the approximate probability of a fish dying on the cutting edge of the impeller.

n is the number of impeller blades.

L is length of the larval fish.

R is the radius of the intake tube.

R_o is the radius of the impeller hub.

The second formulation defining the probability of a fish being killed by the pump assumes the killing region is a band the width of an impeller blade, and uses a new parameter, D which is the width of the blade. The formulation is

$$P' = n\ (4L + D\pi^2)/\pi^3\ (R + R_o)$$

Assuming a length of 1 cm for larval fish, and using the dimensions of the 10 BPM pump (intake radius:10.25 cm, 4 blades of 4 mm leading

edge thickness, impeller hub radius: 4.5 cm, equation (1) becomes

$$P' = 4\ \ 4(1) + 0.4(3.948)\ \ /31.006\ (10.25 + 4.5)$$

which yields

$$P' = 0.07$$

This figure, then represents the minimum mortality expected from physical contact with the impeller blade, and provides a basis for examination of pump-related mortality.

It is expected that as data become available from the experimental program, similar modeling efforts will be feasible for other components of the entrainment process, making a general mathematical treatment of entrainment mortality feasible.

SUMMARY

An experimental program to evaluate the effects of entrainment on aquatic organisms is underway. In order to measure the mortality associated with each component of the cooling system, a power plant cooling system simulator has been designed and is now under construction. The design of the apparatus is such that the internal hydraulics of operating power plant cooling circuits will be effectively reproduced. Experiments will be conducted using fresh water and marine fish and zooplankton species. Rearing and holding facilities have been designed and constructed to assure a supply of specimens and to allow assessment of delayed mortality. The identification of the factors which cause

mortality during entrainment should provide a rational foundation for the redesign of the components in cooling systems such that the environmental impacts of power plants will be minimized.

LITERATURE CITED

1. Jensen, Loren D. (ed) 1974. Entrainment and intake screening. Proceedings of the Second Entrainment and Intake Screening Workshop Electric Power Research Institute Publication No. 74-049-00-5. Waverly Press. 347 p.
2. Fort Calhoun Nuclear Power Plant Unit Two, Preliminary. Draft Environmental Statement. 1976. U.S. Nuclear Regulatory Commision Docket No. 50-48.
3. Atomic Safety and Licensing Board (ASLB) "Partial initial decision" in the matter of Delmarva Power and Light Company and Philadelphia Electric Company (Summit Power Station, Units 1 and 2, Docket Nos. 50-450 and 50-451) U.S. Nuclear Regulatory Commission, Nuclear Regulatory Commission Issuances, August 1975, NRCI - 75/8. (Published by U.S. Energy Research and Development Administration, Office of Public Affairs, Technical Information Center, Oak Ridge, Tennessee, October 1975).
4. Anonymous, 1976. Nuclear Industry. pp. 53-55.
5. Coutant, Charles C. and R. J. Kedl. 1975. Survival of Larval Striped Bass Exposed to Fluid - Induced and Thermal Stresses in a Simulated Condenser Tube. ORNL-TM-4695. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

6. Kedl, R. J. and C. C. Coutant. 1976. Survival of Juvenile Fishes Receiving Thermal and Mechanical Stresses in a Simulated Power Plant Condenser. IN: Thermal Ecology II. ERDA Symposium Series, CONF-750425 Esch. G. W. and R. W. McFarlene, eds. pp. 394-400.

7. Environmental Sciences Division Annual Progress Report for period ending September 30, 1974. March 1975. ORNL-5016. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

8. Environmental Sciences Division Annual Progress Report for Period ending September 30, 1973. March 1974. ORNL-4935. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

9. Power Plant Simulator, Building 1504, Special Conditions. W.O. A-5513. September 8, 1976. 64 pp. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

10. Reference drawing C21224 EA 020. Power Plant Simulator Drawing Index 31 March 1976. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

11. Brkich, Alexander. 1947. How Specific Speed Affects Centrifugal-Pump Performance. Power, March 1947.

12. Church, Austin H. 1944. Centrifugal Pumps and Blowers. John Wiley and Sons. 308 pp.

13. The Effects of Change in Hydrostatic Pressure on Some Hudson River Biota. New York University Institute of Environmental Medicine Progress Report for 1975. 109 pp.

14. Report of a Colloquium on Larval Fish Mortality Studies and Their Relation to Fishery Research. January, 1975. J. R. Hunter, ed. NOAA Technical Report NMFS CIRC-395.

15. Grizzle, J. E., F. C. Starmer, and G. G. Koch, 1969. Analysis of categorical data by linear models. Biometrics 25:489-504.

16. Grizzle, J. E. 1971. Multivariate logit analysis. Biometrics 27:1057-1062.

17. Suffern, J. S. 1973. Experimental analysis of Predation in a Freshwater System. PH.D. thesis, Yale University. 100 pp.

18. Ebey, Sherwood F. and John T. Beauchamp. In press. Larval Fish, Power Plants, and Buffon's Needle Problem. American Mathematical Monthly.

Comparison of Sampling Designs for the Estimation of Mortality Rates and Survival of Larval Fishes[1]

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INTRODUCTION

A review of the literature on mortality of early stages of freshwater fishes (Kramer 1969) indicated a paucity of information on mortality rates. Since that time the demand has increased for such data either for the evaluation of variation in year-class abundance, or for the quantification of environmental disturbances. In either case, the minimum information needed is the average density of fry at a point in time. With knowledge of total volume, density data can be expanded to total population size. This number can then be compared with number of eggs spawned (Clady 1976), number of larvae consumed (Forney 1977), number of larvae impinged or entrained (Hackney 1977), or number of larvae at another point in time to estimate mortality rates.

A major limitation to the estimation of such mortality rates is the ability to recognize distinct cohorts. In much of the U. S., particularly the northern areas, distinction of cohorts poses little problem, because spawning and hatching take place over a fairly short period of time and the entire year-class of larvae can thus be sampled simultaneously. In those cases where continual spawning occurs, Sette and Ahlstrom (1948) suggested a method of back-calculating abundance of eggs spawned. Hackney

[1]Presented at the Symposium on Freshwater Larval Fish, Charlotte, N. C., February 24, 1977.

(1977) has incorporated similar theory into a model to calculate number of larvae produced. Such calculation, which relies upon knowledge of age or growth rate of larvae, rapidly reduces the precision of estimates by interjecting another variable. The complexity of the problem and the present need for refinement of the technique were recently reiterated by Hunter (1976).

Attempts were initiated in 1965 to estimate annual variation in abundance and mortality rates of larval yellow perch (Perca flavescens) in 207-km^2 Oneida Lake, New York, using Miller high-speed samplers (Noble 1968). Estimation of mortality rates of walleyes (Stizostedion vitreum) and yellow perch within a smaller bay was also attempted (Noble 1972). Based in large part upon sampling theory (Cochran 1963; Sampford 1962), sampling programs were developed and modified over the years to provide precise estimates of abundance and mortality rates. In addition, extent of bias due to avoidance of samplers was estimated (Noble 1970, 1971).

For the purposes of this paper, the existence of a defined cohort which is sampled without bias will be assumed. Some statistical theory will be applied to the design of an efficient sampling program and to the analysis of the resulting data. Some practical limitations imposed by the sampling gear and field conditions will also be incorporated based on the Oneida Lake studies.

Distribution of Effort through Time.

Two basic approaches are available to determine changes in abundance through time. Two point estimates of mean density ($\bar{C}$) can be made, and survival expressed as $\bar{C}_2/\bar{C}_1$. Daily mortality coefficients can then be calculated, assuming exponential mortality, as $(\log \bar{C}_2 - \log \bar{C}_1)/\Delta t$ in days. In contrast, periodic estimates of density may be made, and a regression fit to the data assuming an exponential model ($\log_e \bar{C}_t = \log_e \bar{C}_o - Z\ t$), where Z approximates the daily mortality coefficient if t is in days and Z is small (Ricker 1975).

These calculations do not require estimation of population size (N), only mean density. If, however, the volume of the habitat should change (due to water level change or expansion of occupied habitat, such as from inshore to offshore waters), population size could be estimated and mortaltiy rates calculated from the change in $\hat{N}$ rather than $\bar{C}$.

The choice of sampling design probably will depend upon the desired precision of the resulting estimates. For yellow perch larvae, the variability using twice-weekly sampling over approximately a 3-week period was so great that in 2 of 3 years the estimated mortality coefficient was not significantly different from zero, even though the values of Z ranged from .030 to .056 (Noble 1968). Consequently, the sampling program was changed to two intensive samples for yellow perch, one immediately following hatching and one near the end of the pelagic stage. Forney (1975) employed a similar scheme for walleye larvae in Oneida Lake.

A practical consideration in distributing sampling effort through time is the decision of when to start sampling, since it may be important

to have the estimate as soon as possible after hatching. This is not a serious problem with periodic sampling, since the data points will form a typical catch curve, with the ascending limb typifying incomplete recruitment. Unfortunately, however, the data which form the ascending limb are of no use in the estimation of mortality rates, and represent wasted money and effort. In Oneida Lake studies of yellow perch, experience showed that as the average length of larvae approached 8 mm (hatching occurred at about 6 mm), the percentage of prolarvae rapidly approached zero. Consequently, when the sampling program using the two point-estimates was initiated, the population had to be monitored until the average length approached 8 mm. In the 5 years thereafter, only once (the first year) was sampling started too early. Mean lengths in the other 4 years ranged only from 8.3 to 9.1 mm for the first series. Since growth rates during that stage were approximately 0.5 mm per day (Noble 1968), the variation was considered acceptable.

Distribution of Effort through Space.

Usually, available resources dictate effort distribution not only through time, but also through space. Presently, only the allocation of effort through horizontal space will be considered, assuming that the entire water column (or at least that which is occupied by the population) can be sampled at each chosen sampling station or site.

If nothing is known about the horizontal distribution of the target species, but horizontal variations in density are suspected, a systematic sampling regime (e.g., transects) is probably appropriate. This method will, with a minimum of effort, provide density data adequate for estimation of mortality rates, while at the same time providing distribution data useful in the development of a more efficient sampling

design. The major limitations of the technique are that an overestimate of variance is obtained, with corresponding errors in confidence limits, and that the possibility does exist that systematically chosen sampling stations lead to a biased estimate of density by including or excluding unusually high or low density areas. The chances of the latter occurring increases as the number of sampling sites decreases.

If prior knowledge indicates that distribution of larvae is either fairly uniform or unpredictable, a random sampling scheme would be more appropriate than systematic sampling. In this case, all sampling sites are given equal chance of being selected, regardless of any sites already selected. The advantages of this sampling design are that the sample variance is an unbiased estimation of the population variance and that any station, whether of high, low, or intermediate density has the same probability of being selected. Unfortunately, a random selection of sites may accidentally result in a clumping of sites in one area and a paucity of sites in another area, perhaps of greatly differing density. Consequently, some desired information on horizontal variations in abundance may not be obtained.

Except in the case of pilot studies, horizontal variations in density should be somewhat predictable, perhaps because of known spawning areas and current patterns, and some design more efficient that random sampling should be possible (Cochran 1963; Sampford 1962). Stratification and allocation of effort in proportion to larval density (proportional allocation) or variance (optimal allocation) can markedly increase the information gained per unit of sampling effort. Because of the natural relationship between catch and variance in plankton nets (Taft 1960), proportional allocation in this case approaches optimal allocation.

Therefore, the precision of the estimated mean density can be improved without increasing the number of samples, simply by assigning relatively more effort to densely populated areas than to areas of low abundance of larvae.

To this point vertical variations in density have been ignored. Nevertheless, pronounced patterns of vertical distribution often occur, and as with horizontal distribution of sampling effort, allocation of effort based on vertical distribution will be more efficient if assigned in proportion to abundance than if assigned systematically or randomly.

Evolution of the Oneida Lake Sampling Design.

The sampling program for yellow perch larvae in Oneida Lake evolved from an entirely systematic design to a random sampling scheme stratified in both the horizontal and vertical dimensions. Throughout the sampling program, tows at 12.9 km/h were made with four Miller high-speed samplers spaced at equal depths through the water column to the desired depth. Tows were either 1.12 or 1.61 km long.

