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Dynamics of Ichthyoplankton in the Kanawha River, West Virginia

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ABSTRACT

Ichthyoplankton distribution and abundance were examined in the upper Kanawha River in the main channel, main-channel border (nearshore), and shoreline habitats. Drift of larval fish was comprised of 25 taxa distributed among 11 families and occurred from early April to late August, with peak densities in early June. Fish larvae appeared and densities peaked at water temperatures of 8.5°C and 22°C, respectively. Larval freshwater drum (Aplodinotus grunniens) was the most abundant taxa followed by Clupeidae, common carp (Cyprinus carpio), and other Cyprinidae. Clupeidae, common carp, and freshwater drum dominated main channel and nearshore collections. Cyprinidae, Catostomidae, and bluegill sunfish (Lepomis macrochirus) dominated shoreline collections. Most fish larvae (99%) collected in the main channel and nearshore habitats were protolarvae, while the larger larvae, meso- and metalarvae, were more abundant along the shoreline. In the main channel, fish larvae and eggs were generally distributed throughout the water column, but at times were more abundant on the bottom. Generally, larval fish densities were lower in the main channel compared to nearshore habitats.

INTRODUCTION

The effect of anthropogenic disturbances on the early life stages of fish is often expressed differentially across different types of aquatic habitats. For instance, docking facilities and recreational boat traffic generally have their greatest effect on littoral areas (Mueller 1980), while barge and tow-boat movements generally have their greatest influence on mainstream areas (Clafin et al. 1981). Therefore, how fish eggs and larvae are distributed within riverine environments can greatly determine the magnitude of risk a given species has from human activity.

In recent years, attention has focused on the effects of commercial navigation traffic on biota in large rivers. Concerns have arisen about the possible effects the expected increase in commercial traffic on the Mississippi River and its tributaries, including the Kanawha River, may have on river communities (ANSP 1980, UMRBC 1982, USACE 1983). Commercial traffic increased 140% on the

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Kanawha River between 1950 and 1980, and it is expected to increase another 65% by the year 2000 (USACE 1983). Effects of commercial traffic on adult fishes is probably minimal, based on the ability of adult fishes to avoid approaching vessels (ANSP 1980, Lowery et al. 1987). However, fish eggs and larvae are more fragile and less mobile and could, be more susceptible to impacts from commercial navigation traffic.

The distribution of ichthyoplankton in rivers is well documented (Swedberg and Walburg 1970, Hess and Winger 1976, Gale and Mohr 1978, Gallagher and Conner 1980, 1983, Hergenrader et al. 1982, Lathrop 1982, Holland and Sylvester 1983, Holland 1986a, Simon 1986, Odum 1987, Sager 1987, Millard, 1992). However, these studies had only one or two stations located in the main channel and most only collected surface and/or bottom samples. Modifications of navigation locks may be necessary to accommodate the increases of commercial traffic on the Kanawha River. Consequently, it became evident that the dynamics of ichthyoplankton (i.e., species composition, abundance, and spatio-temporal distribution) should be evaluated in detail in a variety of habitats. Thus, that was the purpose of our study.

