Spring distribution and abundance of ichthyoplankton in the tidal Delaware River

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Abstract.–Water quality in the tidal freshwaters of the Delaware River has improved substantially over the last decade. Areas near Philadelphia that were once anoxic now rarely experience dissolved oxygen concentrations lower than 3 ppm. To assess how fish spawning and nursery activity in the river has changed following these water quality improvements, ichthyoplankton were collected from April to June in 1987 and 1988 in the tidal freshwaters of the Delaware River and compared to data available from studies conducted during the mid-1970's. Eighteen taxa were collected in the present study; larval *Morone americana* (white perch), *Alosa sapidissima* (American shad), and *Alosa* spp. (river herring) were the most abundant. Total density of eggs and larvae was highest upstream of Philadelphia, where water quality has historically been highest. Ichthyoplankton density and taxonomic composition in the tributaries were similar to the most productive portions of the mainstem, except in the Schuylkill River. There, water quality is still poor, and ichthyoplankton density was an order of magnitude less than in the mainstem. In comparison to data from the previous decade, the present assemblage of the Delaware River was more diverse. Nine taxa, most notably *A. sapidissima*, were significantly more abundant in at least one portion of the river in the present study, though total ichthyoplankton density was no higher than prior to the water quality improvements. Five taxa, most notably *Cyprinus carpio* (carp), were significantly less abundant in the present assemblage.

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The tidal freshwater portion of the Delaware River was once among the most polluted estuaries in the United States. Water quality was so poor during the 1940's that gases released from the water reportedly tarnished metal and corroded engine parts of naval vessels moored near Philadelphia, PA (Albert, 1988). Conditions were poorest in the Philadelphia area, where much of the river became anoxic during warmer months. This so-called pollution block substantially reduced the upriver migration of anadromous fishes such as *A. sapidissima* and *Morone saxatilis* (striped bass) (Chittenden, 1971, 1974).

Installation of secondary treatment at municipal sewage treatment plants along the river has reduced organic loading by more than 75% since the early 1970's (Albert, 1988). As a result, dissolved oxygen concentration in the river has increased, and the magnitude and duration of the pollution block near Philadelphia has been reduced. In areas that were once anoxic, dissolved oxygen concentrations during the spring are now rarely lower than 5 ppm, or 3 ppm during the summer (Albert, 1988). Fishery resources appear to have responded to the improved water quality conditions; the size of the *A. sapidissima* spawning population has increased substantially (Maurice et al., 1987) and average catch of young-of-year *M. saxatilis* has increased by more than an order of magnitude[1].

Despite the size and importance of the Delaware estuary, little is known about which fish use the tidal freshwater region of the river as a spawning and nursery ground. The most recent regional ichthyoplankton survey was conducted in 1981, but covered 100 km of river with only 20 samples per week and only data for *M. saxatilis* were reported[2]. Numerous ichthyo-plankton collections were conducted in the mid-1970's as part of power plant or industrial-related impact studies, but these were individually limited in spatial extent and have never been integrated to provide a regional description. Most important, however, no regional study has been conducted since the dramatic improvements in water quality occurred. In this study we provide new data to describe present ichthyoplankton distribution and abundance in the tidal Delaware

[1] Weisberg, S. B., W. H. Burton, and H. A. Wilson. 1991. Delaware River striped bass studies: population estimate of the 1990 year class and an evaluation of the young-of-year index of abundance. Rep. to the Delaware Basin Fish and Wildl. Manage. Coop., Trenton, NJ.

[2] Himchak, P. J., J. Carlson, and R. Tilton. 1981. Spawning and recruitment of the striped bass, *Morone saxatilis*, in the Delaware River. Rep. available from New Jersey Dep. Environ. Protection, Trenton, NJ, Bureau of Marine Fisheries.

River and its tidal tributaries, integrate data from the many ichthyoplankton collections conducted during the 1970's, and compare these data to describe how spawning and nursery activity in the area has changed.

Methods

Ichthyoplankton samples were collected weekly from April to June in 1987 and 1988, following a stratified random design. Sampling in 1987 was conducted between Riverton, New Jersey (river kilometer [rkm] 174) and the fall line at Trenton, New Jersey (rkm 214) for nine weeks beginning on 22 April (Fig. 1). The sampling area was stratified into four 10-km regions. Each region was stratified further into three habitats: shoal (river depth of less than 8 m), channel bottom (within 1 m of the bottom in areas with an overall depth >8 m), and channel mid-water. Three randomly placed samples were collected from each habitat in each region during each week. Sampling in 1988 was conducted between Bristol, Pennsylvania (rkm 191), and Artificial Island, New Jersey (rkm 87), for eight weeks beginning on 18 April (Fig. 1). Allocation procedures in 1988 were the same as in 1987, except that the area was stratified into nine equally-sized regions, and in the channel bottom habitat, only two samples were collected.

