Final Report

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Bio-Monitoring and Assessment of American Shad and River Herring in the Susquehanna River Basin

July 1, 1999 to ~~June 30, 2001~~ March 31, 2001

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Introduction

Historically, the Susquehanna River Basin in Pennsylvania sustained one of the largest runs of alosids on the east coast of the United States. Since the early 1900's, migrations of anadromous fish have been blocked by four large hydroelectric dams; Conowingo Dam (r.m. 9.9); Holtwood Dam (r.m. 24.8), Safe Harbor Dam (r.m. 31.7); and York Haven Dam (r.m. 54.7).
The Pennsylvania Fish Commission, now the Pennsylvania Fish and Boat Commission (PFBC), was created in 1866 for the specific purpose of restoring American shad to the Susquehanna River. Renewed efforts to restore anadromous fish began in the 1960's and are presently conducted under the auspices of the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC). SRAFRC membership includes the PFBC, New York Department of Environmental Conservation, Maryland Department of Natural Resources (MDNR), Susquehanna River Basin Commission, U.S. Fish and Wildlife Service (USFWS), and National Marine Fisheries Service.

The primary focus of the restoration to date has been the American shad. The restoration approach involves egg collection (Delaware, Hudson, and Susquehanna river sources); hatchery production; collection, transport and release of pre-spawn adults; bio monitoring of adult and juvenile populations; and special studies as identified by SRAFRC. Efforts to restore river herring have also been conducted. The population of American shad returning to the Susquehanna to spawn, based on fish lifts catches at Conowingo Dam, has increased from fewer than one hundred in the early 1980's to more than 150 thousand in the late-1990's. An index of adult American shad abundance in the upper Chesapeake Bay has also increased steadily since 1984 (first years monitored). The goal of the restoration is to produce a self-sustaining spawning population of three million adult American shad and 15 million river herring.

The cornerstone of the restoration has been the development of a mass marking technique in which otoliths of all hatchery fish are marked using tetracycline antibiotics. These marks can be detected in ground otolith sections using ultraviolet microscopy. Application of these techniques to systematic samples of juvenile or adult shad collected in the wild permits evaluation of the relative contribution of hatchery production and natural reproduction to the overall restoration. Multiple marking allows refinement of restoration activities by permitting evaluation of the relative survival of groups which receive unique marks based upon stocking sites, size/age at stocking, and egg-source rivers. Perhaps the most important contribution of the marking technique is its utility in demonstrating that extirpated populations of American shad can be restored to the Susquehanna Basin through hatchery introductions and trap and transport efforts.

Through the 1999 production year, the PFBC's Van Dyke Hatchery has produced 155 million American shad larvae and 1.6 million fingerlings stocked in the Susquehanna Basin. Since 1982, more than 275 thousand pre-spawn adult shad and thousands of pre-spawn adult river herring have been collected at Conowingo Dam and transported to upstream spawning areas. Otolith analysis of juvenile American shad has demonstrated survival among the fry stocked in the Susquehanna River and tributaries. Likewise, the general trend for the percentage of wild verses hatchery adults in the population indicate that stocks is rebuilding themselves through natural reproduction.

Funding support for restoration initiatives has been provided by settlement agreements with the utilities. In 1993, owners of the three upstream dams agreed to install fish passage facilities. The 1993 Settlement Agreement provided for continued funding for egg collection and hatchery operation until fish passage has been achieved at all four main stem dams in the year 2000. Funding for bio-monitoring was not addressed by the 1993 agreement and expired at the end of 1994. Beginning in 1995, managing the fishery, including bio-monitoring, has been the responsibility of state and federal fishery agencies. Funding provided by the Atlantic Coastal Fisheries Cooperative Management

Act, Environmental Protection Agency's Chesapeake Bay Program, and the PFBC are currently supporting Susquehanna River Basin bio-monitoring efforts.

With the completion of fish lifts at Holtwood and Safe Harbor dams in 1997, the East Lift at Conowingo began directly lifting fish over the dam. There was obligation for Conowingo to continue operation of the West Lift. In acknowledgment of the importance of the West Lift operation for continuity of the restoration effort, SRAFRC entered into an agreement with Susquehanna Electric Company whereby the company refurbished the lift and continued its operation for an additional five years. The fishery agencies are responsible for funding transport, monitoring, and research activities as they pertain to West Lift operation. A portion of funding for continuation of West Lift operation is being provided under this project.

In addition, this project includes a study to determine if migrating shad are attracted upstream by the presence of other shad, and, if so, what chemical cue(s) are involved. The study has the potential to significantly increase American shad passage efficiency through fish passage facilities at dams. Catches of American shad at the Holtwood Dam fish lift have been much lower than desirable for the facility. In 1997, Holtwood Dam, second upstream on the Susquehanna River, passed 31% of the shad lifted over Conowingo Dam. In 1998, only 21% of the shad passed at Conowingo was lifted over Holtwood.

Bio-monitoring and assessment of adult and juvenile shad and herring is essential for tracking the progress of the restoration, and maximizing products and benefits from the limited resources available to support the restoration effort. In addition to providing specimens for otoliths analysis, bio-monitoring of adult and juvenile shad has also provided information on the timing of migration, distribution, growth, reproduction, and relative abundance.

This report provides information on bio-monitoring and assessment for American shad and river herring under funding provided by the FFY' 1999/00 Atlantic Coastal Cooperative Fisheries Management Act. Due to the structure of the federal funding cycle, the project period includes two different calendar years and address jobs to evaluate the 1999 juvenile year-classes, as well as the 2000 spawning stocks. Ancillary information on restoration initiatives (alosid passage at lower Susquehanna hydroelectric projects, hatchery production, stocking, and otolith mark analysis) not funded under this project is provided because of their direct bearing on project results. Overall study objectives of the Susquehanna River Basin alosid bio-monitoring effort as it pertains to juvenile and adult alosids includes:

Juvenile Bio-monitoring Objectives

1) Determine which methods are feasible for sampling juvenile alosids (what?, where?, when?);

2) Determine relative effectiveness of alternative methods for sampling juvenile alosids;
3) Determine distribution of juvenile alosids;
4) Assess (index) abundance of juvenile alosids;
5) Provide specimens to evaluate hatchery stockings and wild contribution to juvenile year-class;
6) Assess growth;
7) Define timing and duration of juvenile out migration.

Adult Bio-monitoring Objectives

1) Determine distribution of adult alosids (particularly at blockages);
2) Evaluate fidelity to natal rivers;
3) Define timing of migration;
4) Assess adult alosid spawning stock abundance and composition.

Summary of Biological Monitoring, Jobs 1-13: July 1, 1998 through June 30, 1999.

The fiscal year 1999/00 bio-monitoring project includes thirteen jobs: 1) tributary haul seining for juvenile alosids (Summer and Fall 1999); 2) lower river haul seining for juvenile alosids in the main-stem Susquehanna River (Summer and Fall 1999); 3) upper river electrofishing for the collection of juvenile alosids from sites in the main-stem Susquehanna River area between Clarks Ferry and Sunbury and sites in the area between the Juniata River from Amity Hall to Huntingdon (Summer and Fall 1999); 4) lift-netting for juvenile alosids from Holtwood Dam Inner Fore bay (Summer and Fall 1999);5) electrofishing for adult alosids - large tributaries (Spring 2000); 6) electrofishing for adult alosids - small tributaries (Spring 2000); 7) electrofishing for adult alosids - main stem dams (Spring 2000); and 8) push-netting for juvenile alosids - Susquehanna River (Spring/Summer 2000); 9) Conowingo Dam West Fish Lift operation for the collection of adult alosids (Spring 2000); 10) American shad pheromone study, phase II (Spring 2000); 11) contract administration and project oversight (July 1, 1998 through March 31, 2000); 12) 1999 juvenile American shad otolith mark analysis (not funded under this project); 13) 2000 adult American shad otolith mark analysis (not funded under this project).

This report utilizes Geometric Mean Catch-Per-Unit Effort (GM CPUE) to interpret catch results as recommended by the Atlantic State Marine Fisheries Committee Alosid Management Plan. GM CPUE is used for job 2, lower river haul seining, and job 4; lift-netting in Holtwood Dam inner forebay. GM CPUE is not used in other jobs due to lack of sufficient catch data. By using GM CPUE it is hoped that an index of juvenile abundance can be developed that will effectively predict future spawning stock (adult) abundance. The use of GM CPUE as an index of juvenile abundance was first employed in the 1998/1999 Bio-monitoring

Final Report (NA06FG0356). Initially, GM CPUE for seine and lift-net for a given year were computed from the daily mean catch. It has been determined that GM CPUE computed from the mean catch of individual sampling events is a more desirable statistic. Comparison of GM CPUE among years requires standardized sampling protocols that were initiated for haul seine and lift-net beginning in 1997. Catch data prior to 1997 was not used in this report to calculate GM CPUE. It may be used in future reports providing an acceptable correction factor can be developed.

Project Duration

This project was originally scheduled to begin on July 1, 1999 and terminated September 30, 2000. The project was amended to terminate on June 30, 2001 to allow an additional nine months for data analysis and report preparation.

Susquehanna River Basin Alosid Assessment - July 1, 1999 through June 30, 2001

Job 1. Juvenile Alosid Sampling - Tributaries

Objective: Collection of juvenile alosids to monitor species composition, abundance, growth, out migration, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Six sites, on each of the Conestoga River and Little Conestoga Creek, Lancaster County; West Conewago Creek, York

County; Conodoguinet Creek, Cumberland County; and Swatara Creek, Dauphin/Lebanon Counties (Figure 1) were sampled for juvenile alosids using a 30-x 6-ft haul seine with 3/8-in stretch mesh. Sites were sampled weekly (two hauls per site) for five consecutive weeks from late July through August 1999. Sampling sites are listed in Table 1.

Results: A total of 300 seine hauls was made in the five tributaries between 26 July and 25 August 1999. No American shad or river herring were captured.

Job 2. Lower River Haul Seining for Juvenile Alosids

Objective: Collection of alosids to monitor abundance, growth, out migration, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Lower river haul seining was conducted at sites on the Susquehanna River upstream of Safe Harbor Dam near the towns of Columbia and Marietta (Figure 1). Haul seines measured 400 x 6-ft with 3/8-in stretch mesh. Seining was conducted by anchoring one end of the seine on shore and deploying the unattached end in a semicircle downstream by jonboat. Sampling began in mid-July and continued through late October 1999. Sampling was conducted after sunset at a rate of one day per week over a fifteen-week period with a minimum of six seine hauls per day. All sampling was confined to the section of river near the Columbia Borough Boat Launch, Lancaster County.

Results: A total of 322 juvenile American shad was captured in 90 seine hauls from 13 July through 20 October (Table 2). Shad were collected on 11 of 15 sampling days. Sampling during the week of 5 September was cancelled due to high flows (< 50,000 cfs @ Columbia) associated with Hurricane Dennis. It was rescheduled and two sampling days were conducted during the second week of September. Of the 322 captured, 182 juveniles were taken on 15 September at a water temperature of 72.5° F and river flow of 5,780 cfs; 137 shad were captured in one haul (Table 2). Excluding the four sampling events when no shad were collected, Daily Catch-Per-Unit-Effort (D CPUE) ranged from 0.17 shad per haul (26 July, 3 August, 29 September) to 30.33 shad per haul on 15 September (Table 3). Most shad (93.5%) were collected during the month of September following a major precipitation event. The average size of juvenile shad varied from 80-mm TL on 3 August to 145-mm TL on 20 October (Table 4). GM CPUE for the entire sampling season was 0.668 (variance 0.509) fish per haul (Table 5).

Job 3. Upper River Electrofishing for Juvenile Alosids

Objective: To locate and sample suitable upstream sites for collection of alosids to monitor abundance, growth, out migration, and provide specimens for otolith analysis of hatchery contribution.

Methods: Night-time electrofishing was conducted in the reaches between Clarks Ferry and the Fabri Dam on the Susquehanna River, and Amity Hall and Huntingdon on the Juniata River (Figure 1). Sampling site selection/location was determined based on habitat type (pools), water depth, substrate composition, and observed alosid activity (dimpling on the water surface). Electrofishing was conducted using a Coffelt VVP-15 variable voltage pulsator, powered by a 3.5-kw generator, and mounted in a 14-ft aluminum jonboat. Pulsed DC current (250 to 500 volts) was used. Each reach was sampled weekly for eight weeks beginning the first full week in August and continuing through September. Individual sampling days consisted of four electrofishing runs of short duration (approximately 15 minutes). Sampling began immediately after sunset and ending after four runs were completed.

Results: The determined location of the sampling sites were in the areas of Clemson Island on the Susquehanna, and Mifflintown on the Juniata River. A total of 126 juvenile American shad was captured in 986 minutes of electrofishing from 3 August to 23 August (Table 6). The majority of shad (124) were taken from the Juniata River near Mifflintown. Over 75% of juveniles captured were taken in September. The shad ranged in size from 77 to 120-mm TL, with a mean length of 104.3-mm TL, most were between 90 and 119-mm TL (Table 7). Water temperature ranged from 61.3

to 84.2° F. River flow varied from 3,130 to 33,200 cfs on the Susquehanna, and 553 to 1,220 cfs on the Juniata. CPUE was highest on 17 September and generally high over the period 2 to 17 September (Table 8).

Job 4. Lift-netting in Holtwood Dam Inner Forebay

Objective: Collection of alosids to monitor abundance, growth, out migration, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Lift-netting was conducted at Holtwood Dam inner forebay (Figure 1) every three days beginning mid-September and continuing through mid-December. The lift-net was 8-ft square steel frame outfitted with a ½-in stretch mesh and 1/4-in stretch mesh inner liner. The net was lowered and raised manually by a rope fitted through a pulley attached to a 20-ft steel beam. A 13-in diameter 5 gallon bucket nested in the center of the lift-net. The bucket could be pulled up independently from the lift-net to remove fish, which funneled into the water filled bucket. Each sampling day consisted of ten lifts with minimum ten minute internals between lifts. Sampling began at sunset and continued into the evening until ten lifts were completed.

Results: A total of 490 juvenile American shad was captured in 300 lifts between 13 September and 9 December 1999 (Table 9). The first juvenile shad was taken on 16 September at a water temperature of 72.5° F and a river flow of 23,000 cfs (Table 9, Figure 2). All shad were captured between 16 September and 25 October. The peak collection (108) occurred on 25 October, at a water temperature of 64.4° F and a river flow of 27,700 cfs. The last American shad were collected on 25 October, at a water temperature of 53.6° F and a river flow of 11,600 cfs. Most American shad (461, 94.1%) were captured when river flow exceeded 15,000 cfs. Total length of juvenile shad ranged from 70 to 150-mm; 81% were 101 to 130-mm (Table 10). The highest D CPUE (10.80) occurred on 22 September (Table 11). Slightly more than 39% of the total shad were captured on 19 and 22 September, followed by 43% of the shad emigrating on 5 sampling dates between 1 and 13 October. GM CPUE for the entire sampling season was 0.498 (variance 0.334) fish per lift (Table 12).

Job 5. Electrofishing for Adult Alosids - Large Tributaries

Objective: Locate and sample suitable upstream sites for the collection of adult alosids to monitor abundance, growth, migration, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Day-time electrofishing surveys were conducted on the Conestoga River and Little Conestoga Creek, Lancaster County; West Conewago Creek and Muddy Creek, York County; Swatara Creek, Dauphin/Lebanon County; and Conodoguinet Creek, Cumberland County from early-May to mid-June 2000 (Figure 1). Electrofishing was conducted using a Coffelt VVP-15 variable voltage pulsator, powered by a 3.5-kw generator, and mounted in a 6-ft raft, 14-ft or 18-ft aluminum boat depending upon stream conditions. Pulsed DC current (250 to 300 volts) was used. Sampling sites were confined to the vicinity of the first blockage to migration on each tributary, or areas with favorable habitats. Surveys began about 500 to 1000-m below the impediment and were concluded after one hour or when the upstream barrier was reached. Electrofishing was concentrated along the shorelines, riffles, pools and other habitats typically utilized by adult American shad. All tributaries were sampled on five dates except Swatara and Conodoguinet creeks that were sampled on two dates.

