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Evaluating The Use of Fairmount Dam Fish Passage Facility By Anadromous Fishes In The Schuylkill River, Philadelphia, Pennsylvania

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Abstract
The Schuylkill River in Southeaster Pennsylvania once supported massive spring runs of anadromous fishes until the construction of dams in the early 1800's. American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), 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 (13.6 rkm) was built. The dam served as a physical barrier to migratory fishes, completely blocking upstream movement and access to critical spawning grounds. 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 the fishway was abandoned in 1984. No fish counts were conducted from 1984 to 2004, until Philadelphia Water Department biologists 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 allows direct observation of fishes swimming through the fishway and is a primary means for evaluating fish passage. In 2004, there were 6,438 fish of 23 species that ascended Fairmount 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, marking an astonishing 279% increase in American shad passage from 2004 to 2006. The interannual trend in relative abundance of American Shad below Fairmount Dam increased, as did overall shad passage trends in the fishway. Continued monitoring of fish passage will be a critical component in assessing anadromous fish restoration efforts on the Schuylkill River.

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ABSTRACT

The Schuylkill River in Southeastern Pennsylvania once supported massive spring runs of anadromous fishes until the construction of dams in the early 1800's. American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), 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 (13.6 rkm) was built. The dam served as a physical barrier to migratory fishes, completely blocking upstream movement and access to critical spawning grounds. 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 the fishway was abandoned by 1984. No fish counts were conducted from 1984 to 2004, until Philadelphia Water Department biologists 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 allows direct observation of fishes swimming through the fishway and is the primary means for evaluating fish passage. In 2004, there were 6,438 fish of 23 species that ascended Fairmount 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, marking an astonishing 279% increase in American shad passage from 2004 to 2006. The interannual trend in relative abundance of American shad below Fairmount Dam increased, as did overall shad passage trends in the fishway. Continued monitoring of fish passage will be a critical component in assessing anadromous fish restoration efforts on the Schuylkill River.

INTRODUCTION

Pennsylvania has a rich history of massive 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. The Schuylkill River, as 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 and blueback herring) ascended the Schuylkill River as far upstream as Pottsville (160 river kilometers), but have not done so since 1820, when Fairmount Dam was built. 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 uncontrolled industrial river pollution was rampant, resulting in the demise of anadromous fishes in the Schuylkill River.

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). Following the spawning and hatching process, young shad inhabit riverine nursery areas and later migrate to sea within a year of hatching and remain there until sexually mature (Olney et al. 2003). Adult shad will first spawn at ages 3-7, with approximately 80% mature by age five (Maki et al. 2001).

For more than 150 years, American shad disappeared from the Schuylkill River. Then, in the 1970's, Pennsylvania Fish and Boat Commission (PFBC) biologists conducting tidal river fish surveys were astonished to find American shad making their way up the Schuylkill River as far as Fairmount Dam. Subsequent PFBC surveys revealed that river water quality and habitat in the Schuylkill River could again support a population of American shad as well as other anadromous fishes, if there was a way to get fish above Fairmount Dam. Therefore, in 1979, with funding from the City of Philadelphia, United States Fish and Wildlife Service, and PAFBC, a vertical slot fish passage facility was constructed on the west side of Fairmount Dam, across from the Philadelphia Museum of Art. During the first few years of operation, Fairmount Dam fishway was used heavily by resident fish populations, however, very few shad or herring were utilizing the passage. Since none of the upstream dams were passable and few anadromous fishes were passing, Fairmount fishway was abandoned by 1984 and restoration efforts focused on the Lehigh River.

No fish counts were conducted from 1984 to 2004, until Philadelphia Water Department biologists 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 Fairmount Dam fishway, as the most downstream passageway, is especially critical to the overall success of restoring migratory fish runs in the Schuylkill River watershed. All upstream work will be affected by the success or failure of the Fairmount Dam fishway at passing migratory species during spawning runs. Resident fish species will benefit from the enhanced potential to reach suitable spawning and

nursery habitat, and from a larger forage base provided by juvenile anadromous species. Improving fish passage at the Fairmount fishway will benefit the entire ecology and economy of the Schuylkill River watershed.

The primary means for evaluating fish passage and ultimately all anadromous fish restoration efforts is recorded video of fish moving past the viewing window. This method is used and recommended by PA Fish and Boat Commission for fish passage facilities. The recorded video allowed biologists to identify and enumerate species ascending and descending the fishway. These quantitative data of diversity and abundance of fish can be compared to river electrofishing data and therefore determine passage utilization. Monitoring fish passage will allow us to determine the size of the American shad run and compare those numbers to the upstream passage facilities and other ladders 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.

My study will present and summarize several years of research I personally conducted including establishing the experimental design, carrying out all field work and electrofishing surveys on the river, laboratory taxonomic fish identification, deploying the digital video recording systems, management and archiving of digital video files, analyzing and processing video files, quality control and quality assurance, data entry, and data analysis. These data collected from years of research will be used to evaluate the use of Fairmount Dam fishway by anadromous fishes in the Schuylkill River.

METHODS AND MATERIALS

Project Site Description

The Schuylkill River, the largest tributary of the Delaware River, is located in Southeastern Pennsylvania (Figure 1) and is approximately 198 kilometers in length from its confluence with the Delaware River in Philadelphia to its headwaters in Pottsville. The Fairmount Dam fishway (Figure 2) is situated within the Philadelphia City limits on Fairmount Park property, Philadelphia County, Pennsylvania. Fairmount Dam is positioned 13.6 kilometers upstream from the Schuylkill's confluence with the Delaware River and is the uppermost reach of the Schuylkill that is influenced by tidal fluctuations.

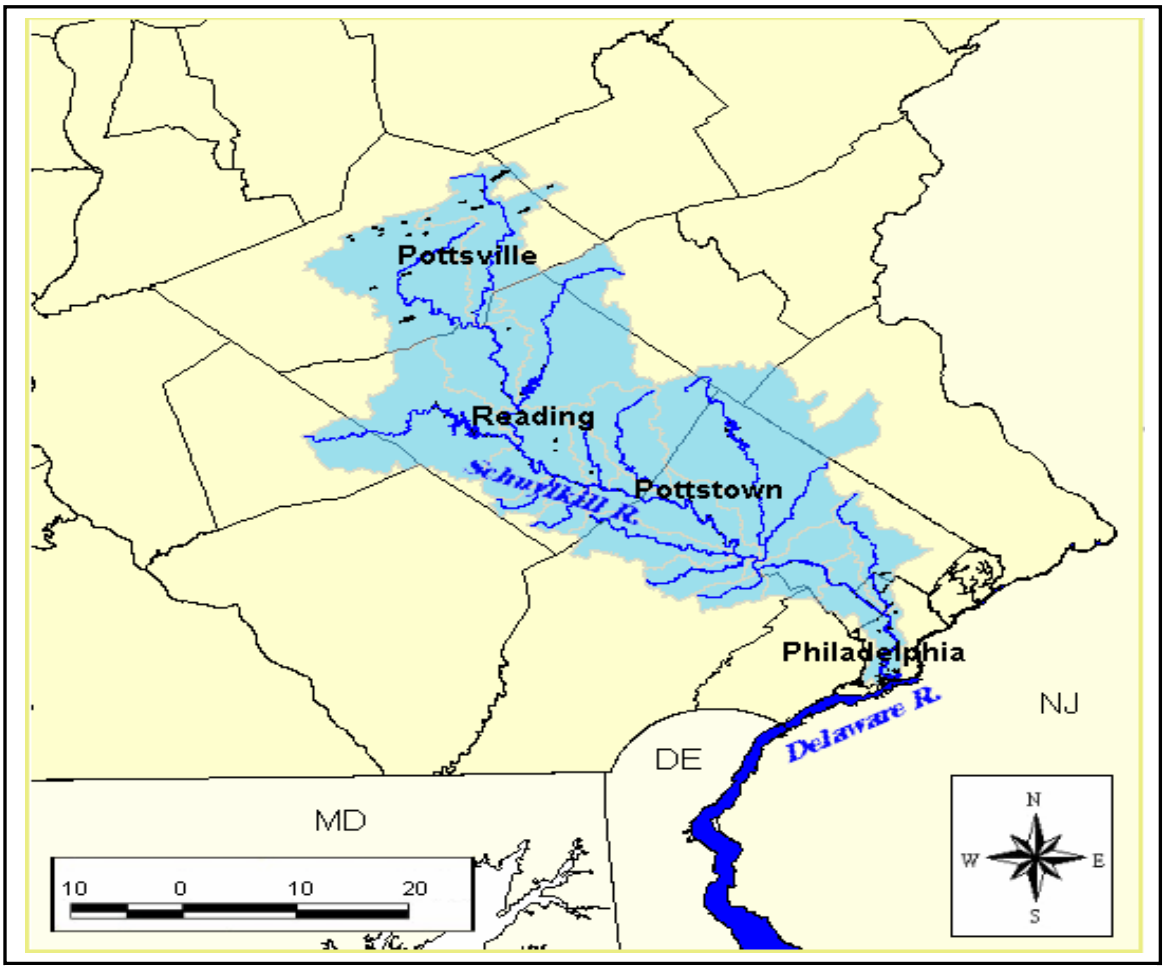

Figure 1. Regional map of the Schuylkill River watershed located in Southeastern Pennsylvania.