The sampling of the river in 1987 also included tributary stations in Martin's Creek, Neshaminy Creek, Dredge Harbor, and Rancocas Creek. In 1988, tributary stations were established in the Schuylkill River, Raccoon Creek, Oldman's Creek, the Christina River, and at two stations in the Chesapeake Bay and Delaware River (C&D) Canal. Tributary stations were located approximately 1 km upstream of the confluence with the Delaware River, except for the second C&D Canal station, which was located near the Rt. 13 bridge, about 4 km from the river. One mid-water sample was collected from each tributary station each week, except for the C&D Canal stations, where both mid-water and bottom samples were taken weekly.

Samples from the bottom habitat were collected by using a 1-m diameter epibenthic ichthyoplankton sled; water column and shoal habitats were sampled using stepped oblique tows with a 0.5-m bongo net. Both types of gear were fitted with 505-μm mesh plankton nets. The volume of water that each net filtered was estimated with a General Oceanics digital flowmeter mounted at the mouth of the epibenthic sled and to one side of the bongo net. Tows were conducted against the current for five minutes at a speed of approximately 1.0 m/sec. The catch was preserved in 10% formalin, stained with rose bengal, and taken to the laboratory for analysis.

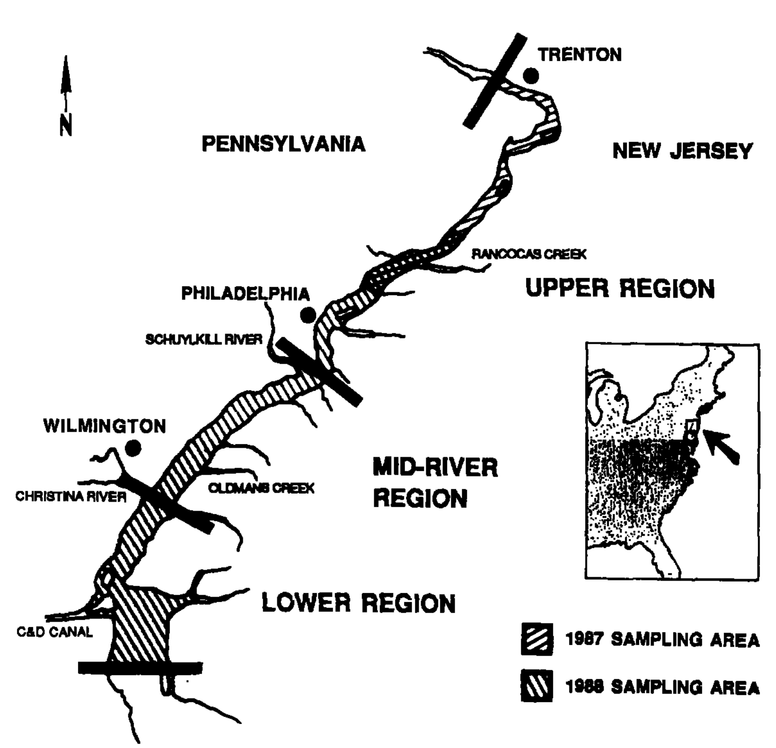

Figure 1
Map of the study area.

Physico/chemical data (temperature, dissolved oxygen, pH and conductivity) were collected weekly with a calibrated Hydrolab Surveyor II in each of the river regions, the C&D Canal, and at each of the tributary stations. Measurements in the river and in the C&D Canal were taken at surface, mid-depth, and bottom. In the tributaries, measurements were taken at surface and bottom. Water transparency was measured with a 20-cm Secchi disk.

In the laboratory, all eggs with diameters greater than 1.0 mm were removed from the collections and inspected to determine if they were *M. saxatilis* or *A. spidissima* based on the size of the perivitelline space relative to the diameter of the egg. Small eggs (less than or equal to 1.0 mm in diameter) consisted mostly of *M. americana*, *Alosa aestivalis* (blueback herring), or *Alosa pseudoharengus* (alewife), but were not differentiated quantitatively. *M. americana* yolk-sac larvae were distinguished from *M. saxatilis* larvae based on the smaller size of *M. americana* at this stage and on gut morphology, which in *M. americana* parallels the notochord for about six myomeres before turning downward. Post yolk-sac *M. americana* and *M. saxatilis* larvae less than 8 mm in length were separated by size and the formation of fin rays, (formation of fin rays occurs at about 5 mm and 8 mm, respectively). Post yolk-sac larvae of 8 mm and longer were identified by clearing and staining the specimens and examining the pterygiophore/neural spine interdigitation patterns (Olney et al., 1983). *A. sapidissima* larvae were separated from *Alosa* spp. by counting post-anal myomeres (Lippson and Moran, 1974[3]; Chambers et al., 1976).

For the purpose of data presentation, the Delaware River sampling effort was post-classified into lower river, mid-river, and upper river regions (Fig. 1). These regions corresponded to Artificial Island (rkm 87) to the Christina River (rkm 114), Christina River to the Schuylkill River (rkm 148), and Schuylkill River to Trenton, NJ (rkm 214), respectively. Density estimates were calculated for each region during each week as the simple average of all samples collected in that region. A Friedman's rank-sum test, blocked on week, was used to test for differences in density among regions (Conover, 1980).