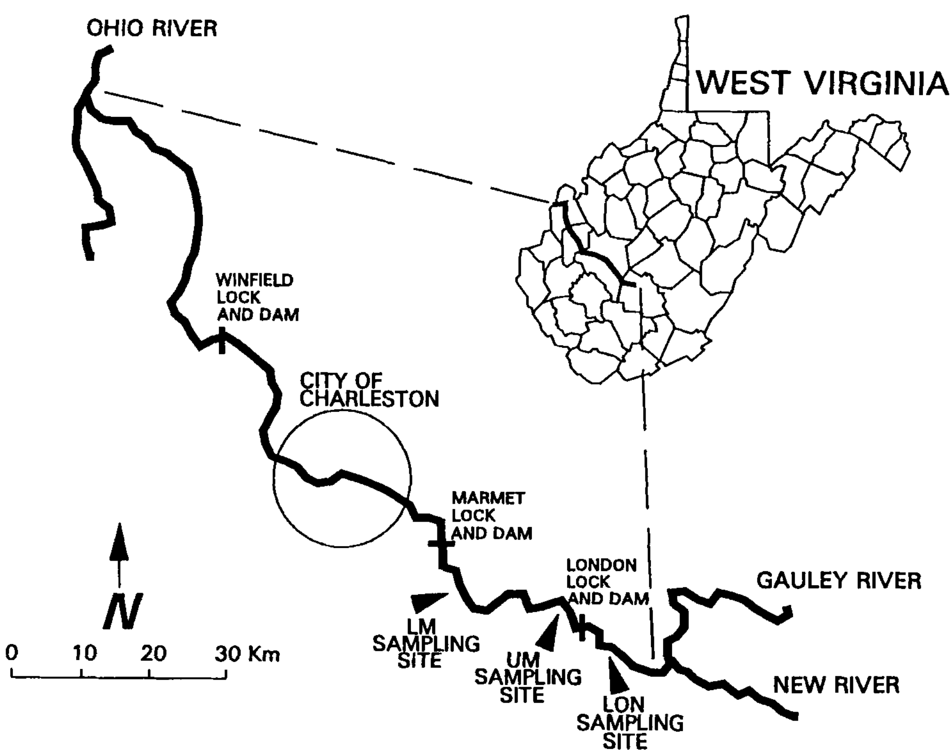

Figure 1. Location of ichthyoplankton sampling sites in the upper Kanawha River, West Virginia, March-August, 1989. Lower Marmet (LM), upper Marmet (UM), and London (LON) sites were located at river km 115, 127.5, and 137, respectively.

METHODS AND MATERIALS

The Kanawha River is a sixth-order tributary of the Ohio River fonned by the confluence of the New and Gauley Rivers (Figure 1). The Kanawha River contains 153 km of commercially navigable waters in its 188 km length, and three sets of locks and dams create three navigational pools. Ichthyoplankton sampling was conducted in the London Pool (LON sampling site) at river km 137. In the Marmet Pool, collection sites were located at river km 128 (UM sampling site) and 115 (LM sampling site). The river width at LON, UM, and LM was 200, 213, and 287 m, respectivley, and river width was 8.7, 6.3, and 6.3 m, respectively.

Ichthyoplankton sampling was conducted weekly from 11 April to 15 August 1989 during the daytime at each site. The river was divided in half, from middle of the main channel to the right ascending bank at each sampling site. Only half of the river at each site was sampled because of logistical considerations, including the presence of navigation traffic and time limitations. For each site, six sampling stations were located in the main channel, one station was located in the nearshore area, and one station was located along the shoreline. Main-channel stations were approximately 12, 13, and 17 m apart at LON, UM, and LM sampling sites, respectively. Main channel encompassed the navigation channel (depth > 2.75 m, high flows, and bottom structurally simple), while the nearshore area (depth < 2.75 m, low flows, and bottom structurally complex) was confined by the edge of the main channel to the river bank (Nielsen et al. 1986). The area near the river edge where sampling vessels could not operate (<1.0 m in depth) was considered the shoreline.

Ichthyoplankton was sampled with two experimental United States Army Corps of Engineers (USACE) modified Isaacs-Kidd ichthyoplankton nets. Two identical nets were deployed from separate vessels in a stationary position at each sampling site and date. These nets sampled concurrently at each site, however, different stations and depths were sampled by each net. The nets were 7 m long, fitted with 500-μm mesh netting and attached to 2.1 x 2.1 m steel frames. The net mouth could be remotely opened and closed to prevent contamination from other strata while deploying and retrieving the net. The mean volume filtered was 241.9 m^3 for main-channel collections and 129.7 m^3 for nearshore areas. Standard sampling duration was five minutes at a velocity of 15 cm/s, which was maintained by monitoring a Marsh-McBirney 2010 flowmeter mounted in the net frame.

Surface (surface of the water to 2.3 m below the surface) samples were collected at each main-channel station. When station depth was less than 3.3 m, as with all nearshore stations, only the surface was sampled. If main-channel station depth was between 3.3 m and 5.7 m, then samples were collected at the surface and bottom. If station depth was greater than 5.7 m, then three strata (i.e., surface, mid-depth, and bottom) were sampled. Bottom samples were collected with the net approximately 0.3 m off the river bottom. Triplicate samples (i.e., three hauls per station/depth with one net) were collected from each station and depth among dates and sites.

Table 1. Taxonomic and percent composition (%), and number (n) of larval fishes collected from the upper Kanawha River, West Virginia, March-August, 1989.