The Fairmount fishway is located on the west shore of Fairmount Dam on the Schuylkill River across from the historic Fairmount Water Works and Philadelphia Museum of Art.

Fairmount Dam, owned by the city of Philadelphia, is 304.8 meters long and has a crest elevation of approximately 3.2 meters. The dam, built of hickory log cribs, was constructed in 1821 to provide a source of drinking water, as well as waterpower to pump river water up to a reservoir. The Fairmount Water Works' mill house was constructed to house the water wheels which would drive the water-powered pumps. Gates were installed to control the flow of water diverted by the dam into the forebay or mill race, carved from rock behind the new building. In 1909 the Fairmount Water Works was decommissioned because the river had become severely polluted from industrial and municipal sources. Today, however, Fairmount Dam still serves its function to provide an impoundment of water for two drinking water intakes for the city of Philadelphia.

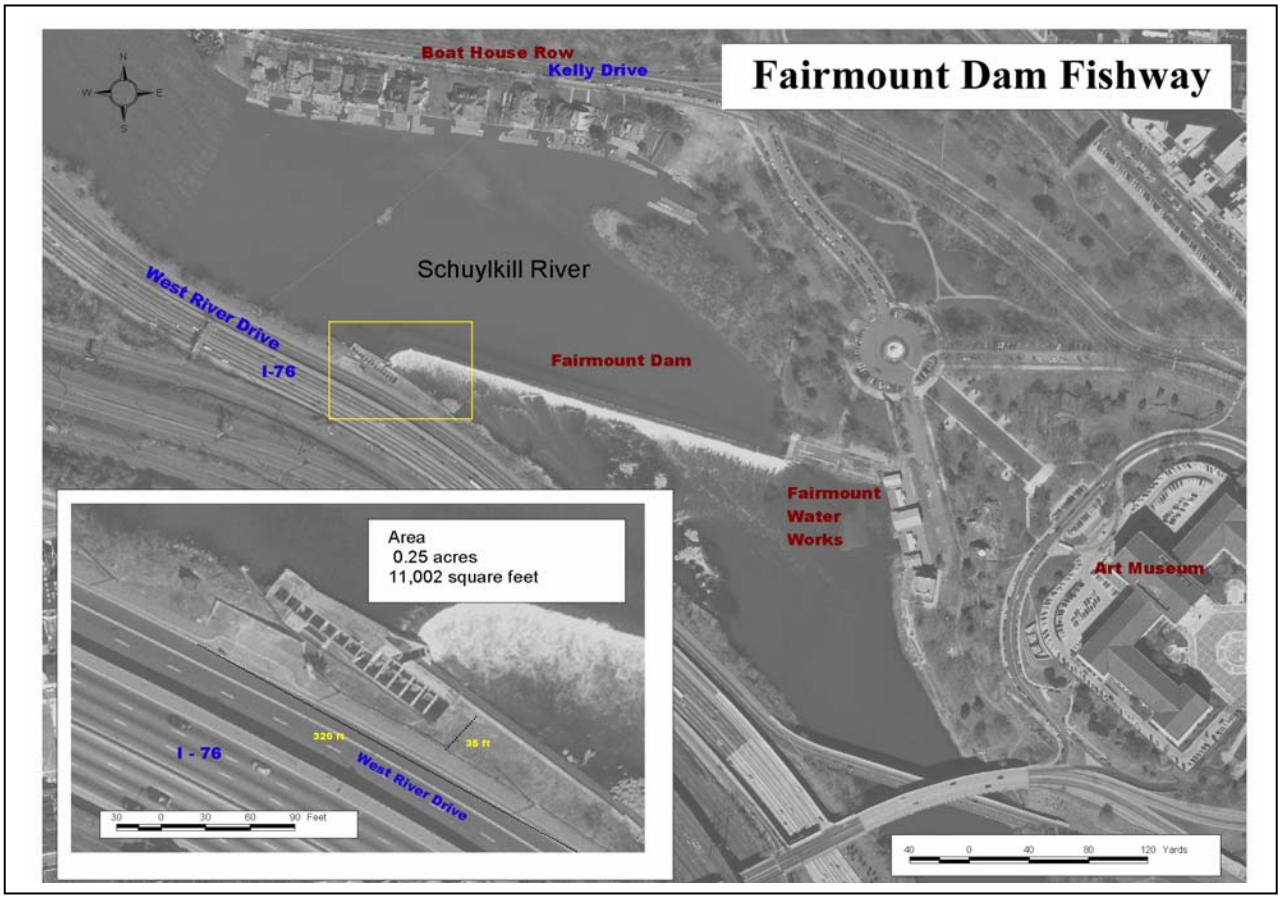

Figure 2. Aerial view of Fairmount Dam and vertical slot fishway (left insert) located on the west bank of the Schuylkill River at river km 13.6, Philadelphia, Pennsylvania.

Fishway Design and Operation

The water elevation at the fishway entrance is effected by the tide as well as the discharge over the spillway and will range from an elevation of 1.1 m to -0.95 m during the operating period from March through June (White 2003). The fish passage facility is a vertical slot style fishway with an entrance attraction water diffuser, 14 pools, and an exit flume. Flow through the fishway pools varies depending primarily on water elevation upstream of the dam.

The fishway entrance diffuser draws water from a chamber inside the fishway adjacent to the fishway exit. A 0.61 meter diameter pipe connects the attraction water intake to the attraction water diffuser. Flow from the pipe freely discharges into a 90 degree elbow pipe that conveys the attraction water under a wall and up through a 2.4 meters wide by 1.8 meters long floor diffuser located immediately upstream of the entrance channel near the first baffle. The fishway entrance channel is 1.8 m wide with the floor at elevation -2.8 m and the fishway entrance is 0.61 m wide with a fixed sill at elevation -1.6 m (White 2003).