Data from over 2,000 ichthyoplankton samples collected from the Delaware River during the 1970's were obtained from reports submitted as part of regulatory requirements or environmental impact studies (ANSP, 1974[4]; Anselmini, 1974[5]; Anselmini 1976[6]; Potter et al., 1974, a and b[7,8]; Harmon and Smith 1975[9]; PECO, 1977, a–e[10,11,12,13,14]; IA, 1979, a and b[15,16]; RMC, 1979[17]). While none of these studies individually provided coverage of the entire tidal river, collectively they provided excellent coverage. To compare present ichthyoplankton composition and abundance with that in the 1970's, these data were digitized and summarized.

To maximize comparability of data between periods, we extracted for analysis from the historical reports only those samples which were collected between mid-April and mid-June with a 500-μm mesh gear that was towed for at least five minutes and filtered at least 40 m^3. Where studies differed in taxonomic level of identification, data from all studies were restated to the higher taxonomic group. From these data, weekly average densities were estimated for each region and year. Historic abundances for each region were taken as the simple averages of weekly estimates. We included data for only years in which collections were taken in at least eight weeks between April and June to ensure that our comparison was not biased by data sets with limited temporal coverage. Comparisons of average abundance with the present study were accomplished separately for each region by using a Friedman's test blocked on week.

Results

Water quality

Water temperature during the 1987 and 1988 survey ranged from 11 to 26°C. Differences in temperature between regions were less than 1°C in both years.

[3] Lippson, A. J., and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River estuary. Available from Maryland Department of Natural Resources. Ref. No. PPSP–MP–13, 282 p.

[4] ANSP (Academy of Natural Sciences of Philadelphia). 1974. Ecological studies in New Jersey, Oldman's Creek, Raccoon Creek, Birch Creek, and the Delaware River 1972–1973. Prep. by ANSP, Philadelphia, Pennsylvania for the Shell Oil Company, Philadelphia, PA.

[5] Anselmini, L. D. 1974. An ecological study of the Delaware River in the vicinity of the Mercer Generating Station, Trenton, NJ. Prep. by Ichthyological Associates, Inc., Ithaca, NY, for Public Service Electric and Gas Co., Newark, NJ.

[6] Anselmini, L. D. 1976. An ecological study of the Delaware River in the vicinity of Newbold Island. Prep. by Ichthyological Associates, Inc., Ithaca, NY, for Public Service Electric and Gas Co., Newark, NJ.

[7] Potter, W. A., D. C. Smith, and P. L. Harmon. 1974a. An ecological study of the Delaware River in the vicinity of Chester Generating Station. Chester Progress Rep. 1. Prep. by Ichthyological Associates, Inc., Ithaca, NY, for the Philadelphia Electric Co., Philadelphia, PA, 94 p.

[8] Potter, W. A., D. C. Smith, and P. L. Harmon. 1974b. An ecological study of the Delaware River in the vicinity of Eddystone Generating Station. Eddystone Progress Rep. 3. Prep. by Ichthyological Associates, Inc., Ithaca, NY, for the Philadelphia Electric Co., Philadelphia, PA, 42 p.

[9] Harmon, P. L., and D. C. Smith. 1975. An ecological study of the Delaware River in the vicinity of Eddystone generating station. Eddystone Progress Rep. 4 to Philadelphia Electric Co., Philadelphia, PA.

[10] PECO (Philadelphia Electric Company). 1977a. Chester Generating Station, 316(b) Rep., Permit No. PA 0011614. Rep. to the EPA, Philadelphia, PA.

[11] PECO. 1977b. Richmond Generating Station, 316(b) Rep., Permit No. PA 0011649. Rep. to the EPA, Philadelphia, PA.

[12] PECO. 1977c. Southwark Generating Station, 316(b) Rep., Permit No. POA 00116-65. Rep. to the EPA, Philadelphia, PA.

[13] PECO. 1077d. Delaware Generating Station, 316(b) Rep., Permit No. PA 0011622. Rep. to the EPA, Philadelphia, PA.

[14] PECO. 1977e. Eddystone Generating Station, 316(b) Rep., Permit No. PA 00137-14. Rep. to the EPA, Philadelphia, PA.

[15] Ichthyological Associates (IA). 1979a. Effect of the cooling water intake structure, intrainment and impingement of fishes. Burlington Generating Station Demonstration for Section 316(b) of the Federal Water Pollution Control Act Amendments of 1972, PL 95-500. Prep. by IA, Ithaca, NY, for Public Service Electric and Gas Co., Newark, NJ.

[16] Ichthyological Associates (IA). 1979b. Effect of the cooling water intake structure, intrainment and impingement of fishes. Mercer Generation Station Demonstration for Section 316(b) of the Federal Water Pollution Control Act Amendments of 1972, PL 95-500. Prep. by IA, Ithaca, NY, for Public Service Electric and Gas Co., Newark, NJ.