The program evolved from nine systematically chosen stations sampled twice weekly the first year to two horizontal strata sampled twice weekly at 12 randomly chosen sites the second year, to three horizontal strata sampled twice weekly at 12 randomly chosen sites the third year (Figure 1). After 3 years, the program was changed to two point-estimates each based on four horizontal strata and 42 sites. Identical strata were used in each of the two series (Figure 2). After two more years, it became obvious that vertical distribution patterns and changes in horizontal distribution from the first series of samples to the second should be accounted for in the sampling design. In the sixth year, an efficient sampling design employing both horizontal and vertical stratification

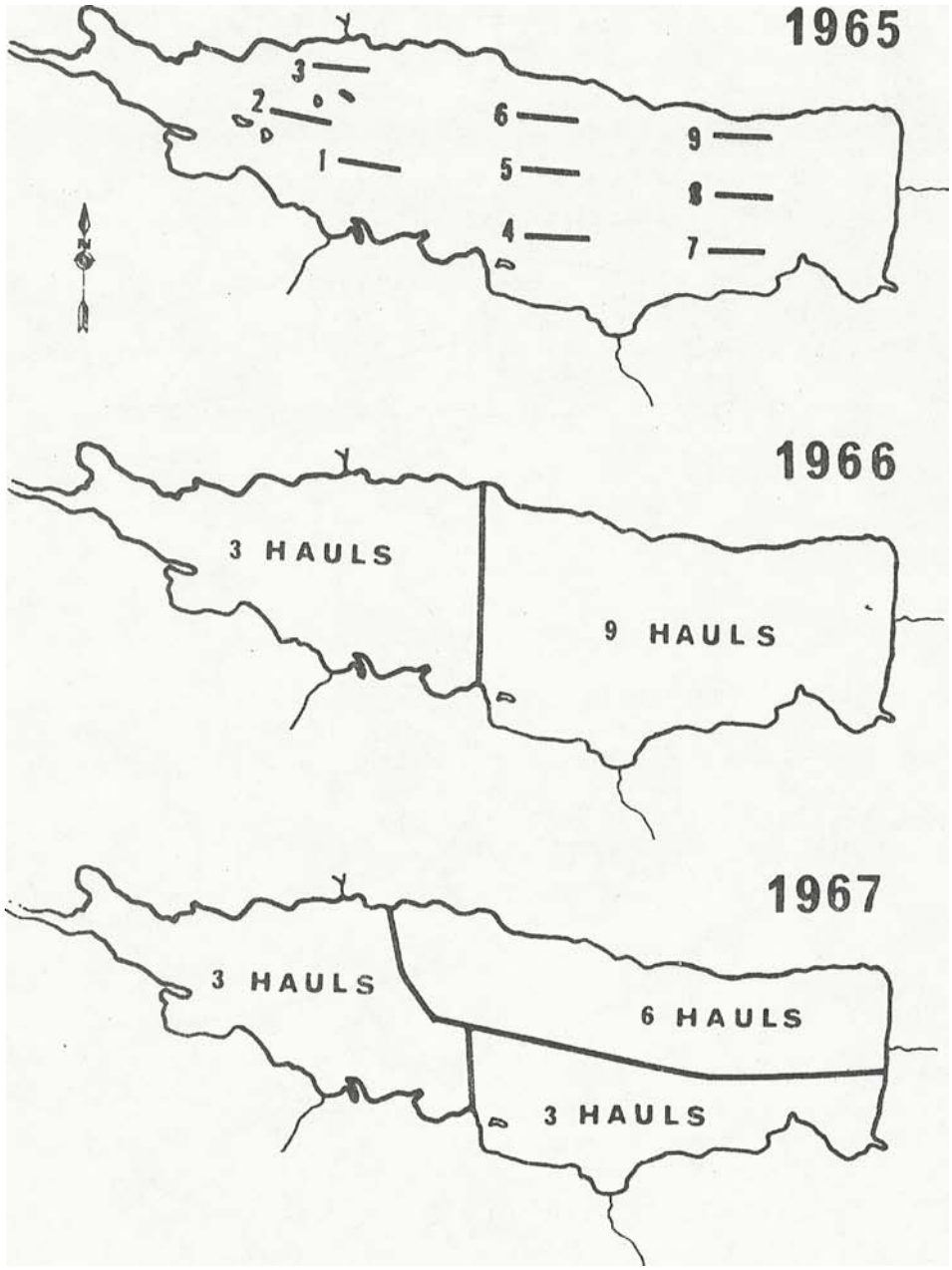

Figure 1. Distribution of sampling effort in Oneida Lake, 1965-1967. Each sample consisted of four equally-spaced samplers to a depth of no more than 6 m.

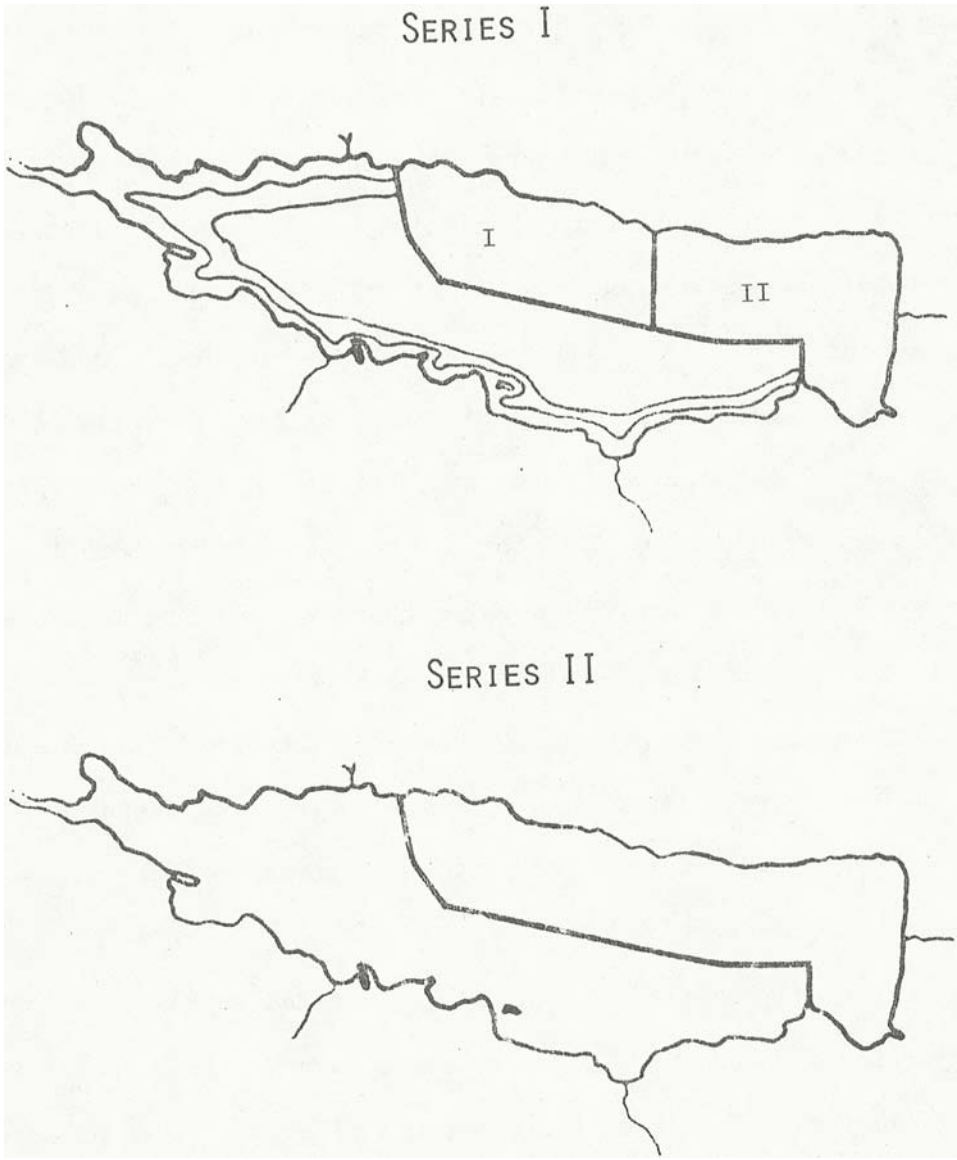

Figure 2. Horizontal distribution of sampling effort in Oneida Lake, 1970-1976. In Series I, an additional stratum (3-6 m) below Strata I and II was also used. In Series II, an additional stratum (3-6 m) occurs below each of those shown.

was finalized. This design utilized six strata in the first series and four in the second. The stratified random sampling regime consisted of 54 sampling sites in the first sampling series taken when mean length of larvae first exceeded 8 mm, and 42 sites approximately 3 weeks later when fish averaged approximately 18 mm (Table 1).

Precision of the estimates obtained using the stratified random sampling design relative to that which should have resulted from a completely random design using identical effort was calculated according to Sampford (1962) for each sampling series conducted from 1968 to 1976 (Table 2). Relative precision of estimates for the years in which the final sampling design was used ranged from 0.62 to 1.90 for the first series and from 0.87 to 3.97 for the second series. Both low efficiencies occurred in 1975, when additional sites were selected in certain strata to increase precision of walleye larvae estimates which were being obtained simultaneously. With the exceptions of 1975 when design was altered, variations in relative precision resulted from the annual differences in conformity of actual distribution of larvae to that anticipated in the sampling design.

Forney (1976) also developed a stratified random sampling program for walleye larvae in Oneida Lake using three strata, two of which included inshore shallow waters and one offshore. Over an 8-year period, relative precision varied from 0.67 to 4.97, also depending upon the conformity of larval distribution to that expected (Forney 1975).

Table 1. Distribution of sampling effort for yellow perch larvae in Oneida Lake, New York.

Series	Stratum	% of Volume	Depth Sampled (m)	No. of Samples
I	1	10.1	0-3	10
	2	12.1	0-3	10
	3	19.7	3-6	6
	4	41.7	0-6	10
	5	5.7	0-2	8
	6	10.8	0-4	10
II	1	22.2	0-3	20
	2	19.7	3-6	6
	3	32.6	0-3	10
	4	25.5	3-6	6

Table 2. Relative precision of stratified random sampling for estimating densities of larval yellow perch in Oneida Lake, New York.

Relative Precision of Stratified Random Sampling		
Year	Series I	Series II
1968	1.62 (4)	3.37 (4)
1969	1.57 (4)	0.99 (4)
1970	3.25 (6)	1.28 (4)
1971	2.64 (6)	2.46 (4)
1972	1.06 (6)	2.33 (4)
1973	1.90 (6)	1.54 (4)
1974	0.89 (6)	1.98 (4)
1975	0.62 (6)	0.87 (4)
1976	1.67 (6)	3.97 (4)
Mean	1.19	2.09

ESTIMATION PROCEDURES

Density and Population Size

Methods of estimation of parameters based upon systematic and random sampling are straight-forward and will not be discussed. Calculations for a point estimate based upon stratified random sampling, however, are somewhat more complex. Overall mean density ($\bar{\bar{C}}$) is calculated as a weighted mean of the mean stratum densities ($\bar{C}_j$) based on n_j samples where weighting factors (p_j) are the proportion of the total volume occurring in each stratum. The square of this constant (p_j^2) must be incorporated into the estimate of variance. Since sites within each stratum are selected at random, stratum mean densities ($\bar{C}_j$) and variance ($s^2\{\bar{C}_j\}$) are calculated by conventional methods.

Stratum Density: $\bar{C}_j = \Sigma C_j/n_j \quad s^2\{\bar{C}j\} = \Sigma(C_j-\bar{C}_j)^2/n_j(n_j-1)$

Overall Density: $\bar{\bar{C}} = \Sigma p_j \bar{C}_j \quad s^2\{\bar{\bar{C}}\} = \Sigma p_j^2 \, s^2\{\bar{C}_j\}$

With knowledge of total volume of each stratum and the volume filtered by the average tow, expansion of density data to stratum population and total population is straight forward.