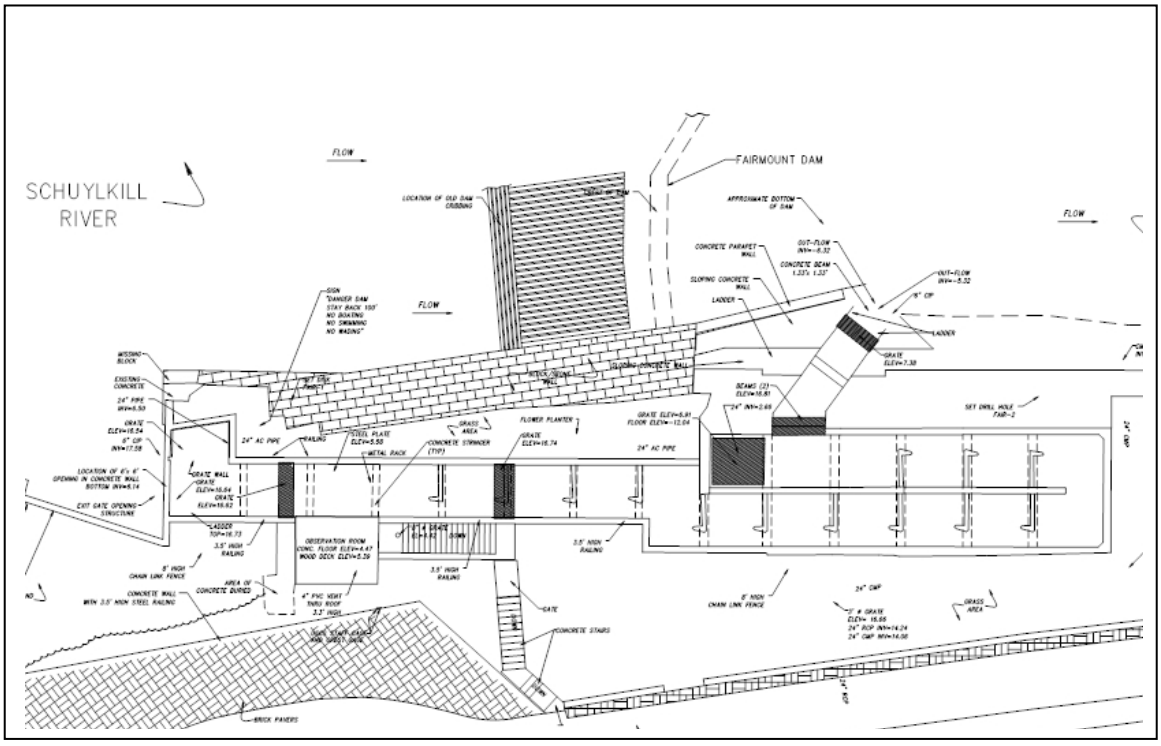

Figure 3. Engineering plan view of Fairmount Dam fishway by United States Army Corps of Engineers.

The 14 pools are each 3.1 m long by 2.4 m wide with exceptions at pool 4, the turning pool, and at pool 10 where there is an offset in the fishway. The baffles forming the slots between the pools are all similar with a 0.31 m slot width. Each slot contains baffle blocks to restrict the flow of water through the fishway pools. The bottom block in each slot is positioned 0.15 m above the floor to allow flow at the floor of the fishway.

The existing fishway discharge capacity was rated for river flows between 311 m^3/s and 21 m^3/s. The attraction water flow was regulated with a 0.61 m control valve to limit the attraction flow to 1.1 m^3/s. Velocity measurements were taken at 0.31 m and 1.25 m depths downstream of the entrance, in the entrance channel, downstream of each baffle and in the exit channel (White 2003). Fishway entrance velocities ranged from 3.35 m/s to 1.83 m/s at 0.31 m depth and from 1.04 m/s to 0.06 m/s at 1.25 m depth measurements. In the typical pool, the flow entered the pool through the upstream slot and moved across the pool until it was deflected by the far wall along the downstream baffle wall and then out through the downstream slot. Regions of backflow were formed on both sides of the stream.

Figure 4. Ground level picture of Fairmount Fishway surrounded by security fencing; Philadelphia Museum of Art, Fairmount Water Works, and Philadelphia skyline in the background.

Figure 5. Overhead view looking into Fairmount fishway. Pools are formed by concrete walls and separated by baffles, which create vertical slots for fish to swim through. Fish will swim from one pool to another by passing through the slots, incrementally making their way to the top of the fishway and above the dam.

Monitoring

Standardized sampling techniques are required for evaluating the use of Fairmount Dam Fish Passage Facility by anadromous fishes in the Schuylkill River. The tidal fish assessment involves careful, standardized field collection, species identification and enumeration, and analyses using aggregated biological attributes or quantification of the numbers of key species (Moulton et al. 2002). The role of experienced fisheries scientists in the adaptation and application of the tidal assessment and the taxonomic identification of fishes is extremely important. The fish survey yields an objective discrete measure of the condition of the fish assemblage. Although the fish survey can

usually be completed in the field by qualified fish biologists, difficult species identifications will require laboratory confirmation.

All fish sampling gear types are generally considered selective to some degree; however, electrofishing has proven to be the most comprehensive and effective *single* method for collecting stream fishes (Moulton et al. 2002). Pulsed DC (direct current) electrofishing is the method of choice to obtain a representative sample of the fish assemblage at each sampling station. A Smith-Root, Inc. (Vancouver, WA) Gas Powered Pulsator (GPP) 5.0 Portable Electrofisher with two anode booms and two adjustable umbrella arrays were mounted to a Grumman (Marathon, NY) aluminum flat bottom boat. The power was supplied by a Honda gas generator and the cathode wire from the junction box was connected to the hull of the boat. A foot switch controlled by the operator administered two to four direct current amps at a frequency of 60 pulses per second with a pulse width of 15 to 35 percent, achieving a peak output of approximately 500 volts.

Figure 6. Electrofishing boat conducting fish survey on Schuylkill River below Fairmount Dam.

GPP settings and output varied based on water conductivity, fish conductivity, fish size, water temperature, and substrate (Smith-Root 1998). In order to determine proper electrofishing settings, I deployed a digital YSI Model 85 (Yellow Springs, OH) Handheld Dissolved Oxygen, Conductivity, Salinity, and Temperature analytical meter to obtain pertinent water chemistry values. The YSI Model 85 meter was calibrated and validated in accordance with Bureau of Laboratory Services quality assurance procedures. Incremental adjustments to GPP settings were occasionally necessary at a given sampling station due to the response and recovery of various fishes to the electrical field. We strove to use the lowest possible electrical output in order to minimize injury to fish and allow for successful release of nearly all fish collected.

As with any fish sampling method, I obtained the proper scientific collection permit from Pennsylvania Fish and Boat Commission before commencement of any electrofishing activities. The accurate identification of each fish collected is essential, and species-level identification is required (including hybrids in some cases). Because the collection methods used are not consistently effective for young-of-the-year fish and because their inclusion may seasonally skew bioassessment results, fish less than 20 millimeters total length were not identified or included in standard samples (Moulton et al. 2002). Electrofishing surveys were conducted three to four times per month from April 1 to July 1, in the vicinity of Fairmount Dam, between 2002 and 2006. Late summer and early fall electrofishing surveys were conducted from September to November (depending on water temperatures) from the Schuylkill River confluence up to Flatrock Dam in order to assess relative abundance of juvenile Alosinae.

The unique physical and hydrological conditions found directly below Fairmount Dam pose certain hazards that required slight modification in boat handling and collection techniques. The electrofishing boat moved in an **upstream** direction instead of the downstream technique used for other tidal fish assessments. This helped to ensure safe boat handling near the hydraulic "boil" of the dam by keeping the engine downstream to allow for maximum power while reversing the boat. Standardized electrofishing surveys below Fairmount Dam were conducted only at low tide in order to maximize capture efficiency and reduce sampling bias. National Oceanic and Atmospheric Administration's (NOAA) tide prediction charts and "Water Level Observation Network" data were used to select dates and times for conducting electrofishing surveys (www.noaa.gov).

Collection effort was standardized by **area** rather than time; however, total electrofishing time (in seconds) was recorded from the GPP counter to field data sheets for calculating catch per unit effort (CPUE). There were four fixed stations located between Fairmount Dam and Spring Garden Street Bridge (Figure 7). Each station was thoroughly sampled regardless of electrofishing time; time was still recorded on the field data sheet. The map below shows an aerial view of the assessment area with each station represented by different colors.