[17] Radiation Management Corporation (RMC). 1979. An evaluation of the cooling water intake at the Edge Moor Power Station. Edge Moor Power Station section 316(b) Evaluation. Permit No. DE-000058. Prep. by RMC, Pottstown, PA, for Delmarva Power and Light Co., Wilmington, DE.

Temperature, dissolved oxygen, and salinity were not vertically stratified in the water column and did not differ substantially between tributaries and the nearest mainstem water quality sampling locations.

Average dissolved oxygen values decreased over the sampling period during each year of the study, ranging from greater than 10 mg/L during the first week to less than 8 mg/L during the last week. Dissolved oxygen differed by as much as 3 mg/L among regions, with the lowest values occurring downstream of Philadelphia. However, only a single measurement below 5 mg/L was recorded in 1988, and no measurements below 6 mg/L were recorded in 1987.

The river was consistently fresh upstream of Pea Patch Island (km 98); salinity averaged less than 2 ppt in the regions downstream of Pea Patch Island. The highest salinity (5 ppt) was observed in the C&D Canal during the second week of sampling in 1988. A storm and subsequent freshwater runoff during the sixth week of the 1988 sampling turned the entire mainstem sampling area fresh but had little effect on salinity in the C&D Canal, which never fell below 2 ppt.

Distribution of eggs and larvae

Eighteen taxa, comprising 15 families, were collected from the Delaware River during 1987 and 1988 (Table 1). Seventeen of these taxa also were found in the tributaries (Table 2); no taxon occurred only in the tributaries. Most taxa were not abundant. Only three,

Table 1

Average density (no./100 m^3) of ichthyoplankton in the lower, mid- and upper regions of the Delaware River during the present and previous (1972–1978) studies. Values in bold represent regional densities that were significantly ($P<0.05$) different between the present and previous studies.

	Present study			Previous studies		
	Lower river	Mid river	Upper river	Lower river	Mid river	Upper river
Percichthyidae						
Morone saxatilis (eggs)	0.2	0.2	<0.1	0.1	0.3	0
Morone saxatilis	0.1	**0.4**	0.1	0.3	0.1	0
Morone americana	0.5	**8.4**	48.3	1.1	0.4	27.2
Clupeidae						
Alosa sapidissima (eggs)	0.1	**0.1**	**0.4**	0	0	0.1
Alosa sapidissima	**0.8**	**15.0**	**49.0**	0	0	0
Other *Alosa* spp.	0.2	5.4	33.5	**4.1**	22.8	**339.7**
Brevoortia tyrannus	**0.1**	0.1	0	0	0	0
Dorosoma cepedianum	0	0	0	0	<0.1	0
Ictaluridae	0	0	0.1	0	0	0
Anguillidae						
Anguilla rostrata	<0.1	<0.1	<0.1	**0.8**	**0.4**	**0.2**
Percidae						
Perca flavescens	<0.1	0	**0.7**	0	0	<0.1
Etheostoma sp.	<0.1	<0.1	0.2	0	0	0.6
Cyprinidae	0.1	1.3	0.5	**1.0**	**6.8**	**10.5**
Soleidae						
Trinectes maculatus	**0.1**	**0.1**	<0.1	0	0	0
Centrarchidae						
Lepomis sp.	<0.1	<0.1	**0.1**	0	0	0
Pomoxis sp.	0	0	0	0.1	0	<0.1
Catostomidae						
Carpiodes cyprinus	<0.1	**0.4**	0.6	0	0	**3.4**
Castostomus sp.	0	0	0	0	0	**1.0**
Engraulidae						
Anchoa mitchilli	0.6	0.1	<0.1	0.2	0	0
Gasterosteidae	<0.1	<0.1	<0.1	0	0	0
Cyprinodontidae						
Fundulus sp.	0	0	<0.1	00.1	<0.1	
Sciaenidae						
Leiostomus xanthurus	**0.5**	**0.1**	<0.1	<0.1	0	0
Atherinidae						
Menidia sp.	0.2	<0.1	<0.1	0.4	0	0
Umbridae						
Umbra pygmaea	0	0	0	0	0	<0.1

Table 2
Average density (no./100 m³) of ichthyoplankton in the Delaware River tributaries among samples collected in 1987 and 1988.