Stratum Population: $\hat{N}_j = \left(\frac{\text{Vol. of Stratum}}{\text{Vol. of Tow}}\right) \bar{C}_j$

$$s^2\{\hat{N}_j\} = \left(\frac{\text{Vol. of Stratum}}{\text{Vol. of Tow}}\right)^2 s^2\{\bar{C}_j\}$$

Total Population: $\hat{N} = \Sigma\hat{N}_j$

$$s^2\{\hat{N}\} = \Sigma s^2\{\hat{N}_j\}$$

Survival Rates and Mortality Coefficients

With density and population estimates acquired for two points in time, it is possible to proceed with calculation of survival rates and mortality coefficients, since survival (S) can be estimated from ratios of either overall mean density or population estimates at two points in time. Because the estimate is based upon the ratio of two variables, variance includes components of each.

$$\hat{S} = \frac{\hat{N}_2}{\hat{N}_1} = \frac{\bar{\bar{C}}_2}{\bar{\bar{C}}_1}$$

$$s^2\{\hat{S}\} \doteq \frac{1}{\bar{\bar{C}}_1^2} s^2\{\bar{\bar{C}}_2\} + \frac{1}{\bar{\bar{C}}_2^2} s^2\{\bar{\bar{C}}_1\}$$

Survival thus calculated represents that for the time period between the two samples, but since the interval may vary from year to year, it is usually desirable to calculate daily mortality coefficients. Because the coefficient is essentially the slope of a regression line fit to two points of estimated variance, the variance of the slope can be approximated.

$$Z = \frac{\log_e \bar{\bar{C}}_2 - \log_e \bar{\bar{C}}_1}{\Delta t}$$

$$s^2\{Z\} = \left(\frac{1}{\Delta t}\right)^2 \left[\frac{1}{\bar{\bar{C}}_1^2} s^2\{\bar{\bar{C}}_1\} + \frac{1}{\bar{\bar{C}}_2^2} s^2\{\bar{\bar{C}}_2\}\right]$$

If more than two point estimates are available and a constant mortality rate over the time period can be expected, it may be more convenient to calculate a mortality coefficient by least-squares regression, using $\log_e \bar{\bar{C}}$ regressed against time. Estimation of the slope and its variance, as well as variance for estimates at any point in time, and consequently for survival rates, can be accomplished by conventional regression techniques.

SAMPLING BIAS

A major limitation is often imposed by the gear available for sampling. Perhaps more exactly, the limitation is imposed by the behavioral characteristics of the fish in relation to the sampling gear.

Catches (per unit volume) in Miller high-speed samplers were initially compared with those in bridled meter nets used previously (Noble 1971). That study indicated that daytime avoidance of meter nets by yellow perch begins before larvae reach 10 mm in length. Consequently, avoidance of Miller samplers towed at 12.9 km/h was hypothesized. Subsequent evaluations indicated that catches could be increased by night sampling, towing faster, using a less conspicuous sampler, and preceding the sampler by an electrical field (Noble 1970). These studies indicated that avoidance capabilities were attained almost immediately following yolk sac absorption.

One solution to the problem was to attempt to define the avoidance function, and apply adjustments for avoidance to catch data based upon mean size of fish in each sample. This technique inflated variances, but did provide a more realistic estimate of larval abundance and survival than did the actual catch data, which underestimated both. If the project were to be repeated, night sampling would be used for the entire second sampling series to minimize avoidance.

Gear development is presently the principal obstacle to estimation of mortality rates where a given cohort can be followed through time. Avoidance functions are probably much more complex than presently known, but unless such functions can be defined, abundance estimates, and mortality estimates, will be restricted to the very short period immediately following hatching. However, given some knowledge of the larval fish population, reasonably constant distribution and behavior of larvae, and adequate gear to quantitatively collect the larvae, sampling programs can be designed which will produce unbiased estimates of acceptable precision for most research.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Clady, M. D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, Perca flavescens. J. Fish. Res. Bd. Canada 33:1887-1893.

Cochran, W. G. 1963. Sampling techniques. Wiley, N. Y. 413 pp.

Forney, J. L. 1975. Abundance of larval walleyes (Stizostedion vitreum) estimated from the catch in high-speed nets. FAO EIFAC Tech. Pap. 23 (Suppl. 1) 2:581-588.

_____. 1976. Year-class formation in walleye (Stizostedion vitreum vitreum) population of Oneida Lake, New York, 1966-73. J. Fish. Res. Bd. Canada 33:783-792.

_____. 1977. Reconstruction of yellow perch cohorts from examination of walleye stomachs. J. Fish Res. Bd. Canada 34: (in press).

Hackney, P. 1977. Methods for calculating survival rate, biomass production, and proportion entrained of lacustrine ichthyoplankton. Presented at Freshwater Larval Fish Symposium. Charlotte, N. C. March, 1977.

Hunter, J. R. 1976. Report of a colloquium on larval fish mortality studies and their relation to fishery research, January 1975. NOAA Tech. Rept. NMFS Circ. 395. 5 pp.

Kramer, R. H. 1969. A preliminary bibliography on extent and causes of early mortality in freshwater fish (diadromous fishes excluded). FAO Fish. Circ. 307. 20 pp.

Noble, R. L. 1968. Mortality rates of pelagic fry of the yellow perch, Perca flavescens (Mitchill), in Oneida Lake, New York, and an analysis of the sampling problem. Ph.D. Thesis, Cornell Univ., Ithaca, N.Y. 111 pp.

_____. 1970. Evaluation of the Miller high-speed sampler for sampling yellow perch and walleye fry. J. Fish. Res. Bd. Canada 27:1033-1044.

_____. 1971. An evaluation of the meter net for sampling fry of the yellow perch, Perca flavescens, and walleye, Stizostedion v. vitreum. Ches. Sci. 12:47-48.

_____. 1972. Mortality rates of walleye fry in a bay of Oneida Lake, New York. Trans. Am. Fish. Soc. 101:720-723.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Canada Bull 191. 382 pp.

Sampford, M. R. 1962. An introduction to sampling theory with applicaitons to agriculture. Oliver and Boyd, Edinburg. 292 pp.

Sette, O. E. and E. H. Ahlstrom. 1948. Estimations of abundance of the eggs of the Pacific pilchard (Sardinops caerulea) off Southern California during 1940 and 1941. J. Mar. Res. 7:511-542.

Taft, B. A. 1960. A statistical study of the estimation of abundance of sardine (Sardinops caerulea) eggs. Limnol. Oceanogr. 5:245-264.

Methods for Calculating Survival Rate, Biomass Production, Growth Rate, and Assessing Entrainment of Lacustrine Ichthyoplankton

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METHODS FOR CALCULATING SURVIVAL RATE, BIOMASS PRODUCTION, GROWTH RATE, AND ASSESSING ENTRAINMENT OF LACUSTRINE ICHTHYOPLANKTON

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ABSTRACT

A method of determining the number of larvae hatched in lacustrine environments is proposed. Data requirements are: taxonomic entity, density, and length of individuals through time (sample periods). From these basic data, methods and models are developed to determine survival as a function of length and time, biomass production, growth, and recruitment.

Results using larval crappie (Pomoxis sp.) as an example revealed that survival increased with increasing length of the individual; however, changes in survival rate due to increasing age were not apparent. Growth in length accelerated with increasing age. Biomass production of 5 to 10 mm crappie larvae was 1.93 kg ha^{-1}, a small percentage of that for all species and sizes of larvae.

An estimate of entrainment for a proposed steam electric power plant located on an embayment of Pickwick Reservoir, Mississippi, indicates that only 1.04 percent of the total number of crappie larvae hatched will be entrained. However, the consequences of prolonged vulnerability resulting in entrainment of older and larger larvae were projected to be great, with an estimated reduction of 7.2 to 14.8 percent of the 20 mm crappie recruits.

INTRODUCTION

Few species of North American freshwater fishes spawn planktonic eggs. As a consequence, egg production normally cannot be determined from plankton samples. However, the larvae of many taxa become planktonic immediately or very soon after hatching. This suggests that, although egg production cannot normally be determined, it might be possible to estimate the number of larvae hatched or recruited to the water column from ichthyoplankton samples. Although the ability to make such determinations has broad application in fisheries work, the need to estimate the impact of larval fish entrainment at steam electric power plants located on lakes was specifically responsible for this work. In particular, we wanted to know what proportion of the fish larvae produced in a lake is entrained and what effects these losses have on the population and dynamics of the population.

Assessing the impact of ichthyoplankton entrainment in lakes presents a number of problems. The number entrained may be estimated by formulae as simple as:

$$E = \sum_{i=1}^{n} d_i V_i \qquad (1)$$

Where

E is the number entrained,

d_i is the average ichthyoplankton density (number/unit volume) during the i^{th} sample period, and

V_i is cooling water intake volume during period i.

The total number of larvae produced in the lake is generally unknown. Therefore, entrainment of 10^6 to 10^8 larvae may appear to be a large

number; however, if the total number hatched is of the order 10^{12} to 10^{16} larvae, then entrainment losses may be inconsequential.

An additional problem resulting from locating steam electric power plants on lakes is that larvae are vulnerable to entrainment during the entire period of their planktonic existence. They are not just instantaneously vulnerable as are stream dwelling larvae which are transported past cooling water intakes.

METHODOLOGY

Number of Ichthyoplankters Hatched

If larval length or developmental stage at hatching is known and growth or development is rapid enough initially to permit identification of individuals less than 24 hours old, then there is a simple method of estimating the number of larvae hatched. The density of recently hatched individuals, those less than 24 hours old, is plotted through time as in Figure 1. The resulting density curve, $\dot{N}_h$ (the dot notation symbolizes the first derivative with respect to time), is also a hatching rate because it describes the change in density through time of newly hatched individuals. Total larvae hatched or entering a unit volume of water (symbolized as N_h in Figure 1) during the season is thus estimated by the area under the curve with $N_h = \int \dot{N}_h$. This area can be determined in a number of ways; however, considering the variability usually associated with this type of data, it is doubtful if the sophistication of calculus will yield a significantly better estimate than the trapezoidal summation indicated in Figure 1. Trapezoidal integration or summation to obtain the number hatched in a unit volume of water is easily accomplished as:

$$N_h = \sum_{i=0}^{n-1} \left(t_{i+1} - t_i\right)\left(\dot{N}_{h,i} + \dot{N}_{h,i+1}\right) /2 \qquad (2)$$

Where

N_h is the total number of larvae hatched annually per unit volume of water,

n is the number of trapezoids,

t_i is the date of the i^{th} sample period (t_o is the date of first occurrence of recently hatched larvae, and

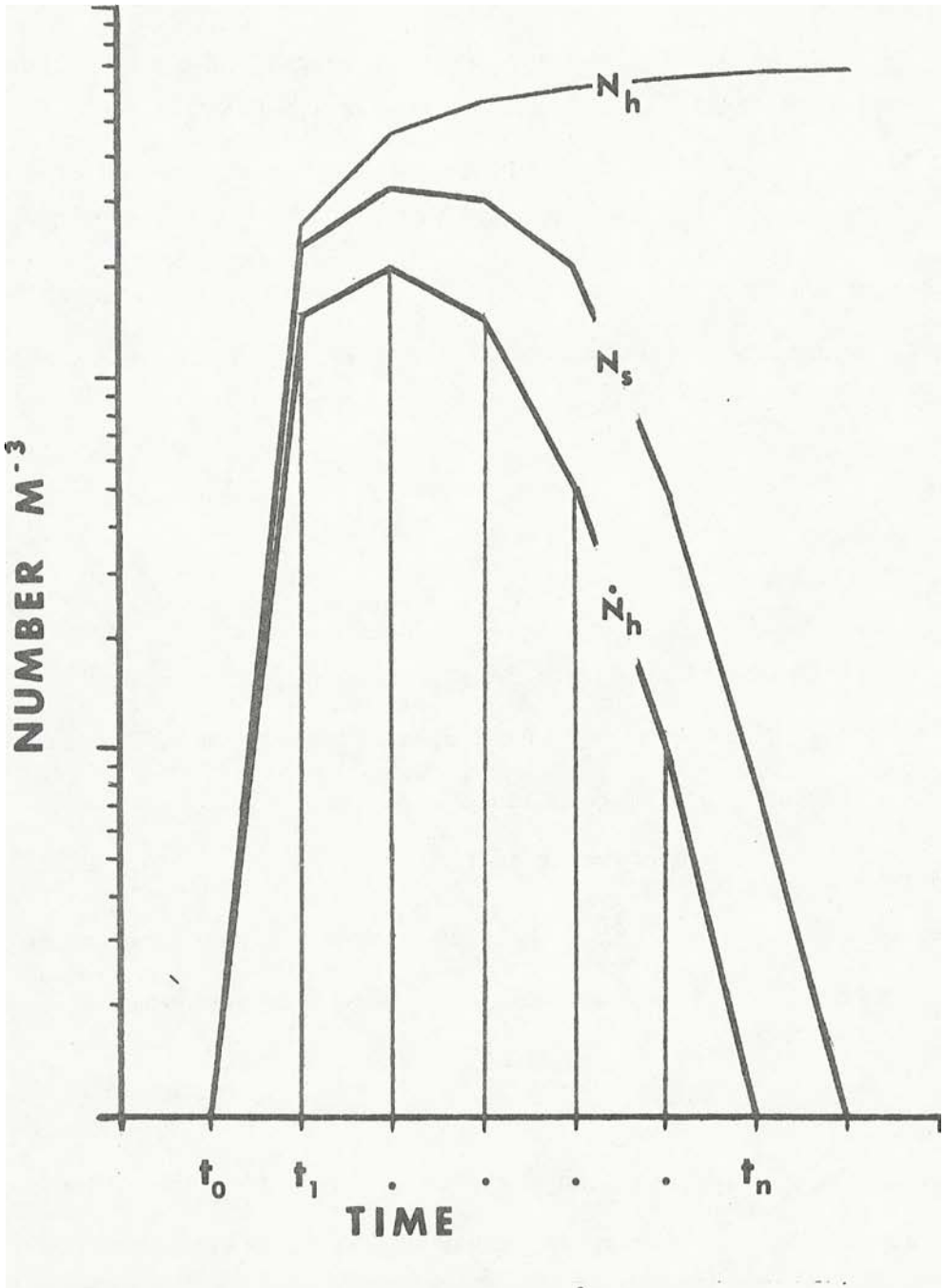

Figure 1. Densities of recently hatched (N_h) fish larvae, surviving (N_s) larvae, and cumulative number hatched (N_h). t_o is initiation of hatching with t_n cessation of hatching. See text for explanations.