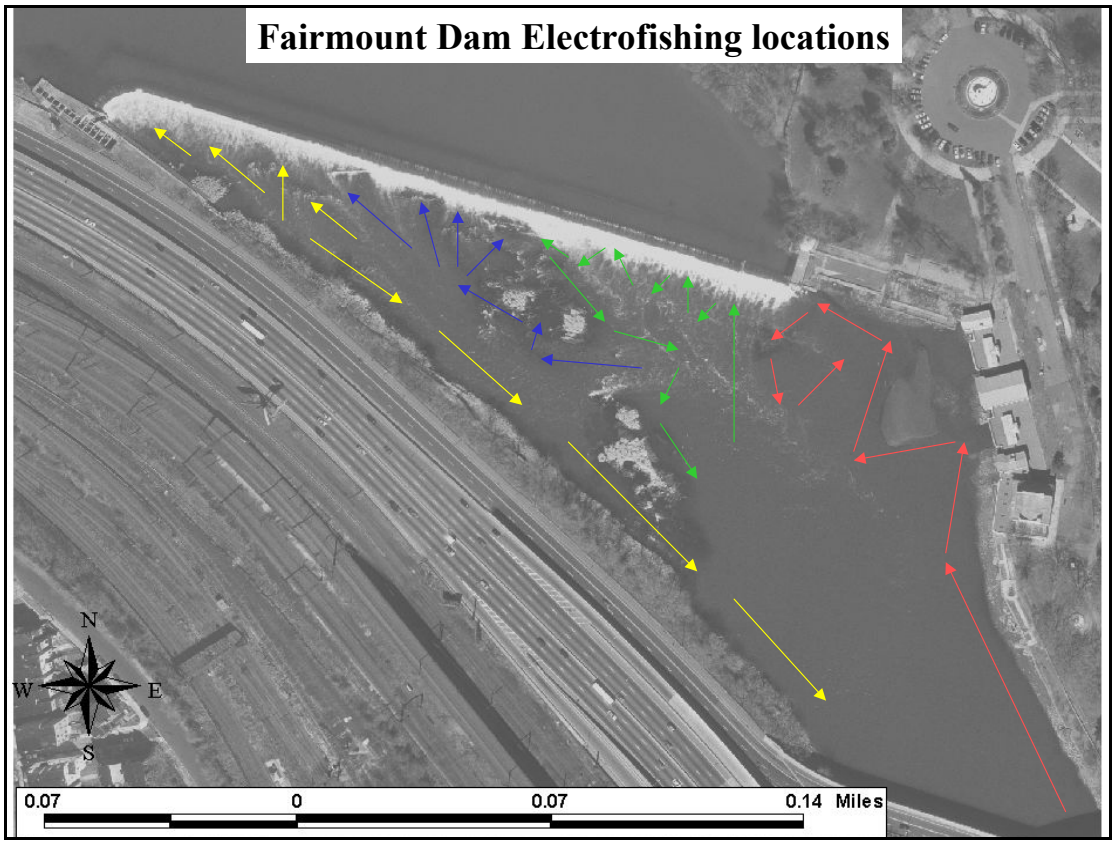

Figure 7. Aerial view of electrofishing station locations on the Schuylkill River at Fairmount Dam. Each set of colored arrows represents separate stations and overall movement of electrofishing boat. Photograph taken at low tide.

I received specific instructions from PA Fish and Boat Commission that prohibits bringing American shad and hickory shad into the boat's live wells for processing. American shad and hickory shad are extremely susceptible to mortality once placed in live wells and thus were only handled minimally for identification purposes and immediately released. These two species were counted while in the water when stunned. The accurate identification of each fish is essential, and species-level identification is required (including hybrids in some cases). An experienced fisheries biologist was always on the front of the boat to identify shad in the water without bringing them into the boat. Field identifications are acceptable; however, voucher specimens were retained for laboratory verification, particularly if there was any doubt about the correct identity of

the specimen. Hickory shad have an Endangered status in Pennsylvania and therefore were released immediately without excessive handling. Nearly all other species were netted using specialized pultruded fiberglass (non-conductive) electrofishing landing nets and placed in the boat's live wells until the sweep was finished.

I conducted maintenance activities at the Fairmount Fishway one to three times per week during the spring migration (April, May, June) and monthly/bimonthly from late fall to late winter. Maintenance included removal of all debris and obstructive materials from the exit trash rack, attraction flow grate, crowder grate, and all vertical slots in order to allow for safe fish passage throughout the migration. A floating trash boom installed at the exit trash rack to keep unwanted material from clogging the Fishway was cleared on a weekly basis. The underwater viewing window was also cleaned constantly in order to keep clear a line of site for the digital video camera.

I established a scientifically valid monitoring program for assessing fish passage at Fairmount Dam, which was approved by the state regulatory agencies and generates over 2,200 hours of digital video per year. Video monitoring protocols remained consistent over the three year period and required running the camera and lights 24 hours a day, seven days a week from April 1 until July 1. The monitoring program utilizes an IQeye digital video camera (San Clemente, CA) and OnSSI Surveillance Recording System (Suffern, NY) software to capture images of all fishes swimming by the underwater viewing window. This network-based digital video management system contains motion detection functions which will only record video to the capture computer's hard drive when triggered by an object passing by the viewing window. When there is no motion in the viewing window, the system still scans the window for

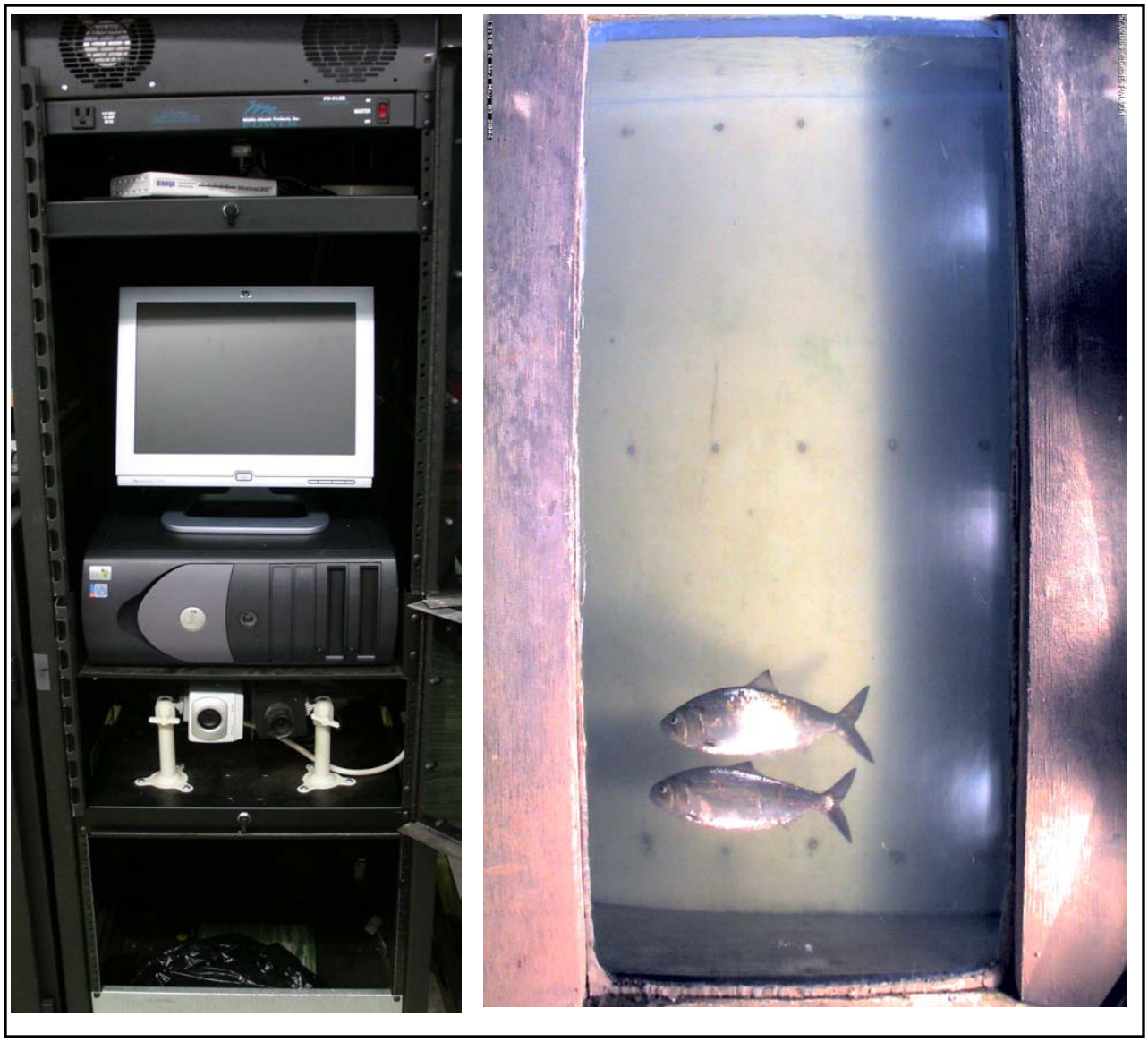

Figure 8. Picture of digital video monitoring system used in viewing room at Fairmount fishway (left) and viewing window with two American shad passing through (right).

movement, but does not record any video data. Video files saved on the computer's hard drive were purged and transferred every two to three days to an external hard drive in order to maintain sufficient memory capacity on the capture computer. Data from the

external hard drive were taken back to the Bureau of Laboratory Services and transferred again to a large capacity (terabyte) data storage drive (LaCie, Hillsboro, Oregon) for archiving and analysis. Video analysis protocols required watching every hour of recorded video for each day of the spring migration monitoring period.