	C&D Canal	Christina River	Oldman's Creek	Raccoon Creek	Schuylkill River	Dredge Harbor	Rancocas Creek	Neshaminy Creek	Martin's Creek
Percichthyidae									
Morone saxatilis (eggs)	5.7	0.2	0	0.2	0	0	0	0	0
Morone saxatilis	0	0	0.7	1.5	0	0	0	0	0
Morone americana	0.1	21.5	8.0	30.9	1.4	4.0	36.9	8.8	2.4
Clupeidae									
Alosa sapidissima (eggs)	<0.1	0	0	0	0	0	1.6	0	0
Alosa sapidissima	0	41.4	168.4	247.3	1.3	80.7	199.9	46.6	75.5
Other *Alosa* spp.	0	28.6	106.4	160.6	1.0	52.0	194.5	52.7	57.8
Anguillidae									
Anguilla rostrata	0	0	0	0	0	0	0	0.1	0
Percidae									
Perca flavescens	<0.1	1.0	0	0	0	0	1.3	0	0
Etheostoma sp.	<0.1	2.2	0.2	0.1	0	0	0.1	0.1	0
Cyprinidae	0	0.6	0.8	7.4	0.6	0	<0.1	2.1	0
Soleidae									
Trincectes maculatus	0.1	0	0	0	0	0	0	0	0
Centrarchidae									
Lepomis sp.	0	0	0	0.4	0	0.3	0.6	0.4	0.5
Catostomidae									
Carpiodes cyprinus	0	2.8	0.2	0.8	0	0.1	0.7	0.2	0
Engraulidae									
Anchoa mitchilli	0.1	0	0	0	0	0	0	0	0
Gasterosteidae	0.1	0	0	0	0	0	0	0	0
Cyprinodontidae									
Fundulus sp.	0	0	0	0	0	0	<0.1	0	0
Sciaenidae									
Leiostomus xanthurus	1.8	0	0	0	0	0	0	0	0
Atherinidae									
Menidia sp.	0.1	0	0	0	0	0	0	0	0

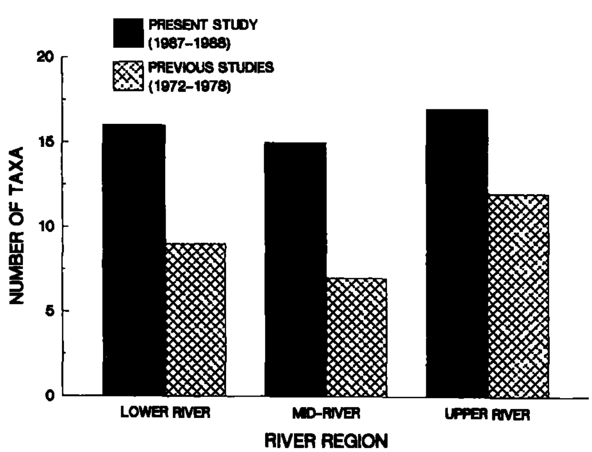

Figure 2
Number of ichthyoplankton taxa found in each of the three regions of the tidal Delaware River in the present (1987–1988) and in previous (1972–1978) studies.

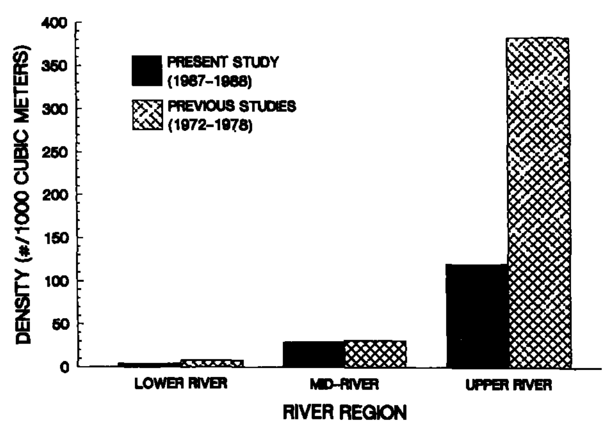

Figure 3
Average ichthyoplankton density (#/1000 m³) in each of the three regions of the tidal Delaware River in the present (1987–1988) and in previous (1972–1978) studies.

A. sapadissima, M. americana, and *Alosa* spp., occurred at average densities greater than 10/100 m³ in either the mainstem or the tributaries.

Numbers of taxa did not differ significantly among the three regions of the river (Fig. 2), but average ichthyoplankton density did ($P<0.001$) (Fig. 3). Density was greatest in the upper region (between the Schuylkill River and Trenton, NJ) where it averaged more than 120 larvae/100 m³ during the study. In contrast, density in the mid-river region (between Phila-

Table 3

Comparison of highest weekly ichthyoplankton density (no./100 m^3) found in the lower, mid, and upper river sampling regions between the 1987–1988 study and historical studies.

