Journal of the Pennsylvania Academy of Science 83(1): 24–33, 2009

EVALUATING THE USE OF FAIRMOUNT DAM FISH PASSAGE FACILITY WITH APPLICATION TO ANADROMOUS FISH RESTORATION IN THE SCHUYLKILL RIVER, PENNSYLVANIA[1]

JOSEPH A. PERILLO[2] and LANCE H. BUTLER[3]

ABSTRACT

Many anadromous fish stocks throughout Atlantic slope drainages have been decimated because of the construction of dams. Prior to the creation of the Fairmount Dam in 1820, migratory species, such as American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*) and river herring (alewife, *Alosa pseudoharengus* and blueback herring, *A. aestivalis*) enjoyed unimpeded movement throughout the Schuylkill River drainage as far upstream as Pottsville, Pennsylvania (160 rkm). In 1979, a vertical slot fish passage facility was constructed on the west side of Fairmount Dam. However, very few anadromous species were utilizing the passage and by 1984 fish restoration activities were diverted to other drainages within the Delaware River basin. Between 2002 and 2006 the Philadelphia Water Department directed its monitoring efforts above and below the Fairmount Dam fishway. In 2004, 6,438 fish of 23 species ascended the Fairmount Dam fishway, including 91 American shad, 161 striped bass, and 2 river herring. A total of 8,017 fishes representing 25 species were counted passing through the fishway in 2005, including 41 American shad, 127 striped bass, and 5 river herring. In 2006, a total of 16,850 fishes representing 26 species were counted passing through the fishway including 345 American shad, 9 hickory shad, 61 striped bass, and 7 river herring. Electrofishing sampling results between 2004 and 2006 showed *A. sapidissima*, *A. aestivalis* and *A. pseudoharengus* were the dominant species below Fairmount Dam during spring, with peak assemblage contributions in 2006. The interannual trend in relative abundance of American shad below Fairmount Dam increased, as did overall shad passage trends in the fishway. Results also suggest that photoperiod may play a critical roll in movement through the fish passage facility, although additional physiochemical signals can not be ruled out at this time. With expected rehabilitation efforts on the Fairmount Dam fishway to begin in 2008, this study as well as future monitoring activities will be important components in measuring the efficacy of anadromous fish restoration activities within the Schuylkill River watershed.

[J PA Acad Sci 83(1): 24–33, 2009]

INTRODUCTION

Pennsylvania has a rich history of substantial spring runs of anadromous fishes. Nowhere was this more apparent than in the Philadelphia region, where centuries of annual American shad (*Alosa sapidissima*) migrations helped shape the natural, cultural and economic heritage of the area (Hallock 1894). The Schuylkill River, the largest tributary to the Delaware River, supported large numbers of American shad until the construction of dams in the early 1800's. Historical records indicate that shad and river herring (alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis*) ascended the Schuylkill River as far upstream as Pottsville (160 rkm), but have not done so since 1820, when Fairmount Dam was built (Mulfinger and Kaufmann 1981). The dam served as a physical barrier to migratory fishes, completely blocking upstream movement and access to critical spawning grounds. In the years to follow, eight more dams were erected and unregulated industrial pollution into the Schuylkill River resulted in the demise of anadromous fishes in the Schuylkill River.

For more than 150 years, American shad appeared to have been extirpated from the Schuylkill drainage (Sykes and Lehman 1957). However, in the 1970's, Pennsylvania Fish and Boat Commission (PFBC) biologists documented the presence of American shad in the tidal reach of the Schuylkill River below Fairmount Dam. Subsequent surveys by PFBC revealed that river water quality and habitat in the Schuylkill River could again support a substantial population of American shad as well as other anadromous fishes, provided that fish passage was created at the Fairmount Dam (Mulfinger and Kaufmann 1981). In 1979, with funding from the City of Philadelphia, United States Fish and Wildlife Service (USFWS), and PAFBC, a vertical slot fish passage facility was constructed on the west side of Fairmount Dam. During the first few years of operation, Fairmount Dam fishway was heavily used by resident fish populations; however, very few American shad or river herring were successfully ascending the fishway (Mulfinger and Kaufmann 1981). Since none of the upstream dams were passable and few anadromous fishes were passing at Fairmount, the fishway was no longer actively maintained or monitored, and by 1984 restoration efforts refocused on the

[1]Submitted for publication 4 March 2008; accepted 21 July 2008.

[2]Philadelphia Water Department, Bureau Of Laboratory Services, 1500 East Hunting Park Avenue, Philadelphia PA 19124.
[3]Philadelphia Water Department, Office Of Watersheds, 1101 Market Street, 4th floor, Philadelphia PA 19107. (215).685.4947

Lehigh River, an upstream tributary to the Delaware River. No fish counts were conducted from 1984 to 2004, until the Philadelphia Water Department (PWD) took responsibility for maintenance and operation of the fishway and developed a digital video monitoring system to record fish passage. An underwater viewing room and window allow direct observation of fishes swimming through the fishway.

The primary means for evaluating fish passage and anadromous fish restoration efforts is recorded video of fish moving past the viewing window. The recorded video allows frame-by-frame analysis to identify and enumerate species ascending and descending the fishway. These quantitative data of diversity and abundance of fish are compared to river electrofishing data in order to determine passage utilization. Monitoring fish passage will allow us to establish the size of the American shad run and compare those numbers to the upstream passage facilities and other fishways on the Delaware River. The U.S. Fish and Wildlife Service has estimated that the Schuylkill River has adequate habitat to support 700,000 to 800,000 American shad and that 200,000 to 250,000 American shad per year may utilize Fairmount fishway during upstream migration (USFWS 1999). The only way to verify the utilization and efficiency is by video recording actual fish passage at the viewing window.

As the most downstream passageway, the Fairmount Dam fishway is especially critical to the overall success of restoring migratory fish runs in the Schuylkill River watershed. American shad annually migrate from mixed stock assemblages in the open oceans to their natal freshwater streams and rivers to spawn (Talbot and Sykes 1958; Walburg 1960; Carscadden and Leggett 1975; Glebe and Leggett 1981). Shad fidelity to their spawning river is thought to be high, and spawning populations are genetically distinct (Bentzen et al. 1989; Nolan et al. 1991; Epifanio et al. 1995). Therefore, all planned upstream fish passage projects will be affected by the success or failure of the Fairmount Dam fishway at passing migratory species during spawning runs. Moreover, successful colonization and gene flow (i.e., genetic transference) of resident species is highly contingent upon minimizing the effects of fish barriers on movement (Albanese et al. 2004). Resident fish species within the Schuylkill drainage should benefit from the enhanced potential to reach suitable spawning and nursery habitat, and from a larger forage base provided by juvenile anadromous species.