t_n is the date of their last occurrence)

units for t_i will usually be days so that,

$t_{i+1}-t_i$ is the number of days between the i^{th} and $(i+1)^{th}$ sample period,

$\dot{N}_{h,i}$ is the density (number per unit volume) of newly hatched larvae on the i^{th} sample period (day t_i),

$(\dot{N}_{h,i}+\dot{N}_{h,i+1})/2$ is the average density for the period from t_i to t_{i+1}.

Total number hatched in the lake can now be estimated by applying this technique to each of the areas and stratum from which data are available. Thus,

$$N_{hT} = \sum_{ij} N_{h,i,j}\, V_{ij} \qquad (3)$$

Where

N_{hT} is the total number of larvae hatched in the lake,

$N_{h,i,j}$ is the number per unit volume found in the i^{th} area and j^{th} stratum (N_h from equation 2).

V_{ij} is the volume of water in the i^{th} area and j^{th} stratum.

Another method to obtain N_{hT} using the same data would be to derive an average N_h weighted by volume and multiply it by the total volume.

Survival

Inspection of Figure 1 suggests that, since the cumulative number of larvae hatched (N_h) and the total number of larvae still extant (N_s) at some instant in time are both known, it should be possible to determine the survival rate. This is seen more easily in Figure 2 where the densities of

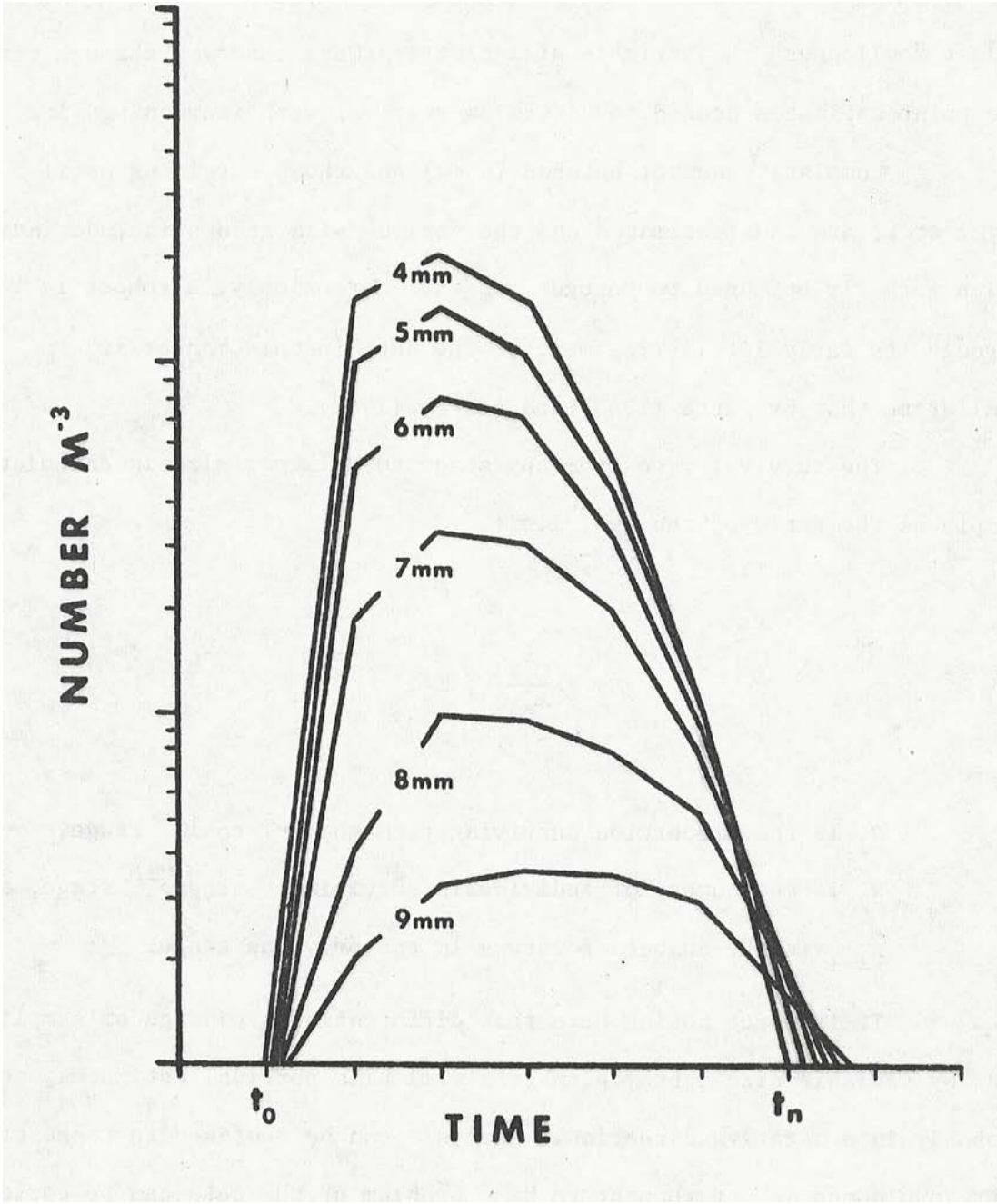

Figure 2. Larval densities through time by length increments (mm).

recently hatched (4 mm) and larger larvae are shown. The number of individuals attaining each length interval is determined by applying equation 2 to each curve in Figure 2 and is shown in Figure 3. Analysis of the data in this manner "collapses" the variable size distributions observed through time into the point estimates needed to determine survival with increasing size.

Cumulative number hatched (4 mm) and those surviving until 5 mm, 6 mm, etc., are thus estimated and the various size groups include individuals which formerly belonged to younger stages. More simply, a cohort is followed through its early life. Treatment of the data in this manner is similar to that by Sette (1943) and Pearcy (1962).

The survival rate from any stage to a larger size is calculated simply as the ratio of the two, i.e.:

$$S_i = \frac{x_i}{x_{i-1}}, \quad i>1$$

Where

S_i is the proportion surviving from the i-1 to i^{th} stage,

x_i is the number of individuals surviving to the i^{th} stage, and

x_{i-1} is the number of larvae in the previous stage.

It is worth noting here that differential avoidance of sampling gear by variable size ichthyoplankters will bias survival estimates, most probably in a negative direction. Analysis can be confined to those groups where avoidance is not thought to be a problem or the data can be corrected for avoidance (see Noble 1970, 1972).

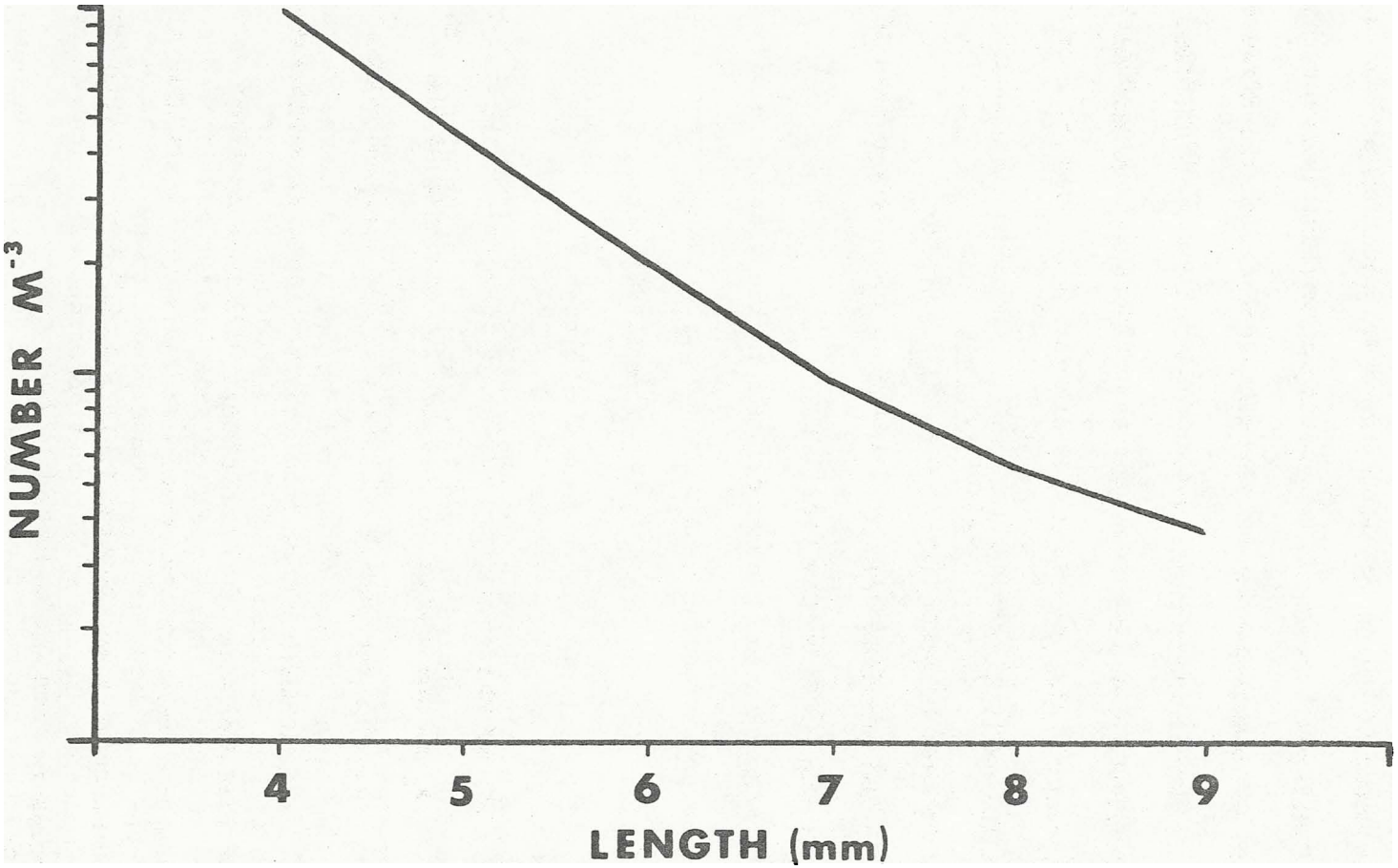

Figure 3. Cumulative (total) number of larvae m^{-3} by length increments during the larval season.

Production

Production can be obtained from a modification of Figure 3. Total population number must be used, not just relative density. Lengths are converted to biomass at length (Table 1) and the data replotted as in Figure 4. Production is simply the area under the curve. This is the Allen (1950) graphic approach and it is independent of time (except that it occurs during the first summer of life).

Entrainment Losses

Further, factors frequently ignored in the assessment of entrainment impacts can now be examined.