Results: Three adult American shad were collected, two in the Conestoga River and one in West Conewago Creek between 22 May and 5 June (Table 13). All adult shad were partially spent males in good condition. The shad ranged from 432 to 447-mm TL and weighed 710 to 740-g. They were collected at water temperatures between 57.2 and 68.9° F. Stream flow was generally above median flow for each tributary, due to the unusually wet spring experienced in 2000. Total shock time (all tributaries combined) was 2,030 minutes. D CPUE for tributaries where adult were captured ranged from zero to 0.17 fish per hour. Adult shad from the Conestoga River and West Conewago Creek were captured at the base of the Lancaster Water Works Dam (r.m. 32.8) and Detter's Mill Dam (r.m. 27.7), respectively.

Job 6. Electrofishing for Adult Alosids - Small Tributaries

Objective: Locate and sample suitable upstream sites for the collection of adult alosids to monitor abundance, growth, migration, and provide specimens for otolith analysis of hatchery contribution.

Methods: Day-time electrofishing surveys, one hour in length, were conducted in Fishing Creek and Peters Creek, Lancaster County from mid-May to early June 2000 (Figure 1). Each tributary was sampled on three dates following the passing of 10,000 alosids by the Conowingo East Fish Lift. Electrofishing was conducted using a Coffelt VVP-15 variable voltage pulsator, powered by a 3.5-kw generator, and mounted in a 6-ft raft. Pulsed DC current (250 to 300 volts) was used. Sampling sites began where the influence of Conowingo Pond was no longer evident and concluded after one-hour elapsed or an upstream blockage to migration was reached. Surveys were concentrated along shorelines, riffles, pools and other habitats utilized by adult river herring.

Results: No adult alosids were collected in either of the two small tributaries sampled between 15 May and 12 June. Total shock time (both tributaries combined) was 390 minutes. Water temperature in the tributaries ranged from 53.6 to 67.1° F.

Job 7. Electrofishing for Adult Alosids - Main Stem

Objective: Locate and sample suitable upstream sites for the collection of adult alosids to monitor abundance, growth, migration, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Night-time electrofishing surveys were conducted at the base of one or more the following dams: 1) Warriors Ridge Dam on the Juniata River; 2) Raystown Dam on Raystown Branch of the Juniata River; and 3) the Fabri Dam at Sunbury on the Susquehanna River (Figure 1). Electrofishing was conducted using a Coffelt VVP-15 variable voltage pulsator, powered by a 3.5-kw generator, and mounted in a 18-ft aluminum jonboat. Pulsed DC current (250 to 300 volts) was used. Electrofishing was conducted after dark during the month of June.

Results: Boat electrofishing at the base of the Fabri-dam (r.m. 125.5) on the Susquehanna River resulted in the capture of four adult American shad in 600 minutes of shock time (Table 14). Daily CPUE ranged from zero to 1.00 shad per hour of electro-fishing (Table 15). All shad collected were partially spent males ranging in size from 422 to 517-mm TL and weighed 580 to 860 g (Table 15). Shad were captured at water temperatures from 62.6 to 71.6° F and flows from 27,300 to 32,300 cfs (Table 15). Three additional adult shad were observed during sampling but eluded capture. Sampling at Raystown and Warrior Ridge was not conducted in spring 2000 due to unusually high flows.

Job 8. Push-netting for Juvenile Alosids

Objective: Development of sights and methods for collecting juvenile alosids by push-net to monitor abundance, species composition, and to provide specimens for otolith analysis of hatchery contribution.

Methods: Push-netting for juvenile alosids was conducted at various sites in the upper portion of Conowingo pool during June and early July for a total of 13 sampling dates (Figure 1). A total of 10 stations were sampled during each date (five minute push per station). The push-net utilized was a 5-ft beam trawl with a 60-in square mouth opening lashed to a 4-ft 11-in by 4-ft 11-in steel frame. The net was made of No.63 knotless 1/4-in stretch mesh netting. It was tailored and tapered to a length of 7-ft terminating at a 12-in canvas collar cod-end. The net was attached to the front of an 18-ft jonboat. For each survey the push-net was suspended in water and pushed into the water current for five minutes. Push-netting was conducted during the evening hours in deep pools or runs and along shorelines of islands in upper Conowingo pool and in the vicinity of Muddy Run Pump Storage Station.

Results: No juvenile American shad were collected in approximately 1,493 minutes of push-netting between 1 June and 7 July, 2000. Results of otolith analysis for juvenile shad collected by push-net in June/July 2000 will be reported in the 00/01 bio-monitoring final report.

Job 9. Conowingo Dam West Fish Lift Operation and Transport of Adult Alosids

Objective: Operate Conowingo Dam West Fish Life for: 1) collection of up to 10,000 pre-spawn American shad for transport and release above York Haven Dam; 2) collection of adult American shad for research and monitoring; 3) collection of pre-spawn American shad for live tank spawning; and 4) collection of pre-spawn river herring for transport and release in tributaries.

Methods: Under the 2000 SRAFRC Work Plan, West Lift operation and transport of alosids was tentatively scheduled to begin late April and continue until early June providing water temperature, flows, and East Lift catches indicated the presence of migratory alosids.

Results: Operation of the Conowingo West Lift from 28 April through 4 June 2000 resulted in the capture of 458,000 fish of 37 taxa (Table 16 and 18). The West Lift operated for 34 days and made a total of 375 lifts in 312.6 hours of operation time (Table 17). Capture of alosids included 9,785 American shad, 14,326 blueback herring, 9,189 alewife, and 1 hickory shad (Table 18).

West Lift CPUE for American shad was 30.9 shad per hour of operation (Table 17). A total of 197 Adult shad was sacrificed for otolith analysis. Scale samples and sex ratios were also obtained from random sampling (every 50th fish) of the American shad captured. Overall sex ratio of sacrificed American shad was 2.3:1, male verses female. Males averaged 410-mm fork length and weighed 862-g, while females averaged 462-mm and 1402-g.

Of the 9,785 shad captured, a total of 2,088 was transported and released in Susquehanna River and tributaries, or provided to the PFBC and USFWS for special studies (Table 19). American shad (1,726) were also provided to MDNR. A total of 4,783 blueback herring and 2,026 alewives were transported and released in Susquehanna tributaries. Length and weight of herring was not recorded. Alosids not utilized were released back into the Conowingo tailrace.

Job 10. American Shad Pheromone Study - Phase II

Objective: Continuation of the study testing, in hatchery raceways, the concept of an American shad pheromone. This is envisioned as the second phase of the study to determine if American shad use olfactory cues to locate each other and, eventually, if a pheromone appears involved, to identify the chemical and methods for mass production.

Methods: Appendix I provides a detailed summary of methods used in phase I and II of the study.

Results: Appendix I provide a detailed summary of results of phase I and II of the study.

Job 11. Contract Administration and Project Oversight

Objective: Administer vendor contract and oversee project to insure project protocols are followed and objectives obtained.

Methods: This job required a percentage of the time of a Fisheries Biologist II and included: 1) preparing alosid bio-monitoring proposal for Atlantic Coastal Cooperative Management Funding; 2) preparing an invitation for bid for the acquisition of contractors to conducted jobs outlined in the proposal; 3) coordination, supervision, and oversight of selected contractors during performance of jobs; 4) processing and tracking of invoices for payment of contractor's services.

Results: Progress reports on the project were completed and delivered to NOAA in a timely fashion. A no-cost time extension to the project was required to sufficiently provide deliverables outlined in the introduction.

Job 12. 1999 Juvenile American Shad Otolith Mark Analysis.

Objective: Determine the relative contribution of hatchery verses wild American shad in the juvenile population using specimens collected during the summer/fall 1999 sampling season. Information obtained will be used to monitor the Susquehanna River Basin restoration effort as a whole, as well as provide information for special studies as outlined in the SRAFRC Annual Work Plan.

Methods: Methods for processing and analyzing juvenile American shad otoliths is outlined in Appendix II.

Results: Results of juvenile otolith analysis is summarized below, for a detailed report reference Appendix II.

Otoliths from 791 juvenile American shad taken in the 1999 summer and fall collections were analyzed for hatchery marks. The total percentage of hatchery fish above Conowingo was 95% with 5% being wild (Table 21). A total of 245 juvenile shad otoliths from seine and electrofishing collections above Holtwood Dam were successfully processed. Overall, 149 (96%) of the fish were hatchery marked and the remaining 6 (4%) fish were wild. All of the 126 juveniles collected by electrofishing at Clemson Island, Susquehanna River (2), and at Mifflintown, Juniata River (124) were hatchery fish. Seine collections from Columbia included 110 (96%) hatchery fish and 9 (4%) wild fish.

Otoliths from 546 juvenile American shad collected at Holtwood Dam and Conowingo Pond were successfully processed (Table 21). Overall, 517 (95%) of the fish were marked and the remaining 29 fish (5%) were wild. Both of the juvenile American shad captured by push-net in Conowingo Pond and Safe Harbor impoundment were wild fish. Otolith analysis included two juvenile American shad collected by push-net in upper Conowingo Pond between 1 June and 6 July 1999 as part of 98/99 bio-monitoring project funded under NOAA Award Number NA86FG0215.

Job 13. 2000 Adult American Shad Otolith Mark Analysis

Objective: Determine the relative contribution of hatchery verses wild American shad in the adult population using specimens collected from the Spring 2000 spawning migration. Information obtained will be used to monitor the Susquehanna River Basin restoration effort as a whole, as well as provide information for special studies as outlined in the SRAFRC Annual Work Plan.

Methods: Methods for processing and analyzing adult American shad otoliths is outlined in Appendix III.

Results: Results of adult otolith analysis is summarized below, for a detailed report reference Appendix III.

A total of 197 adult American shad otoliths were processed from fish sacrificed at the Conowingo Dam West Fish Lift (Table

22). Based on tetracycline marking and otolith microstructure, 54% of the 193 readable otoliths were identified as wild and 46% hatchery.

Discussion

I. 1999 Juvenile Alosid Assessment

A. Origin of American Shad and River Herring, 1999 Year-Classes

Juvenile American shad in the Susquehanna River above Conowingo Dam could have been derived from three sources: 1) natural reproduction of adult spawners transferred upstream via the fish lifts at Conowingo, Safe Harbor, and Holtwood; 2) natural reproduction of adult spawners collected at Conowingo West Lift, transported, and released above Susquehanna River hydroelectric projects; and 3) stocking of marked shad larvae from PFBC Van Dyke Hatchery and USFWS Lamar Hatchery during the 1999 production season. Juvenile blueback herring originate from the same sources with the exclusion of hatchery production.

River conditions during 1999 could be characterized by normal spring flows, followed by extreme drought conditions and elevated water temperatures in early to mid-summer. Passage of shad and herring by the fish lifts at Conowingo, Holtwood, and Safe Harbor are influenced by river flows. When flows exceed project station capacity, spilling occurs and lift efficiency decreases because fish moving upstream have a difficult time locating attraction flows and finding entrance to the lifts. Station capacity for Conowingo, Holtwood, and Safe Harbor is exceeded at river flows 85,000, 32,000, and 110,000 cfs, respectively. Spring river flows on the Susquehanna during 1999 were excellent for passing migratory alosids. Station capacity at Conowingo was exceeded on 10 dates from 1 April to 15 April and was never exceeded from 16 April to 3 June when lift operation was terminated following the conclusion of the migratory season. At Holtwood Dam, station capacity was only exceeded on the first seven days of lift operation from 25 April to 1 May. Safe Harbor Dam had no days of spilling during the 1999 spawning migration.

Summer drought conditions were relieved by hurricanes Dennis and Floyd in late summer. At Holtwood Dam, precipitation from Dennis resulted in a ten-fold increase in average daily river flow from 6 September (4,200 cfs) to 8 September (50,900 cfs). A dramatic increase was also associated with Floyd when flows swelled from 6,400 cfs on 15 September to a peak of 54,000 cfs on 18 September. Extremes in river flows during summer/fall 1999 had implications on the collection of juvenile alosids.

1. Adult Alosid Passage at Susquehanna River Dams, spring 1999.

Conowingo Dam.

The East Fish Lift at Conowingo Dam passed approximately 69,712 American shad, 130,625 blueback herring, and 14 alewives.

These fish would have access to a fifteen-mile stretch of main stem river up to Holtwood Dam, as well as access to numerous tributaries (Figure 1). Numbers of American shad and Blueback passed by the East Lift in 1999 was the second highest ever recorded for the facility (Table 29).

Holtwood Dam

Fish lifts at Holtwood Dam passed approximately 34,702 American shad (tailrace lift - 33,042, spillway lift - 1,660), 73 blueback herring, and 1 alewife representing 49.8, 0.0005, and 0.07, respectively, of the total number of these species released into Conowingo Pond by the East Lift. These fish would have access to a seven-mile stretch of main stem river up to Safe Harbor Dam, as well as access to numerous tributaries (Figure 1). The number of American shad passed in 1999 was a new record for the facility (Table 29).

Safe Harbor Dam

The fish lift at Safe Harbor Dam passed 34,156 American shad and 31 blueback herring representing 98.4 and 42.5%,respectively, of the total number of these species released into Lake Aldred by the lifts at Holtwood. These fish would have access to a twenty-three mile section of main stem river up to York Haven Dam, as well as access to numerous tributaries (Figure 1). The number of American shad passed in 1999 was a new record for the facility (Table 29).

2. Pre-Spawn Adult Alosids Trap and Transport, spring 1999

Operation of the Conowingo West Lift began on 23 April and continued through 4 June. The West Lift captured 9,658 American shad, 8,546 blueback herring, 1,795 alewives, and 32 hickory shad. Transports included 5,508 adult American shad released upstream of York Haven Dam at Tri-County Boat Club. This compares to 4,593 adults released at Tri-County in 1998. In addition, 1,082 and 1,471 adult shad were provided to USFWS-Lamar and Maryland DNR, respectively, for tank spawning; and 390 to Benner Spring for the pheromone study. Total mortalities of transported shad amounted to 232 fish (3.3%). A total of 1,310 blueback herring was stocked in Little Conestoga Creek, and 795 in the Conestoga River. This compares to 3,653 herring stocked in the Little Conestoga and 1,102 at Tri-County in 1998. Heads were collected from 193 adult shad and provided to PFBC for otolith analysis. Overall sex ratio for American shad collected in the West lift was 1.1:1.0 favoring male. Sex ratios for adult American shad in 1998 were 0.9 male for every female.

3. American Shad Hatchery Production and Fry/Fingerling Stockings, spring 1999.

The PFBC reared and released 13.5 million shad fry in the Susquehanna watershed above dams during the 1999 production season. This level compares with 3 to 11 million fry stocked each year in 1991-1998. The fry were released between 17 May and 21 June in the following numbers and locations (days of age for tetracycline marks in parentheses):

Juniata River (various sites)	10.229 million aged 5-10 days (3)
West Branch Susquehanna River	0.986 million aged 17-22 days (3,6,9,15)
North Branch Susquehanna River	1.126 million aged 17-20 days (3,6,12,15,18)
Conodoguinet Creek	0.373 million aged 14 days (3,6,9,12)
Conestoga River	0.236 million aged 20 days (3,9,12,15)
Swatara Creek	0.249 million aged 20 days (3,6,9,15,18)
West Conewago Creek	0.321 million aged 19 days (3,6,9,12,18)

B. Juvenile Alosid In-Stream Movements and Timing of Out Migration, Summer/Fall 1999.

The 1999 drought appears to have had a pronounced impact on the in-stream movement and timing of out migration for juvenile American shad in the Susquehanna River Basin. Haul seine collections at Columbia were lowest in July and August, and highest in September and October, in contrast to 1998 when catches were highest in July and August, and lowest in September and October (Table 24). Approximately 93% of the 1999 juvenile shad catch by seine occurred in September and coincided with increased river flow from precipitation associated with Hurricane Dennis (Table 2). Low flows during July and August may have altered juvenile shad distribution in comparison to years with normal flows. This coupled with unusually clear water conditions may have influenced catch rates.