Our objective was to enumerate and identify all fishes passing by the viewing window to species level, however, turbid river conditions at certain times made positive taxonomic identification impossible and therefore we categorized to the genus level on those rare occasions. We recorded hour, minute, and second for every fish passing by the window in an upstream direction. Fish moving downstream were identified to species and subtracted from the total count for that day. The video player software (OnSSI Surveillance Recording System, Suffern, NY) allowed use to quickly review periods with little passage and detailed frame-by-frame analysis of periods with heavy passage or for difficult to identify species. This software also enabled us to capture single-frame images (i.e. pictures) of the video, so we could save an image of a given fish in question, and then email the image as a "jpeg" to state and/or federal fisheries biologists for positive taxonomic identification. I also used this feature as a quality control measure to ensure sound data.

Numerous abiotic factors such as water temperature and stream discharge may affect passage rates of migratory fishes (Weaver et al. 2003). We deployed YSI Model 600XLM data sondes (YSI Inc., Yellow Springs, OH) placed mid-depth in the fishway entrance channel to obtain temperature, depth, dissolved oxygen, and conductivity values. The data sondes collected and logged data at 30 minute intervals for the month of April, May, and June over the 2004 to 2006 time period.

RESULTS

Table 1 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 (*Morone saxatilis*), and 2 river herring (alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis*).

Table 1. 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
Stizostedion vitreum	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.

In 2004, 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. While the presence of hickory shad, another anadromous species, was documented in the Schuylkill River below Fairmount Dam by electrofishing surveys, none were observed ascending the fishway in 2004. Channel catfish (*Ictalurus punctatus*) and quillback (*Carpiodes cyprinus*) were the numerically dominant species and accounted for 56.3% of total spring fish passage. White suckers (*Catostomus commersoni*), common carp (*Cyprinus carpio*), and gizzard shad (*Dorosoma cepedianum*) were also abundant in the fishway during the spring migration.

A total of 8,017 fishes representing 25 species were counted passing through the fishway in 2005, compared to 6,438 counted in 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, there were decreases in numbers of two anadromous species (American shad and striped bass) for 2005. The increase in total fish passage in 2005 was mainly from increased abundance of white sucker, quillback, common carp, and white perch (*Morone americana*). Several power and software failures with the video monitoring system resulted in loss of video at peak passage times for American shad during the spring migration. The loss of video from these critical days in 2005 suggests that actual passage numbers of American shad were higher than recorded.

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. Whereas the presence of hickory shad, another anadromous species, was documented in the Schuylkill River below Fairmount Dam by electrofishing surveys, none were observed ascending the fishway in 2005. Quillback and white sucker were the numerically dominant species and accounted for 47.5% of total spring fish passage. Common carp, gizzard shad, and channel catfish were also abundant in the fishway and when combined with quillback and white sucker, compromised 90.1% of fish passage during the spring migration. There were several species documented in 2005 that were missing compared to 2004 including rock bass (*Ambloplites rupestris*), satinfin shiner (*Cyprinella analostana*), and pumpkinseed sunfish (*Lepomis gibbosus*). Conversely, only one species, grass carp (*Ctenopharyngodon idella*), was observed in 2004, but not in 2005. Both rock bass and grass carp are introduced species and not native to the Schuylkill River watershed.

In 2006, a total of 16,850 fishes representing 26 species were counted passing through the fishway, compared to 6,438 counted in 2004 and 8,017 fishes in 2005. This is a remarkable increase in fishway activity as total fish passage increased 161.7% from 2004 to 2006 and 110.2% from 2005 to 2006. The year 2006 also marked an astonishing increase in American shad passage, with a 279.1 % increase from 2004 to 2006 and 741.5% increase in American shad in 2006 when compared to 2005. 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. Despite this massive swell in the number of American shad passed, the overall percentage of anadromous fishes did not

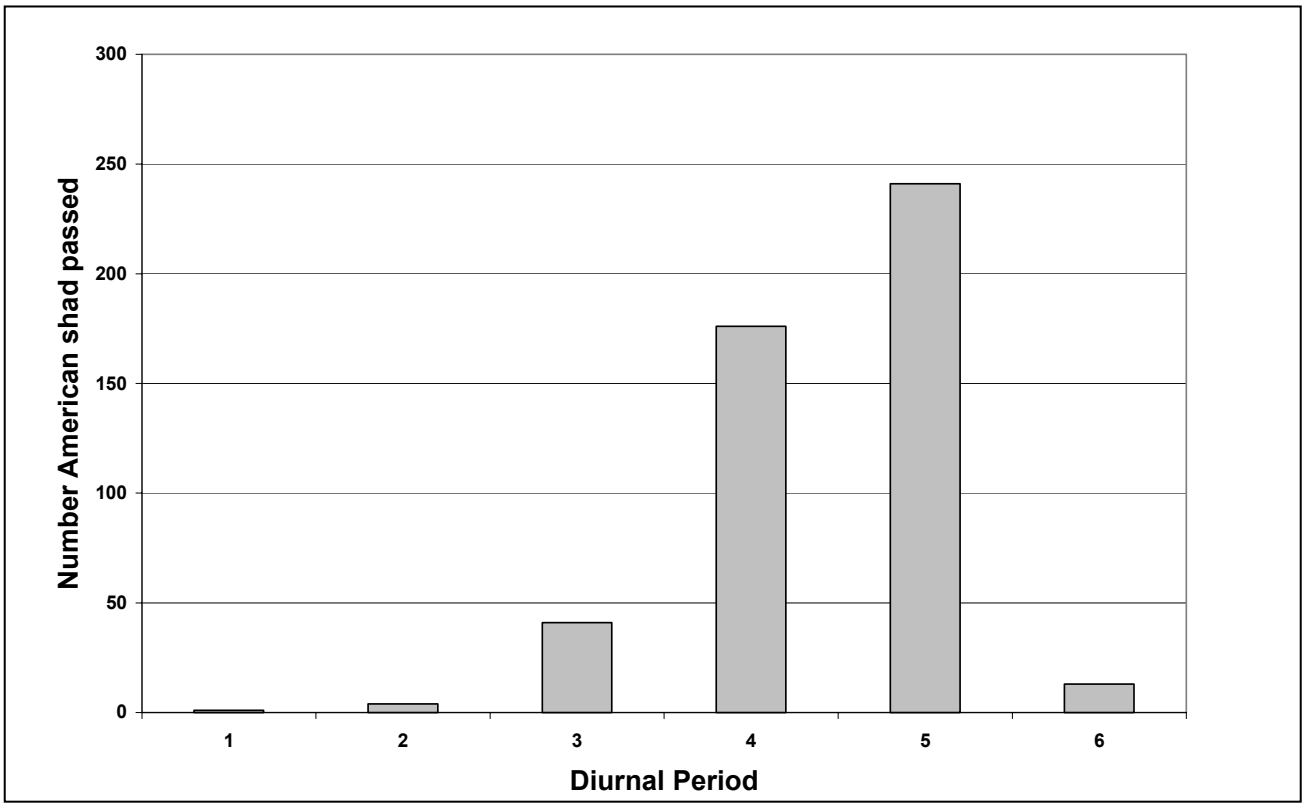

Figure 9. Diurnal pattern of passage for American shad at Fairmount Dam vertical slot fishway from 2004 to 2006. Diurnal periods are as follows: 1 = 00:00 to 03:59 hrs; 2 = 04:00 to 07:59 hrs; 3 = 08:00 to 11:59 hrs; 4 = 12:00 to 15:59 hrs; 5 = 16:00 to 19:59 hrs; and 6 = 20:00 to 24:00.