Biomass: Larval biomass taken into the plant is easily calculated. The numbers by size frequency estimated to be entrained are determined from equations (1) and (2) and are rearranged as in Figures 2, 3, and 4. In this case, individuals in the various size groups are independent of one another if, as in closed cycle cooling, they are presumed to be killed and therefore cannot be sampled at some later stage (larger size). These fish are not a cohort followed through early development. Because of this, the area under the curve (Figure 4) derived for entrained larvae represents the biomass of ichthyoplankton taken into the cooling system. It is not production, at least in the sense used both earlier and in the next section, but is perhaps best described as biomass predation by the plant.

Production foregone: Production which is foregone (i.e., larvae killed before they can make their full contribution to production) as a

Table 1. Density (No./1000 m^3) calculations for swim-up larval crappie in Yellow Creek embayment, Pickwick Reservoir, Mississippi, during 1976. See text for symbol definition and computational methodology.

i	t_i	$\dot{N}_{h,i}$	$[t_{i+1}-t_1]$	$(N_{h,i+1}+N_{h,i})$ /2	$N_{h,i}$
0	0	0.0	1	1.004	1.004
1	1	2.008	7	2.369	16.658
2	8	2.730	7	1.365	9.555
3	15	0.0	7	22.215	155.033
4	22	44.295	7	124.298	870.086
5	29	204.301	7	172.131	1,204.914
6	36	139.960	7	299.894	2,099.258
7	43	459.828	7	477.460	3,342.220
8	50	495.092	7	364.432	2,551.021
9	57	233.771	7	156.126	1,092.882
10	64	78.481	7	126.557	885.899
11	71	174.633	7	127.780	894.460
12	78	80.927	7	116.241	813.687
13	85	151.555	7	78.742	551.191
14	92	5.928	7	3.298	23.083
15	99	0.677	7	0.339	2.370
16	106	0.0	7	0.0	0.0
17	113	0.0	7	0.0	0.0
18	120	0.0			
	TOTAL				14,513.321

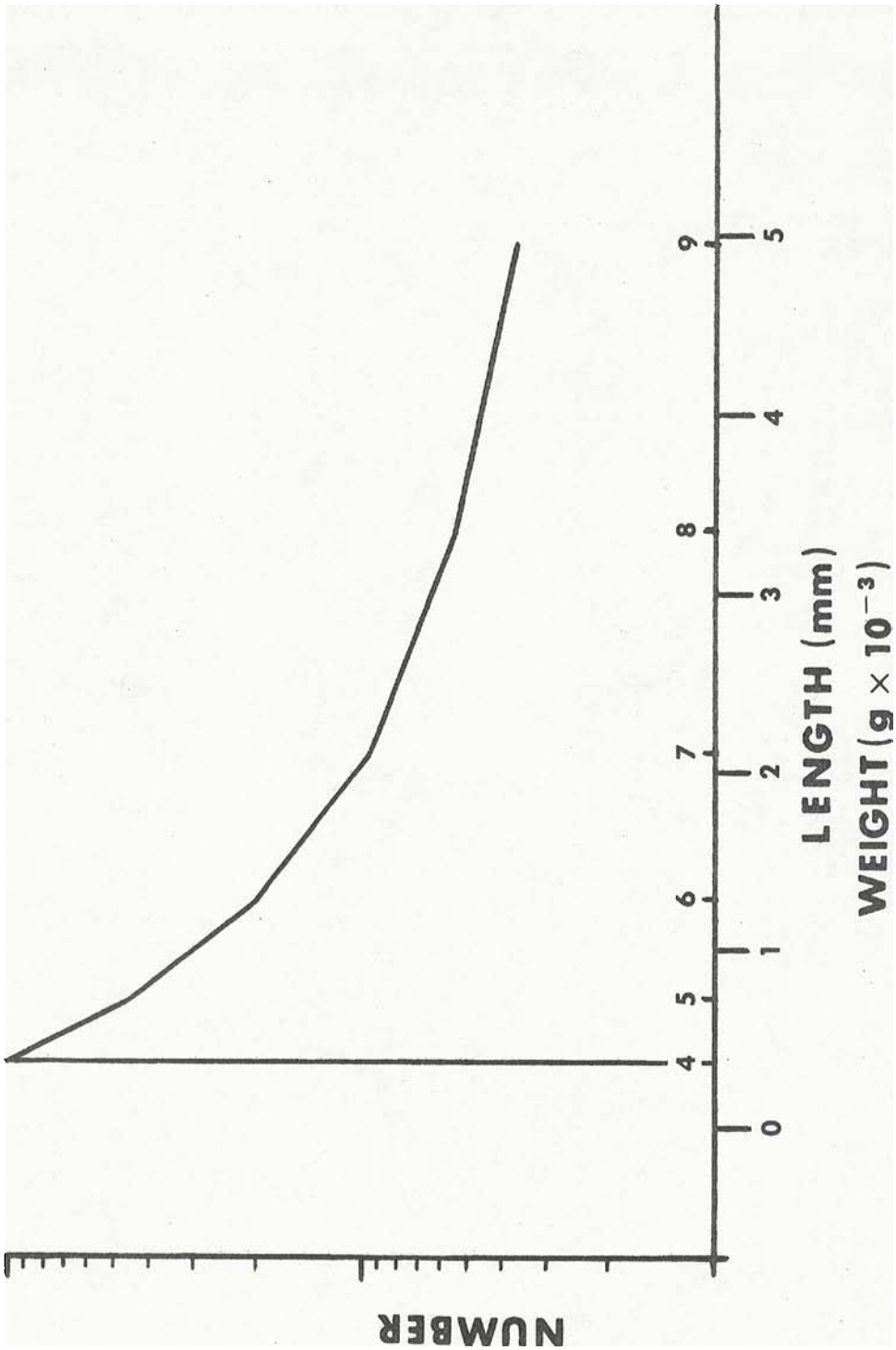

Figure 4. Production (Allen) graph for larval fish.

result of entrainment can also be determined. The logic employed is that if survival rate of the nonentrained population and the numbers of larvae entrained are both known, then it should be possible to estimate production for these larvae, had they not been entrained. This may be thought of as the true net predation by the plant.

Computational procedure for this method is in two stages. The number of survivors expected at successive stages is first estimated by the recursion formula,

$$N_i = N_{i-1} S_i, \quad i > 1 \tag{5}$$

e.g.,

$$N_1 = N_1 \quad , i = 1$$

$$N_2 = N_1 S_1 \quad , i = 2$$

$$N_3 = N_2 S_2 \quad , i = 3$$

$$\cdots$$

$$\cdots$$

$$N_n = N_{n-1} S_{n-1}, \quad i = n$$

Where

N_i is the number of surviving larvae expected at the i^{th} stage (length or weight class) from an initial number N_1 and stage.

S_i is the proportion of N_{i-1} expected to survive from the $(i\text{-}1)^{th}$ to i^{th} stage.

A series of Allen (1950) curves are thus constructed. This is demonstrated graphically in Figure 5. The area under curve A of Figure 5 is the production expected from the 4 mm larvae entrained, had they remained in the lake. Because, as discussed above, individuals in the various size

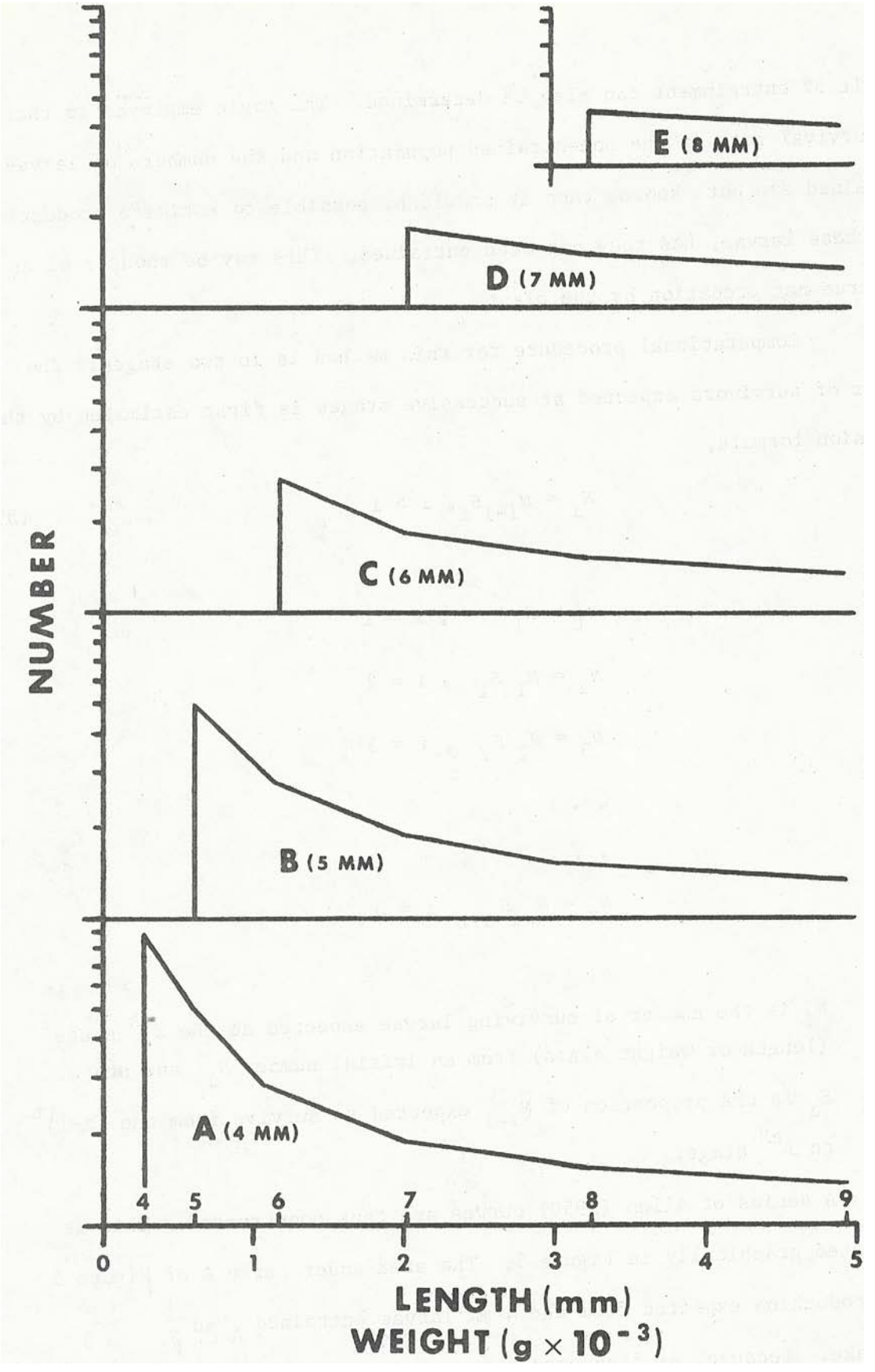

Figure 5. Ichthyoplankton production lost due to entrainment.

groups are independent of one another, this method must be applied to each size category in succession. Production loss due to entrainment mortality is estimated by the sum of areas A to E in Figure 5.

Production can now be calculated as:

$$P = \sum_{i=1}^{n} \left(W_{i+1} - W_i\right) \left(N_i + N_{i+1}\right) /2 \qquad (6)$$

Where

P is production,

W_i is biomass of an individual larval in the i^{th} stage of development, and

N_i is as given for equation 5 above.

An example of this computation procedure is shown in a later section.

ASSUMPTIONS

Assumptions of these methods are that: (1) recently hatched larvae can be distinguished from individuals one or more days old and can be identified to a suitable taxonomic level, (2) the lake has been sampled by a design which allows a reasonably realistic estimate of total larval numbers (i.e., densities weighted by stratum, region, and surface area), (3) recently hatched larvae are vulnerable to the sampling technique, and (4) larvae of all sizes have been sampled in proportion to their abundance. An additional assumption closely linked with (1) above is that mortality is nonexistent or negligible during the first 24 hours after hatching.

It is probable that most, if not all, of the above assumptions will be violated. However, unless such violations are severe, the methods appear to have great utility. Violation of assumptions (1) and (3) above will result in an underestimate of population number and consequently an overestimate of entrainment impacts.