The first marked fish collected at Columbia by seine occurred on 26 August. These included six shad stocked in the Juniata River (various sites) suggesting a movement of approximately 60 - 80 miles in 87 days or less. In general, the 1999 cohort of juvenile shad required more time than the 1998 cohort to travel a comparable distance suggesting that lower flows inhibit downstream drift prior to the directed emigration that occurred in September and October.

Based on lift-net catches, peak out migration of juvenile American shad at Holtwood Dam occurred from 16 September through 25 September (Table 9, Figure 2). The first American shad taken by lift- net occurred on 16 September at a water temperature of 72.5° F and a river flow of 23,000 cfs. The majority (82%) of the American shad emigrated past Holtwood in association with increased river flows stemming from hurricanes Dennis and Floyd (Figure 2). Most American shad were captured when river flows exceeded 15,000 cfs. The peak collection (108) occurred on 22 September at a water temperature of 64.4° F and a river flow of

27,700 cfs. The last American shad were collected on 25 October at a water temperature of 53.6° F and a river flow of 11,600 cfs.

Generally, out migration of juvenile American shad based on lift net sampling at Holtwood dam is episodic in nature. Typically it occurs when water temperature falls below 60.1° F and river flow increases, with the majority of the out migration occurring in a one to four week period. In 1999, 68% of the out migration occurred in a three-week period when water temperatures were between 64.4° F and 60.8° F and with a seasonally high river flow which was greater than 25,000 cfs (Figure 2). This pattern is consistent with previous years but somewhat earlier than the 1 October through 16 December out migration period observed in 1998. Shad catches by haul seine and lift net in 1999 were associated with increases in river flows with most juvenile shad being captured when flows exceeded 15,000 cfs (Table 2 and Table 9, Figure 2, respectively). There appeared to no difference between the timing of out migration for wild verses hatchery juveniles.

C. Juvenile Alosid Abundance, Summer/Fall 1999

Comparison of relative abundance of juvenile shad in the Susquehanna River Basin from year to year is difficult due to the opportunistic nature of net sampling and wide variation in river conditions which may influence catches. GM CPUE by seine during 1999 was 0.668 (var. 0.509) (Table 5). This compares to 3.359

(var. 1.01) and 0.497 (var. 0.345) for 1997 and 1998, respectively. GM CPUE by lift net during 1999 was 0.498 (var. 0.334) (Table 12). This compares to 0.607 (var. 0.657) and 0.219 (var. 0.138) for 1997 and 1998, respectively. GM CPUE for seine and lift-net are the second highest recorded since 1997. Prior to 1997, seine and lift-net sampling was not standardized and comparison of GM CPUE's (pre-1997 verses post-1997) is erroneous. Correction factors for pre-1997 seine and lift-net catch data are being developed so comparisons can be made in future reports.

Tributary seining efforts resulted in the capture no juvenile shad. However, otolith analysis of out migrants shows the relative survival of shad stocked in tributaries was high (Appendix II). Low flows brought about by the drought in early spring may have reduced sampling effectiveness by seine in tributaries. In both 1997 and 1998, seining was effective in collecting juvenile shad in major tributaries.

Since 1996, efforts to use electrofishing to overcome difficulties in net sampling to catch juveniles have experienced marginal success. Total CPUE (fish per hour) for juvenile shad by electrofishing in 1999 (Mufflintown and Clemson Island combined) was 7.7, almost three times than that observed in 1998; Electrofishing CPUE at Mifflintown was 15.2 (Table 6). This compares to zero, 12.6 and 0.3 during approximately the same time period in 1998, 1997 and 1996, respectively. CPUE at Clemson

Island was 0.2. This compares to zero, 5.2 and 2.2 during approximately the same time period in 1998, 1997 and 1996, respectively. Higher catches observed at Mifflintown may be the result of stocking five times as many fry in the Juniata verses the upper Susquehanna, proximity of the sampling site to stocking sites on the Juniata River, or low relative survival of shad fry stocked in the North and West Branches of the Susquehanna (Section I, A-3). Electrofishing should become more efficient as a sampling method as juvenile densities increase and less than optimal habitat is utilized in response to overall increases in stock density. Unlike previous years, no electrofishing was conducted at Columbia or Greenwood during 1999.

Push-netting has been demonstrated to be successful at catching juvenile alosids in Virginia. It was felt that changes in push net design and sampling techniques the end of the 1997 sampling season would improve catches in subsequent years. Although increased catches in Conowingo Pond were observed in 1998, they declined in 1999 and remain below anticipated levels.

Nearly 131,000 adult blueback herring passed the Conowingo East Fish Lift in 1999, yet only 73 passed Holtwood suggesting that most remained in Conowingo Pool (Table 29). Collections of juvenile herring impinged by Conowingo strainers (Table 25) and at Peach Bottom (Table 26) during October through December 1999 infer that reproduction within the basin occurred. Failure to capture juvenile blueback herring by the Holtwood lift-net in 1999 reflects that fact that few pre-spawn adults were released upriver and, as a result, wild reproduction above Holtwood was limited. Similar results were observed in 1998. In 1997, twenty-six juvenile blueback herring were captured by lift-net with approximately six times as many adults transported than in 1998 and 1999. The concurrent high numbers blueback herring collected from intake screens at Peach Bottom and strainers at Conowingo in 1999 suggests that environmental conditions permitted spawning and survival of young blueback herring in Conowingo Pond. A portion of these juveniles must have remained in the impoundment and should have been better represented in push-net samples. It is uncertain if lower than anticipated push net catches are due to poor net design and techniques, low abundance, gear avoidance due to water clarity, or some other undetermined factor(s).

Despite concerns over the effectiveness of push-netting, it remains the only feasible method of capturing juvenile alosids in Susquehanna impoundments. If natural reproduction is taking place within Conowingo Pond and progeny are out-migrating before impingement sampling in the fall, push-netting is important to document reproductive success. Continued modifications to the net and sampling techniques as well as increases in alosid abundance may improve push-net sampling effectiveness in future years.

During each of its first two operating seasons, the fish lift at Holtwood Dam lifted less than 30% of the American shad passed at Conowingo Dam (Table 29). In 1999, the Holtwood lift passed less than 50% of American shad passed at Conowingo. Reproductive success of adult shad that passed Conowingo but not Holtwood may be substantial, however poor catches by push-net in the Conowingo pool did not substantiate this hypothesis. It is hoped that low catches of juvenile American shad by push-net is a function of unrefined design and sampling techniques rather than low abundance or poor reproductive success.

Approximately 13.4 million American shad were cultured and released in the Susquehanna River Basin above Conowingo Dam in 1999. Both hatchery and wild juveniles were captured by all sampling methods with the exception of upper river electrofishing. If the susceptibility of hatchery and wild juvenile shad to capture by current methodologies is the same, hatchery fish were 20 times more abundant (95% hatchery verses 5% wild) than wild fish during 1999 (Table 21).

D. Growth of Juvenile Alosids, Summer/Fall 1999

Juvenile hatchery shad collected with seines at Columbia averaged 108-mm total length (TL) from 26 August to 31 August (range 98 - 130-mm) and grew to an average 117-mm (range 99 - 147-mm) by 12 to 20 October. Wild juveniles captured by seine averaged 79-mm TL from 26 July to 3 August and grew to an average

114-mm TL (range 112 - 115-mm). Growth of wild fish was difficult to assess due to few individuals captured, but growth of hatchery and wild fish appeared to be similar.

Growth in the 1999 cohort appeared to be considerably less than that observed in the 1998. Juvenile shad collected from the Conowingo strainers on 6 December to 10 December, the last samples obtained in 1999, averaged 120-mm TL (range 110 - 145-mm). This compares to the average of 158-mm TL (range 140 - 169-mm) from juveniles collected on 10 December 1998. However, growth of juvenile shad in 1999 falls within the range observed in previous cohorts.

E. Juvenile American Shad Stock Composition, Summer/Fall 1999

Of the 791 juvenile shad otoliths analyzed from collections above Conowingo Dam, 38 (5%) were unmarked (Table 21). This compares to 5% wild fish in 1998 collections, and 11-58% from 1991 through 1997. The high percentage of hatchery juveniles observed in 1999 may be due, in part, to the large numbers of fry stocked, or improvements in stocking procedures first implemented in 1998. Fry were stocked at numerous sites throughout the Juniata drainage rather than one or two sites. Spreading the fish out may have reduced predation by eliminating conditioned response behavior in piscivorous fishes attuned to sustained stocking at a single site. Reduced numbers of pre-spawn adult shad trucked and released above dams, and the stress associated with these transfers, may have also contributed to low natural reproduction. Reproductive success of adults and survival of young may have been impacted by unusual high water temperatures in May or some other environmental factor(s).

Over 34,000 adult American shad were passed at Safe Harbor in 1999 (Table 29). This compares to approximately 6,000 and 20,000 in 1998 and 1997, respectively. These fish had access to a twenty-five mile section of free flowing river between Safe Harbor and York Haven. It is difficult to assess the contribution this habitat had to the overall production of wild fish. The low numbers of wild fish at Holtwood, Peach Bottom, and Conowingo suggests that larvae spawned below York Haven were not abundant, were swamped by high survival of hatchery fish, or drifted below Conowingo before sampling began. Survival of the 1999 year-class will not be determined until they are fully recruited as adults. Relative survival of larval shad from the various stocking locations is discussed in Appendix II. All stockings sites with the exception of the West Branch of the Susquehanna River were represented in the Holtwood collections.

II. 2000 Adult Alosid Assessment

A. Origin of Adult Alosid Spawning Stocks, Spring 2000

Adult American shad and blueback herring in the Susquehanna River Basin, Pennsylvania, are derived from two sources: 1) those passed upstream via the fish lifts at Conowingo, Holtwood, Safe Harbor, and York Haven dams; and, 2) those collected by the Conowingo West Lift, transported by truck, and released above Susquehanna hydroelectric dams.

1. Adult Alosid Passage at Susquehanna River Dams, Spring 2000.

Conowingo Dam

High river flows in April, along with a serious debris problem at Conowingo, delayed startup of operations of the East lift until 18 April (Figure 8). Hopper hoist motor failure shut down operation during 29 April until 3 May, and daily operations commenced thereafter. Record number of shad (127,768) was passed from 4 - 13 May. During that time flows dropped to a season low of 22,900 cfs (May 12) and water temperature increased to the mid-70's° F. Following 12 May, river flows steadily increased until operations were again suspended from 27 to 29 May due to flows exceeding 100,000 cfs and a poor shad catch on 26 May. Operation resumed on 30 May with the catch dropping off to an average of less than 1000 shad per day (range 74 - 1,089) until operations terminated on 9 June. For the season, the East Lift operated 45 days, made 570 lifts and passed 153,546 American shad (new season record), 14,963 blueback herring, and 2 alewives (Table 23). Flows exceeded station capacity (85,000 cfs) on fourteen days from 10 April until 9 June.

Holtwood Dam

The tailrace lift at Holtwood operated 36 days during 6 May through 14 June, fishing for 295 hours and making 363 lifts (Figure 9). Because of flows and the placement and replacement of flashboards, the spillway lift only operated on 23 days making 208 lifts in 182 hours. Flows exceeded station capacity (35,000 cfs) nearly 70% of the time (25 of 36 operation days). The fishway did not operate from 26 to 29 May due to high river flows (71,700 to 114,500 cfs), and the lack of shad in the catch from 22 to 25 May. A total of 29,421 American shad (second highest on record) were passed - 21,110 at the tailrace and 8,311 at the spillway. Other alosids passed included 27 blueback herring (Table 29). Peak day of passage for American shad was 15 May (2,880 fish). Shad passage rate at Holtwood was only 19.2% of shad passed at Conowingo East Lift, a substantial decline from 1999 when about 50% of the East Lift count passed Holtwood. During spring 2000, fish lift operations had to contend with some level of spillage on all but four operating days.

Safe Harbor Dam

Safe Harbor lift operated for 269 hours during 35 days between 8 May and 15 June and made 585 lifts (Figure 10). Total alosid passage included 21,079 American shad (second highest on record), 159 blueback herring, and 657 alewives (Table 29). Peak day of American shad passage was 8 May (1,651). Safe Harbor passed 72% of the shad passing Holtwood and only 13.7% passing Conowingo. During 1999, Safe Harbor passed 98% and 49% of the American shad that passed Holtwood and Conowingo, respectively. River flows never exceeded station capacity (110,000 cfs) during spring 2000.

York Haven Dam

During its inaugural season, Fish ladder operations began at York Haven's East Channel Dam on 12 May and continued for 39 days until 19 June (Figure 11). Shad were observed passing ever day of operation with peak passage occurring on 19 May (425 fish). For the season, total alosid passage amounted to 4,687 American shad and 2 alewives (Table 29). High velocities may have precluded the use of the "cut weir" and flow control gates as passage avenues for shad. York Haven passed 3.1, 15.9, and 22.2% of American shad passed by Conowingo, Holtwood, and Safe Harbor, respectively.

2. West Lift Operation/Pre-Spawn Adult Alosids Trap and Transport, Spring 2000

As previously mentioned, the West Lift captured 9,785 American shad, 14,326 blueback herring, 9,189 alewives, and 1 hickory shad (Table 16). This compares to 9,658 American shad, 8,546 blueback herring, 1795 alewives, and 32 hickory shad captured in 1999. Of the shad captured, a total of 856 was transported and released at Columbia (Table 19). This compares to 5,508 adults released in 1999. Adult shad were also transported and released in the Conestoga River (495), and Muddy Creek (59). No adult American shad were stocked in Susquehanna tributaries during 1999. In addition, shad were provided to MDNR (1,726) and USFWS (1,179) for live tank spawning, and PFBC Benner Spring Fish Research Station (644) for a pheromone attraction study or otolith analysis. Total mortalities of transported shad amounted to 2 fish (0.1%). Blueback herring were transported and released in Little Conestoga Creek (502), Conestoga River (2,481), and Muddy Creek (1,800) during 2000 (Table 19). This compares to 1,310 herring stocked in the Little Conestoga and 795 at Tri-County in 1999. Some 2,026 alewives were also stocked in the Little Conestoga River in spring 2000 (Table 20).

Heads were collected from 197 adult shad and provided to PFBC for otolith analysis. Overall sex ratio for American shad collected by the West Lift was 2.3:1.0 favoring males (Appendix III). This compares to 1.1 males for every female in 1999.

B. Adult Alosid Timing of Spawning Migration and In-Stream Movements, Spring 2000

The timing and duration of the spawning migration is affected by three natural factors: 1) river flow, 2) water temperature, and 3) number of returning fish. Anthropogenic factors (lift operation/mechanics) can also influence the timing and duration of the spawning migration by delaying upstream passage at hydroelectric facilities. Spring river conditions for most of the Susquehanna River Basin during 2000 could be characterized by highly variable and above normal flows. Following high flows (>85,000 cfs) in late March and early April, two major flow events occurred from 20 to 27 April, and 26 to 18 May at which time flows exceeded station capacity at Conowingo Dam (Figure 8). During the entire 2000 operating season, flows measured at Conowingo Hydroelectric Station exceeded station capacity nearly 33% of the time during lift operation (15 of 45 operation days). Likewise, flows at Holtwood Hydroelectric Station (Figure 9) exceeded station capacity nearly 70% of the time during lift operation (25 of 36 operation days). Water temperatures were also highly variable. Unseasonably warm weather in early May caused rapid increases in water temperatures in the lower Susquehanna Basin (Figure 8). River temperatures at Conowingo jumped twenty degrees Fahrenheit in a ten-day period from 30 April to 10 May. Temperatures peaked (75.2° F) on 10 May and dropped steadily, in conjunction with a prolonged cold spell, until reaching a monthly low (60.8° F) on 24 May. Temperatures rebounded in June and remained in the high 60's and low to mid 70's ° F until lift operations at Conowingo was suspended for the season on 9 June.