Family	Scientific Name	Common Name	(%)	n
Lepisosteidae	Lepisosteus osseus	longnose gar	0.01	6
Clupeidae	-----	shads and herrings	22.8	11,427
Hiodontidae	Hiodon tergisus	mooneye	0.03	17
Cyprinidae	Cyprinus carpio	common carp	20.1	10,022
other Cyprinidae (combined)	Notropis atherinoides	emerald shiner		
	Notemigonus crysoleucas	golden shiner		
	Pimephales notatus	bluntnose minnow		
	Pimephales promelas	fathead minnow	10.0	4,995
Catostomidae	Ictiobus bubalus	smallmouth buffalo	2.1	1,050
	Carpiodes spp.	carpsuckers	1.1	549
other Catostomidae (combined)	Minytrema melanops	spotted sucker		
	Moxostoma spp.	redhorses		
	unidentifiable below family level		1.4	677
Ictaluridae	Ictalurus punctatus	channel catfish	0.01	4
Atherinidae	Labidesthes sicculus	brook silverside	0.13	64
Percichthyidae	Morone chrysops	white bass	1.4	699
Centrarchidae	Lepomis macrochirus	bluegill sunfish	4.9	2,465
	Lepomis megalotis	longear sunfish	0.05	33
	Pomoxis annularis	white crappie	0.5	250
	Pomoxis nigromaculatus	black crappie	0.5	250
	Ambloplites rupestris	rock bass	0.08	39
	Micropterus dolomieui	smallmouth bass	0.3	152
	Micropterus salmoides	largemouth bass	0.07	33
Percidae	Percina caprodes	logperch	2.0	998
	Percina copelandi	channel darter	1.0	499
	Stizostedion canadense	sauger	0.02	10
Sciaenidae	Aplodinotus grunniens	freshwater drum	31.5	15,712
TOTAL			100	49,951

Ichthyoplankton shoreline sampling was conducted with a 2.6-m long x 1-m deep, 500-μm mesh seine. Seining was conducted less than 1% distance across the river from the right ascending bank at all three sites. Ten samples were collected along the shoreline on each sample date.

All larval fishes collected were identified to the lowest possible taxon using several references (May and Gasaway 1967, Taber 1969, Hogue et al. 1976, Auer 1982, Fuiman et al. 1983) and assigned to a developmental stage according to Snyder et al. (1977). Fish eggs were enumerated but not separated by taxa. Juveniles (full complement of adult fin rays and absorbed finfold) were excluded. Total lengths (TL) were measured to the nearest 0.1 mm for the dominant taxa.

Water temperature was measured at the surface with a YSI model 57 oxygen meter on each sampling date. Mean daily water discharge rates were measured at Kanawha Falls, West Virginia by the United States Geological Survey (USGS 1990).

Densities of ichthyoplankton were computed as the number of fish eggs or larvae per $100m^3$ of water filtered through each net. Statistical procedures were conducted on natural logarithmic transformations to normalize the data. Statistical significance was set at $P \leq 0.05$. Because we sampled fixed stations over time, a repeated-measures analysis of variance (ANOVA) was used to compare densities and total lengths (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Taxonomic Composition

A total of 25 taxa from 11 families was collected in the upper Kanawha River during 1989. Freshwater drum (Aplodinotus grunniens) (31.5%), Clupeidae (22.8%), common carp (Cyprinus carpio) (20.1%), other Cyprinidae (10%), and bluegill sunfish (Lepomis macrochirus) (4.9%) constituted nearly 90% of the 49,951 larvae collected (Table 1). Species composition in the upper Kanawha River was similar to other navigable and channelized rivers such as the lower Kanawha, Missouri, Ohio, and Mississippi Rivers (Tondreau 1979, Gallagher and Conner 1980, 1983, Holland and Sylvester 1983, Simon 1986, Shaeffer and Nickum 1986, ESE 1989, Millard 1992). These results are not unexpected as these taxa also dominated the adult fish population in the lower and upper Kanawha River (VPI&SU 1985, Knight and Margraf 1992).

Temporal Distribution

Larval fish abundance peaked in early June and averaged 57 larvae/100 m^3 at a mean water temperature of 22°C (Figure 2). Mean daily water discharge was relatively low (1,062 to 5,067 ha-m day) during the period of peak larval fish abundance. Fish eggs appeared in collections from late May through early August and peaked in late June at a mean of 132 eggs/100 m^3.

Darters were the first larvae to appear in early April at a water temperature of 8.5°C. Odom (1987) first collected Percidae larvae in early May in the lower

Kanawha River. By late April, with water temperatures near 11°C, sauger (Stizostedion canadense) larvae were collected. No peaks were evident for these two taxa, because few larvae were collected.

Smallmouth buffalo (Ictiobus bubalus) and carpsuckers (Carpiodes spp.) both appeared and peaked from mid to late May, at water temperatures ranging from 16°C to 18°C. Wrenn (1968) and Gale and Mohr (1976) reported similar water temperatures when the majority of smallmouth buffalo and carpsucker larvae were collected. Most taxa were first collected in late May or early June and peaked in early June. These included Clupeidae, other Cyprinidae, common carp, Catostomidae, bluegill sunfish, and freshwater drum. Peak abundances occurred at