EXAMPLE

Yellow Creek embayment is an arm of Pickwick Reservoir (Tennessee River) connected to the main lake by a narrow channel. Water exchange through this channel is low and variable in direction such that the embayment is more or less a lake in itself. The embayment was sampled for ichthyoplankton from March 25, 1976, until July 23, 1976. A detailed description of the area, ichthyoplankton, sample stations, and techniques is given in TVA (1976). Ichthyoplankton sampling methodology in 1976 (not discussed in the above report) consisted of oblique full stratum tows in areas of seven meters or less depth. Deeper waters were separated into two strata (0 to 4 m and 5 m and greater), and each was sampled by an oblique tow. Volumes by strata and sample station areas were determined and used as weighting factors for determining respective ichthyoplankton densities. Only larvae of the genus (Pomoxis) are used in this example.

Number Produced

Because crappie become "swim-up" larvae at 4.1 to 4.6 mm length (Siefert 1969) and rapidly achieve 4.5 mm, a length which is classed as 5 mm in our laboratory, all individuals less than the 6 mm group (less than 5.5 mm length) were considered to be recently hatched larvae for this example.

The use of equation (2) to determine the number of swim-up larvae produced is demonstrated in Table 1. Densities of swim-up larvae are mean numbers per 1,000 m^3 of water, weighted by volume of stratum from which they were collected. Multiplication by the total volume of

Yellow Creek embayment ($6.34 \times 10^7 m^3$) yields an estimate of 9.2×10^8 swim-up crappie larvae produced in 1976.

Weighted mean denisty (no $1,000\ m^{-3}$) by 5-mm length increments through the sample season is shown in Figure 6. Curves are seen to match the idealized theoretical form of Figure 2 reasonably well except for what at first appears to be "noisy" variation. Closer inspection reveals that "noisy" sample variation in density for the smallest individuals is reflected in the larger fish on later dates (after a period of growth). This suggests that perhaps there is not as much "error" in the data as first suspected.

Determination of the area under the curves for all length classes plotted as in Figure 7, (using equation 2) offers further support of the idea that density variations are not sample error. Mortality models call for a smooth curve and the data are consistent with this concept.

Estimated Entrainment

Yellow Creek Nuclear Plant will require about $3.5\ m^3\ s^{-1}$ of make-up water for closed cycle cooling. From data collected near the proposed intake, we estimated from equation (1) that, had the plant been operational, about 9.58×10^6 crappie larvae or about 1.04 percent of the total number produced in 1976 would have been entrained.

Inspection of Figure 7 suggests that classing 4 and 5 mm larvae as recently produced individuals and summing the numbers together (necessary because swim-up biology and the measuring technique are out of phase) yields too high an estimate for the number of swim-up larvae. It seems likely that had a measurement interval of 4.1-5 mm been used to delineate the estimated

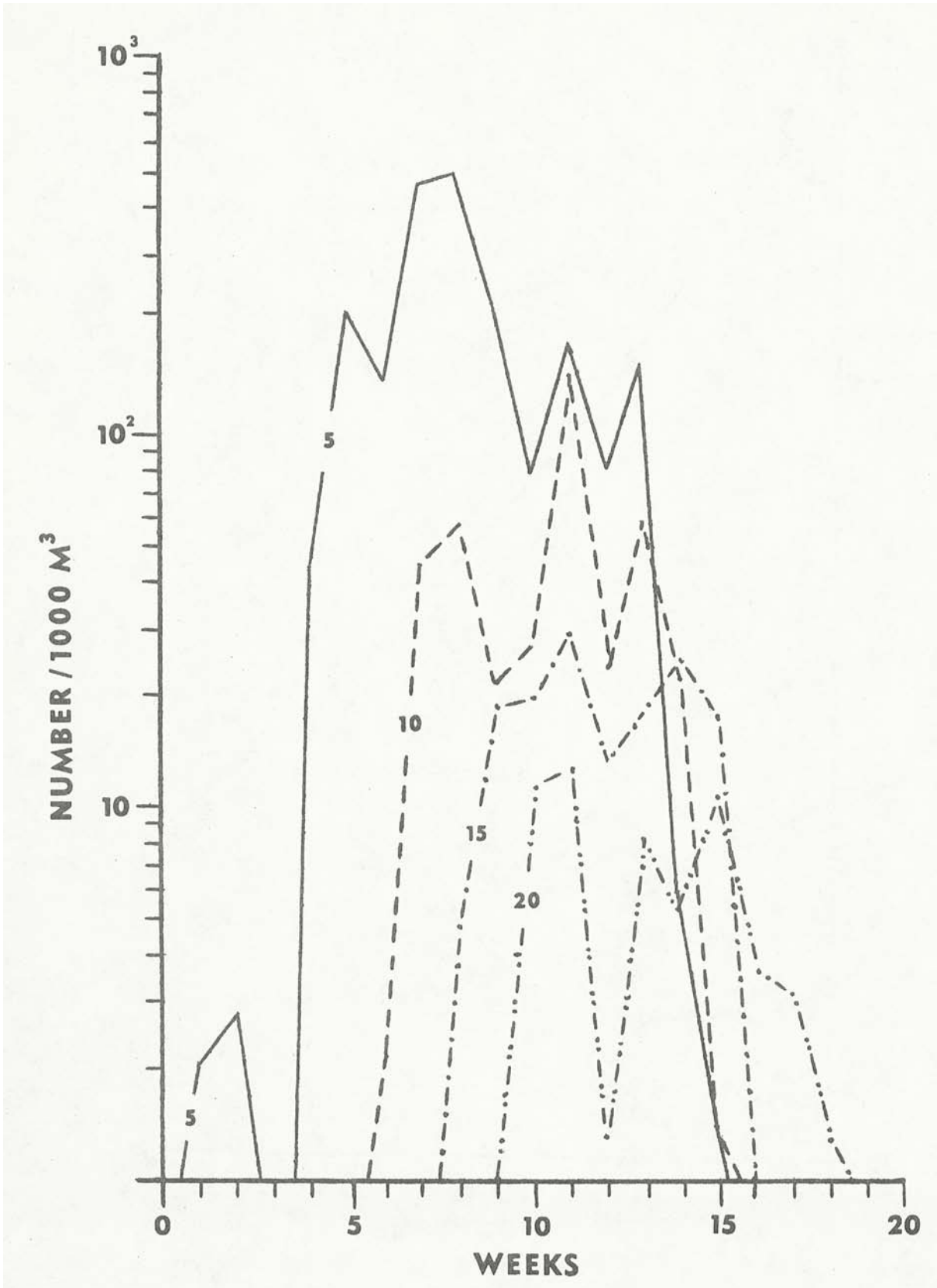

Figure 6. Density (no/1000 m^3) of larval crappie through time for selected length groups. Compare with Figure 2.

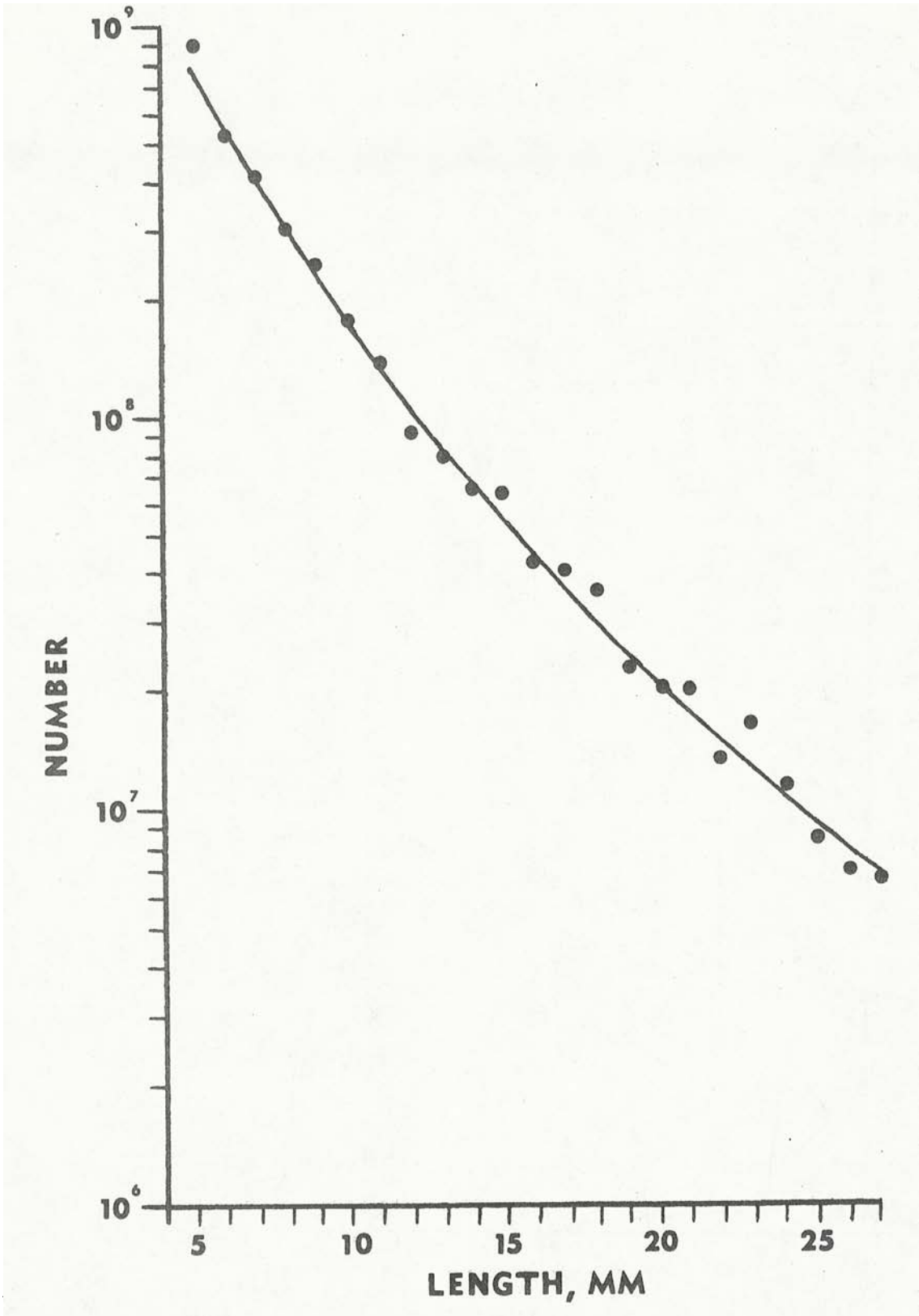

Figure 7. Decrease in numbers of larval crappie (Pomoxis sp.) with increasing length.

number of swim-up crappie, it might have solved this problem. A value of 7.6 x 10 swim-up crappie is estimated by the curve in Figure 7. This increases the proportion estimated to be entrained only slightly (from 1.04 percent to 1.26 percent).

Survival

Most quantitative entrainment studies have attempted to predict impact to adult stocks through potentially reduced recruitment. Compensatory growth and/or survival are unknown factors which could easily offset entrainment losses. In Figure 7 it can be seen that as larval crappie grow in length, their chance of survival is increased (if the curve was linear, survival rate would be the same for all sizes). The relationship is doubtless even more dramatic since suspected gear avoidance by the larger individuals would yield an underestimate of abundance, thereby depressing the right limb of the curve. If growth is inversely density dependent, then a reduction in the number of crappie larvae would result in faster growth and, as predicted by Figure 7, increased survival. High mortality thus should be at least partially compensated by both survival and production. Recruitment levels, therefore, might remain relatively stable for large annual variations in survival and/or numbers produced.

The familiar model takes the form:

$$N_{l+\Delta l} = N_l e^{-M\Delta l}$$

Where

Δl is the change in length in mm,

N_l is number at some length,

$N_{l+\Delta l}$ is number at some new length $l+\Delta L$, and

M is the mortality coefficient,

This is inadequate to describe the relationship in Figure 8, because

$$\ln\left(\frac{N_{l+\Delta l}}{N_l}\right) = \ln\left(e^{-M\Delta l}\right) = -M\Delta l$$

which is log-normal or semi-log relationship. In this model, the mortality coefficient (M), and consequently the survival rate (S), are constant throughout the entire length range, obviously not true in this case. Because

$\log\left(\frac{N_l}{N_0}\right) = -M \log l$, a useable formula would be

$$N_l = N_0\, l^{-M}$$

where l is length.

This adequately models the log-log relationship evident in Figure 8. Description of survival in this manner approaches Ware's (1975) idea that, "Clearly, it would be far more accurate to eventually describe the death process as a size (emphasis mine) and density-dependent function of the available food supply and predation rate."