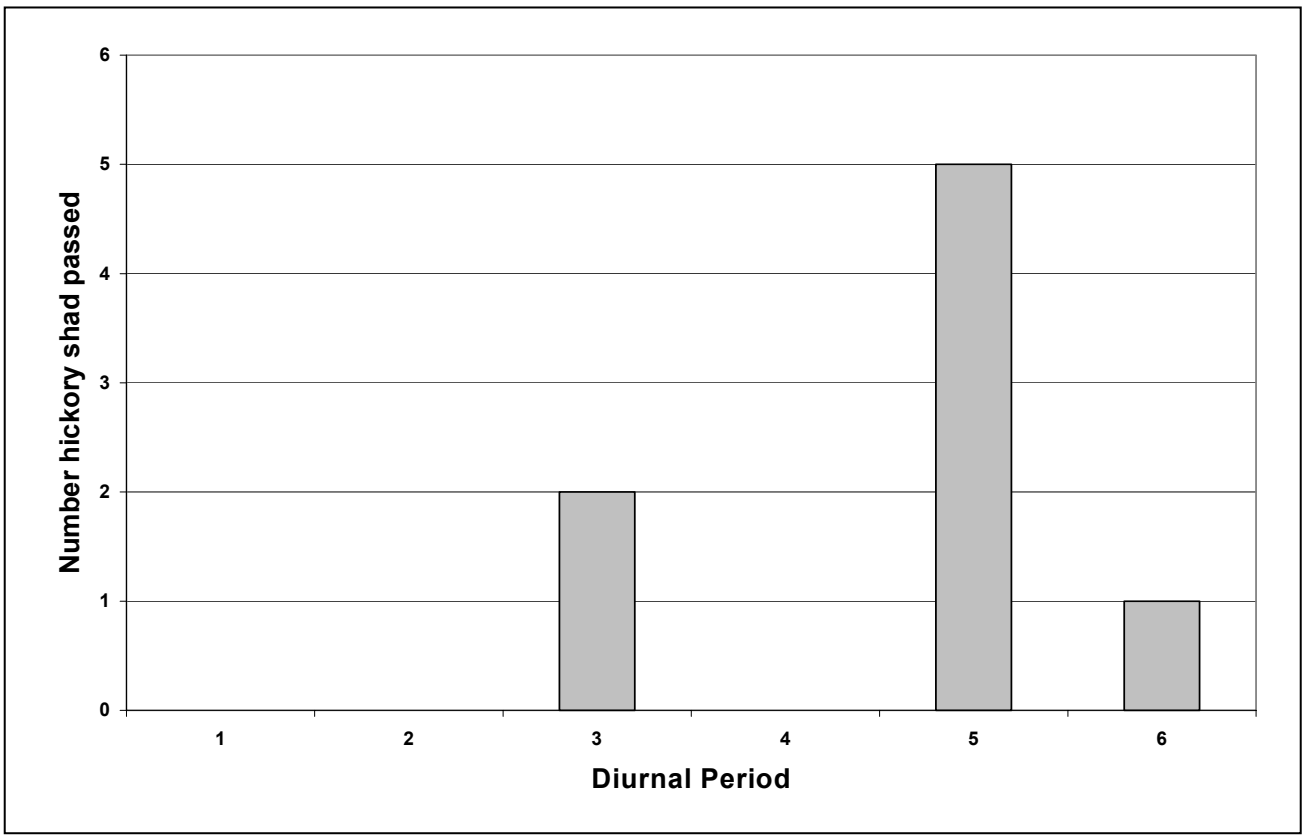

Figure 10. Diurnal pattern of passage for hickory shad at Fairmount Dam vertical slot fishway from 2004 to 2006. Diurnal periods are as follows: 1 = 00:00 to 03:59 hrs; 2 = 04:00 to 07:59 hrs; 3 = 08:00 to 11:59 hrs; 4 = 12:00 to 15:59 hrs; 5 = 16:00 to 19:59 hrs; and 6 = 20:00 to 24:00.

correspondingly increase because the overall passage numbers more than doubled, thus resulting in a "diluting" effect.

In 2006, American shad were observed passing by the viewing window from April 11 to June 6; striped bass were documented from May 14 to June 24; river herring were counted from May 2 to June 20; and the 9 hickory shad that passed through Fairmount fishway did so in only a three day period from 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 the hickory shad in early historical fisheries accounts for the Delaware Estuary in Pennsylvania (Majumdar et al. 1986). Whereas hickory shad have been officially documented in the Schuylkill River below Fairmount Dam since 2002, this was thought to be the furthest extent of their range until video evidence from this study proved otherwise. This important discovery will provide critical insight into restoration efforts for the state endangered hickory shad.

Similar to the previous years, white sucker, quillback, common carp, gizzard shad, and channel catfish were extremely abundant in the fishway, accounting for 83.4% of total fish passage in 2006. Of these 5 species, channel catfish was the numerically prevailing species during 2006 study period. Several new species were recorded and documented. There were 2 species documented in 2006 that were missing in 2004 and 2005, namely hickory shad and bullhead catfish (*Ameiurus sp*.), and grass carp were observed in 2004 and 2006 only. Conversely, rock bass and satinfin shiner were observed in 2005, but not in 2004 or 2005.

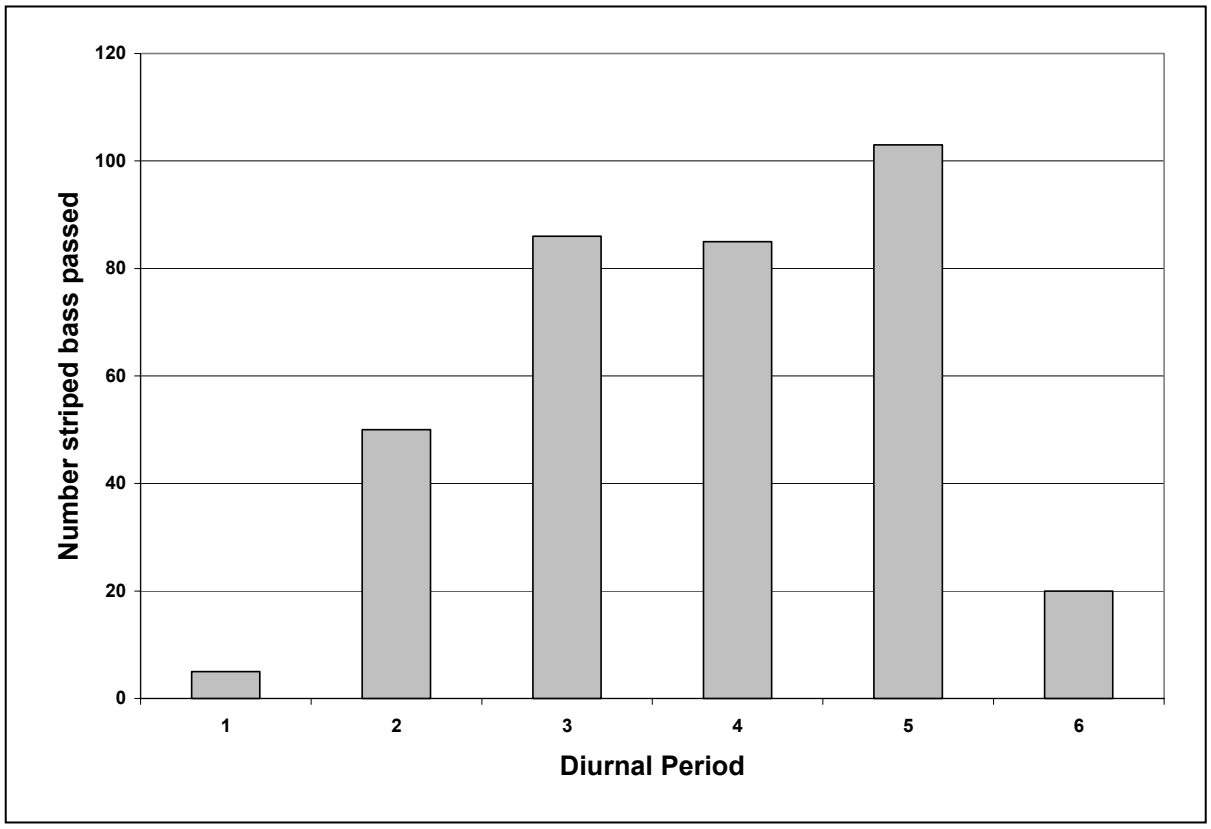

Figure 11. Diurnal pattern of passage for striped bass at Fairmount Dam vertical slot fishway from 2004 to 2006. Diurnal periods are as follows: 1 = 00:00 to 03:59 hrs; 2 = 04:00 to 07:59 hrs; 3 = 08:00 to 11:59 hrs; 4 = 12:00 to 15:59 hrs; 5 = 16:00 to 19:59 hrs; and 6 = 20:00 to 24:00.