This study describes the temporal variation of migratory and resident fish assemblages of the tidal Schuylkill River and their utilization of the Fairmount Fishway during the spring migratory period. We report on the abundance and interannual variation of fishes in the tidal Schuylkill River during spring migration, as well as temporal variability of fish passage utilization. In order to evaluate the progress of anadromous fish restoration, we examine the relationship between relative abundance downstream of Fairmount Dam and annual fish passage counts at the fishway.

MATERIALS AND METHODS

Site Description and History

The Schuylkill River, the largest tributary of the Delaware River Basin, is located in Southeastern Pennsylvania and is approximately 198 km in length from its headwaters in Pottsville, Schuylkill County to its confluence with the Delaware River in Philadelphia, Pennsylvania (Figure 1). Fairmount Dam is positioned 13.6 km upstream from the Delaware confluence and represents the boundary between tidal and non-tidal influences on the Schuylkill River. The Fairmount Dam Fishway is situated within the City of Philadelphia on the western bank of the Schuylkill River in Fairmount Park, Philadelphia (Figure 2).

A municipally-owned facility, the Fairmount Dam is 304.8 m in length with a crest elevation of approximately 3.2 m. Completed in 1821, the Fairmount Dam provided a source of drinking water as well as a pumping system for the distribution of water throughout the city of Philadelphia. However, this structure also prevented passage of fish from 1818 until 1979. Initiated in 1977 and completed in 1979, the Fairmount Dam Fishway provided a means of upstream dispersal of resident and migratory fishes. However, due to design and maintenance limitations, the function and efficiency of the Fairmount Dam Fishway has been an area of concern among fisheries biologists. Recently, the Philadelphia Water Department and the United States Army Corps of Engineers (USACE) have partnered in the restoration effort of the fishway with construction anticipated to begin in spring 2008.

Monitoring Techniques

Tidal Fish Assessments

Temporal variation of resident and migratory fish assemblages inhabiting the tidal portions of the Schuylkill River were assessed through standardized electrofishing techniques (Moulton et al. 2002). Electrofishing surveys were conducted three to four times per month from April 1st to July 1st, between 2002 and 2006. A Smith-Root gas-powered pulsator (GPP) portable electrofisher with two anode booms and adjustable umbrella arrays were mounted to a 17 ft aluminum flat bottom boat (model Grumman). Power to the GPP was supplied by a Honda gas generator and electrical current was regulated by a foot control switch.

Due to the unique physical and hydrologic conditions found directly below the Fairmount Dam, slight modifications in boat handling and collection techniques were applied. To ensure safe boat operation and maximize capture efficiency, surveys were conducted in an upstream fashion during low tide. Four fixed stations between the Fairmount Dam and Spring Garden Street Bridge were standardized based on sampling time (i.e., Catch Per Unit Effort) (Figure 3).

Fish were temporarily stunned by administering 2–4 amps direct current (DC) at a frequency of 60 pulse/sec.

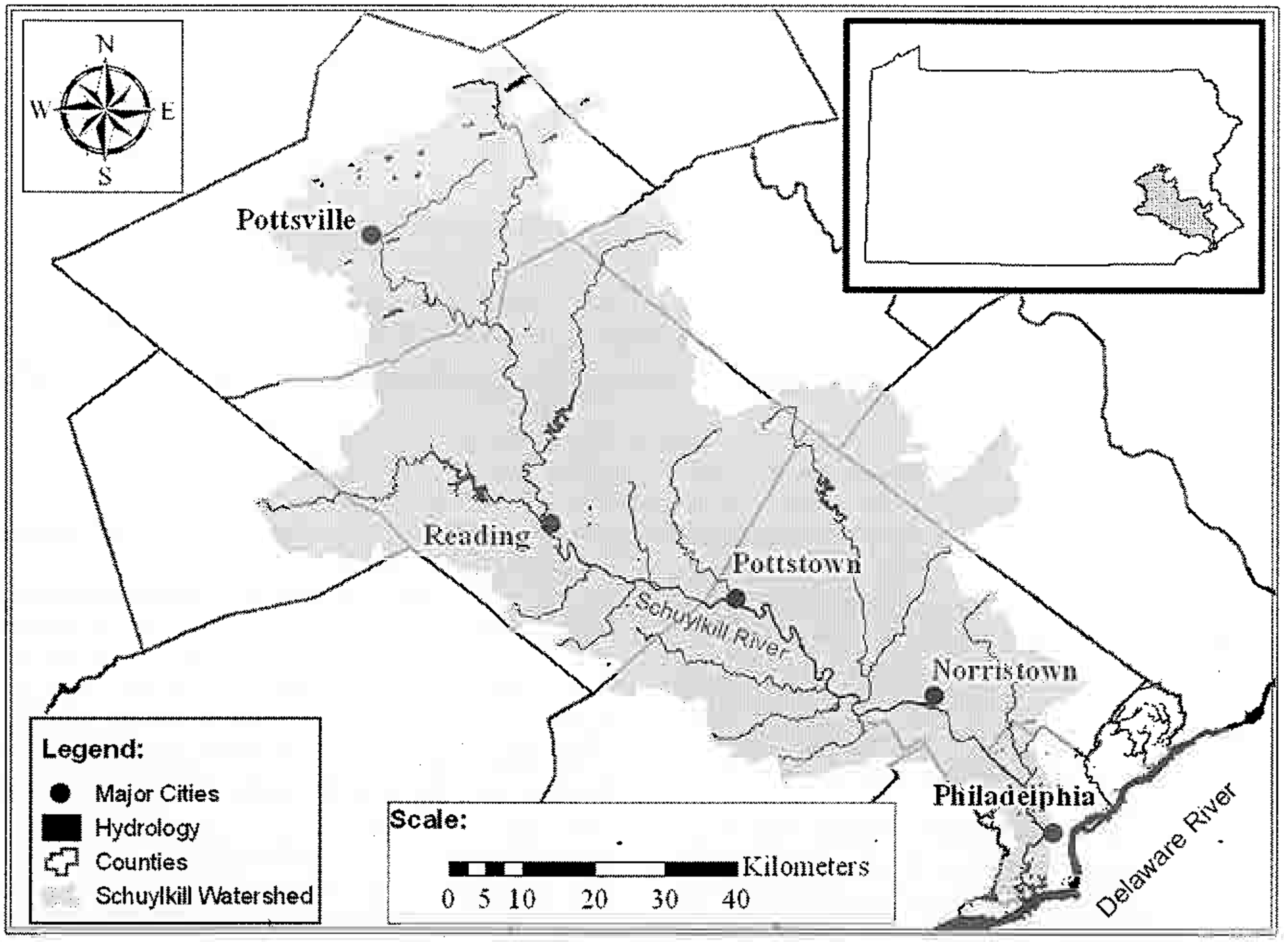

Figure 1. Regional map of the Schuylkill River Watershed located in Southeastern Pennsylvania.