Survival rate, although it increases with growth, is probably still underestimated because of gear avoidance. This idea is supported by Figure 8, which suggests that avoidance for crappie larvae may begin at about 10 mm length and may increase proportionally with growth. However, the validity of correcting for avoidance by using the uppermost relationship in Figure 8 remains to be determined.

Production

Production for the first six length groups was calculated using equation (6) and is shown in Table 2. Both standing biomass and production

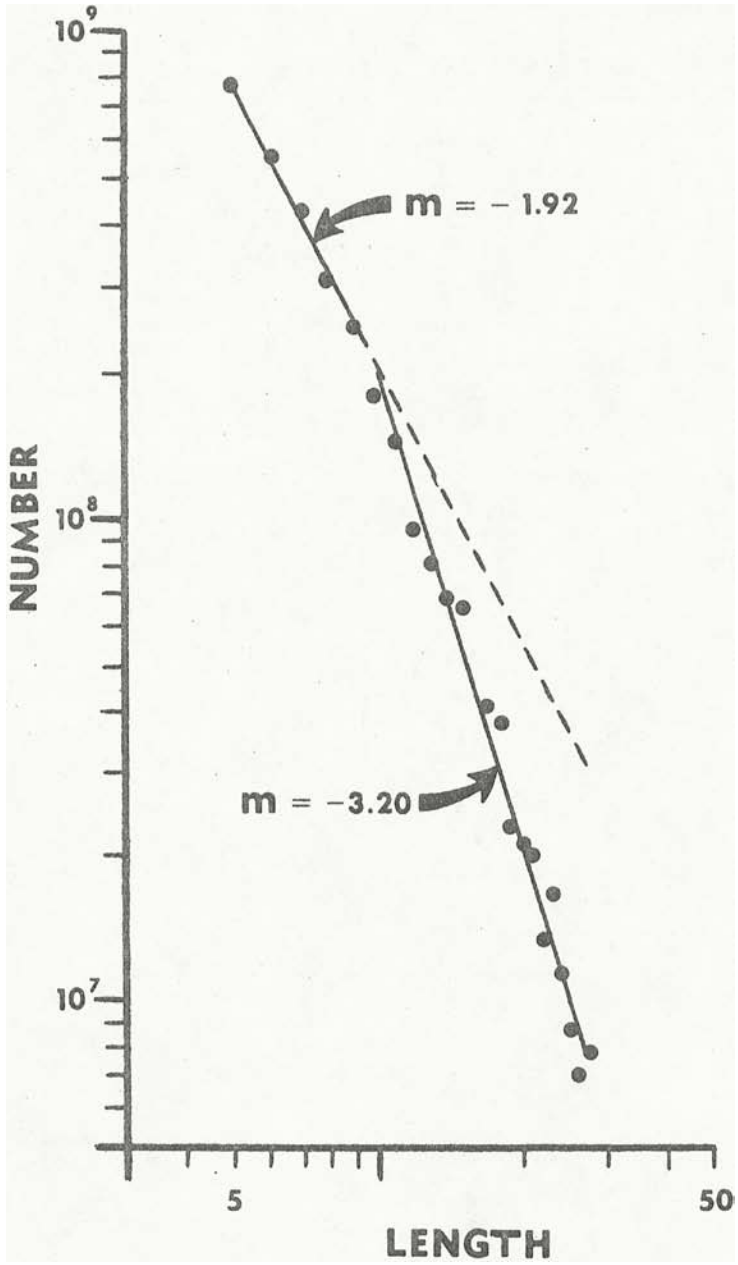

Figure 8. Log-log relationship between number and length of crappie (Pomoxis sp.). Note apparent slope change at 10 mm length.

Table 2. Production computations for larval crappie. See text for symbol definition and methodology.

Length (mm)	i	W_l ($\times 10^{-3}$)	N_i	$(w_{i+1}-w_i)$	$(N_{i+1}+N_i)/2$ ($\times 10^6$)	P_i (kg)	S_i
4-5	1	0.60	930.978				
				0.55	739.68	406.82	0.589
6	2	1.15	548.381				
				0.87	488.10	424.65	0.780
7	3	2.02	427.821				
				1.23	368.02	452.66	0.720
8	4	3.25	308.210				
				1.69	278.00	469.82	0.804
9	5	4.94	247.783				
				2.25	212.97	479.18	0.719
10	6	7.19	178.166				
TOTAL						2,233.13 kg	

are seen to increase with increasing size. Production for these first six size groups of crappie larvae is estimated to be 2,233 kg or 1.93 kg ha^{-1} for the Yellow Creek embayment. Since crappie constituted only 7 percent of the number of all larvae collected, production for all species and size groups of ichthyoplankters taken collectively would be much greater.

Biomass Entrained

Numbers by size class estimated to be entrained were determined from samples taken in the vicinity of the proposed intake structure. The data were treated in the manner shown in Table 2. Because of considerations given earlier, the resulting estimate of 13.029 kg is biomass entrained and not production foregone. This is a direct loss to the community of organisms which prey on crappie larvae. However, it is extremely doubtful if the effects of this minor loss of biomass (0.011 kg ha^{-1} for the embayment) could be detected.

Production Foregone

The data of Figure 7 were reorganized in Table 3. Number surviving to succeeding sizes was estimated for a mortality rate (equation (7), $M = 0.20668$) derived from the data in Figure 7, thus avoiding the variation of S_i observed in Table 2 which was calculated from equation (4).

The resulting 42.794 kg of production foregone is an indirect loss from entrainment. This loss is again insignificiant, being only 1.9 percent of the production calculated earlier for the entire embayment. It is valid

Table 3. Calculations to determine production foregone as a result of entrainment. See text.

L	Length 5	6	7	8	9	10
5	2,548,795	1,503,656	962,441	653,912	465,008	342,782
6		760,291	486,637	330,636	235,121	173,320
7			921,053	625,791	445,011	328,041
8				696,454	495,260	365,082
9					579,648	427,289
10						543,774
N_l	2,548,795	2,263,947	2,370,131	2,306,793	2,220,048	2,180,288
w_l	0.00060	0.00115	0.00202	0.00325	0.00494	0.00730
$N_l w_l$	1.274	2.604	4.7403	7.382	10.878	15.916

$$\sum_{L=5}^{10} N_L w_L = 42.794$$

only for the case where compensatory growth-survival does not occur, i.e., when survivors are unable to compensate for this loss. However, estimated production foregone may be useful in situations where conservative (i. e., worst case) impact assessments are desired.

Inspection of Figure 6 suggests that, since the data include time, numbers, and length, it should be possible to determine average growth rate of the population's individuals; because numbers through time form a distribution for any given size class, the mean of this distribution should represent the date on which the average individual achieved the length in question. This may be seen in Figure 9 where t_5, t_{10}, t_{15}, t_{20} are the dates on which the average individual attained 5, 10, 15, and 20 mm length respectively. (Additional length classes have been omitted from Figure 9 for the sake of clarity.)

Note that gear avoidance by the larger individuals will not shift the means of the distributions unless it varies on a seasonal basis, i.e., if avoidance is greater at either the beginning or end of the sample season. However, peaks of the distributions may be depressed as a result of avoidance.

A plot of t_L against L, where L is length, is presented in Figure 10. This represents average growth rate of individuals over the season. When determined in this manner, growth becomes a variable; i.e., it is not a rate "fixed" from an average of laboratory or field studies (Polgar 1977; Sette 1943). Using this method growth is determined empirically for the population under prevailing conditions. The known plasticity of growth in fishes is thus free to take the form expressed by the population under study; density dependence and compensatory growth are thus included in this model.

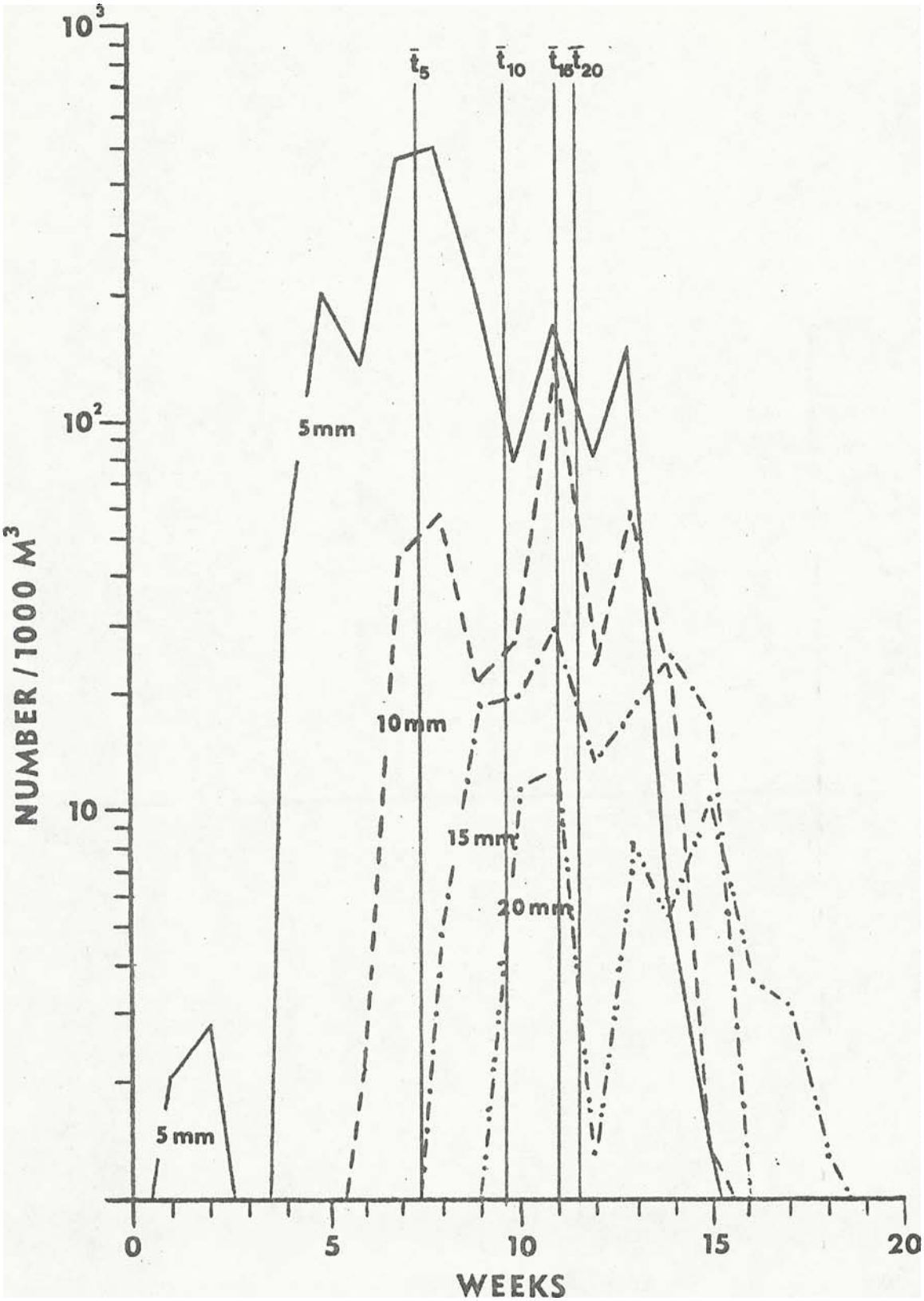

Figure 9. Date upon which the average 5mm crappie achieved that length ($\bar{t}_5$), 10 mm ($\bar{t}_{10}$), 15 mm ($\bar{t}_{15}$), and 20 mm ($\bar{t}_{20}$).