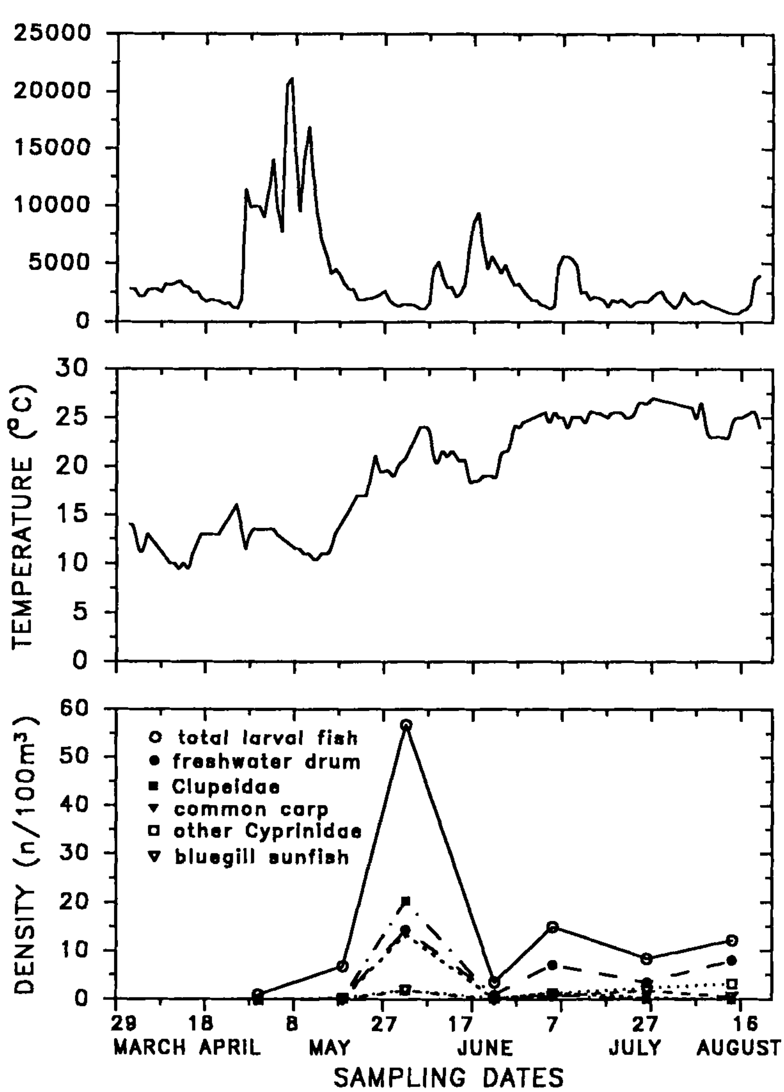

Figure 2. Mean daily discharge (ha-m/day), temperature (°C), and larval fish densities of dominant taxa (number/100m^3) from the upper Kanawha River, West Virginia, March-August, 1989.

water temperatures ranging from 19°C to 22°C. Hess and Winger (1976) observed peak larval fish densities at water temperatures ranging from 18°C to 23°C in the Cumberland River, Tennessee. Because of low abundance, no discernible peaks were apparent for white bass (Morone chrysops), brook silverside(Labidesthes sicculus), mooneye (Hiodon tergisus), longnose gar (Lepisosteus osseus), channel catfish (Ictalurus punctatus), crappie (Pomoxis spp.), rock bass (Ambloplites rupestris), and black bass (Micropterus spp.) (Table 1).

A vast majority of larvae collected were yolk sac or protolarvae. Yolk sac and protolarval freshwater drum, Clupeidae, and common carp accounted for 99.5% of the larvae collected from their respective taxonomic groups. Meso and metalarvae Cyprinidae accounted for 20% of the total Cyprinidae larval fish catch. However, 99% of these older larvae were collected along the shoreline. Protolarvae of these major taxa were collected through August. These results indicated that spawning continued through August.

Size Distribution

Larval fish total lengths were not different ($P > 0.05$) over time for common carp and freshwater drum for most collection dates. The exception being that smaller freshwater drum and common carp larvae were collected in late June. Larger Clupeidae and other Cyprinidae larvae were collected in June than later in the sampling season, again, indicating continuous spawning for these taxa and the possibility that the larger larvae were able to avoid our sampling gear. Over time, other Cyprinidae larvae were larger at the surface than the lower two sampling depths.

No depth differences were evident for Clupeidae, common carp, and other Cyprinidae. Inconsistent differences were evident over time among sampling depths for freshwater drum. Generally, similar size groups of freshwater drum larvae seemed to be equally distributed among depths.