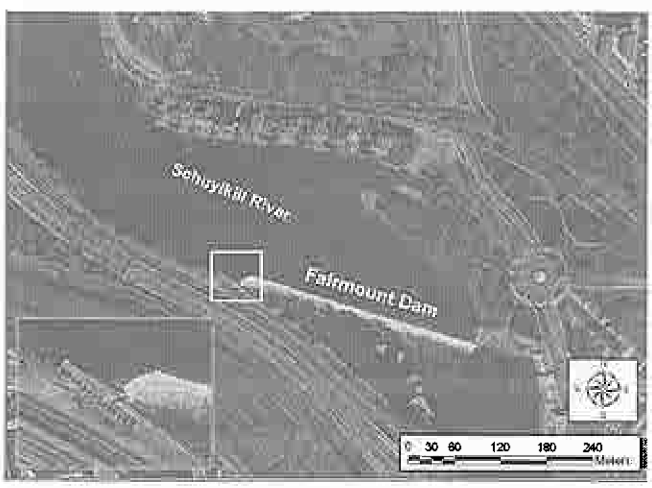

Figure 2. Aerial view of Fairmount Dam and vertical slot fishway (left insert) located on the west bank of the Schuylkill River at river km 13.6, Philadelphia, Pennsylvania.

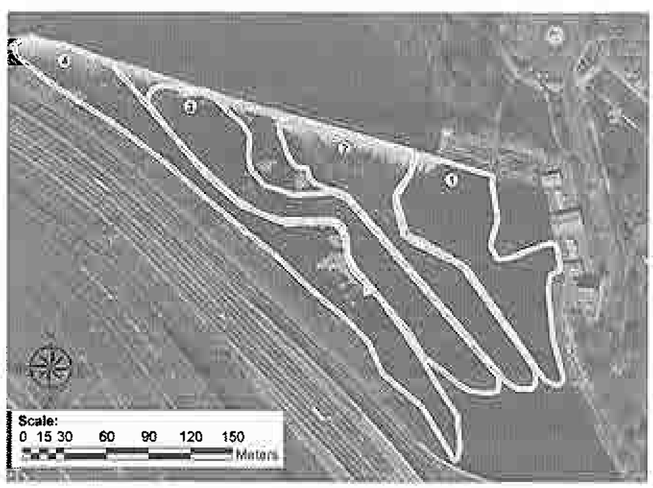

Figure 3. Aerial view of electrofishing stations on the Schuylkill River at Fairmount Dam. Each polygon represents separate sampling locations.

Fish were collected using non-conductive fiberglass nets (ca. 1/2" aperture), placed in a 380 liter aerated tank, and observed for any signs of mortality. Upon completion of a single pass, fish were identified to species, total length (cm) was measured, and fish were subsequently released downstream. Because sampling efficiency was not consistently effective for young-of-the-year (YOY) fish, all individuals less than 20 mm were not included in the sample results. Moreover, to reduce mortality, American shad (*Alosa sapidissima*) and hickory shad (*Alosa mediocris*) were minimally handled through immediate identification in the water or after netting, and placement downstream of the electrofishing boat.

Video Monitoring

A video monitoring program was established in 2003 to assess fish passage at the Fairmount fishway and determine temporal variability of fish assemblages inhabiting the lower Schuylkill River. Video monitoring protocols remained consistent over the three-year period and required continuous operation of the camera system (i.e., 24 h) from April 1 until July 1. The monitoring program utilized an IQeye™ digital video camera (San Clemente, CA) and OnSSI™ surveillance recording system (Suffern, NY) software to capture images of all fishes swimming past an underwater viewing window. The network-based digital video management system contains motion detection functions which only recorded when an object passed in front of the viewing window. All fish captured on video were identified to species, time stamped (i.e., h:m:s) and dispersal direction (i.e., upstream vs. downstream) was recorded.

Analyses

Assessments below the Fairmount Fishway focused on interannual variations in fish assemblages inhabiting the tidal Schuylkill River during the spring migration period (i.e., April 1st–July 1st). Total number of species captured during electrofishing surveys was used as a richness index for each year. Diversity was calculated using the Shannon-Wiener Index (*H'*), a metric that is not highly affected by sample size and that considers the relative abundance of each species to determine the diversity value (Magurran, 2004). *H'* was calculated using the following equation:

$$H' = -\sum p_i \ln p_i, \quad (1)$$

where $p_i = n_i/N$.
The evenness index (E) was derived from the Shannon-Weiner Index (*H'*) and was calculated using the following equation:

$$E = H'/\ln S \quad (2)$$

where S = total number of species.

In addition to interannual fish assemblage comparisons, temporal variation of *A. sapidissima* and *A. mediocris* during migration were also measured in terms of relative abundance (Equation 3).

$$\textbf{Catch Per Unit Effort (CPUE)} = \textbf{No. of individuals captured} \times \textbf{min}^{-1} \quad (3)$$

Diurnal patterns of fish passage usage by migratory species (*A. sapidissima, A. mediocris, A. aestivalis, A. pseudoharengus* and *Morone saxatilis*) were also measured between 2004–2006. Six daily periods were defined as follows: 1 (00:00 h to 3:59 h); 2 (04:00 h to 07:59 h); 3 (08:00 h to 11:59 h); 4 (12:00 h to 15:59 h); 5 (16:00 h to 19:59 h), and 6 (20:00 h to 23:59 h).