When river flows exceed 85,000 cfs at Conowingo Dam, more water is flowing in the Susquehanna than can be directed through the turbines, spilling occurs in the east side crest gates, and fishway efficiency is reduced. Likewise, high river flow may transport large amounts of debris that may result in a variety of problems to lift operation. Under normal procedures, East Lift operation at Conowingo begins no later than 1 April or when water temperature approach 50.0° F. By this time, alosids are expected to be present at the base of the dam effectively trying to migrate upstream. In 2000, the commencement of Conowingo East Lift operation was delayed until 10 April due to copious amounts of debris that accumulated behind the dam encapsulating the fishway's exit trough. Flows measured at Conowingo Hydroelectric Station exceeded 85,000 cfs on twelve dates in April and three dates in late May (Figure 8). River flows at Holtwood hydroelectric station exceeded the 35,000 cfs station capacity on twenty-five dates from 6 May to 14 June 2000 (Figure 9).

Commencement of lift operation does not necessarily result in passage of large numbers of American shad; initial catches are usually low when considering the apparent number of fish present. It usually requires a number of operating days until catches increase substantially. Once sufficient numbers are passed, shad appear to have an easier time locating the fishway and often can be observed concentrating in large numbers at the fishway's entrance. This behavior suggests that some type of pheromone may play a role in upstream orientation and passage (reference Appendix I). Whatever may be responsible for this phenomenon, the impact on the timing and duration of the spawning run is obvious. Those years with copious spring precipitation and/or snow melt runoff and subsequent higher than normal river flows (i.e. 1996, 1998, 2000), typically pass fewer fish in April (Table 28, Figures 4, 6 and 8). Conversely, lift efficiency is optimized in dry springs with low river conditions because the effectiveness of attraction flows to the lifts are enhanced and shad have an easier time locating the fishway's entrance. Such was the case for 1997, and in part 1995 and 1999, when catches during the month of April averaged almost 23% of the total yearly catch (Table 28, Figures 3, 5 and 7).

The American shad spawning run concludes when river temperatures approach 75.0° F, usually within the second week of June. If weather patterns result in above normal river flows and/or below normal water temperatures in late spring, conditions may remain conducive to spawning and the migratory season may be protracted with substantial lift catches occurring in June as they did in 1994 and 1996 (Table 27, 28 and Figure 4). Drought conditions usually shorten the duration of the spawning season because river temperatures quickly rise above 75.0° F. This was true for 1999 when river temperatures first exceeded 75.0° F on 30 May and Conowingo lift operation was terminated on 3 June (Table 27 and 28, Figure 7). In 2000, water temperatures as measured at Conowingo Dam exceeded 75.0° F very early in the run from 10 to 13 May (Figure 6). However, cooler water temperatures returned and the atypical warm spell had no apparent impact on the shad migration. However, it may have impacted adult spawning success and survival of young.

The influence of stock abundance on the timing and duration of the spawning migration is uncertain. Obviously, a positive correlation exists between spawning stock abundance and number of fish passed by the lifts. However, it is unclear if early run fish that are precluded from being passed by the lifts due to environmental factors will remain below the dam until conditions improve enough to facilitate passage, or if they will spawn in river section below the dam. Tagged Susquehanna shad were captured in the Delaware River in 1998 following prolonged high spring flows in the Susquehanna suggesting that straying occurs if upstream migration to natal rivers is blocked. Generally, shad passage at all hydroelectric projects increased throughout the day and peaked in the afternoon, then declined until lift operation was suspended each evening.

The first American shad was passed at Conowingo Dam on 18 April at a water temperature of 53.8° F and river flow of 58,400 cfs (Figure 8). This compares with 53.6° F and 87,100 cfs during 1999, and 52.7° F and 39,200 cfs during the 1997 record season when in excess of 90,000 adults were passed by the East Lift (Figures 7 and 5, respectively). Collection and passage of shad was dramatically influenced by environmental factors (river flows) during the 2000 spawning migration. Despite the apparent large number of American shad at the base of the Conowingo, only 143 shad were passed by the east lift prior to 4 May (Figure 8). Lift operation and efficiency was severely hampered by debris problems, excessive flows, and mechanical breakdowns. Once flows subsided and other problems were addressed, efficiency increased dramatically and over 127,768 (83% of season total) American shad were passed in a ten-day period from 4 May until 13 May. This compares to nearly 87% (60,570) of the shad passed in a twenty-day period between 26 April and 16 May during 1999 (Figure 7).

The East Lift captured and passed over 10,000 shad on seven separate days and on 20 of the 45 days of operation American shad passage exceeded 1,000 fish. Peak passage occurred on 5 May when 22,565 American shad were passed (Figure 9). American shad were passed at water temperatures ranging from 52.3 to 75.9° F and river flows between 22,900 and 114,500 cfs. More than 71% of

American shad were collected at water temperatures >65° F (Table 27). This compares to approximately 53% of collected during 1999.

East lift catch patterns during the 2000 spawning migration suggests that American shad will congregate in large numbers below Conowingo until river conditions permit lifting fish over the dam. However, it remains unclear on how long individual fish are willing to remain below the dam to achieve upstream passage. Peak passage for blueback herring (11,020) occurred on 8 May at a water temperature of 72.0° F and flow of 29,700 cfs. This compares to more than 125,000 captured on 7 May 1999 at a water temperature of 65.3° F and flow of 22,100 cfs.

The first American shad passed at Holtwood Dam on 6 May 2000, the first day of lift operation and eighteen days after the first shad was passed at Conowingo. This suggests an upstream migration of approximately fifteen miles in a maximum of eighteen days. During its first day of operation, 738 American shad passed Holtwood. An equal number of shad were not passed at Conowingo until 4 May suggesting that some made the fifteen mile migration in as little as two days. The first American shad passed at Holtwood in 1999 occurred on 25 April, twelve days after the first shad was passed at Conowingo. High flows and few shad passed at Conowingo were responsible for the delay in start up of the Holtwood fish passage facility during 2000.

The Holtwood lift passed 18,838 American shad during the first ten days of operation (6 to 16 May), representing 64% of the season total (Figure 9). This compares to 2,921 shad passed during the first nine days of operation in 1999, and peak passage between 9 and 18 May when 43% (18,499) shad were passed. During peak period in 2000, the fishway collected and passed more than 1,000 shad on 5 days, and passed more than 2,000 shad on 4 days. River flows averaged 32,670 cfs during the first ten days of lift operations. Peak daily catch occurred on 15 May when 2,880 shad were captured and passed. The spillway lift captured nearly 2,000 of the shad passed on 15 May with the majority of those shad collected in the first two spillway lifts prior to the onset of a heavy spill event. Following the peak (from 16 May to 14 June), a total of 10,583 shad were captured at river flows averaging 53,063 cfs.

American shad were passed at water temperatures between 61.0 and 77.1° F, and river flows ranging from 22,900 to 83,100 cfs. Water temperatures and river flows during the peak catch period (from 6 to 15 May) averaged 73.1° F (66.7 to 75.9° F) and 32,670 cfs (22,900 to 47,700 cfs), respectively. The Holtwood lift was not operated from 26 to 29 May due to high river flows and lack of fish. The number of shad captured by each lift and/or the percentage of daily passage that was attributed to each lift was 21,110 and 8,311 (71.8 and 28.2%) for the tailrace and spillway lifts, respectively. Operation and effectiveness of the spillway lift was dependent on flow conditions in the spillway and east channel. Nearly 41% (3,371 shad) of the total spillway catch was collect during two days of operation (15 and 20 May). Most shad were passed between 1000 and 1659 hrs.

Due to high spring flows, spill events at Holtwood occurred on all but four operating days. Spill episodes greater then 10,000 cfs were common in spring 2000 and may have been responsible for the inconsistent spillway lift performance. The spillway lift shad catch appeared either just after, or just prior to a spill event. The high flow events in spring 2000 were detrimental to fish passage. Despite this, the 2000 American shad passage was the second highest recorded since the fishway's startup in 1997. However, shad and blueback herring catches were still less 20% and 1%, respectively, for those passed at Conowingo (Table 29).

Holtwood Lift efficiency was considerably less than that observed in the previous three years of operation passing nearly 19% of the total number of shad passed by Conowingo East Lift. In 1997, 1998 and 1999, Holtwood passed approximately 31%, 21% and 50% respectively, of the shad passed at Conowingo (Table 29). Lift efficiency remains a concern at Holtwood and merits study should efficiency fail to improve in the future. It remains unclear why the Holtwood facility has been inefficient at passing alosids during its first four-years of operation. Possible explanations may include: 1) unfamiliarity with lift operation because of the newness of the facility; 2) reduced attraction flow efficiency brought about by spilling over the crest of the dam; 3) complex flow regimes caused by the operation of Muddy Run Pump Storage Facility; or 4) recycling of previously passed fish by the East Lift at Conowingo. It is felt that high spring flow greatly reduced lift efficiency at Holtwood during the 2000 spawning migration.

The first American shad passed at Safe Harbor Dam on 8 May 2000, the first day of lift operation and two days after the first shad was passed at Holtwood (Figure 10). This suggests an upstream migration of approximately seven miles in a maximum of two days. A total of 1,651 shad was passed at Safe Harbor during the first day of operation. The passing of the same number of shad at Holtwood did not occur until 7 May when a cumulative total of 2,805 shad was passed by the end of the operation day. This suggests that some individuals migrated seven miles in one day or less.

Passage of shad at Safe Harbor varied daily, albeit steady, through most of May with more than 70% (14,797) of the catch passing in the fifteen-day period prior to 23 May (Figure 10). This compares to over 70% (24,022) passed in the two-week period prior to 22 May 1999. Peak passage occurred on 8 May 2000 when

1,651 shad were passed. American shad were passed at water temperatures ranging from 61.0 to 77.1° F and river flows between 83,100 to 22,900 cfs. The fifteen-day period when most shad passage occurred averaged 70.8° F (62.3 to 75.9° F) and 42,813 cfs (22,900 to 73,600 cfs). Based on counts, Safe Harbor passed 72% of the shad passed at Holtwood. This is a decrease from that observed during 1999 (98%), and the lift's first three years of operation when efficiency averaged greater than 75% (Table 29).

The York Haven Hydroelectric Project includes two dams separated by Three Mile Island (Figure 12). The dams impound approximately five miles of river forming Lake Frederic. The main dam is approximately 5,000 feet long, with a maximum height of 17 feet. The East Channel Dam, where the fishway is located, is approximately 925 feet long with a maximum height of nine feet. Estimated hydraulic capacity of the project is 16,000 cfs. River flow exceeds station hydraulic capacity over 55% of the year that results in water being spilled over the two dams.

The fishway consists of two sections; a "weir cut" and a vertical notch fish ladder. The "weir cut" includes an adjustable weir and stop gate. Flows through the "weir cut" can be regulated and its primary function is to provide attraction flow for the ladder section of the fishway. Under certain flow conditions, fish may be able to pass the dam by using the "weir cut" itself providing velocities do not exceed swimming ability.

Fish passing via the ladder are counted as they pass a viewing window. Fish using the "weir cut" pass without being enumerated.

American shad were passed York Haven at water temperatures of 59.0 and 76.0° F, river flows of 27,000 cfs to 114,800 cfs and/or East Channel flows of 2,650 and 18,200 cfs (Figure 11). The first American shad passed at York Haven occurred on 12 May, the first day of ladder operation and four days after the first shad were passed at Safe Harbor. This suggests an upstream migration of twenty-three miles in a maximum of four days or less. A total of 30 American shad passed York Haven during its first day of operation at a water temperature of 73.0° F. Passage of shad at York Haven varied daily with approximately 94% (4,420) of the shad passing between 13 May and 13 June. In May, the fishway passed over 200 American shad per day on five occasions. Peak shad passage occurred on 19 May when 425 shad were passed. Some 55.4% and 45.6% of the shad passed in May and June, respectively.

American shad passage through the ladder occurred in three waves or pulses. Peak passage occurred between 13 and 20 May. During this period, 1,685 American shad passed the ladder as water temperatures declined from 72.0 to 61.8° F and at river flows that varied from 32,500 to 46,950 cfs. The number of shad that passed declined from 21 to 28 May. This decline coincided with a high flow event that peaked at 114,800 cfs on 26 May.

Following a drop in river flow, two smaller peaks in shad passage were observed between 29 May and 13 June. Of the 2,428 American shad passing during this period, 1,455 and 973 shad passed from 29 May to 6 June, and 7 June to 13 June, respectively. During this period river flows declined from 71,300 cfs on 29 May to 21,850 cfs on 5 June. River flow increased daily to 33,500 cfs on 8 June, fell to 22,800 cfs on 12 June before it increased for the last time during the season to 50,150 cfs on 17 June. Water temperatures varied over 14 degrees during this period, increasing from 61.5° F on 29 May to 71.3° F on 3 June, falling to 63.5° F on 7 June and rising to a season high of 76.0° F on 12 June. Just two alosids other than American shad passed York Haven. Both were alewife that passed on 17 May. Based on passage records at downstream passage facilities, these alewife were apparently transported form the West Lift at Conowingo Dam and were stocked in the Little Conestoga Creek. In the future, American shad will have to pass York Haven at lower water temperatures in order to maximize reproductive potential in upriver areas.

Collection and passage of alosids at Conowingo varied monthly with a 0.1, 97.1, and 2.8% of shad captured and passed during April, May, and June, respectively (Tables 27 and 28). This compares to an average of 15.2, 74.2, and 10.6% passed during April, May and June from 1994 through 1999. The percentage of American shad captured at the East Lift by month during spring 2000 illustrates low catches in April due to delayed startup, followed by high flows and higher than normal catches in May due to elevated water temperatures and large number of fish congregating below the dam. Of the alosids collected in 2000, 28.8% were at water temperatures <65.0° F (Table 18). In comparison, from 1994 through 1999, the percentage of alosids collected at water temperatures of <65.0° F averaged 62.6% (Table 18).

Adult alosid movement and distribution within the basin were evaluated by electrofishing Conowingo Pond, the base of the Fabri-dam on the Susquehanna, as well as selected tributaries, including the Conestoga River, Little Conestoga Creek, and West Conewago Creek. Results of adult American shad otolith analysis are summarized in Appendix III. The single adult American shad captured in Conowingo Pond had a 3, 9, 5, 15 mark indicating that it was stocked as fry in the Conestoga River. Of the adult shad captured at the Fabri-dam, two were wild fish, and two where hatchery with a day 3 or 5 mark indicating they were stocked in the Juniata or Susquehanna River. Both adult shad captured in the Conestoga River at the base of the Lancaster Water Works Dam were hatchery, with one having a day 5 mark and the other a day 3, 9, 12, 15 mark indicating they were stocked in the Juniata or Susquehanna River and the Conestoga River, respectively. The single adult captured in West Conewago Creek had a day 5 mark indicating it was stocked in the Juniata River or Susquehanna River. No adult river herring were collected during the surveys.

The Fabri-dam (r.m. 125.5) is located just near Sunbury (Figure 1) downstream of where the North Branch and West Branch connect to form the main stem Susquehanna River. Captured adult American shad could have reached the base of the Fabri-dam by two avenues: 1) using fish passage facilities at the four downstream hydro-projects, or 2) transport by truck and released at Columbia. Either would have required an additional upstream migration of approximately 70 miles to reach the base of the dam. The two hatchery adults collected at the base of the Fabri-dam originated from fry stockings in the Juniata River or main stem Susquehanna near Montgomery Ferry. Wild adult shad captured at the base of dam could have originated from two sources 1) progeny of fish transported and released above York Haven Dam, or 2) progeny of fish spawned below York Haven Dam.