Generally, the sizes of larval fish in the main channel were equally distributed among sampling stations. For other Cyprinidae and common carp, differences ($P \leq 0.05$) were apparent between habitats. Larger larvae were collected along the shoreline and nearshore areas compared to the main channel. These larvae were more developed, thus, were able to move out of the faster currents into more protected areas such as the shoreline habitat. No differences were apparent for Clupeidae and freshwater drum between habitats.

Spatial Distribution

To determine general trends, we combined our data among dates and sites. There were differences ($P \leq 0.05$) in densities among stations in the main channel for Clupeidae, common carp, and freshwater drum (Figure 3). Freshwater drum occurred at a greater abundance in the middle of the main channel. However, Clupeidae and common carp occurred at higher abundances at sampling stations closer to the nearshore areas. Other Cyprinidae and bluegill sunfish were equally distributed among the main-channel stations. Total larval fish abundance was not ($P > 0.05$) different among main-channel stations.

Table 2. Mean densities (number/100m^3) (±SE) of larval fish taxa among sampling depths in the upper Kanawha River, West Virgina, March-August, 1989. Values followed by the same letter among sampling depths for each taxa are not significantly (P > 0.05) different. Values in parentheses are the sample size.

	Sampling Depth		
	Surface (n=625)	Mid-Depth (n=294)	Bottom (n=439)
Taxa	mean	mean	mean
freshwater drum	1.3^b ±0.2	6.5^{ab} ±1.0	8.8^a ±1.1
Clupeidae	3.9^a ±0.7	2.5^a ±0.6	6.4^a ±1.5
common carp	1.2^b ±0.3	1.7^b ±0.5	6.4^a ±1.5
other Cyprinidae	1.4^a ±0.3	0.5^a ±0.1	1.1^a ±0.2
bluegill sunfish	1.2^a ±0.2	0.4^b ±0.1	0.4^b ±0.1
smallmouth buffalo	0.4^a ±0.2	0.1^a ±0.03	0.3^a ±0.1
carpsuckers	0.2^b ±0.01	1.0^a ±0.01	0.9^a ±0.1
Percidae	1.6^a ±0.5	0.3^a ±0.08	0.5^a ±0.05
total larval fish	11.7^c ±1.2	14.6^b ±1.7	26.8^a ±2.8
fish eggs	24.0^b ±2.3	23.9^b ±3.2	38.2^a ±4.7

Differences in abundance were detected among sampling depths. Common carp, carpsucker, freshwater drum, and fish eggs were more abundant ($P \leq 0.05$) at the bottom (Table 2). Accordingly, total larval fish densities were more abundant ($P \leq 0.05$) at the bottom. Similar findings were reported by Gallagher and Conner (1983), Holland (1986b), and VPI&SU (1985) for freshwater drum. However, Cada and Hergenrader (1980) found greater abundances of freshwater drum in surface drifts. In this study, no depth differences ($P > 0.05$) were apparent for Clupeidae, other Cyprinidae, smallmouth buffalo, and darters. However, Taber (1969), Storck et al. (1978), Tuberville (1979), and Graser (1979) found Clupeidae larvae to be more abundant in surface collections during the daytime. Bluegill sunfish were the only larvae to occur at greater ($P \leq 0.05$) densities at the surface in this study (Table 2). Consonant, Taber (1969) found sunfish larvae to be more abundant in surface collections.

Differences were also apparent for total larval fish densities between main channel and nearshore habitats (Figure 4). Larval fish were detected first in nearshore areas in early April, and were first collected in mid May in the main channel. Densities were similar between the two habitats from late May through late June. However, from late June through late July, larvae were more abundant in nearshore areas, possibly due to migration of larvae to more protected areas. Odom (1987) found that gizzard shad larvae were more abundant in areas closer to the shoreline than in the deeper waters in the lower Kanawha River. Fish larvae located in any shallow main-channel habitat at any depth are potentially vulnerable to commercial navigation traffic induced mortality. Mortality would likely be highest from late May to mid July, when the majority of larval fish are present. The less developed larvae, such as the yolk sac and protolarvae would likely incur the highest mortality rates. The meso and metalarvae tended to move into protected areas (i.e., shoreline or backwater habitats). The effects of increased barge capacity on shoreline larval fish is uncertain. However, we did observe larvae along the shoreline swimming to deeper water when wind or traffic induced waves struck the shoreline. The shoreline and backwater habitats have been identified as crucial nurseries in the Kanawha River (Scott and Nielsen 1988, Rider 1991).