RESULTS

Tidal Fish Assessments

Table 1 summarizes fish collection results during electrofishing surveys from 2002 to 2006. In 2002, a total of 1728 fish representing 23 species were collected during spring sampling events (Table 2). Species diversity was greatest in 2002 (*H' = 2.38*) and a more evenly distributed fish assemblage (E = 0.68) was represented when compared to all of the sampling years (i.e., 2003–2006). Gizzard shad (*Dorosoma cepedianum*), quillback (*Carpoides cyprinus*) and common carp (*Cyprinus carpio*) were dominant contributors to community structure during this period (24.6%, 11.8% and 10.9% contribution, respectfully). Migratory species, such as *A. sapidissima*, represented only 3.6% of the fish assemblage while striped bass (*Morone saxatilis*) contributed approximately 9.6% of the total community structure. Resident sunfish species (*Lepomis auritus, L. gibbosus* and *L. macrochirus*) and channel catfish (*Ictalurus punctatus*) were also significant contributors to fish assemblage structure below the Fairmount Dam (9.1% and 8.3%, respectfully).

Sampling results in 2003 revealed that *D. cepedianum* and *C. cyprinus* were again significant contributors to the fish community structure (29.0% and 13.5%, respectfully). However, alosine species (*A. sapidissima, A. aestivalis* and *A. pseudoharengus*) comprised a majority of the fish assemblage, representing 42.3% of the community structure between 5/1/03 and 7/1/03. Similarly, sampling results between 2004 and 2006 showed *A. sapidissima, A. aestivalis* and *A. pseudoharengus* were the dominant species below Fairmount Dam during spring, with peak assemblage contributions in 2006 (62.7%). The marked increase in migratory species during the five-year study, however, must not overshadow the substantial decrease in certain resident populations or the presence of invasive predatory species in the tidal portions of the Schuylkill River. During 2002, sunfish species (*L. auritus, L. macrochirus,* and *L. gibbosus*) represented 9.1% of the fish community; however, sampling results during 2003–2006 revealed a substantial decrease in the presence of all sunfish species, with only a mean percent contribution of 0.2% ± 0.1%. Moreover, electrofishing surveys in 2006 demonstrated the presence of flathead catfish (*Pylodictis olivaris*) in tidal portion of the Schuylkill River. Although the current numbers of *P. olivaris* may not indicate an immediate threat to resident and migratory species, their presence does warrant continued monitoring to ascertain their effects on fish community structure in the Schuylkill drainage (Brown et al. 2005).

Table. 1. Fish collection counts by species below the Fairmount Dam, Schuylkill River, during spring monitoring, 2002–2006.
**Alosa sp.* include both *A. aestivalis* and *A. pseudoharengus*. ***Lepomis sp.* include all sunfish that were not identified to species.

Species		2002		2003		2004		2005		2006	
Scientifc Name	Common Name	Number (n)	Percent Contribution (%)	Number (n)	Percent Contribution (%)	Number (n)	Percent Contribution (%)	Number (n)	Percent Contribution (%)	Number (n)	Percent Contribution (%)
Alosa mediocris	hickory shad	0	0.0	0	0.0	4	0.2	120	4.2	51	1.0
Alosa sapidissima	American shad	63	3.6	535	32.0	470	26.6	1047	36.2	1950	38.0
*Alosa. sp**	herring*	97	5.6	173	10.3	261	14.8	12	0.4	1215	23.7
Ambloplites rupestris	rock bass	0	0.0	1	0.1	0	0.0	1	0.0	0	0.0
Anchoa mitchilli	bay anchovy	3	0.2	0	0.0	0	0.0	0	0.0	1	0.0
Anguilla rostrata	American eel	35	2.0	26	1.6	39	2.2	65	2.2	40	0.8
Catostomus commersoni	white sucker	107	6.2	44	2.6	56	3.2	193	6.7	67	1.3
Carassius auratus	goldfish	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Carpiodes cyprinus	quillback	204	11.8	226	13.5	145	8.2	310	10.7	337	6.6
Cyprinella spiloptera	spotfin shiner	0	0.0	0	0.0	0	0.0	0	0.0	5	0.1
Cyprinus carpio	common carp	189	10.9	26	1.6	221	12.5	237	8.2	306	6.0
Dorosoma cepedianum	gizzard shad	425	24.6	485	29.0	387	21.9	275	9.5	592	11.5
Esox lucius x Esox masquinongy	tiger muskellunge	0	0.0	0	0.0	1	0.1	0	0.0	1	0.0
Hybognathus regius	eastern silvery minnow	13	0.8	0	0.0	0	0.0	0	0.0	0	0.0
Ictalurus punctatus	channel catfish	146	8.4	48	2.9	37	2.1	134	4.6	178	3.5
Lepomis auritus	redbreast sunfish	3	0.2	3	0.2	6	0.3	1	0.0	3	0.1
Lepomis gibbosus	pumpkinseed sunfish	4	0.2	5	0.3	7	0.4	4	0.1	1	0.0
Lepomis macrochirus	bluegill sunfish	6	0.3	3	0.2	3	0.2	4	0.1	11	0.2
*Lepomis sp***	Lepomis sp**	144	8.3	0	0.0	1	0.1	5	0.2	13	0.3
Menidia beryllina	inland silverside	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Micropterus dolomieui	smallmouth bass	74	4.3	19	1.1	7	0.4	15	0.5	67	1.3
Micropterus salmoides	largemouth bass	21	1.2	28	1.7	5	0.3	16	0.6	37	0.7
Morone americana	white perch	8	0.5	2	0.1	0	0.0	197	6.8	42	0.8
Morone saxatilis	striped bass	166	9.6	40	2.4	102	5.8	153	5.3	127	2.5
Morone saxatilis x Morone chrysops	hybrid striped bass	0	0.0	0	0.0	1	0.1	14	0.5	4	0.1
Notropis amoenus	comely shiner	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0
Notropis hudsonius	spottail shiner	0	0.0	0	0.0	0	0.0	2	0.1	1	0.0
Oncorhynchus mykiss	rainbow trout	0	0.0	0	0.0	0	0.0	1	0.0	0	0.0
Perca flavesins	yellow perch	7	0.4	3	0.2	3	0.2	14	0.5	22	0.4
Pomoxis nigromaculatus	black crappie	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pylodictis olivaris	flathead catfish	0	0.0	0	0.0	0	0.0	0	0.0	3	0.1
Salmo trutta	brown trout	3	0.2	1	0.1	1	0.1	1	0.0	0	0.0
Sander vitreus	walleye	8	0.5	6	0.4	7	0.4	69	2.4	58	1.1
	Total (N)	1728		1674		1764		2890		5133	

Table 2. Fish community metrics for electrofishing surveys below Fairmount Dam during spring migration (2002–2006).