	Present study			Historical studies				
	Lower river	Mid river	Upper river	Lower river	Mid river		Upper river	
	(1988)	(1988)	(1987–1988)	(1978)	(1974)	(1977)	(1972)	(1973)
Percichthyidae								
Morone saxatilis (eggs)	0.6	0.6	0.1	0.3	0	2.9	0	0
Morone saxatilis	0.2	2.5	1.2	1.1	0	0.7	0	0
Morone americana	1.7	31.2	387.2	2.7	2.0	2.5	56.1	125.0
Clupeidae								
Alosa sapidissima (eggs)	0.2	0.4	1.4	0	0	0	1.7	0
Alosa sapidissima	3.5	52.0	219.6	0	0	0	0	0
Other *Alosa* spp.	0.9	26.8	151.9	14.5	202.5	51.3	3231.3	522.9
Brevoortia tyrannus	0.6	0.4	0	0	0	0	0	0
Dorosoma cepedianum	0	0	0	0	0	0.2	0	0
Ictaluridae	0	0	0.8	0	0	0	0	0
Anguilla rostrata	0.1	0.1	0.1	3.7	0.2	0.6	0.5	0
Percidae								
Perca flavescens	0.1	0	3.6	0	0	0	0.3	0.2
Etheostoma sp.	0	0.1	1.1	0	0	0	5.4	1.6
Cyprinidae	0.4	9.1	5.8	4.2	51.8	45.6	84.5	24.6
Soleidae								
Trinectes maculatus	0.4	0.2	0.1	0	0	0	0	0
Centrarchidae								
Lepomis sp.	0.1	0.3	0.3	0	0	0	0	0
Pomoxis sp.	0	0	0	0	0	0	0	0
Catostomidae								
Carpiodes cyprinus	0.3	3.3	2.1	0	0	0	26.4	0.7
Catostomus sp.	0	0	0	0	0	0	24.4	1.8
Engraulidae								
Anchoa mitchilli	1.8	1.1	0.4	0.7	0	0	0	0
Gasterosteidae	<0.1	0.2	<0.1	0	0	0	0	0
Cyprinodontidae								
Fundulus sp.	0	0	0.1	0	0.4	0	0	0
Sciaenidae								
Leiostomus xanthurus	1.8	0.2	<0.1	0	0	0	0	
Atherinidae								
Menidia sp.	0.5	0.1	<0.1	1.8	0	0	0	0
Umbridae								
Umbra pygmaea	0	0	0	0	0	0	0.3	0

delphia, PA and Wilmington, DE) was only about one-fourth of that in the upstream area. Average larval density in the lower region (downstream of Wilmington) was less than 4/100 m^3 and never exceeded 10/100 m^3 during any week of the study (Table 3).

Species composition was fairly consistent between the mid- and upper regions but differed substantially in the lower river region (Table 1). *M. americana*, *A. sapidissima*, and *Alosa* spp. were dominant in the upper river, occurring at densities of an order of magnitude greater than any other taxa. In the region furthest downstream, where salt intrusion begins to occur, species typical of the estuarine environment, such as *Leiostomus xanthurus* (spot) and *Anchoa mitchilli* (bay anchovies), were at least as abundant as *A. sapidissima* and *Alosa* spp. Freshwater species that occurred in the upper river, such as *Etheostoma* sp. (darters) and *Ictaluridae* (catfish), were not found in the more saline region.

With the exception of the Schuylkill River and the C&D Canal, density and taxonomic composition in the tributaries was similar to that in the most upstream region of the tidal mainstem (Table 2). The Schuylkill River is the largest tributary to the Delaware River and flows through a heavily industrialized portion of Philadelphia. Only four taxa were collected there, and they generally occurred at densities 10- to 100-fold lower than in any other tributary. No species occurred there at a density greater than 10/100 m³. The other anomalous tributary was the C&D Canal, which is not a true tributary, but a man-made, free-flowing canal constructed in the early 1900's to link the Delaware and Chesapeake estuaries for navigation. The C&D Canal contains virtually no freshwater drainage, and the species composition there was most similar to the lower region of the mainstem. No clupeid larvae and very few *M. americana* larvae were collected there, but the C&D Canal did contain densities of *M. saxatilis* eggs considerably higher ($P<0.01$) than the mainstem or other tributaries.

Potential bias in the recent survey could exist because sampling in the upper river region was primarily accomplished in 1987, whereas the downstream areas were sampled in 1988. To determine if this was a problem, we compared ichthyoplankton density and species composition in the area sampled in common between the two years. We found that the difference in total ichthyoplankton density between the two years was less than 10% (Table 4) and not significantly different. In addition, none of the dominant taxa had more than a two-fold difference in density between years. Temporal patterns for the dominant taxa were generally consistent across both years of the study (Fig. 4). Seasonal peaks in larval abundance for *Perca flavescens* (yellow perch) preceded that of the *Alosa* spp., followed by *M. americana* and *M. saxatilis*. *A. sapidissima* and *P. flavescens* larval abundance peaked about a week later in 1988 than in 1987. This difference may be attributable to inter-annual variability in spawning peaks; however, since sampling in 1988 was concentrated farther downriver, the difference in temporal patterns between years may partly reflect the time required for downstream transport of larvae from upstream spawning grounds.

Table 4
Average ichthyoplankton density (no./100m³) in the area and weeks samples in common between 1987 and 1988.