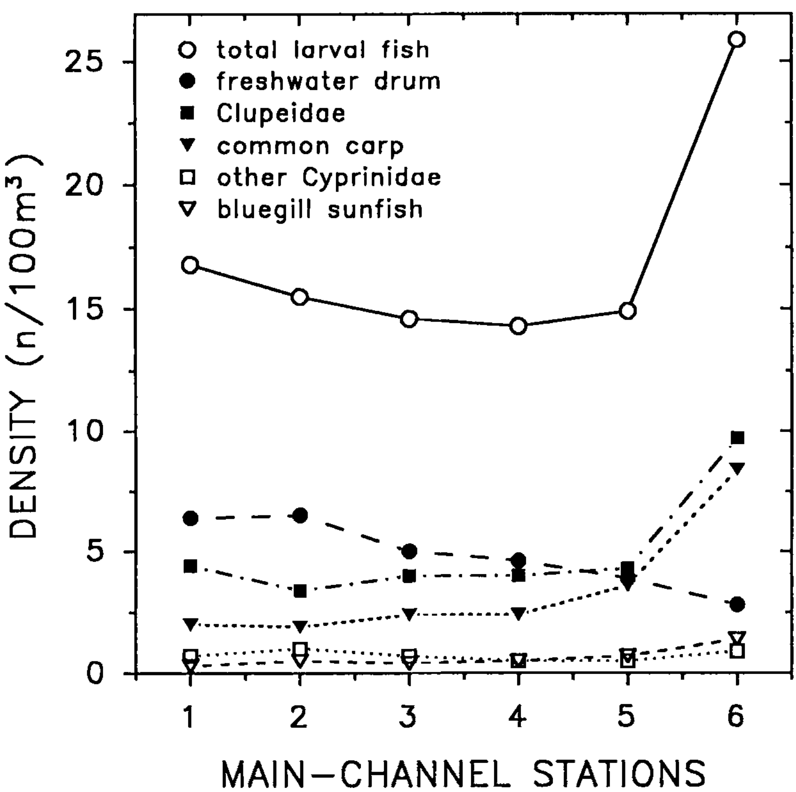

Figure 3. Mean densities (number/100m^3) of dominant larval fish taxa among each sampling station within the main channel of the upper Kanawha River, West Virginia, March-August, 1989. Station 1 is middle of the channel and as station number increases, the stations were closer to the nearshore.

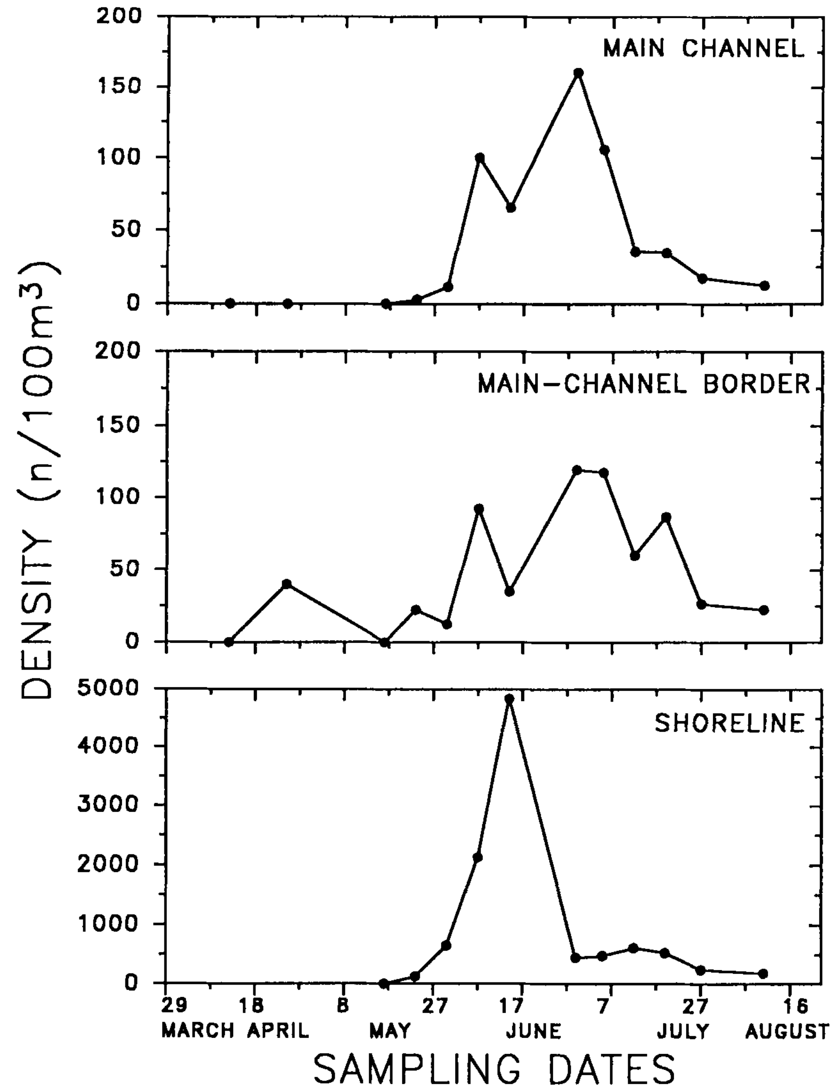

Figure 4. Mean densities (number/100m^3) of all larval fish taxa combined among different habitats and sampling dates, upper Kanawha River, West Virginia, March-August, 1989. Note the Y-axis scales for the different habitats are different.