Despite the presence of adult shad in the river reach between Clemson Island and the Fabri-dam, production of wild shad was low in the upper Susquehanna without a single wild juvenile shad collected during sampling on the Juniata River and Susquehanna main stem above Clemson Island (Table 21). Wild production in the entire Susquehanna Basin appears to have been limited with only 3% of the juvenile shad collected above Conowingo Dam being wild. Low numbers of wild shad in the upper Susquehanna Basin may be attributed to few adults (4,678) passed at York Haven. However, this seems unlikely when considering the reproductive capability of American shad and the low number of wild juveniles observed below York Haven where adults were much more numerous. Planned construction of a fishway at the Fabri-dam will provide passage for migratory alosids in the future. However, fish passage efficiency will need to improve to ensure American shad will reach upstream sections in sufficient time and numbers to reproduce.

The confluence of West Conewago Creek with the Susquehanna is located on the east shore below York Haven Dam. Based on fish counts at Safe Harbor Dam and numbers of shad released at Columbia, 21,935 American shad would have access to West Conewago Creek during the 2000 spawning migration. The presence of the Juniata/Susquehanna mark on the shad captured at Detter's Mill Dam suggests that this individual was a stray. This fish used the lifts at Conowingo, Holtwood, and Safe Harbor dams, or was released at Columbia, then traveled up Conewago Creek 27.7 miles to the base of the dam. Due to the episodic nature of adult sampling, additional American shad may have migrated up West

Conewago and went undetected. Sampling by seine in West Conewago failed to capture any juvenile shad suggesting that if natural reproduction occurred, it was limited, or larvae drifted downstream before sampling occurred. Provisions for fish passage at Detter's Mill Dam should be implemented to ensure passage in the future.

The confluence of the Conestoga River with the Susquehanna is located on the west shore below Safe Harbor Dam. Based on fish counts at Holtwood Dam, 29,421 American shad would have access to the Conestoga River. An additional 495 adult shad were transported and released in the Conestoga River at Bridgeport, approximately one mile below the Lancaster Water Works Dam. It is not known if adult shad captured at the base of the Lancaster Water Works Dam were upstream migrants from the Susquehanna or transported individuals. Considering the limited number of fry stocked in the Conestoga, chances of a Conestoga marked shad being present in the load of transported adults were remote, but possible. Since fry with the Juniata/Susquehanna mark are stocked at much higher densities, chances of a Juniata/Susquehanna marked shad being present were much higher. If the two adult shad captured were migrants and not released transports, they would have traveled a distance of 32.8 miles up the Conestoga to the base of the dam. In 2000, the fishway at the Lancaster Water Works Dam was completed and saw limited service. Additional shad may have used the fishway and were not available for capture by electrofishing. Future plans are to monitor the fishway and electrofish at the base of the next upstream blockage in order to document adult distribution above the Lancaster Water Works Dam. Stocking of pre-spawn adult American shad in tributaries should be suspended in the future to eliminate uncertainties with regard to the origin of adults.

Based on fish counts, Safe Harbor passed 657 blueback herring and 159 alewives. Considering that Holtwood only passed 27 blueback herring, a large proportion of the river herring counted at Safe Harbor could have only originated from fish transported to the Conestoga basin. These herring apparently moved out of the Conestoga after release and continued up the Susquehanna. It is not known if herring spawned prior to moving out of the Conestoga basin. Future releases of river herring in tributaries should be well upstream of their confluence with the Susquehanna, preferably above existing blockages, to discourage downstream movement. Sampling by seine in the Conestoga and Little Conestoga failed to capture any juvenile alosids suggesting that if natural reproduction occurred, it was limited, or larvae drifted out of the basin prior to sampling.

It is largely accepted that transporting and release of pre-spawn alosids and stocking of shad fry is successful at establishing imprinted populations in the main stem Susquehanna River basin and elsewhere. It is too early to determine if the same strategy will be successful at establishing sub-populations in tributaries to the Susquehanna River. Information obtained in 2000 is limited, but suggests that straying by American shad into tributaries is occurring. In addition, the stocking of shad fry may be having success at establishing shad imprinted to the Conestoga River. This is based on the capture of a Conestoga marked adult in the Conestoga River. Marking studies for the Lehigh River in eastern Pennsylvania suggest that American shad will imprint to non-tidal tributaries of the Delaware River.

Whether shad and river herring will return in the future in sufficient numbers to spawn successfully is not yet known. Habitat quality and quantity may also be limiting factors to establishing sub-populations in tributaries. Monitoring of main stem and tributary waters should continue in order to track adult alosid abundance, distribution, wild production, and success of the restoration effort.

C. Adult Alosid Abundance, Spring 2000

Fish counts at the Conowingo lifts have been used to determine the abundance of adult alosids returning to the Susquehanna River each year to spawn, and evaluate the success of the restoration effort. In 2000, the East and West lifts at Conowingo Dam captured a combined total of 163,331 American shad (new season record). This compares to catches ranging from 32,330 to 103,945 from 1994 through 1999 (Table 29). Catches of blueback herring for the East and West lifts combined were 29,289. This compares to catches ranging from 1,132 to 376,072 from 1994 through 1999.

Prior to 1997, fish collected at Conowingo East Lift were sorted according to species and alosids transported by truck and released upstream of York Haven Dam. Fish passage facilities at Holtwood and Safe Harbor Dams were completed in 1997. That same year the East Lift at Conowingo began directly lifting alosids over the dam and releasing them in Conowingo Pond. These changes in lift operations appear to have resulted in increased catches of alosids with less effort (increased CPUE in terms of fish/lift). This is logical when considering that fish would no longer need to be sorted and transported thereby permitting continuous lift cycling and more fishing time. Therefore, when assessing abundance of adult American shad and blueback herring based on East Lift catches, separation (pre 1997 verses 1997 to present) based on operational mode should be considered.

River conditions in terms of average monthly flows from 1997 to 1999 differ substantially by year and may be negatively correlated to the number of fish lifted over the Conowingo Dam in a given year. The spring of 1997 was one of the driest on record and boasts the second highest number of alosids passed at Conowingo Dam (Table 29, Figure 5). Conversely, spring of 1998 was one of the wettest years on record and had the fewest number of alosids passed over the dam (Table 29, Figure 6). The spring of 1999 was average in terms of precipitation and passed fewer fish than in 1997, but more than in 1998 (Table 29, Figure 7). River conditions (flow) during spring 2000 were similar to those observed in 1998 (Table 28). Average monthly flows during lift operation in April 2000 were the highest recorded since 1997, and resulted in less than 1% of the total yearly catch of shad (Table 27 and 28). Flows moderated in May and a record number (149,093) of American shad were passed. Since river condition in 2000 were similar to those observed in previous years, number of shad passed must be a reflection of increased spawning stock abundance (adult recruitment) and not solely a function of lift efficiency.

The East Lift at Conowingo performed 570 lifts resulting in a CPUE of 269 shad per lift during 2000. CPUE for the East Lift in 1997, 1998, and 1999 was 149, 115, and 127-shad per lift, respectively. CPUE for the East Lift during spring 2000 was nearly twice than that observed in 1997, the second highest year (total catch) on record. Likewise, numbers of shad passed by the East Lift in 2000 (153,546) was 1.69 times greater than those passed in 1997 (Table 29). Susquehanna River American shad spawning stocks continued the long-term trend of increase.

Increases in stocks may be attributed to one or more factors including: 1) supplemental stocking of cultured American shad larvae; 2) exploitation of newly accessible spawning and rearing habitat; 3) decreased mortality and increased survival; 4) enhanced wild reproduction from large numbers of pre-spawn adults transported and released upriver in 1993 through 1996.

The spawning run for Blueback herring in the Susquehanna River typically occurs prior to that of the American shad. High flows during April may result in reduced numbers of herring passed by the East Lift at Conowingo Dam (Table 28). Decreased numbers of blueback herring passed by the East Lift in 2000 (Table 29) is most likely associated with reduced lift efficiency rather than a reflection of stock abundance. Long-term trends in herring abundance are difficult to track due to the influence of environmental factors on lift efficiency at the time of the spawning migration.

D. Adult Alosid Age and Growth, Spring 2000

Based on otolith analysis, overall mean age for adult American shad was 4.1 years for males and 5.1 years for females. Mean ages for wild male (4.0) and female (4.8) adult American shad were slightly less than hatchery male (4.3) and female (5.4). Overall sex ratio was 2.3 to 1.0, males to female. This compares to a male to female ratio of 1.1 to 1.0 observed in 1999. The average size of male American shad collected by the

West Lift in 2000 was 410-mm (fork length) and 862-g, while females averaged 462-mm and 1402-g. This compares to 393-mm (fork length) and 662-g for males and 449-mm and 1047-g for females collected in 1999. No consistent difference in length at age is apparent between wild and hatchery fish. Adult river herring were not aged or measured for length and weight. Age and growth data for adult American shad collected in spring 2000 is provided in Appendix III.

E. Adult American Shad Stock Composition, Spring 2000

Based on the analysis of 197 otoliths taken from adult shad at Conowingo West Lift in 2000, 54% of the adult American shad sampled at Conowingo were hatchery origin and 46% were wild (Table 22). This compares to 53% wild and 47% hatchery in 1999, and between 10 and 71% wild in 1989 through 1999. The majority of hatchery fish (34%) carried the single day 3 or 5-tetracycline mark indicating that they were stocked in the Juniata River. Most others (12.4%) were double marked on 5,9; 3,6; or 3,7 released below Conowingo Dam.

Based on the annual analysis of hatchery verses wild shad at Conowingo, age of fish, and known stocking numbers, on average it takes 318 larvae, 134 fingerlings, or 0.86 adults transported to produce each adult return to Conowingo Dam (Appendix III). These numbers are maximum estimate, because the 1994 and 1995 year classes are not fully recruited. A detailed analysis of adult

American shad otoliths for 2000, as well as evaluation of adult recruitment rates is provided in Appendix III.

Summary

- Juvenile American shad were successfully collected by haul seine, electrofisher, push net and lift net.
- Juvenile haul seining on the Susquehanna River in 1999 resulted in a GM CPUE of 0.668(var. 0.509) fish per haul.
- Electrofishing CPUE for juvenile shad (all sites combined) was 7.7 fish per hour, the highest recorded since sampling with that gear began in 1996.
- Lift netting at Holtwood in 1999 resulted in a GM CPUE of 0.498 (var. 0.334) fish per lift.
- Based of haul seine and lift net catches, juvenile abundance in 1999 appeared to be higher than observed 1998, but lower than 1997.
- Peak juvenile alosid out migration based on lift net collections occurred during September and was associated with high flows from hurricanes Dennis and Floyd.
- High river flows associated with hurricanes Dennis and Floyd hastened the juvenile alosid out migration period.
- Otolith analysis determined that 3% of the juveniles collected above Conowingo Dam were of wild origin.

- Several factors may have influenced catches of juveniles including: 1) poor reproductive success of transported adults; 2) low numbers of adults upriver; 3) high juvenile mortality; 4) ineffective sampling methods due to high river flows in the fall; 5) low juvenile abundance in the drainage because young shad were flushed out of the system from high spring river flows.
- The survival and composition (hatchery verses wild) of the 1999 year-class cannot be completely assessed until the cohort is fully recruited as adults.
- A total of 1,351 pre-spawn adult American shad, 4,783 blueback herring, and 2,026 alewives were captured by the West Lift, transported, and released in the Susquehanna Basin above Conowingo Dam; adult shad were also provided to MDNR (1,179) and USFWS (1,726) for tank spawning and the PFBC (447) for pheromone attraction study.
- Relative survival for hatchery shad fry was highest at releases in the Conestoga River (1.00), followed by Swatara Creek (0.81), Conodoguinet Creek (0.77), Juniata River (0.75), North Branch of the Susquehanna River (0.22), West Conewago Creek (0.15), and West Branch of the Susquehanna River (0.00).
- Based on 2000 otolith analyses, 46% of the adult American shad collected at Conowingo were wild and 54% were hatchery.

- Analysis of age composition and otolith marking data indicate that for the 1986-1995 year classes: 1) stocking of approximately 318 hatchery larvae was required to return one adult to the lifts at Conowingo; 2) stocking of 134 fingerlings was required to return one adult to the lifts at Conowingo, and; 3) transport of 0.86 adults to upstream areas was required to return one wild fish to the lifts at Conowingo.
- In 2000, a combined total of 163,331 American shad (new season record) were captured and passed by the East Lift and West Lift at Conowingo Dam; numbers passed at Holtwood, Safe Harbor, and York Haven were 29,421, 21,079, and 4,687 respectively.
- In 2000, a total of 14,963 blueback herring were captured and passed by the East Lift at Conowingo Dam; numbers passed at Holtwood and Safe Harbor were 27 and 159, respectively.
- Testing in the pheromone attraction study appears to validate the expectation that a chemical cue from con-specifics elicits a behavioral response in American shad.

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Table 1

Descriptions of Susquehanna River tributary stations sampled by haul seine in 1999.

Station Number	Latitude Longitude	Description
		Conestoga River
1	39°56'04"N 76°23'05"W	Head of pool below riffle: 1,700 ft downstream from River Road crossing at Safe Harbor park.
2	39°57'42"N 76°21'57"W	Back eddy/pool below riffle: 200 ft upstream of township road 561 crossing at Rock Hill.
3	39°57'59"N 76°21'28"W	Run below riffle; 300 ft downstream of Steinman Road crossing.
4	39°59'47"N 76°18'38"W	Pool on downstream side of island: 300 ft above Route 324 crossing.
5	40°00'40"N 76°18'16"W	Downstream end of pool (water funnel by rock ledge): 0.72 mi downstream of Route 222 crossing.
6	40°02'13"N 76°16'15"W	Run/pool: 300 ft downstream of Route 462 crossing.
		Little Conestoga Creek
1	40°00'19"N 76°22'27"W	Mid pool: 300 ft downstream of Route 999 crossing.
2	39°59'15"N 76°22'52"W	Mid pool; 1,700 ft upstream of Owl Bridge Road crossing.
3	39°59'02"N 76°22'42"W	Run: 150 ft upstream of Owl Bridge Road crossing.
4	39°58'20"N 76°22'32"W	End of pool; 450 ft upstream of Walnut Hill Road crossing.
5	39°57'59"N 76°22'26W	Pool formed by entry of Indian Run into Little Conestoga Creek, near junction of Walnut Hill Road and Creek Road.
6	39°57'39"N 76°22'20"W	Head of pool below riffle: 1,200 ft upstream of township road 561 crossing.
		West Conewago Creek
1	40°06'09"N 76°46'43"W	Pool under Route 83 crossing.
2	40°06'07"N 76°46'06"W	Downstream portion of pool: 250 ft above Hykes Dam.
3	40°06'00"N 76°45'48"W	Downstream end of pool: 1,350 ft below Hykes Dam.
4	40°06'24"N 76°44'28"W	Middle of pool: 300 ft downstream of Bowers Bridge Road crossing.
5	40°05'39"N 76°43'46"W	Downstream end of pool: 1.13 mi downstream of Bowers Bridge Road crossing.
6	40°04'55"N 76°42'57"W	Head of pool below riffle: 750 ft downstream of Route 181 crossing.

Table 1

Continued.

Station Number	Latitude Longitude	Description
		Swatara Creek
1	40°11'46"N 76°43'88"W	Pool: 300 ft downstream of Route 441 bridge, behind pavilion
2	40°13'79"N 76°43'60"W	Pool: mid-pool at Fulling Mill Road
3	43°43'46"N 78°34'88"W	Pool: under Route 322 bridge
4	40°17'19"N 76°40'74"W	Pool: mid-pool in Swatara Creek Park at bridge
5	40°19'11"N 76°37'78"W	Run: left bank, 300 ft below Route 743 bridge
6	40°19'48"N 76°31'60"W	Run: left bank at Old Mill Damon Bindage Road
		Conodoguinet Creek
1	40°16'00"N 76°54'45"W	Run: 150-300 ft upstream of railroad bridge
2	40°15'20"N 76°55'45"W	Under Center Street bridge: mid-pool just downstream of bridge supports
3	40°15'20"N 76°57'40"W	Run: 150 ft upstream of dock at Youth Park
4	40°15'40"N 76°58'45"W	Run: 50 ft upstream of PFBC boat access below Good Hope dam
5	40°15'30"N 77°02'25"W	Pool: lower end of pool in Willow Mill Park
6	40°15'40"N 77°02'30"W	Pool: upper end of pool in Willow Mill Park
7	Alternate Site	Run: under Lambsgap Rd. bridge: just upstream of bridge supports

Table 2

Juvenile American shad catch in each seine haul from the lower Susquehanna River at Columbia, 1999.