Metrics	Year				
	2002	2003	2004	2005	2006
Total (N)	1728	1674	1764	2890	5133
Species Richness	23	19	21	24	26
Shannon Index (H')	2.39	1.85	2.03	2.18	1.92
Evenness (E)	0.68	0.53	0.58	0.62	0.55

Video Monitoring Assessments

Table 3 summarizes the fish passage results from 2004 to 2006. In 2004, there were 6,438 fish of 23 species that ascended Fairmount fishway. Anadromous fishes utilized the fishway and accounted for 3.9% of the total spring passage through the fishway, including 91 American shad, 161 striped bass, and 2 river herring. American shad were observed passing by the viewing window from April 24 to June 25; striped bass were observed from April 26 to June 30; and river herring were observed from May 2 to May 15. Whereas the presence of hickory shad (*Alosa mediocris*), another anadromous species, was documented in the Schuylkill River below Fairmount Dam by electrofishing surveys, *A. mediocris* was not observed ascending the fishway in 2004. Channel catfish and quillback were the numerically dominant species and accounted for 56.3% of total spring fish passage. White suckers (*Catostomus commersoni*), common carp, and gizzard shad were also abundant in the fishway during the spring migration.

A total of 8,017 fish representing 25 species passed through the fishway in 2005, a 20% increase in fish passage by both resident and migratory species compared to 2004. Anadromous fishes accounted for 2.2% of total spring fish passage including 41 American shad, 127 striped bass, and 5 river herring. Despite the increase in total fish passage during 2005, there were decreases in numbers of two anadromous species

Table 3. Fish passage counts by species at the Fairmount Dam Fishway, Schuylkill River, Pennsylvania, during spring monitoring. Species status codes are as follows: NA = native anadromous; NC = native catadromous; NR = native resident; IR = introduced resident; and I = introduced.

Scientific Name	Common Name	Status	2004[a] Number Passed	2005[b] Number Passed	2006[c] Number Passed
Alosa mediocris	hickory shad	NA	0	0	9
Alosa sapidissima	American shad	NA	91	41	345
Ameiurus catus	white catfish	NR	6	1	6
Ameiurus spp.	bullhead catfish	NR	0	0	2
Ambloplites rupestris	rock bass	IR	0	1	0
Anguilla rostrata	American eel	NC	32	70	34
Catostomus commersoni	white sucker	NR	731	1767	2887
Carpiodes cyprinus	quillback	NR	1807	2042	2631
Ctenopharyngodon idella	grass carp	I	2	0	1
Cyprinella analostana	satinfin shiner	NR	0	2	0
Cyprinus carpio	common carp	IR	401	1197	2215
Dorosoma cepedianum	gizzard shad	NR	691	553	2899
Ictalurus punctatus	channel catfish	IR	1816	1663	3421
Lepomis auritus	redbreast sunfish	NR	13	3	4
Lepomis gibbosus	pumpkinseed sunfish	NR	0	7	1
Lepomis macrochirus	bluegill sunfish	IR	22	147	276
Lepomis species	unknown sunfish		72	10	2
Micropterus dolomieui	smallmouth bass	IR	143	124	1225
Micropterus salmoides	largemouth bass	IR	11	10	42
Morone americana	white perch	NR	55	105	112
Morone saxatilis	striped bass	NA	161	127	61
Morone saxatilis x Morone chrysops	hybrid striped bass	IR	20	16	48
Oncorhynchus mykiss	rainbow trout	I	7	13	16
Pylodictis olivaris	flathead catfish	IR	68	43	466
Alosa aestivalis or pseudoharengus	River Herring	NA	2	5	7
hybrid trout	hybrid trout	I	0	8	40
Salmo trutta	brown trout	I	4	7	5
Sander vitreus	walleye	IR	57	33	84
	unknown		172	14	11
	unknown catfish		12	0	0
	unknown minnow		3	7	0
	unknown shad		32	0	0
	unknown trout		7	1	0
TOTAL			6438	8017	16850

[a]Power outages to the viewing room and video monitoring system resulted in 362 hours of lost video data.
[b]Power outages and data corruption of digital video files resulted in 337 hours of lost video data.
[c]Severe river flooding forced us to evacuate all video monitoring equipment from the viewing room and resulted in 168 hours of lost video data.

(*A. sapidissima* and *M. saxatilis*). The increase in total fish passage in 2005 was mainly from increased abundance of *C. commersoni, C. cyprinus, C. carpio*, and *Morone americana.*

Through video surveillance in 2005, American shad were observed passing by the viewing window from April 18 to June 28; striped bass were documented from May 11 to June 30; and river herring were observed from April 8 to June 18. River herring were the only anadromous fishes to increase in abundance from 2004 to 2005. Five resident species (*C. cyprinus, C. commersoni, D. cepedianum, I. punctatus*, and *C. carpio*) constituted 90.1% of fish passage during the spring migration. Moreover, there were several species documented in 2005 that were not represented in 2004, such as rock bass (*Ambloplites rupestris*), satinfin shiner (*Cyprinella analostana*), and pumpkinseed sunfish (*L. gibbosus*).

In 2006, a total of 16,850 fish representing 26 species were counted passing through the fishway, a two-fold increase in fish passage numbers when compared to 2005. Also, American shad passage increased 279.1 % from 2004 to 2006 and 741.5% from 2005 to 2006. Anadromous fishes accounted for 2.5% of total spring fish passage including 345 American shad, 9 hickory shad, 61 striped bass, and 7 river herring. *A. sapidissima* were observed passing by the viewing window from April 11 to June 6; *M. saxatilis* were documented from May 14 to June 24; *A. aestivalis* and *A. pseudoharengus* were counted from May 2 to June 20. In addition, 9 hickory shad passed through Fairmount fishway during a three day period (i.e., May 3 to May 6). This is the first confirmed passage of hickory shad, an endangered species in Pennsylvania, above Fairmount Dam in recorded history for the Schuylkill River. There is no reference to hickory shad in early historical fisheries accounts for the Delaware Estuary in Pennsylvania (Majumdar et al. 1986).