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LITERATUTRE CITED

ANSP (Academy of Natural Sciences of Philadelphia). 1980. Analysis of the effect of tow traffic on the biological components of the Ohio River. Academy of Natural Sciences of Philadelphia, PA.

Auer, N.A. 1982. Identification of larval fishes of the Great Lakes Basin with emphasis on the Lake Michigan drainage. University of Michigan, Special Publication 82-3, Ann Arbor, MI.

Cada, G.F. and G.L. Hergenrader. 1980. Natural mortality rates of freshwater drum larvae in the Missouri River. Transactions of the American Fisheries Society 109:479-483.

Clafin, T.O., R.G. Rada, M.M. Smart, D.N. Nielsen, J.K. Scheidt, and B.A. Biltgen. 1981. The effects of commercial and recreational navigation on selected physical and chemical variables in navigation pool number 9 upper Mississippi River. Environmental Work Team, Upper Mississippi River Basin Commission Master Plan, Minneapolis, MN.

ESE (Environmental Science and Engineering, Inc). 1989. 1988 Ohio River Ecological Research Program, St. Louis, MO.

Fuiman, L.A., J.V. Conner, B.A. Lathrop, G.L. Buynak, D.E. Snyder, and J.J. Loos. 1983. State of the art of identification for cyprinid fish larvae from Eastern North America. Transaction of the American Fisheries Society 112:319-332.

Gale, W.F., and H.W. Mohr, Jr. 1976. Fish spawning in a large Pennsylvania river receiving mine effluents. Proceedings of the Pennsylvania Academy of Sciences 50:160-162.

Gale, W.F., and H.W. Mohr, Jr. 1978. Larval fish drift in a large river with a comparison of sampling methods. Transactions of the American Fisheries Society 107:46-55.

Gallagher, R.P., and J.V. Conner. 1980. Spatio-temporal distribution of ichthyoplankton in the lower Mississippi River, LA, p. 101-115 **In** Proceedings of the Fourth Annual Larval Fish Conference. L.A. Fuiman (ed.). United States Fish and Wildlife Biological Report FWS/OBS-80/43.

Gallagher, R.P., and J.V. Conner. 1983. Comparison of two sampling gears with notes on microdistribution of fish larvae in a large river. Transactions of the American Fisheries Society 112:280-285.

Graser, L.F. 1979. Spatio-temporal distribution of clupeid larvae in Barkley Reservoir, p. 120-138 **In** Proceedings of the Third Symposium on Larval Fish. R.D. Hoyt (ed.). Western Kentucky University, Bowling Green, KY.

Hergenrader, G.L., L.G. Harrow, R.G. King, G.F. Cada, and A.B. Schlesinger. 1982. Larval fishes in the Missouri River and the effects of entrainment, p. 185-223 **In** The Middle Missouri River: A Collection of Papers on the Biology with Special Reference to Power Station Effects. L.W. Hesse, G.L. Hergenrader, H.S. Lewis, S.D. Reetz, and A.B. Schlesinger (eds.). Missouri River Study Group, Norfolk, NE.

Hess, T.B., and P.V Winger. 1976. The occurrence and distribution of larval fish in the Cumberland River. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 20:295-310.

Hogue, J.J., Jr., R. Wallus, and L.K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Technical Note B19, Tennessee Valley Authority, Norris, TN.

Holland, L.E. 1986a. Effect of barge traffic on distribution and survival of and small fishes in the upper Mississippi River. Transactions of the American Fisheries Society 115:162-165.

Holland, L.E. 1986b. Distribution of early life stages of fishes in selected pools of the upper Mississippi River. Hydrobiologia 136:121-130.

Holland, L.E., and J.R. Sylvester. 1983. Distribution of larval fishes related to potential navigation impacts on the upper Mississippi River, Pool 7. Transactions of the American Fisheries Society 112:293-301.

Knight, C.T., and F.J. Margraf. 1992. A study of benthos and fish distribution, abundance and productivity, and trophic relationships in the Kanawha River, West Virginia, Volume 3, Juvenile and Adult Fishes. U.S. Army Corps of Engineers, Huntington, WV.