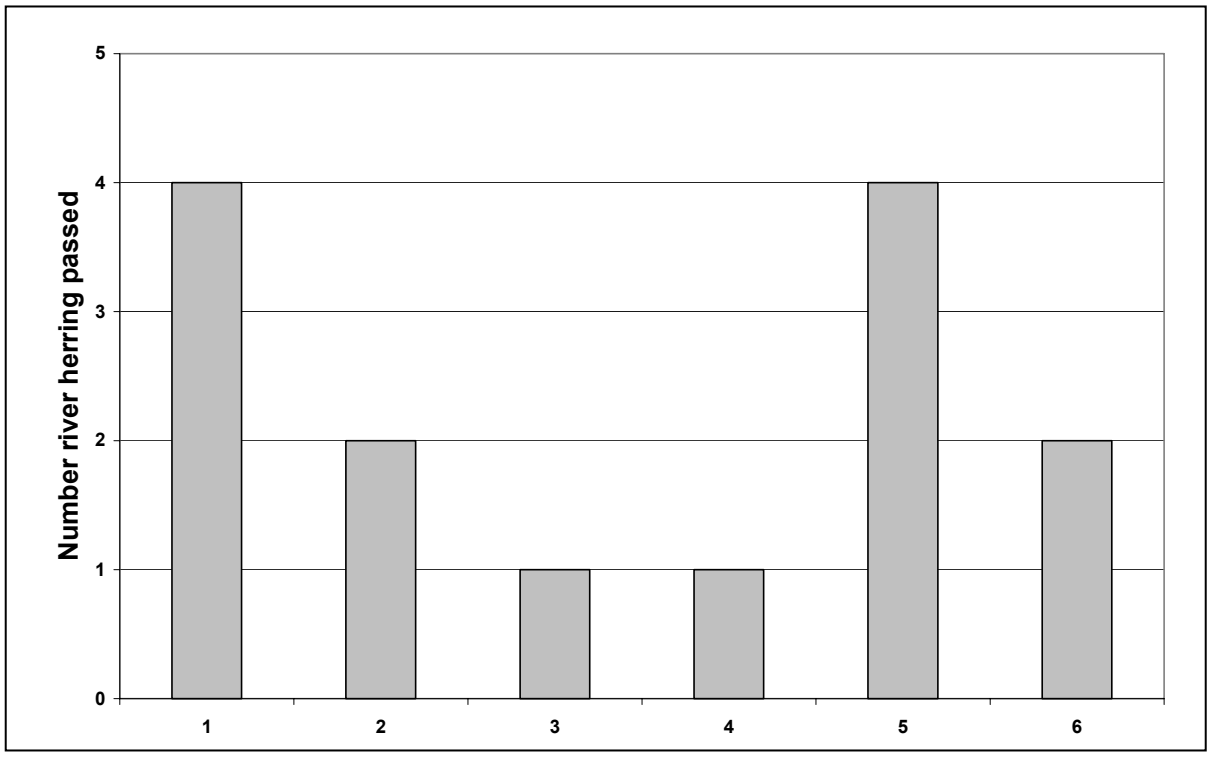

Figure 12. Diurnal pattern of passage for river herring at Fairmount Dam vertical slot fishway from 2004 to 2006. Diurnal periods are as follows: 1 = 00:00 to 03:59 hrs; 2 = 04:00 to 07:59 hrs; 3 = 08:00 to 11:59 hrs; 4 = 12:00 to 15:59 hrs; 5 = 16:00 to 19:59 hrs; and 6 = 20:00 to 24:00.

In all 3 years, 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 1). American shad, smallmouth bass (*Micropterus dolomieui*), flathead catfish (*Pylodictis olivaris*), bluegill (*Lepomis 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. We are concerned that the number of striped bass decreased 62.1% from 2004 to 2006.

Based on the graphical representation of diurnal passage of anadromous species, peak passage generally occurred during periods 4 and 5, which corresponds to late morning through early evening (Figures 9 to 12). Diurnal periods are as follows: 1 = 00:00 to 03:59 hrs; 2 = 04:00 to 07:59 hrs; 3 = 08:00 to 11:59 hrs; 4 = 12:00 to 15:59 hrs; 5 = 16:00 to 19:59 hrs; and 6 = 20:00 to 24:00. American shad passage was documented during each diurnal period; however, peak passage occurred from 16:00 to 19:59, with a secondary peak from 12:00 to 15:59 (Figure 9). Hickory shad only passed during periods 3, 5, and 6, with peak passage also from 16:00 to 19:59 (Figure 10). 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 striped bass occurred from 16:00 to 19:59 (Figure 11). River herring preferred utilizing the fishway during low-light hours more than any other anadromous species, passing mostly during diurnal periods 1 and 5 (Figure 12).

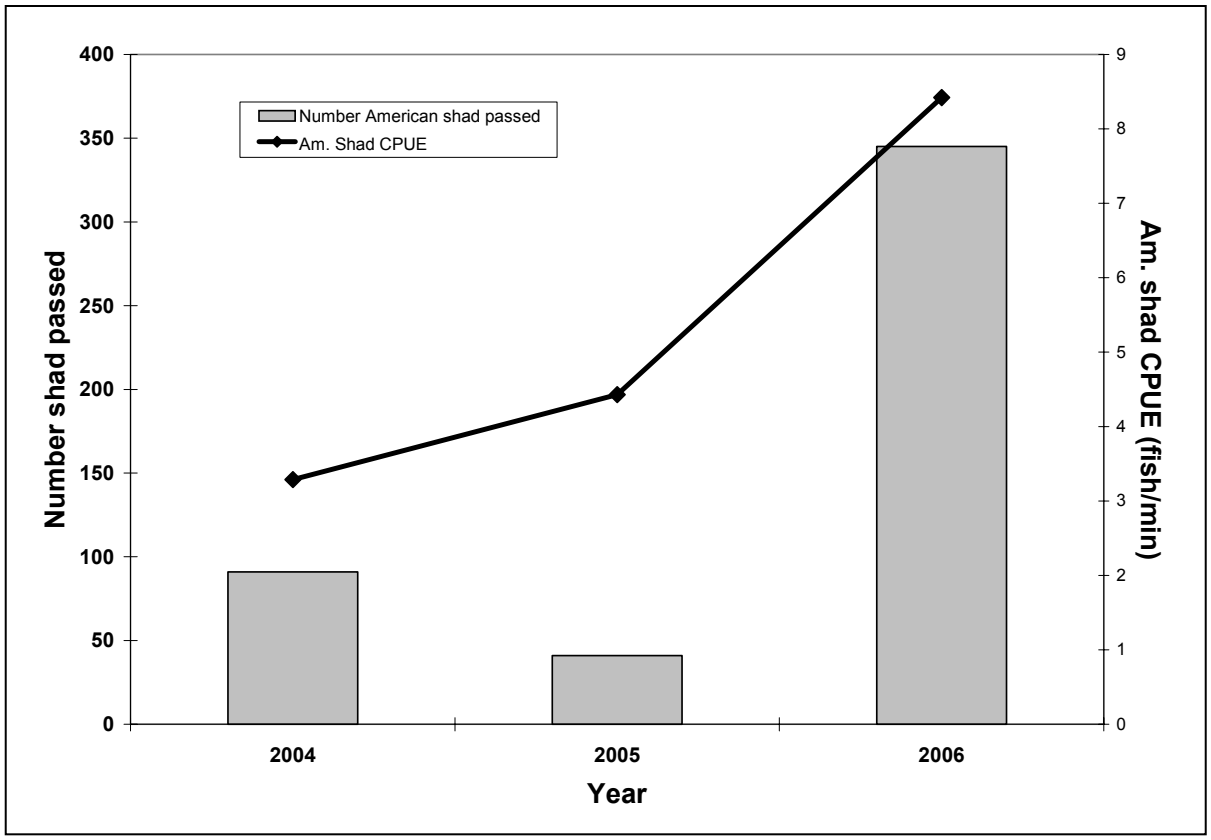

Figure 13. Interannual trend in relative abundance of adult American shad for the period 2004 to 2006 from boat electrofishing compared to the interannual trend in American shad passage at Fairmount Dam vertical slot fishway. CPUE = catch per unit effort.

Relative abundance data on anadromous species for the tidal Schuylkill River below Fairmount Dam was collected by boat electrofishing from 2002 to 2006. Figure 13 does not display the first 2 years of electrofishing data because no corresponding fish passage counts were made in 2002 and 2003. 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 electrofishing. 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 (Figure 13). 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. Several power and software failures with the video monitoring system in 2005 resulted in loss of video at peak passage times for American shad during the spring migration. The loss of video from these critical days in 2005 suggests that actual passage numbers of American shad were higher than recorded. Under this assumption, we expect passage rates to correspondingly increase as relative abundance below the dam also increases.