Similar to the previous years, *C. commersoni, C. cyprinus, C. carpio, D. cepedianum*, and *I. punctatus* were extremely abundant in the fishway, accounting for 83.4% of total fish passage in 2006. New records of fish passage were also documented for hickory shad and bullhead catfish (*Ameiurus sp.*) while previous recordings of rock bass and satinfin shiner (*C. analostana*) were not observed in 2006.

During the 2004–2006 migratory periods, channel catfish (n = 6,900) and quillback (n = 6,480) were the numerically dominant species. White sucker, common carp, and gizzard shad were also relatively abundant compared to other species (Table 2). American shad, smallmouth bass (*Micropterus dolomieui*), flathead catfish, bluegill (*L. macrochirus*), and gizzard shad numbers increased dramatically from 2004 to 2006, while most species displayed relatively minor interannual fluctuations. It should be noted that redbreast sunfish (*Lepomis auritus*) and striped bass numbers decreased during the study period.

Diurnal Passage

Based on diurnal passage studies of anadromous species from 2004–2006 (Figures 4 to 7), peak passage generally

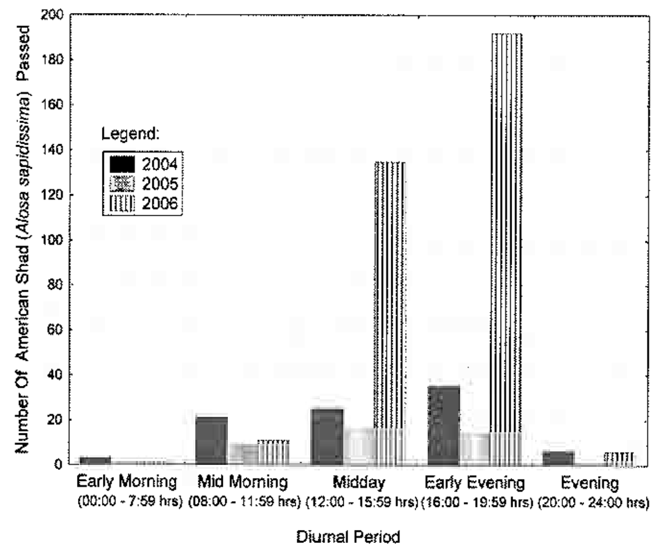

Figure 4. Diurnal pattern of passage for American shad (*A. sapidissima*) at Fairmount Dam fishway (2004–2006).

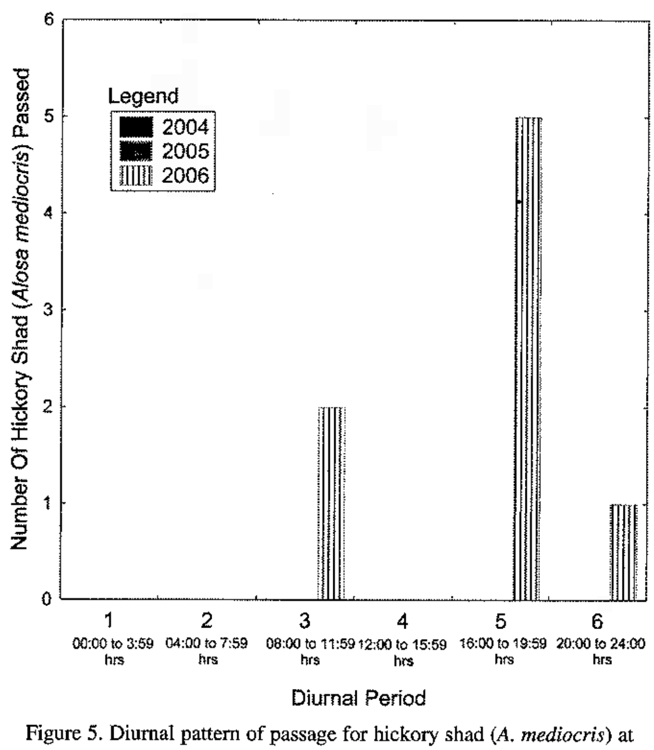

Figure 5. Diurnal pattern of passage for hickory shad (*A. mediocris*) at Fairmount Dam fishway (2004–2006).

occurred during periods 4 and 5, which corresponds to late morning through early evening. American shad passage was documented during each diurnal period; however, peak passage occurred from 16:00 hrs to 19:59 hrs, with a secondary peak from 12:00 hrs to 15:59 hrs (Figure 4). Hickory shad only passed during periods 3, 5, and 6, with peak passage also from 16:00 hrs to 19:59 hrs (Figure 5). Striped bass displayed a complex passage pattern, utilizing the fishway at all hours of the day, but mostly passing during the daylight hours. Peak passage for *M. saxatilis* occurred from 16:00 hrs to 19:59 hrs (Figure 6). River herring preferred utilizing the fishway during low-light hours more than any other anadromous species, with a majority of passage occurring during diurnal periods 1 and 5 (Figure 7).

Catch Per Unit Effort (CPUE)

Relative abundance of anadromous species for the tidal Schuylkill River below Fairmount Dam was collected from 2002 to 2006 (Figure 8). Catch per unit effort (CPUE) was used as an index of population (i.e., relative abundance) and expressed in the number of fish collected per minute of elec-

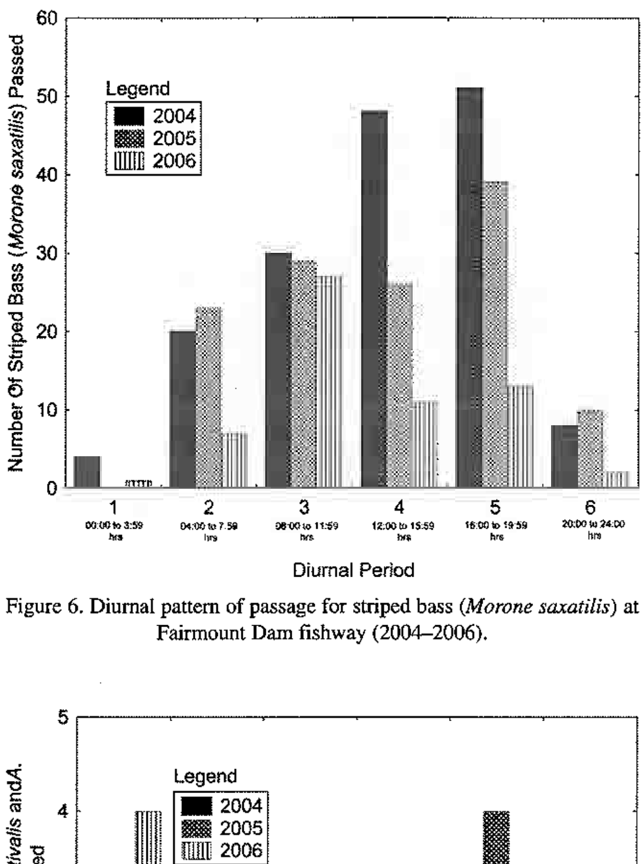

Figure 6. Diurnal pattern of passage for striped bass (*Morone saxatilis*) at Fairmount Dam fishway (2004–2006).