Date	Water Temp. (°C)	River Flow (cfs)	Secchi (in)	Time	Upper Shore of East Bank	Upper East Shore of Tire Island	Lower East Shore of Tire Island	East Shore of 1st Old Bridge Pier	South End of 1st Old Bridge Pier	Columbia Boat Ramp	Total
13 Jul	26.5	6,110	48	20:25-21:42	0	0	0	0	0	0	**0**
20 Jul	29.9	4,190	38	20:34-22:20	0	0	0	0	0	0	**0**
26 Jul	30.0	4,190	30	20:25-21:55	0	0	0	1	0	0	**1**
03 Aug	28.0	3,305	31	20:20-21:30	0	0	0	0	1	0	**1**
12 Aug	29.0	2,600	35	19:30-2100	0	0	0	0	0	0	**0**
17 Aug	28.0	5,430	32	20:10-21:32	0	0	0	0	0	0	**0**
26 Aug	25.0	5,270	30	19:48-21:15	0	0	0	4	0	4	**8**
31 Aug	23.5	5,540	28	19:45-21:15	0	0	0	0	0	2	**2**
13 Sep	24.0	6,720	27	19:16-21:05	3	1	1	26	50	1	**82**
15 Sep	22.5	5,780	28	19:05-20:42	5	0	1	33	137	6	**182**
23 Sep	17.5	24,300	30	19:05-20:30	8	0	0	6	2	1	**17**
29 Sep	19.8	16,200	21	18:40-20:05	11	4	0	2	3	0	**20**
06 Oct	15.5	29,100	25	18:45-20:10	0	0	1	0	0	0	**1**
12 Oct	16.0	23,600	20	18:30-19:55	0	1	2	0	0	0	**3**
20 Oct	12.5	16,100	40	18:20-19:32	0	0	0	0	5	0	**5**
TOTAL					**27**	**6**	**5**	**72**	**198**	**14**	**322**

Table 3

Juvenile American shad catch per effort (CPUE), standard deviation, variance, and confidence for haul seining at Columbia on the lower Susquehanna River, 1999.

Date	Number of Hauls	Number of American Shad	CPUE	Standard Deviation	Variance	Confidence Interval
13 Jul	6	0	0.00	0.00	0.00	0.00
20 Jul	6	0	0.00	0.00	0.00	0.00
26 Jul	6	1	0.17	0.41	0.17	0.33
03 Aug	6	1	0.17	0.41	0.17	0.33
12 Aug	6	0	0.00	0.00	0.00	0.00
17 Aug	6	0	0.00	0.00	0.00	0.00
26 Aug	6	8	1.33	2.07	4.27	1.65
31 Aug	6	2	0.33	0.82	0.67	0.65
13 Sep	6	82	13.67	20.33	413.47	16.27
15 Sep	6	182	30.33	53.66	2879.87	42.94
23 Sep	6	17	2.83	3.37	11.37	2.70
29 Sep	6	20	3.33	4.08	16.67	3.27
06 Oct	6	1	0.17	0.41	0.17	0.33
12 Oct	6	3	0.50	0.84	0.70	0.67
20 Oct	6	5	0.83	2.04	4.17	1.63

Table 4

Length frequency for subsample of juvenile American shad collected by haul seine in the lower Susquehanna River at Columbia, 1999.

TL(mm)	13 Jul	20 Jul	26 Jul	03 Aug	12 Aug	17 Aug	26 Aug	31 Aug	13 Sep	15 Sep	23 Sep	29 Sep	06 Oct	12 Oct	20 Oct	Total
51-55																0
56-60																0
61-65																0
66-70																0
71-75																0
76-80				1												1
81-85			1													1
86-90									1	2	1	3				7
91-95								1	2	8	3	1				15
96-100							2		7	7	3	3		1		23
101-105							2		14	8	5	4				33
106-110							2		6	5	2	6	1	1		23
111-115							1	1	1	1	1	3		1	2	11
116-120											1				1	2
121-125															1	1
126-130																0
131-135							1									1
136-140																0
141-145															1	1
Total	0	0	1	1	0	0	8	2	31	31	16	20	1	3	5	119

Table 5. Index of abundance for juvenile American shad collected b
haul seine in at Marietta, Columbia and Wrightsville, 1985-1999.

Year	No. Hauls	No. Fish	CPUE	GM CPUE	Variance	Recruitment to Lifts
1985						
1986						22,897
1987						17,096
1988						20,466
1989	-	1580	-			35,307
1990	68	258	3.79	*	*	50,323
1991	128	154	1.20	*	*	34,448
1992	87	269	3.09	*	*	37,740
1993	110	218	1.98	*	*	79,692
1994	101	376	3.72	*	*	86,708
1995	48	409	8.52	*	*	
1996	105	283	2.70	*	*	
1997	90	879	9.77	3.359	1.011	
1998	94	230	2.45	0.497	0.345	
1999	90	322	3.58	0.668	0.509	

* data unavailable

Table 6

Summary of the electrofishing catch of juvenile American shad in the Susquehanna River near Clemson Island, 1999.

Date	River Flow (cfs)	Water Temperature (°C)	Secchi Disk (in)	Duration (min)	Volts Pulsed (DC)	Amps	Dimpling?	Number of Shad Captured	Shad Observed
3 Aug	3,130	28.7	60	62	170 - 190	7.0	No	0	0
10 Aug	2,950	24.7	65	61	150	7.0	No	1	0
17 Aug	6,130	29.0	70	64	140 - 170	7.0	No	0	0
24 Aug	6,540	24.0	29	61	200 - 250	7.0	No	1	0
31 Aug	4,490	23.0	55	64	160 - 180	7.0	No	0	0
8 Sep	33,200	22.0	8	60	350 - 370	5.5	No	0	0
14 Sep	5,270	21.3	71	61	210 - 230	7.0	No	0	0
21 Sep	23,500	16.3	31	60	250 - 270	7.0	No	0	0
Total				*493*				*2*	*0*
Mean	*10,651*	*23.6*	*48.6*		*150.0*	*6.8*			

Table 6, Continued

Summary of the electrofishing catch of juvenile American shad in the Juniata River at Mifflintown, 1999.

Date	River Flow (cfs)	Water Temperature (°C)	Secchi Disk (in)	Duration (min)	Volts Pulsed (DC)	Amps	Dimpling?	Number of Shad Captured	Shad Observed
5 Aug	553	27.3	70	60	170 - 190	5.0 to 7.0	Yes	2	5
12 Aug	553	28.0	80	60	200 - 220	7.0	Yes	10	3
19 Aug	553	26.2	95	65	180 - 200	7.0	Yes	12	4
26 Aug	647	23.9	75	60	180 - 200	7.0	Yes	7	0
2 Sep	667	24.8	20	62	220 - 260	7.0	Yes	30	16
7 Sep	914	25.0	31	60	200	7.0	Yes	19	8
17 Sep	1,220	18.8	23	60	250 - 280	7.0	Yes	32	17
23 Sep	778	18.5	85	66	230 - 250	7.0	Yes	12	12
Total				*493*				*124*	*65*
Mean	*736*	*24.1*	*59.9*		*200.0*	*7.0*			

Table 7

Length frequency distribution of juvenile American shad captured with a boat-mounted electrofisher from the Susquehanna River near Clemson Island and the Juniata River at Mifflintown, August through September 1999.

Total Length (mm)	5 Aug	10 Aug*	12 Aug	19 Aug	24 Aug*	26 Aug	2 Sep	7 Sep	17 Sep	23 Sep	Total
70-79		1									1
80-89			8	3	1	2					14
90-99	2		2	9		5	13	1			32
100-109							17	17	18		52
110-119								1	13	11	25
120-129									1	1	2
TOTAL	***2***	***1***	***10***	***12***	***1***	***7***	***30***	***19***	***32***	***12***	***126***

* Susquehanna River near Clemson Island.

Table 8

Catch per unit of effort (CPUE), standard deviation, variance, and confidence interval for juvenile American shad collected with a boat-mounted electrofisher from the Juniata River, August through September 1999.

Date	Number of Shad	CPUE (No./hour)	Mean	Standard Deviation	Variance	Confidence Interval
5-Aug	2	2.00	0.50	0.58	0.33	0.33
12-Aug	10	10.00	2.50	2.08	4.33	4.25
19-Aug	12	11.08	3.00	2.58	6.67	6.53
26-Aug	7	7.00	2.33	3.21	10.33	11.69
2-Sep	30	29.03	7.50	5.26	27.67	27.11
7-Sep	19	19.00	4.75	6.95	48.25	47.28
17-Sep	32	32.00	10.67	14.36	206.33	233.48
23-Sep	12	10.91	3.00	3.37	11.33	11.11
TOTAL	*124*	*15.09*	*4.13*	*5.84*	*34.05*	*13.09*

Table 9.

American shad catch by lift of the 8ft x 8 ft lift net from the Holtwood Power Station inner forebay, 13 September to 9 December, 1999.

Date	Water Temp (C)	River Flow (cfs)	Secchi (in)	Time	Lift Number 1	2	3	4	5	6	7	8	9	10	Total (per day)
13-Sep	24.5	6,790	20	1826-1956	-	-	-	-	-	-	-	-	-	-	**0**
16-Sep	22.5	23,000		1815-2028	-	-	1	-	-	-	2	1	2	1	**7**
19-Sep	18.0	38,200	20	1820-2000	5	3	17	21	3	3	12	14	3	4	**85**
22-Sep	18.0	27,700	27	1825-2005	7	1	3	3	7	3	4	10	3	67	**108**
25-Sep	18.0	21,200	30	1834-2010	1	-	-	-	-	-	-	2	-	1	**4**
28-Sep	20.0	17,500	30	1824-1933	-	-	-	-	-	-	-	-	-	2	**2**
1-Oct	19.5	45,200	28	1825-2008	-	1	-	-	-	1	-	5	13	5	**25**
4-Oct	18.0	28,000	23	1753-1933	18	19	1	11	4	7	-	13	8	14	**95**
7-Oct	16.0	26,200	30	1735-1915	-	4	4	1	4	3	1	-	-	3	**20**
10-Oct	16.0	21,700	30	1733-1913	-	-	-	-	-	-	-	3	-	21	**24**
13-Oct	16.0	22,400	30	1736-1916	-	6	1	-	2	-	-	-	5	35	**49**
16-Oct	15.5	18,700	30	1725-1905	4	-	-	-	3	-	-	-	-	1	**8**
19-Oct	14.0	15,700	24	1746-1910	2	-	3	-	-	-	-	4	11	14	**34**
22-Oct	13.5	14,400	40	1730-1910	-	-	-	-	-	-	-	4	2	8	**14**
25-Oct	12.0	11,600	41	1822-1922	-	-	-	-	-	-	3	4	3	5	**15**
28-Oct	12.0	10,100	38	1745-1900	-	-	-	-	-	-	-	-	-	-	**0**
31-Oct	12.5	9,170	45	1633-1813	-	-	-	-	-	-	-	-	-	-	**0**
3-Nov	13.0	8,930	30	1630-1750	-	-	-	-	-	-	-	-	-	-	**0**
6-Nov	12.5	15,300	35	1635-1740	-	-	-	-	-	-	-	-	-	-	**0**
9-Nov	11.0	14,700	38	1619-1749	-	-	-	-	-	-	-	-	-	-	**0**
12-Nov	10.0	11,200	40	1614-1750	-	-	-	-	-	-	-	-	-	-	**0**
15-Nov	10.0	9,390	30	1605-1745	-	-	-	-	-	-	-	-	-	-	**0**
18-Nov	9.0	9,000	42	1615-1725	-	-	-	-	-	-	-	-	-	-	**0**
21-Nov	8.0	8,950	28	1605-1735	-	-	-	-	-	-	-	-	-	-	**0**
24-Nov	9.0	7,590	50	1600-1730	-	-	-	-	-	-	-	-	-	-	**0**
29-Nov	11.0	61,800	30	1556-1731	-	-	-	-	-	-	-	-	-	-	**0**
1-Dec	6.0	48,300	24	1610-1725	-	-	-	-	-	-	-	-	-	-	**0**
3-Dec	5.5	35,500	30	1556-1730	-	-	-	-	-	-	-	-	-	-	**0**
6-Dec	6.0	26,900	40	1600-1702	-	-	-	-	-	-	-	-	-	-	**0**
9-Dec	7.0	24,400	40	1605-1730	-	-	-	-	-	-	-	-	-	-	**0**
TOTAL (A.shad per lift number)					37	34	30	36	23	17	22	60	50	181	

Table 10

Length frequency of juvenile American shad collected for otolith analysis by an 8 ft x 8 ft lift net in the Holtwood Power Station inner forebay, 16 September to 25 October 1999. Only dates when American shad were caught are presented.

Total Length	September					October									
(mm)	16	19	22	25	28	1	4	7	10	13	16	19	22	25	Total per Length
61-70	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
71-80	1	2	2	1	-	1	-	-	-	-	-	-	-	-	7
81-90	-	1	-	-	-	-	-	-	-	2	1	-	-	-	4
91-100	2	7	4	-	-	-	-	5	1	3	1	1	-	-	24
101-110	3	15	13	-	1	9	14	13	7	8	2	5	3	3	96
111-120	1	4	7	-	-	9	8	2	6	9	1	18	5	7	77
121-130	-	1	4	2	1	3	3	-	8	9	2	4	5	4	46
131-140	-	-	-	-	-	2	4	-	2	1	-	2	1	1	13
141-150	-	-	-	-	-	1	1	-	-	-	-	-	-	-	2
Total	*7*	*30*	*30*	*4*	*2*	*25*	*30*	*20*	*24*	*32*	*7*	*30*	*14*	*15*	270

Table 11

Catch per unit effort (CPUE), standard deviation, variance, and confidence interval for juvenile American shad collected by an 8 ft x 8 ft lift net at the Holtwood Power Station inner forebay, 13 September to 9 December 1999.

Date	Number of Shad	CPUE	Standard Deviation	Variance	Confidence interval*
13 Sep	0	0.00	0.00	0.00	NA
16 Sep	7	0.70	0.55	0.30	0.48
19 Sep	85	8.50	6.87	47.17	4.26
22 Sep	108	10.80	19.93	397.07	12.35
25 Sep	4	0.40	0.58	0.33	0.65
28 Sep	2	0.20	0.00	0.00	NA
1 Oct	25	2.50	4.90	24.00	4.29
4 Oct	95	9.50	6.11	37.28	3.99
7 Oct	20	2.00	1.35	1.81	1.00
10 Oct	24	2.40	12.73	162.00	17.64
13 Oct	49	4.90	14.24	202.70	12.48
16 Oct	8	0.80	1.53	2.33	1.73
19 Oct	34	3.40	5.36	28.70	4.70
22 Oct	14	1.40	3.06	9.33	3.46
25 Oct	15	1.50	0.96	0.92	0.94
28 Oct	0	0.00	0.00	0.00	NA
31 Oct	0	0.00	0.00	0.00	NA
3 Nov	0	0.00	0.00	0.00	NA
6 Nov	0	0.00	0.00	0.00	NA
9 Nov	0	0.00	0.00	0.00	NA
12 Nov	0	0.00	0.00	0.00	NA
15 Nov	0	0.00	0.00	0.00	NA
18 Nov	0	0.00	0.00	0.00	NA
21 Nov	0	0.00	0.00	0.00	NA
24 Nov	0	0.00	0.00	0.00	NA
29 Nov	0	0.00	0.00	0.00	NA
1 Dec	0	0.00	0.00	0.00	NA
3 Dec	0	0.00	0.00	0.00	NA
6 Dec	0	0.00	0.00	0.00	NA
9 Dec	0	0.00	0.00	0.00	NA

* 95 percent confidence level

Table 12. Index of abundance for juvenile American shad collected by lift net in the forebay of Holtwood Hydroelectric Station, 1985-1999.