	1987	1988
Percichthyidae		
Morone saxatilis (eggs)	0	<0.1
Morone saxatilis	0	0.1
Morone americana	23.7	38.4
Clupeidae		
Alosa sapidissima (eggs)	1.2	0.8
Alosa sapidissima	40.2	65.0
Other *Alosa* spp.	31.4	21.0
Anguillidae		
Anguilla rostrata	<0.1	0
Percidae		
Perca flavescens	1.7	0.5
Etheostoma sp.	0.2	1.0
Cyprinidae	0.1	0.4
Soleidae		
Trinectes maculatus	0	<0.1
Catostomidae		
Carpiodes cyprinus	1.1	0.2
Sciaenidae		
Leiostomus xanthurus	0	<0.1
Gasterosteidae	0	<0.1

Comparison with historical data

When we compared our data to the historic data, we found that average density of all eggs and larvae did not differ significantly in the two lower regions and that historical density was higher ($P<0.01$) in the most upstream region (Fig. 3). The larger difference among periods was in composition and dominance; the number of taxa caught in each region in the present study was almost double that in the historical data (Fig. 2), despite the greater number of sampling years encompassed by the previous studies. Whereas river herring accounted for more than half of the catch in every region during the 1970's, no taxon accounted for more than 40% of total catch in any region in the present study (Table 1).

Density of nine taxa increased significantly in at least one region since the previous decade (Table 1). Of these, the increase was most dramatic for *A. sapidissima*. In the earlier studies, *A. sapidissima* eggs were rarely found, and larvae were not encountered at all. In contrast, the density of shad larvae in the upper river region exceeded 100/100 m³ during several weeks of our study (Table 3). Five taxa decreased significantly in number in at least one region, and cyprinids (minnows) and *Anguilla rostrata* (elvers) declined significantly in all three regions. Cyprinids were only about one-tenth as abundant in our study. Although we did not identify all of the cyprinids in our study, the cyprinids collected consisted primarily of juvenile *Notropis* spp., whereas most cyprinids in previous studies were identified as juvenile *C. carpio*.

Discussion

The dramatic decline of *A. sapadissima* productivity in the Delaware River since the last century (Chittenden, 1974) has been attributed to reductions in the amount of usable spawning habitat (Chittenden, 1976). Shad have historically used all of the Delaware River as spawning and nursery grounds, but spawning during most of this century was limited to areas 200-km upstream from the tidal freshwater areas we studied. Size of the spawning ground was reduced for two reasons (Chittenden, 1976). First, only the earliest arriving shad, which typically spawn farthest up-