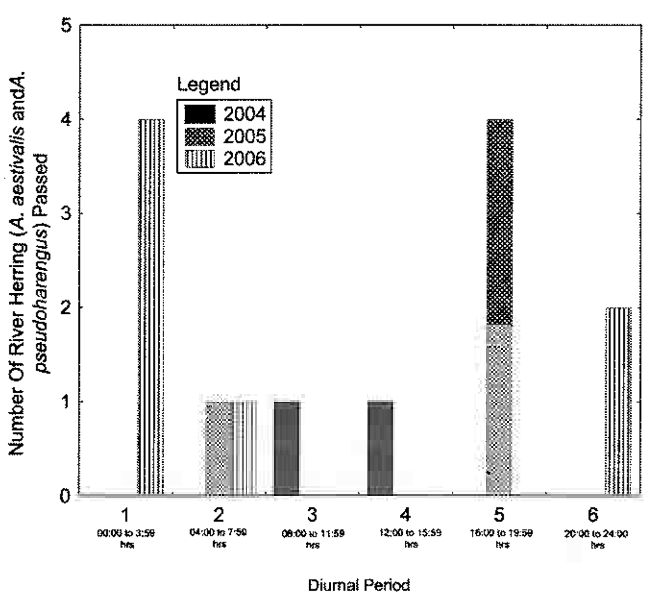

Figure 7. Diurnal pattern of passage for river herring (*Alosa aestivalis* and *A. pseudoharengus*) at Fairmount Dam fishway (2004–2006).

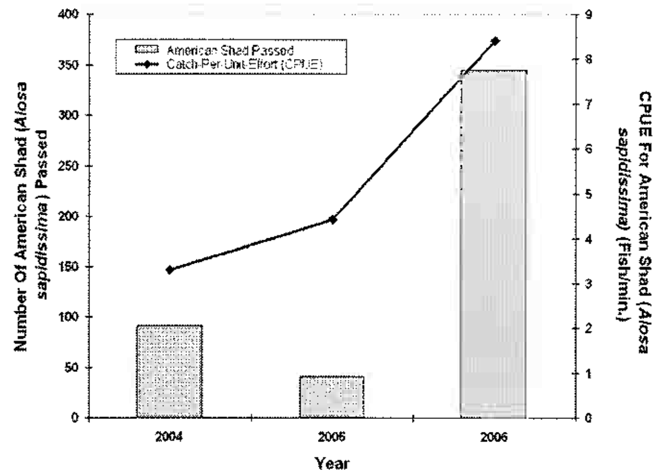

Figure 8. Interannual trends of adult American shad (*Alosa sapidissima*) in relative abundance (CPUE) below Fairmount Dam and fish passage (2004–2006).

trofishing. This means of normalizing data allows for interannual evaluation in trends of relative abundance as well as comparing data with state and federal fisheries agencies and among other river systems.

During the study period, the increasing trend in relative abundance of American shad below Fairmount Dam was correlated with the general increasing trend in American shad passage at the fishway. CPUE for *A. sapidissima* increased from 3.29 in 2004 to 8.42 in 2006 (Figure 8). Similar trends in passage of *A. sapidissima* were also observed, with 91 American shad (*A. sapidissima*) passing through the ladder in 2004 and 345 passing in 2006. The decrease in American shad passage from 2004 to 2005 was most likely due to lost video data rather than an actual decrease in fish passage. Power outages to viewing room and video monitoring system resulted in 362 hours of lost video data in 2004, 337 hours in 2005 and 168 hours in 2006. While the number of hours lost in 2004 was greater than in 2005, video data corruption in 2005 occurred at expected peak passage times (i.e., mid-May) for American shad. The loss of video from these critical days in 2005 suggests that actual passage numbers of *A. sapidissima* were higher than recorded.

DISCUSSION

The tidal reach of the Schuylkill River serves as a vital conduit for resident and migratory fish species within the Delaware River basin. Nowhere is this more evident than at the Fairmount Dam fishway. The Fairmount Dam fishway acts as a gateway to the rest of the Schuylkill River, allowing upstream dispersal of both migratory and resident fishes. Without access to critical spawning habitat above the dam, the long-term sustainability of migratory fish populations within the Schuylkill Drainage may not be feasible. Based on this study, it is evident that the Schuylkill River supports a relatively diverse fish assemblage composed of various native anadromous, catadromous, and resident fishes, as well as introduced species, several of which have become established. More importantly, video surveillance has revealed that both resident and migratory species readily ascend the Fairmount Dam fishway. Weaver et al. (2003) showed similar results in their study of the James River, implying that resident species ascending the fishway may result in additional ecological benefits to the river and its tributaries.

During our three-year study, a total of twenty-six species of fish, as well as several hybrid species, were documented using the fishway during spring migrations. Anadromous fishes, such as American shad, hickory shad, striped bass, and river herring, frequently utilized the fishway for passage above the dam, and the presence of juvenile alewife upstream of the fishway in 2005–2006 suggests that quality spawning and nursery habitats still exist above Fairmount Dam. Moreover, fish passage counts for adult American shad show a discernable increase during the three-year period and although the numbers are significantly lower than historical records, fish surveys below Fairmount Dam indicate increasing trends in fish density during spring migrations.

Analysis of diurnal passage patterns revealed that the majority of anadromous species utilized the fishway during daylight periods (i.e., 12:00 and 19:59 hours), with some species specific variation. These findings corroborate with those of Weaver et al. (2003) at a James River vertical slot fishway in Virginia and Arnold (2000) at two Lehigh River vertical slot fishways in Pennsylvania. Our findings suggest that photoperiod may be one of the primary factors triggering upstream dispersal of migratory fish through the Fairmount Dam fishway; however, additional studies on physicochemical variables (e.g., temperature) and biotic interactions (e.g., predation) may need to be addressed before a definitive conclusion can be made.