Year	No. Lifts	No. Fish	CPUE	GM CPUE	Variance	Larvae stocked	Cohort Recruitment to Lifts
1985	378	3626	9.59	*	*	5,415,400	
1986	404	2926	7.24	*	*	9,899,430	22,897
1987	428	832	1.94	*	*	5,179,790	17,096
1988	230	929	4.04	*	*	6,450,685	20,466
1989	286	556	1.94	*	*	13,464,650	35,307
1990	290	3988	13.75	*	*	5,619,000	50,323
1991	370	208	0.56	*	*	7,218,000	34,448
1992	240	39	0.16	*	*.	3,039,400	37,740
1993	240	1095	4.56	*	*	6,541,500	79,692
1994	250	206	0.82	*	*	6,420,100	86,708
1995	230	2100	9.13	*	*	10,001,000	
1997	160	1372	8.58	0.607	0.657	8,019,000	
1998	230	180	0.78	0.219	0.138	11,757,000	
1999	140	490	3.50	0.498	0.334	13,501,000	

* data unavailable
1996-lift net not used

Table 13. Summary of electrofishing surveys conducted in large tributaries to the Susquehanna River during spring 2000.

Date	Location	Water Temperature (°C)	Start Time (h)	End Time (h)	Number of American Shad	CPUE (No./h)
09 May	Muddy Creek	19.5	1025	1135	0	0.000
				Subtotal	*0*	*0.000*
16 May	Muddy Creek	15.0	1455	1600	0	0.000
16 May	West Conewago Creek	19.5	0900	1010	0	0.000
16 May	Little Conestoga Creek	15.0	1145	1255	0	0.000
17 May	Conestoga River	17.0	0905	1015	0	0.000
				Subtotal	*0*	*0.000*
22 May	Conestoga River	14.0	0900	1005	1	0.017
23 May	Muddy Creek	13.0	0825	0930	0	0.000
26 May	West Conewago Creek	17.0	0850	0955	0	0.000
26 May	Little Conestoga Creek	15.0	1125	1240	0	0.000
				Subtotal	*1*	*0.004*
01 Jun	Muddy Creek	13.0	1245	1350	0	0.000
31 May	West Conewago Creek	15.5	0905	1010	0	0.000
31 May	Little Conestoga Creek	13.0	1140	1255	0	0.000
01 Jun	Conestoga River	16.0	0915	1030	1	0.017
				Subtotal	*1*	*0.004*
05 Jun	West Conewago Creek	20.5	0905	1015	1	0.017
05 Jun	Little Conestoga Creek	16.7	0012	1245	0	0.000
06 Jun	Muddy Creek	15.0	1340	1445	0	0.000
07 Jun	Conestoga River	15.0	0845	0950	0	0.000
				Subtotal	*1*	*0.004*
12 Jun	Little Conestoga Creek	22.0	1245	1355	0	0.000
12 Jun	West Conewago Creek	27.0	1545	1658	0	0.000
13 Jun	Swatara Creek	21.0	1015	1125	0	0.000
13 Jun	Conodoguinet Creek	21.5	1240	1355	0	0.000
14 Jun	Conestoga River	19.0	0840	0950	0	0.000
				Subtotal	*0*	*0.000*
21 Jun	Swatara Creek	19.7	0925	1035	0	0.000
21 Jun	Conodoguinet Creek	22.7	1145	1250	0	0.000
				Subtotal	*0*	*0.000*
			Large Stream Surveys Total		*3*	*0.002*

Table 14.

Summary of American shad collected in 2000 with a boat-mounted electrofisher downstream of the Shikellamy State Park inflatable dam on the Susquehanna River near Sunbury, Pennsylvania.

Date	River Flow (cfs)	Water Temperature (°C)	Duration (min)	Volts Pulsed DC	Amps	No. of Shad Captured	Shad Observed
8 Jun	27,300	17.0	120	300	7.0	1	1
12 Jun	21,500	22.0	120	200	3.5	1	0
14 Jun	32,300	18.5	120	240	3.5	2	0
16 Jun	57,900	19.5	120	330	7.0	0	2
20 Jun	37,100	20.0	120	350	7.0	0	0
Total			*600*			*4*	*3*
Mean	*35,220*	*19.4*		*284.0*	*5.6*		

Table 15.

Catch per unit of effort (CPUE) of American shad collected in 2000 with a boat-mounted electrofisher downstream of the Shikellamy State Park inflatable dam on the Susquehanna River near Sunbury, Pennsylvania.

Date	No. of Shad	Total Length (mm)	Weight (g)	Sex	CPUE (No./hour)
8-Jun	1	501	860	Male	0.50
12-Jun	1	517	940	Male	0.50
14-Jun	2	422	580	Male	1.00
		465	680	Male	
16-Jun	0	NA	NA	NA	0.00
20-Jun	0	NA	NA	NA	0.00
TOTAL	*4*				
MEAN		*476*	*765*		*0.40*

NA = Not Applicable.

Table 16

Catch of fishes at the Conowingo Dam West Fish Lift, 2000.

Number of days	*34*
Number of lifts	*424*
Fishing time (hours : minutes)	*206:32*
Number of taxa	*37*
AMERICAN SHAD	9,785
ALEWIFE	9,189
BLUEBACK HERRING	14,326
GIZZARD SHAD	366,099
HICKORY SHAD	1
STRIPED BASS	2,453
White perch	40,318
American eel	735
Rainbow trout	5
Brown trout	8
Carp	3,236
Comely shiner	1
Spotfin shiner	32
Quillback	154
White sucker	44
Shorthead redhorse	1,317
White catfish	351
Yellow bullhead	16
Brown bullhead	94
Channel catfish	8,394
Rock bass	119
Redbreast Sunfish	123
Green Sunfish	17
Pumpkinseed	13
Bluegill	292
Smallmouth bass	764
Largemouth bass	63
White crappie	30
Black crappie	8
Yellow perch	161
Walleye	177
Atlantic needlefish	7
Sea lamprey	11
Greenside darter	1
Hybrid striped bass	1
Northern hogsucker	2
Splake	2
TOTAL	*458,349*

Table 17. Catch and effort for American shad taken at the Conowingo Dam West fish lift during primary collection periods[1] in 1985-2000.

Year	Number Days	Number Lifts	Number Fishing Hrs.	Total Catch	Catch/ Day	Catch/ Lift	Catch/ Hour
1985	37	883	330.3	1531	41	2	4.6
1986	53	780	427.0	5187	98	7	12.1
1987	49	1294	480.5	7653	156	6	15.9
1988	54	1216	467.5	5133	95	4	11.0
1989	46	1075	442.4	8301	180	8	18.8
1990	62	1372	567.5	15958	257	12	28.1
1991	59	1222	526.1	13330	226	11	25.3
1992	61	1535	573.4	10333	169	7	18.0
1993	41	961	392.6	5319	130	6	13.5
1994	44	937	423.1	5607	127	6	13.3
1995	64	1216	632.2	15588	244	13	24.7
1996	27	454	253.8	11468	425	25	45.2
1997	44	611	295.1	12974	295	21	44.0
1998	26	361	175.0	6558	252	18	37.5
1999	43	709	312.6	9658	225	14	30.9
2000	31	375	190.4	9784	316	26	51.4

1/ Excludes early and late season catch and effort when less than 10 shad/day were taken

Table 18. Operations and Fish Catch at Conowingo West Lift, 1985-2000

Year	Number Days	Total Fish	Number Taxa	American Shad	Hickory Shad	Alewives	Blueback Herring
1985	55	2.318M	41	1,546	9	377	6,763
1986	59	1.831M	43	5,195	45	2,822	6,327
1987	60	2.593M	46	7,667	35	357	5,861
1988	60	1.620M	49	5,169	64	712	14,570
1989	53	1.066M	45	8,311	28	1,902	3,611
1990	72	1.188M	44	15,964	77	425	9,658
1991	63	0.533M	45	13,330	120	2,649	15,616
1992	64	1.560M	46	10,335	376	3,344	27,533
1993	45	0.713M	37	5,343	0	572	4,052
1994	47	0.564M	46	5,615	1	70	2,603
1995	68	0.995M	44	15,588	36	5,405	93,859
1996	28	0.233M	39	11,473	0	1	871
1997	44	0.346M	39	12,974	118	11	133,257
1998	34	0.575M	38	6,577	6	31	5,511
1999	43	0.722M	34	9,658	32	1,795	8,546
2000	34	0.458M	37	9,785	1	9,189	14,326

Table 19.

Summary of American shad transported from the Conowingo Dam West Fish Lift, 2000.

Date	Number of Shad Transported	Location	Observed Mortality	Percent Survival
5 May	103	PFBC Benner Springs	1	99.0%
6 May	117	Conestoga River	0	100.0%
8 May	59	Muddy Creek	0	100.0%
10 May	2	Conestoga River	0	100.0%
12 May	118	Conestoga River	0	100.0%
12 May	95	PFBC Benner Springs	0	100.0%
15 May	115	Conestoga River	1	99.1%
17 May	143	Conestoga River	0	100.0%
19 May	100	PFBC Benner Springs	0	100.0%
20 May	101	USFWS Lamar Hatchery	0	100.0%
24 May	615	Columbia PFBC Launch	0	100.0%
25 May	90	Columbia PFBC Launch	0	100.0%
26 May	91	PFBC Benner Springs	0	100.0%
27 May	92	Columbia PFBC Launch	0	100.0%
30 May	82	USFWS Lamar Hatchery	0	100.0%
1 June	58	PFBC Benner Springs	0	100.0%
5 June	107	USFWS Lamar Hatchery	0	100.0%
TOTAL	*2,088*		*2*	*99.9%*

Table 20.

Summary of alewife and blueback herring transported from the Conowingo Dam West Fish Lift, 2000.

Date	Number Collected	Water Temperature (°F)	Number Transported	Stocking Location	Observed Mortality	Percent Survival	D.O. (ppm) Start	D.O. (ppm) Finish	Water Temperature (°F) at Stocking Location
				Alewife					
1 May	3,025	57.6	1,020	Little Conestoga	0	100.0%	9.2	11.5	59.0
2 May	1,145	60.8	1,006	Little Conestoga	1	99.9%	11.9	11.0	60.8
TOTAL	*4,170*		*2,026*		*1*				
				Blueback herring					
8 May	2,750	68.9	502	Little Conestoga	0	100.0%	11.2	15.0	69.9
"	"	"	800	Muddy Creek	0	100.0%	13.0	10.2	71.6
9 May	5,240	71.6	1,059	Conestoga River	0	100.0%	10.0	11.0	66.2
"	"	"	1,000	Muddy Creek	0	100.0%	13.3	13.8	73.1
10 May	422	72.5	422	Conestoga River	2	99.5%	11.0	12.5	72.5
26 May	2,175	64.9	1,000	Conestoga River	0	100.0%	14.0	13.0	65.3
TOTAL	*10,587*		*4,783*		*2*				

Table 21. Analysis of juvenile American shad otoliths collected in the Susquehanna River, 1999.

Collection Site	Coll. Date	Immersion marks: Day 3 — Jun. R.	Days 3,6,9,12 — Conodoguinet Cr.	Days 3,6,9,12,18 — W. Conewago Cr.	Days 3,6,9,15,18 — Swatara Cr.	Days 3,9,12,15 — Conestoga Cr.	Days 3,6,9,15 — W. Br. Sus. R.	Days 3,6,12,15,18 — N. Br. Sus. R.	Hatchery Total	Wild	Total
Susq. R.	8/10/99							1	1		1
Clemson I.	8/24/99							1	1		1
									0		
Juniata R.	8/5/99	2							2		2
at Mifflintown	8/12/99	10							10		10
	8/19/99	12							12		12
	8/26/99	7							7		7
	9/2/99	30							30		30
	9/7/99	19							19		19
	9/17/99	32							32		32
	9/23/99	12							12		12
Columbia	7/26/99								0	1	1
	8/3/99								0	1	1
	8/26/99	6							6	2	8
	8/31/99	1							1	1	2
	9/13/99	29			2				31		31
	9/15/99	27		1	1				29	1	30
	9/23/99	9	2		3				14	2	16
	9/29/99	13	2	5					20		20
	10/6/99			1					1		1
	10/12/99	1		2					3		3
	10/20/99	3		1	1				5		5
									0		0
Safe Harbor Reservoir	6/16/99								0	1	1
Above Holtwood		213	4	10	7	0	0	2	236	9	245
Percent		87%	2%	4%	3%	0%	0%	1%	96%	4%	

(continued on the next page)

Table 21. Analysis of juvenile American shad otoliths collected in the Susquehanna River, 1999.

		Immersion marks									
		Day 3	Days 3,6, 9,12	Days 3,6,9, 12,18	Days 3,6,9, 15,18	Days 3,9, 12,15	Days 3,6, 9,15	Days 3,6,12, 15,18			
Collection Site	Coll. Date	Jun. R.	Conodo-guinet Cr.	W. Cone-wago Cr.	Swat-ara Cr.	Conest-oga Cr.	W. Br. Sus. R.	N. Br. Sus. R.	Hatchery Total	Wild	Total
Holtwood	9/16/99	6				1			7		7
	9/19/99	25		1	2	2			30		30
	9/22/99	26				1			27	2	29
	9/25/99	1				2		1	4		4
	9/28/99	1							1		1
	10/1/99	19				1		4	24	1	25
	10/4/99	27						3	30		30
	10/7/99	17	1		1				19		19
	10/10/99	18			1			2	21	2	23
	10/13/99	22	3		2				27	5	32
	10/16/99	4	1		2				7		7
	10/19/99	25	2		1	1			29	1	30
	10/22/99	12	1					1	14		14
	10/25/99	12	2			1			15		15
Conowingo Pond Pushnet	6/19/99	(1 alewife)							0		0
	6/25/99	(1 alewife)							0		0
	7/1/99								0	1	1
Conowingo Pond- trawl	10/26/99					1			1		1
Peach Bottom Impingement	10/20/99	1							1		1
	10/29/99							1	1		1
	11/1/99	1							1		1
	11/17/99	15	1						16	2	18
	11/19/99	13	1		1	1			16	3	19
	11/22/99	8							8	1	9
	11/24/99	2	1					1	4		4
	11/29/99	3				1			4	1	5
	12/1/99	2							2		2
	12/3/99	14							14		14
	12/6/99	103	2		1			2	108	7	115
	12/8/99	7							7		7
	12/10/99	7			1			1	9		9
Conowingo Strainers	10/8/99	1	1			1			3		3
	10/15/99	3							3		3
	10/18/99	1							1		1
	10/22/99	3							3		3
	10/28/99	2							2		2
	11/5/99			1		1			2		2
	11/19/99	12							12	2	14
	11/24/99	7							7		7
	12/3/99	11	1						12		12
	12/6/99	11							11		11
	12/10/99	14							14	1	15
Holt./P. Bot./Con.		456	17	2	12	14	0	16	517	29	546
Percent		84%	3%	0%	2%	3%	0%	3%	95%	5%	
Total		669	21	12	19	14	0	18	753	38	791
Percent		85%	3%	2%	2%	2%	0%	2%	95%	5%	

Note: The following collections were omitted due to the potential for misidentification of blueback herring as American s
Peach Bottom Impingement: 10/22- 2 fish, 10/25- 3 fish, 11/3- 3 fish, 11/8- 60 fish, 11/10- 12 fish, 11/12- 42 fish, 1
Conowingo Strainers: 11/10- 3 fish.