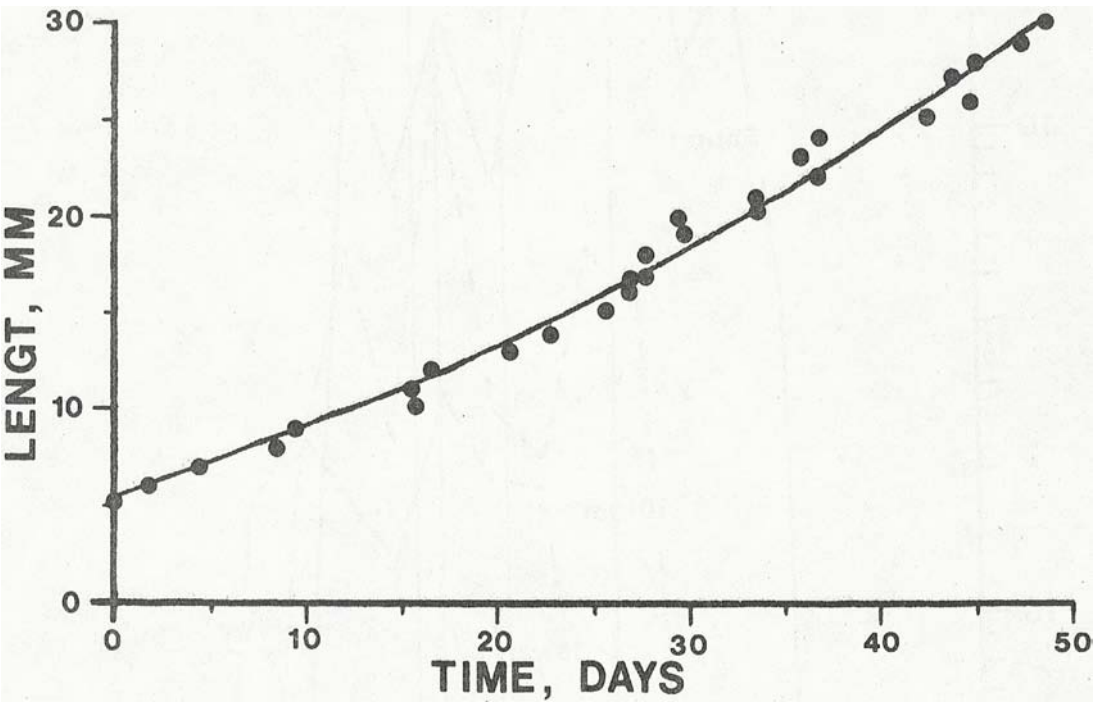

Figure 10. Growth of larval crappie.

MORTALITY THROUGH TIME

Mortality can be expressed as a time rate function in addition to relating it to length as was done in Figure 7. The relationships of length at age (days in Figure 10) and number at length (Figure 7) were combined to produce Figure 11. The result is mortality with increasing age for a cohort of larval crappie.

In this case the "fit" of the data, although satisfactory for most purposes, is not as good as might be hoped. It seems likely that progression of error has occurred because of combining the data estimates of length at age and numbers at length.

Surprisingly, the relationship in Figure 11 suggests that as young crappie increase in age (and length) their chance of survival per unit time remains constant. This is inconsistent with Figure 7. Evidently the apparent increase in survival with increasing length in Figure 7 is due to accelerating growth in length (Figure 10) and not age.

Other possibilities are that either the growth data of Figure 10 are incorrect or that the variation (error) in Figure 11 does not permit detection of a weak curvilinear relationship. Regardless, it seems likely that if the data in Figure 11 could be corrected for avoidance, the relationship would show increasing probability of survival with greater age.

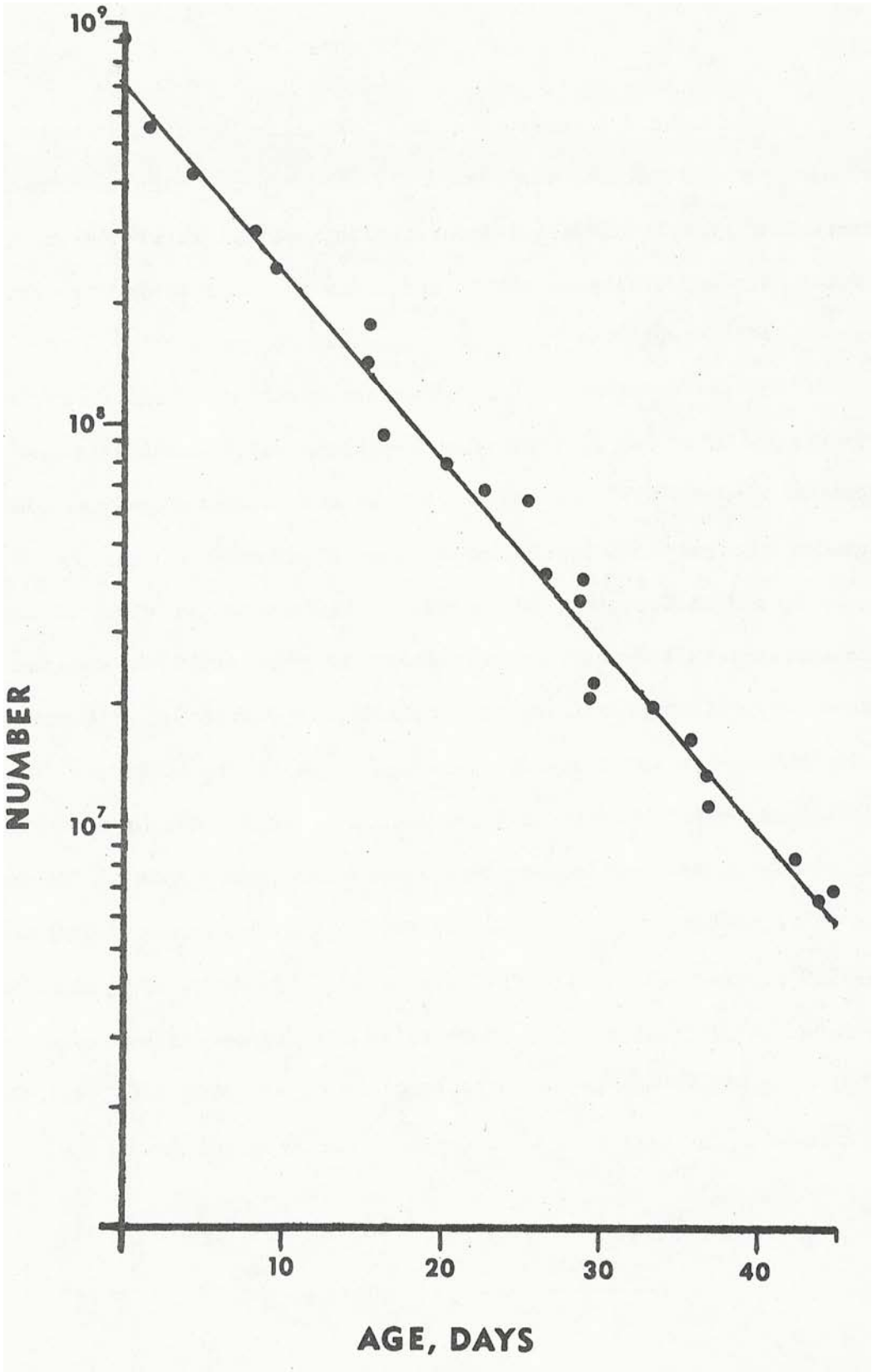

Figure 11. Mortality of larval crappie with increasing age.

RECRUIT LOSSES

Method 1

Recruitment reduction resulting from entrainment losses may be estimated under the assumptions of density independence with no compensation in survival or growth, homogenous distribution and all sizes present in proportion to their true abundance. Additionally, a decision concerning the sizes or ages of young fish that are vulnerable to entrainment is required.

Although it is probable that vulnerability to entrainment decreases with increasing size and age, for the purposes of this example it was assumed that crappie of 20 mm length or less are completely vulnerable to entrainment and that individuals larger than 20 mm are not entrained. In Figure 10 it may be seen that 20 mm length was attained in about 32 days. Since the proposed plant will entrain about 0.5 percent of the embayment volume per day, then the conditional mortality rate if no other sources of mortality existed is 0.005 day^{-1}. Survival is therefore 0.995 day^{-1} and for 32 days is (0.995^{32}) = 85.18 percent. Thus, plant-induced mortalities are, under the above assumptions, expected to reduce the number of 20 mm crappie by 14.82 percent. This result similarly obtains from a model of exponential decrease which includes natural and fishing (entrainment) mortality. Such a model is applicable since there is no curvilinear trend evident in Figure 11. A natural mortality coefficient (M) of 0.1067697 (r^2 = 0.986) was calculated from these data with a plant fishing mortality of (e^{-F} = 0.995) F = 0.0050125. Thus,

$$\frac{1-e^{-(M+F) \times 32}}{e^{-M \times 32}} = 0.1482 \text{ or } 14.82\ \%.$$

During the 32 days required to achieve 20 mm length, cumulative reduction in numbers as a result of entrainment is estimated to be 14.82 percent. However,

since the assumptions of uniform distribution and sizes present in proportion to the best estimate of their true abundance were both in serious violation for the proposed intake site, this estimate is considered to be substantially higher than the actual value.

Method 2

A second method of estimating recruitment losses due to entrainment is to follow a line of reasoning similar to that used earlier for estimating production losses. The numbers entrained are determined by size group (N_L). Similarly, the survival rate (S_L) from length L to 20 mm is determined from the relationship in Figure 8. The number of individuals expected to survive to a length of 20 mm, had they not been killed by the plant, is estimated simply as

$$N_{20} = \sum_{L=5}^{20} N_L S_L$$

The previous assumption of density independence still applies. In addition, natural mortality in the vicinity of the intake is assumed to be identical to that for the entire population; however, the assumptions of uniform distribution and sizes present in proportion to their true abundance are dropped. This seems more realistic than the previous method although it must be noted that because larval distribution by size and density will likely vary from year to year, this type of estimate legitimately pertains only to the year for which it was made.

Application of this latter method to the Yellow Creek larval crappie data suggests that the proposed plant would have reduced the number of 20 mm crappie by 7.18 percent in 1976. A partial tabulation of these computations is shown in Table 4.

Estimated impact to the juvenile crappie population, as calculated by both methods, is well above that which might be intuitively guessed from the ratio of numbers entrained to the total number of swim-up larvae (1.04 percent). It is clear that the consequences of prolonged vulnerability (32 days in this case) to entrainment as opposed to instantaneous vulnerability for intakes located on streams are to increase plant fishing mortality.

DISCUSSION

Impact assessment of ichthyoplankton entrainment at steam electric power plants is a science in its infancy. Before accurate predictions can be made, knowledge of ichthyoplankton contribution to, and interaction with, the aquatic community is needed. It is in this vein that the methods proposed in this work are advanced. The methodologies presented provide a realistic means of estimating number hatched, mortality, and production for lacustrine ichthyoplankton, using data collected and processed in a conventional manner.

As Eberhardt (1976) has observed,

> One of the most difficult problems in attempting to predict the effect of impacts . . . centers around the concept of "compensatory" mortality.

As he notes, this is a question which has formerly been difficult, if not impossible, to address. However, if numbers or relative densities of larvae hatched can be estimated, use of the earlier given methods to determine survival and biomass production may provide insight into compensatory survival and/or production; i.e., if larval density is low then food resources per individual may be high; growth should be rapid, possibly reducing mortality and increasing production for the various life stages. Compensatory growth (production) and survival obviously occur in fishes. Whether this occurs, and to what degree, in larval fishes is unknown, at least to me. Studies to this effect would do much to advance the infant science or "art" of assessing entrainment impact.

LITERATURE CITED

Allen, K. R. 1950. The computation of production in fish populations. N. Z. Sc. Rev. 8:89.

Eberhardt, L. L. 1976. Quantitative ecology and impact assessment. J. Env. Manag. 4(1):27-70.

Noble, R. L. 1970. Evaluation of the Miller high-speed sampler for sampling yellow perch and walleye fry. J. Fish. Res. Board Can. 27:1033-1044.

Noble, R. L. 1972. Mortality rates of walleye fry in a bay of Oneida Lake, New York. Trans. Amer. Fish. Soc. 101(4):720-723.

Pearcy, W. G. 1962. Ecology of an estuarine population of winter flounder, Pseudopleuronectes americanus (Walbaum)

Polgar, T. T. 1977. Striped bass icthyoplankton abundance, mortality, and production estimation for the Potomac River population, pp.110-127. In Assessing the Effects of Power Plant-Induced Mortality on Fish Populations. Pergamon Press, Elmsford, N.Y.

Sette, O. E. 1943. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part I: Early life history, including the growth, drift, and mortality of the egg and larval populations. U.S. Fish and Wildlife Service, Fish. Bull. 50:149-237.

Seifert, R. 1968. Reproductive behavior, incubation, and mortality of eggs and postlarval food selection in white crappie. Trans. Amer. Fish. Soc. 97(3):252-259.

Tennessee Valley Authority. 1976. Yellow Creek Nuclear Plant. Units 1 and 2. Environmental Report, Vol. 1, 2, and 3. Docket Nos. STN 50-566, STN 50-567.

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