This study represents the first detailed examination of fish community structure and fish ladder utilization by resident and anadromous species in the lower Schuylkill River Drainage in approximately twenty years. More specifically, Mulfinger and Kauffmann (1981) showed that annual American shad counts did not exceed twenty-two (n=22), while the current study documented a maximum of 345 American shad in 2006. Moreover, only one striped bass was observed passing through the fishway from 1979 to1984; whereas, 349 striped bass passed between 2004 to 2006. During this period, significant improvements in water quality have been made, while ecosystem-based restoration strategies, including dam removals and fish passage restorations, within the Schuylkill River basin have only recently been addressed. Currently, the Philadelphia Water Department and the United States Army Corps of Engineers have joined resources to restore the Fairmount Dam fishway, with construction efforts planned to commence in 2008. The Pennsylvania Fish and Boat Commission have also begun to refocus their efforts of American shad restoration by strengthening their shad fry stocking program in the Schuylkill River. In addition, there are several proposed plans for either fish passage facilities or dam removals for the remaining barriers on the Schuylkill River, with an ultimate goal of providing 160 kilometers of vital upstream habitat for resident and migratory species.

While the current restoration strategies along the Schuylkill River continuum may have a synergistic effect on the success of resident and migratory fishes, it is imperative that emphasis be placed on the largest, and perhaps, most important fishway. The fish passage facility at Fairmount Dam must be redesigned and built to optimize fish passage, otherwise precious resources and current restocking programs will have been wasted (Weaver et al., 2003). Preliminary results from our study indicate that proper operation, maintenance, and monitoring of the fishway may have a critical role in reestablishing anadromous fish populations throughout the Schuylkill River watershed. Although the total number of anadromous fish passed between 2004–2006 is relatively low, this interannual trend will serve as a baseline for pre-restoration efforts and will allow scientists to gauge the success of this fishway and future ecosystem-based activities within the Schuylkill River drainage.

ACKNOWLEDGMENTS

Our appreciation is extended to W. Richardson, S. Ostrowski, and J. Cruz of the Philadelphia Water Department for support throughout this project. D. Arnold and M. Kaufmann of Pennsylvania Fish and Boat Commission provided valuable insight into establishing monitoring protocols and video identification techniques. Drexel University student interns J. Deni, J. Bravo, J. Andraccio, and L. Siler assisted with counting fish and data entry. D. Mora, P. Ford, and the rest of the PWD waterways restoration unit provided support with fishway maintenance and repairs. Also, E. Grusheski, R. Madison, and several other staff at the Fairmount Water Works Interpretive Center provided logistical and financial support during the entire study.

LITERATURE CITED

Albanese, B., P. L. Angermeirer, and S. Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia Streams. Canadian Journal of Fisheries and Aquatic Sciences 61: 857–869.

Arnold, D. A. 2000. Lehigh River American shad: the first six years. Pennsylvania Angler and Boater 69(3):18–20.

Bentzen, P., G. G. Brown, and W. C. Leggett. 1989. Mitochondrial DNA polymorphism, population structure, and life history variation in American shad (*Alosa sapidissima*). Canadian Journal of Fisheries and Aquatic Sciences 46:1446–1454.

Brown, J. J., J. A. Perillo, T. J. Kwak and R. J. Horwitz. 2005. Implications of *Pylodictis olivaris* (flathead catfish) introduction into the Delaware and Susquehanna drainages. Northeastern Naturalist 12(4): 473–484.

Carscadden, J. E., and W. C. Leggett. 1975. Life history variation in population of American shad, *Alosa sapidissima*, spawning in tributaries of the St. John River, New Brunswick. Journal of Fish Biology 7:595–609.

Epifanio, J. M., P. E. Smouse, C. J. Kobak, and B. L. Brown. 1995. Measuring mitochondrial DNA divergence among populations of American shad (*Alosa sapidissima*): how much variation is enough for mixed-stock analysis? Canadian Journal of Fisheries and Aquatic Sciences 52:1688–1702.

Glebe, B. D., and W. C. Leggett. 1981. Latitudinal differences in energy allocation and use during the freshwater migrations of American shad (*Alosa sapidissima*) and their life history consequences. Canadian Journal of Fisheries and Aquatic Sciences 38:806–819.

Hallock, C. 1894. When Shad were a Penny A-Piece. Transactions of the American Fisheries Society: Vol. 23, No. 1 pp. 18–21

Magurran, A. E. 2004. Measuring biological diversity. Oxford: Blackwell Science.

Majumdar, S. K., F. J. Brenner, and A. F. Rhoads, editors. 1986. Endangered and Threatened Species Programs in Pennsylvania and other States: Causes, Issues and Management. The Pennsylvania Academy of Science, pp. 518.

Moulton, S. R., J. G. Kennen, R. M. Goldstein, and J. A. Hambrook. 2002. Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program. U.S. Geological Survey Report 02-150.

Mulfinger, R. M., and M. Kaufmann. 1981. Fish passage at the Fairmount fishway in 1979 and 1980 with implications for the Schuylkill River fisheries through future fishway construction. Pages 101–124 in Proceeding of The Schuylkill River Symposium, The Academy of Natural Sciences of Philadelphia. September 24 and 25, 1980.

Sykes, J. E., and B. A. Lehman. 1957. Past and present Delaware River shad fishery and considerations for its future. U.S. Fish and Wildlife Service. Res. Rep. No. 46. 25 pp.

Talbot, G. B., and J. E. Sykes. 1958. Atlantic coast migrations of American shad. U.S. Fish and Wildlife Service Fishery Bulletin 58:473–490.

United States Fish and Wildlife Service. 1999. Restoring anadromous fishes to the Schuylkill River basin. Fact Sheet.

Walburg, C. H. 1960. Abundance and life history of shad, St. John's River, Florida. U.S. Fish and Wildlife Service Fishery Bulletin 177:487–501.

Weaver, L. A., M. T. Fisher, B. T. Bosher, M. L. Claud, and L. J. Koth. 2003. Boshers Dam vertical slot fishway: a useful tool to evaluate American shad recovery efforts in the upper James River. American Fisheries Society Symposium 35:323–329.