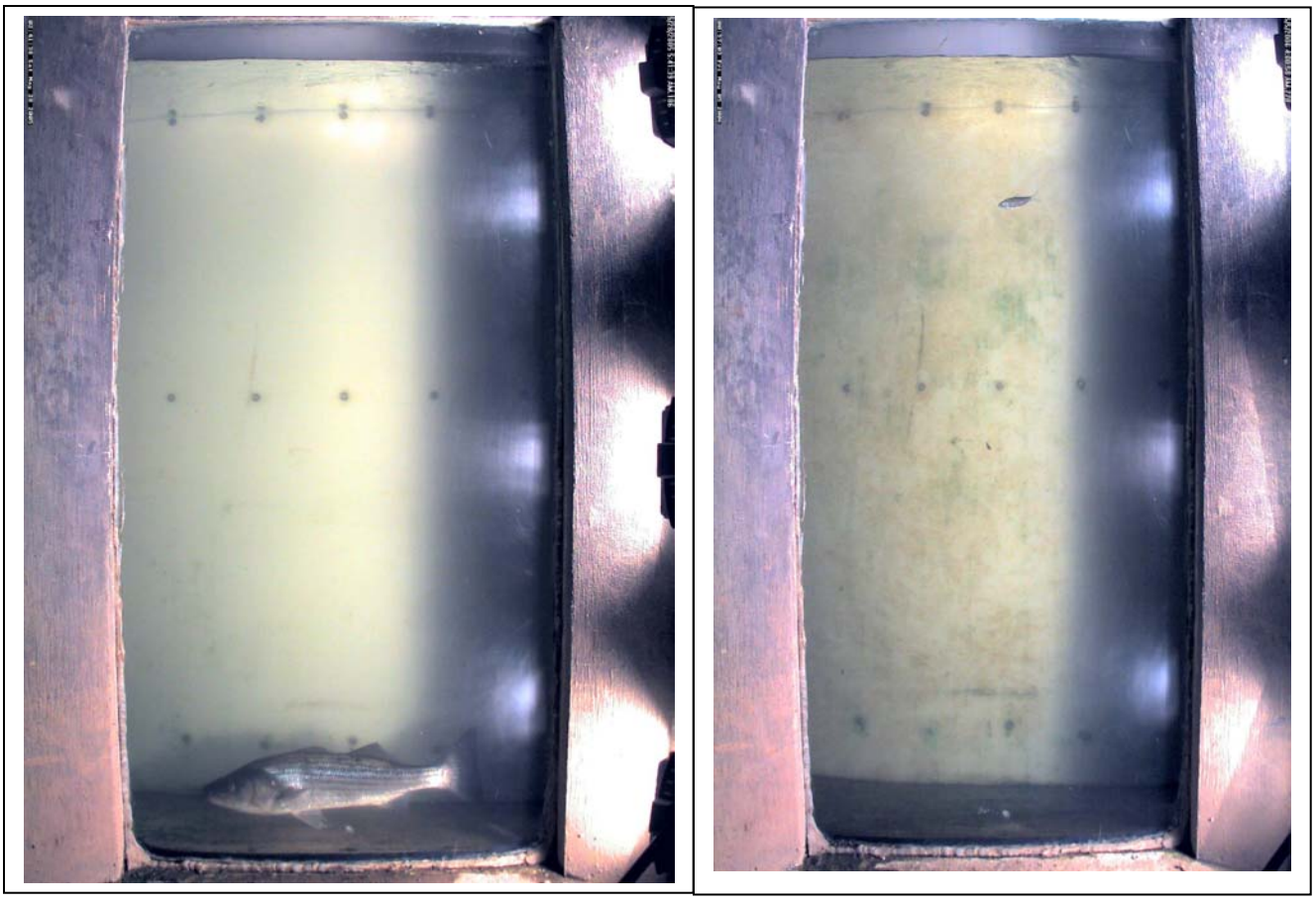

Figure 14. Still images taken from video monitoring system in the viewing room at Fairmount Dam fishway. A striped bass is pictured on the left and a river herring is pictured on the right (very small, towards top).

DISCUSSION

Anadromous fish restoration in the Schuylkill River watershed depends on successful fish passage at Fairmount Dam. Without access to critical spawning habitat above the dam, the long-term sustainability of migratory fish populations is not feasible. Fairmount Dam fishway is in essence the gateway to the rest of the Schuylkill River and the first of 7 dams on the river. There are several plans being discussed for either fish passage facilities or dam removals for the remaining barriers on the Schuylkill River, with hopes of opening up 160 kilometers of river. Since funding is a critical limiting factor, fish passage facilities (i.e. fishway) must be designed and built correctly otherwise precious time and money is wasted (Weaver et al. 2003). The main goal of my study was to conduct monitoring in the river by boat electrofishing and at the fishway using digital video recordings to evaluate and document the use of Fairmount fishway by anadromous fishes.

The monitoring program I established resolved two vitally important questions. First, a plethora of different fish species are able to ascend the fishway, which will likely result in additional ecological benefits for the Schuylkill River and its tributaries. A total of 26 different species of fish, as well as several hybrids, were documented using the fishway during spring migrations of the three year study period. Second, and most importantly, anadromous fishes frequently utilized the fishway for passage above Fairmount Dam. American shad, hickory shad, striped bass, and river herring all used the fishway during their spring spawning migrations. Interannual trends in both relative abundance and fish passage counts for adult American shad increased dramatically

during the three year period. Wild striped bass and river herring juveniles were found upstream of the fishway in 2005 and 2006 suggesting that quality spawning and nursery habitats still exist above Fairmount Dam. Preliminary results 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.

The analysis of diurnal passage patterns for anadromous species revealed that the majority passed during daylight periods between 12:00 and 19:59 hours (Figures 9 to 12), 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 for passage patterns of American shad. However, my study was uniquely different in that video recording was conducted 24 hours a day, seven days a week and digital recordings were triggered by motion detection software. Weaver et al. (2003) did not record 24 hours a day, whereas Arnold (2000) did record for the entire day but used time-lapsed, analog video recorded to VHS cassettes. Because we documented anadromous fishes utilizing the fishway at night, monitoring the entire 24 hour period may be important. Various abiotic parameters such as temperature, flow, tidal variation, moon phase, and fishway attraction flow rates will be analyzed in the future for correlation with fish passage and may possibly result in improved fishway operation and monitoring.

For more than 150 years, American shad disappeared from the Schuylkill River primarily due to severe industrial pollution and the construction of dams in the early 1800's. Today, significant improvements in river water quality, increases in both dam removals and construction of additional fish passage facilities, combined with restocking

efforts from Pennsylvania Fish and Boat Commission, have yielded measurable results in anadromous fish restoration. Nonetheless, progress has been modest when compared to historical numbers and continued multi-agency collaborative restoration efforts are still needed. Full restoration in the Schuylkill River may take several decades and monitoring interannual trends of anadromous fish passage at Fairmount Dam is a critical indicator of success.

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REFERENCES

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.

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.

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.

Maki, K.L., J.M. Hoeing, and J.E. Olney. 2001. Estimating proportion mature at age when immature fish are unavailable for study, with application to American shad (*Alosa sapidissima)* in the York River, Virginia. Canadian Journal of Fisheries and Aquatic Sciences 21:703-716.

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.

Nolan, K., J. Grossfield, and I. Wirgin. 1991. Discrimination among Atlantic coast population of American shad (*Alosa sapidissima*) using mitochondrial DNA. Canadian Journal of Fisheries and Aquatic Sciences 48:1724-1734.

Olney, J.E., D. Hopler, T. Gunter, K. Maki, and J. Hoenig. 2003. Signs of recovery of American shad in the James River, Virginia. American Fisheries Society Symposium 35:323-329.

Smith-Root Inc. 1998. Electrofishing and product guide manual. Vancouver, WA.

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.

White, D.K. 2003. Hydraulic model study of fish passage facility at Fairmount Dam, Philadelphia, Pennsylvania. Report to U.S. Army Corps of Engineers. Alden Research Laboratory, Holden, MA.