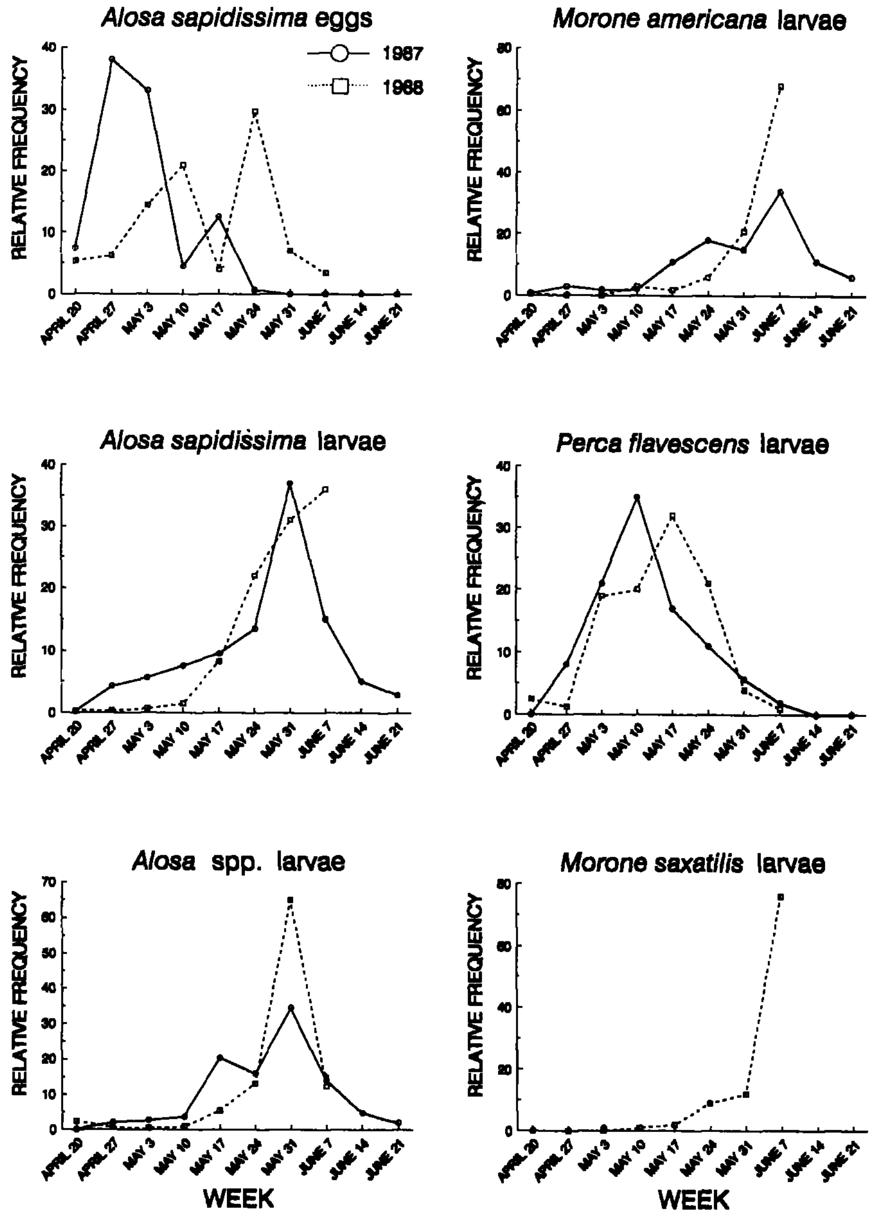

Figure 4
Temporal patterns of abundance for the dominant larval fish of the tidal Delaware River. Solid and dashed lines represent 1987 and 1988, respectively.

stream (Glebe and Leggett, 1981; Maurice et al., 1987), could get past Philadelphia before hypoxic conditions developed. Second, only fish migrating out of the river late in the season, that is fish spawned in the most upstream reaches, arrived in the Philadelphia area after the lethal dissolved oxygen conditions dissipated.

Our data suggest that the spatial extent of *A. sapidissima* spawning habitat in the Delaware River has expanded over the last decade, coincident with the water quality improvements near Philadelphia. While we found no evidence of spawning or nursery activity in tidal freshwater during the 1970's, prior to water quality improvements, by the late 1980's the density of larvae there was as high as in non-tidal upstream reaches. The suggestion of expanded spawning ground for shad is consistent with Maurice et al. (1987), who documented substantial increases in spawning activity during the last decade in the lower reaches of the non-tidal river. Presumably, expansion of the spawning and nursery grounds is a first step in recovery of the stock.

There was little difference in *M. americana* abundance in the Delaware River between our study and the historical data (Tables 1 and 3), suggesting that the poor water quality may have had little impact on *M. americana* spawning and nursery activities in the Delaware River. We observed that most *M. americana* larvae were concentrated upstream of Philadelphia in an area where water quality was not as seriously impacted as below Philadelphia (Albert, 1988). Unlike *A. sapidissima*, which leave the estuary and must return through the Philadelphia region to spawn, *M. americana* remain in the estuary throughout their life cycle. Presumably, these life history characteristics have allowed *M. americana* to avoid effects of the poor water quality of the Philadelphia area more effectively than shad.

We found that larval *M. saxatilis* were primarily concentrated in the area downstream of Philadelphia. Since this area historically had the worst water quality, the *M. saxatilis* population should have benefitted from water quality improvements. The Delaware River beach seine monitoring survey, conducted annually by the State of New Jersey, showed a consistent increase in young-of-year *M. saxatilis* abundance throughout the 1980's[1]. However, we did not find the density of eggs to be higher in our study than in the 1970's, and the density of larvae was only slightly higher. We did find that present densities of *M. saxatilis* eggs and larvae in the Delaware River are considerably less than in the Hudson River[18] or the Chesapeake Bay (Setzler-Hamilton et al., 1981; Grant and Olney, 1991). This may be due, in part, to a year effect, since juvenile abundance in the Delaware River in 1988, as measured by the beach seine survey, was lower than in any other year since 1985. However, it is possible that higher juvenile abundance in the late 1980's resulted from better survival of larvae as water quality improved (Burton et al., 1992), rather than from increased egg production.

We found that the density of *M. saxatilis* eggs was considerably higher in the C&D Canal than in the mainstem Delaware River. This finding seems to support studies suggesting that the mechanism for maintenance of the Delaware River *M. saxatilis* population is transport of eggs spawned in the Chesapeake Bay through the C&D Canal (Chittenden, 1971; Johnson and Koo, 1975). Our data, however, are probably more consistent with that of Kernehan et al. (1981), who suggested that most of the eggs transported through the canal are not viable. In spite of finding considerably elevated densities of eggs in the C&D Canal, no larvae were found there, and we collected fewer than 10 larvae within 10 km of where the C&D Canal empties into the Delaware River estuary. Most of the *M. saxatilis* larvae we found in the Delaware River were collected between the Delaware Memorial (rkm 111) and Commodore Barry (rkm 132) bridges, more than 30 km upstream of the C&D Canal. This distance represents about three tidal excursion distances, and while upstream transport of eggs is possible in some estuarine systems (Norcross and Shaw, 1984), it is unlikely to occur in this portion of the Delaware because of the lack of a well-defined thermocline or pycnocline that would allow for two-layer circulation. Thus, it is more likely that most of the *M. saxatilis* larvae found in the Delaware River were actually spawned in the river.

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