Lathrop, B.F. 1982. Ichthoplankton density fluctuations in the lower Susquehanna River, Pennsylvania, from 1976 through 1980, p.28-36 In Proceedings of the Fifth Annual Larval Fish Conference. C.F. Bryan, J.v. Conner, and F.M. Truesdale (eds.). Lousiana Cooperative Fish Research Unit, Baton Rouge, LA.

Lowery, D.R., E.M. Scott, and R.W. Pasch. 1987. Hydroacoustic survey of fish populations of the lower Cumberland River. U.S. Army Corps of Engineers, Nashville, TN.

May, E.B., and C.R. Gasaway. 1967. A preliminary key to the identification of larval fishes of Oklahoma, with particular reference to Canton Reservoir, Including a selected bibliography. Oklahoma Department of Wildlife and Conservation, Contribution No. 164, Norman, OK.

Millard, M.J. 1992. Nearshore habitat use by larval fishes near two islands in the upper Ohio river. Ph.D. dissertation, West Virginia University, Morgantown, WV.

Mueller, G. 1980. Effects of recreational river traffic on nest defense by longear sunfish. Transactions of the American Fisheries Society 109:248-251.

Nielsen, L.A., R.J. Sheehan, and D.J. Orth. 1986. Impacts of navigation on riverine production in the United States. Polish Archives of Hydrobiology 33:277-294.

Odom, M.C. 1987. Distribution of larval fishes in the Winfield Pool, Kanawha River, and direct impacts of commercial navigation traffic on larval fish survival. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Rider, S.J. 1991. Distribution and abundance of ichthyoplankton in the London and Marmet Pools, Kanawha River, West Virginia. M.S. thesis, West Virginia University, Morgantown, WV.

Sager, D.R. 1987. Distribution of larval gizzard shad in the upper Cape Fear River, North Carolina. American Fisheries Society Symposium 2:174-178.

Scott, M.T., and L.A. Nielsen. 1989. Young fish distribution in backwaters and main-channel borders of the Kanawha River, West Virginia. Journal of Fish Biology 35:21-27.

Sheaffer, W.A., and J.G. Nickum. 1986. Backwater areas as nursery habitats for fishes in Pool 13 of the upper Mississippi River. Hydrobiologia136: 131-140.

Simon, T.P. 1986. Variation in seasonal, spatial, and species composition of ichthyoplankton, Ohio River miles 569-572. Transactions of the Kentucky Academy of Science 47:19-26.

Snyder, D.E., B.M. Snyder, and S.C. Douglas. 1977. Identification of golden shiner (Notemigonus crysoleucas), spotfin shiner (Notropis spilopterus), and fathead minnow (Pimephales promelas), larvae. Journal of the Fisheries Research Board of Canada 34:1397-1409.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill Publishing. New York, NY.

Storck, T.W., D.W. Dufford, and K.T. Clement. 1978. The distribution of limnetic fish larvae in a flood control reservoir in central Illinois. Transactions of the American Fisheries Society 107:419-424.

Swedberg, D.V., and C.H. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri River. Transactions of the American Fisheries Society 99:560-570.

Taber, C.A. 1969. The distribution and identification of larval fishes in the Buncombe Creek Arm of Lake Texoma with observations on spawning habits and relative abundance. Ph.D. dissertation, University of Oklahoma, Norman, OK.

Tondreau, R.E. 1979. Ichthyoplankton distribution in the Missouri River. M.S. thesis, University of Iowa, Iowa City, IA.

Tuberville, J.D. 1979. Vertical distribution of ichthyoplankton in upper Nickajack Reservoir, Tennessee, with comparison of three sampling methodologies, p. 185-203 In Proceedings of the Third Symposium on Larval Fish. R.D. Hoyt (ed.). Western Kentucky University, Bowling Green, KY.

UMRBC (Upper Mississippi River Basin Commission). 1982. Comprehensive master plan for the management of the upper Mississippi River system. Upper Mississippi River Basin Commission, Minneapolis, MN.

USACE (U.S. Army Corps of Engineers). 1983. Kanawha River navigation reconnaissance report and appendices. U.S. Army Corps of Engineers, Huntington, WV.

USGS (U.S. Geological Survey). 1990. Water resources data, West Virginia, water year 1989. U.S. Geological Survey Water-Data Report WV-89-1, Charleston, WV.

VPI&SU (Virginia Polytechnic Institute and State University). 1985. Development and application of an energy flow model to analyze impacts of navigation changes on the Kanawha River in West Virginia. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Wrenn, W.B. 1968. Life history aspects of smallmouth buffalo and freshwater drum in Wheeler Reservoir, Alabama. Proceedings of the Annual Conference Southeastern Association Fish and Wildlife Agencies 22: 479-495.

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