Table 22.Origin of adult American shad collected at Conowingo Dam Fish Lifts, based on otolith analysis. Every 50th or 100th fish to enter the lifts was sacrificed for analysis.

	Hatchery										
	Larvae										
	Susquehanna		below Conowingo Dam		Fingerling		Unmarked**	Naturally reproduced		Total sample size
Year	N	%*	N	%*	N	%*	N	N	%	
1989	36	82	.		.		94	29	18	159
1990	49	73	1	1	.		42	32	26	124
1991	111	67	8	5	3	2	63	68	27	253
1992	154	73	8	4	2	1	19	54	23	237
1993	76	64	21	18	2	2	4	21	17	124
1994	217	81	22	8	3	1	17	28	10	287
1995	255	77	19	6	4	1	1	52	16	331
1996	180	48	22	6	4	1	1	172	45	379
1997	84	34	12	5	4	2	0	150	60	250
1998	29	22	7	5	2	2	0	92	71	130
1999	90	48	9	5	1	1	0	88	47	188
2000	78	40	11	6	0	0	0	104	54	193
Totals	1,359	59	140	6	25	1	241	890	34	2,655

*Unmarked hatchery fish distributed among groups based on annual percentage.
**Distinguished from naturally-reproduced fish by otolith microstructure.

Table 23.

Summary of selected operation and fish catch statistics at the Conowingo Dam East Fish Passage Facility, 1991 to 2000.

Year	Number of Days Operated	Number of Lifts	Operating Time (hrs)	Catch (millions)	Number of Species	American shad	Blueback herring	Alewife	Hickory shad
1991	60	1168	647.2	0.651	42	13,897	13,149	323	0
1992	49	599	454.1	0.492	35	26,040	261	3	0
1993	42	848	463.5	0.530	29	8,203	4,574	0	0
1994	55	955	574.8	1.062	36	26,715	248	5	1
1995	68	986	706.2	1.796	36	46,062	4,004	170	1
1996	49	599	454.1	0.492	35	26,040	261	3	0
1997	64	652	640	0.719	36	90,971	242,815	63	0
1998	50	652	640.0	0.713	33	39,904	700	6	0
1999	52	610	467.0	1.184	31	69,712	130,625	14	0
2000	45	570	367.8	0.494	30	153,546	14,963	2	0

Table 24

Weekly number of juvenile American shad captured by haul seine on the lower Susquehanna River at Columbia, PA, July-October, 1989-1999.

Week of:	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
04 Jul				0		2						**2**
11 Jul	1,048		0	120	0	27		2	44	10	0	**1,251**
18 Jul			0	6		70	53	18	28	14	0	**189**
25 Jul	45	31			0	60	24	15	22	144	1	**342**
01 Aug		0	0	20	0	24	29	32	14	30	1	**150**
08 Aug	61	0	0	2	8	13	35	56	20	0	0	**195**
15 Aug	7	69	0	16	0	46	40	43	171	9	0	**401**
22 Aug					13		42	39	120	10	8	**232**
29 Aug		25	12		20		43	34	129	3	2	**268**
05 Sep		4			15	50	31	3	46	3	*	**152**
12 Sep		93	16		26	25	34	1	89	3	264	**551**
19 Sep		28	30		27	14	46	12	59	1	17	**234**
26 Sep		0	73		11	5	15	15	32	0	20	**171**
03 Oct		0	69	2	22	5	19	10	91	3	1	**222**
10 Oct		0	7		0	2	31	3	0	0	3	**46**
17 Oct			5			10			14	0	5	**34**
24 Oct			0	0			0	0				**0**
Total	**1,161**	**250**	**212**	**166**	**142**	**353**	**442**	**283**	**879**	**230**	**322**	**4,440**

* No sampling this week due to high river flows.

TABLE 25. 1999 Conowingo Strainer Samples.

Sample Date	Collections processed by technician trained in Alosa ID: Positive ID from specimen: American Shad	Positive ID from specimen: Blueback Herring	Collections processed by technician untrained in Alosa ID: ID from otolith morphology: American Shad	ID from otolith morphology: Blueback Herring	otoltih morphology inconclusive*	ID from OTC tag American Shad	Total
10/8/99						3	3
10/15/99						3	3
10/18/99						1	1
10/22/99						3	3
10/28/99	2						2
11/5/99						2	2
11/10/99				2		1	3
11/19/99	14	25					39
11/24/99**	7	9					17
12/3/99	15	15					30
12/6/99**	12	1					14
12/10/99***	16	3					19
Totals	66	53	0	2	0	13	136

* or otoliths not extracted or ground out (some specimens too rotted to extract otoliths)

** Included one specimen too decomposed to ID

*** collection included 23 additional specimens not frozen for otolith analysis

TABLE 26. 1999 Peach Bottom Impingement.

Sample Date	Collections processed by technician trained in Alosa ID: Positive ID from specimen American Shad	Positive ID from specimen Blueback Herring	Collections processed by technician untrained in Alosa ID: ID from otolith morphology American Shad	ID from otolith morphology Blueback Herring	otoltih morphology inconclusive*	ID from OTC tag American Shad	Total
10/20/99	1						1
10/22/99				1		1	2
10/25/99				1		2	3
10/27/99					1		1
10/29/99						1	1
11/1/99						1	1
11/3/99				3			3
11/8/99			2	22	19	17	60
11/10/99			1	1	2	6	10
11/12/99			4	20	6	12	42
11/15/99			7	4		10	21
11/17/99	26	5					31
11/19/99	19	16					35
11/22/99	9	8					17
11/24/99	4 2	2					8
11/29/99	5	1					6
12/1/99	2						2
12/3/99	14	3					17
12/6/99	122	1					123
12/8/99	7	1					8
12/10/99	11						11
Totals	220	37	14	52	28	50	403

* or otoliths not extracted or ground out (some specimens too rotted to extract otoliths)

Table 27. Catch of American shad and blueback herring at the Conowingo Dam East and West Fish Lifts by month and water temperature, 1993-2000.

	Total Catch		Percent of Total Catch (SHAD) by Month and Water Temperature			
Year	American shad	Blueback herring	April	May	June	<65F
2000	163,331	29,289	0.9	96.3	2.8	29.4
1999	79,370	139,171	18.4	81.5	0.1	46.8
1998	46,481	6,211	5.1	92.0	2.9	39.0
1997	103,945	376,513	30.3	65.8	3.9	90.0
1996	37,513	1,132	4.9	70.1	25.0	71.0
1995	61,650	97,863	21.5	73.4	5.1	59.0
1994	32,330	2,851	10.9	62.2	26.9	70.0
1993	13,546	8,626	*	*	*	*

*Insufficient data.

Table 28. Catch of American shad and blueback herring at the Conowingo Dam East Fish Lift by month and average monthly flow, 1997-2000.

	Total Catch		Percent of Total Catch (SHAD) by Month and Average Monthly River Flow					
Year	American Shad	Blueback herring	April	Avg mthly flow (cfs)	May	Avg mthly flow (cfs)	June	Avg mthly flow (cfs)
2000	153,546	14,963	0.1	89,600	97.1	53,000	2.8	36,400
1999	69,712	130,625	18.4	59,200	81.5	19,900	0.1	10,800
1998	39,904	700	5.1	84,400	92.0	73,300	2.9	20,300
1997	90,971	242,815	30.3	33,700	65.8	31,000	3.9	40,600

Table 29.

American shad and blueback herring catches at Susquehanna River hydroelectric projects, 1991- 2000.

	American Shad Catch				Blueback Herring Catch			
Year	Conowingo	Holtwood	Safe Harbor	York Haven	Conowingo	Holtwood	Safe Harbor	York Haven
1991	13,897				13,149			
1992	26,040				261			
1993	8,203				4,574			
1994	26,715				248			
1995	46,062				4,004			
1996	26,040				261			
1997	90,971	28,063	20,828		242,815	1,042	534	
1998	39,904	8,235	6,054		700	62	16	
1999	69,712	34,702	34,156		130,625	73	30	
2000	153,546	29,421	21,079	4,678	14,963	27	159	0

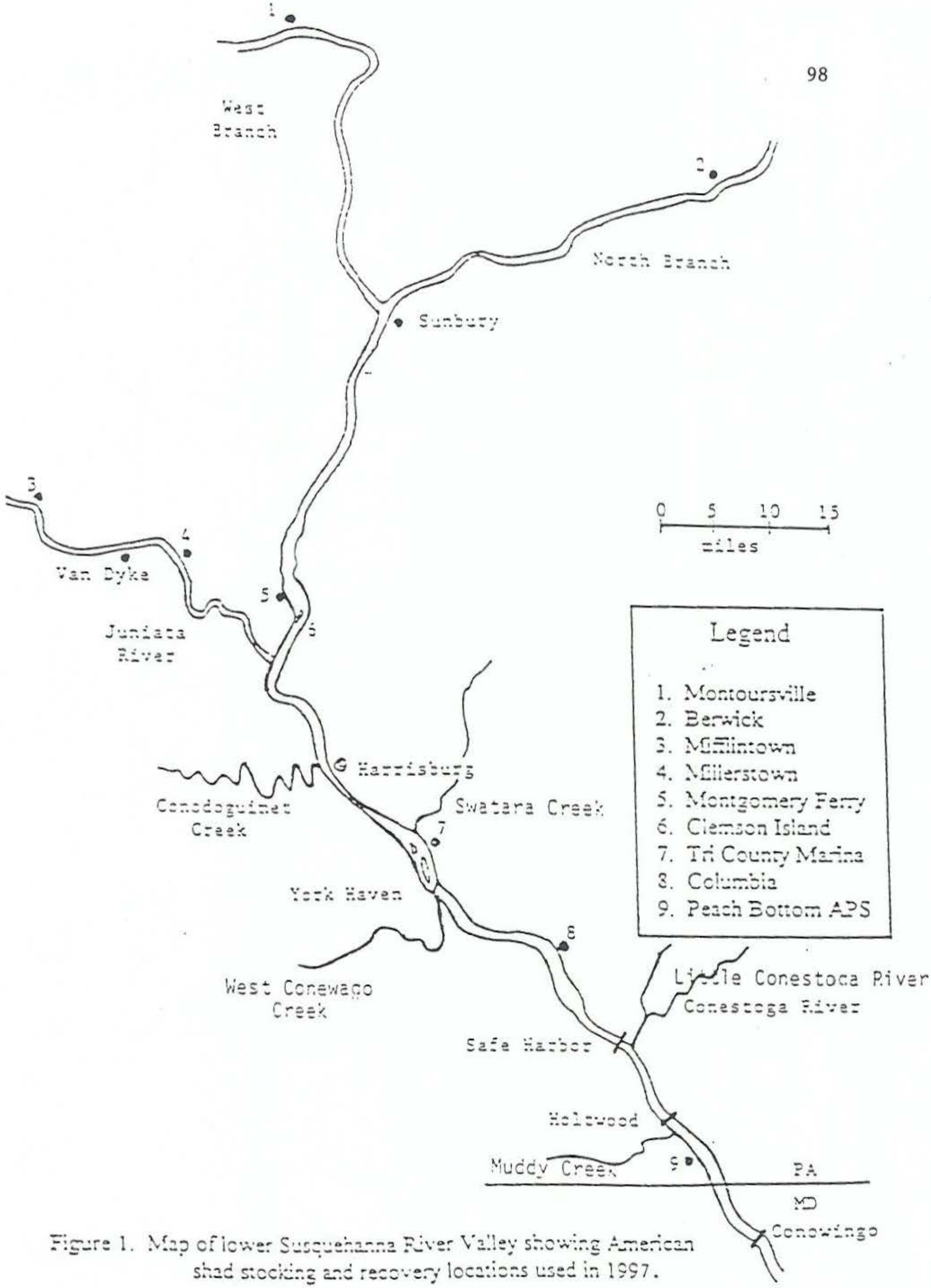


Figure 1. Map of lower Susquehanna River Valley showing American shad stocking and recovery locations used in 1997.

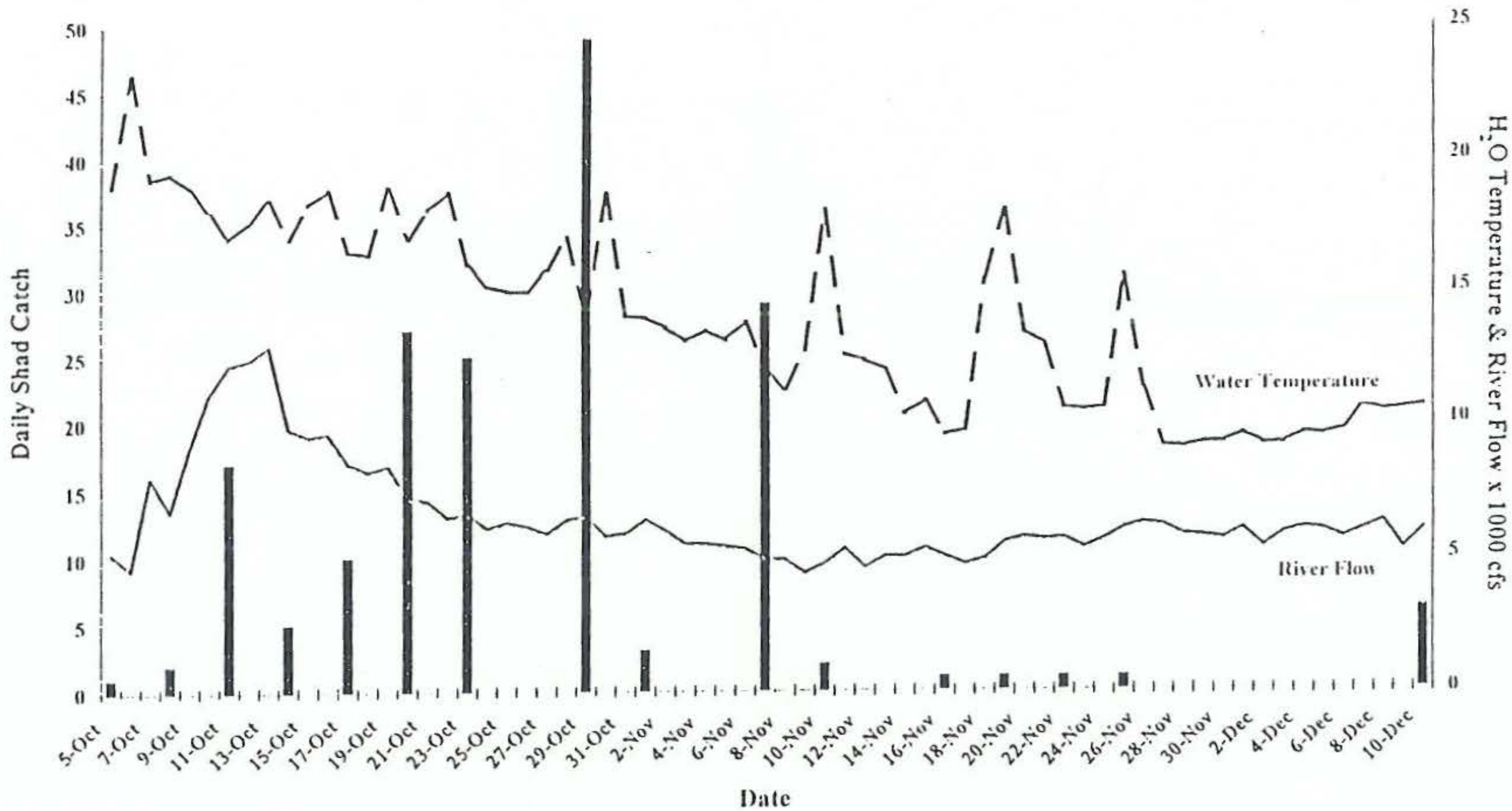


Figure 2

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the American shad lift net catch from the Holtwood Power Station inner forebay, 5 October through 10 December 1998.

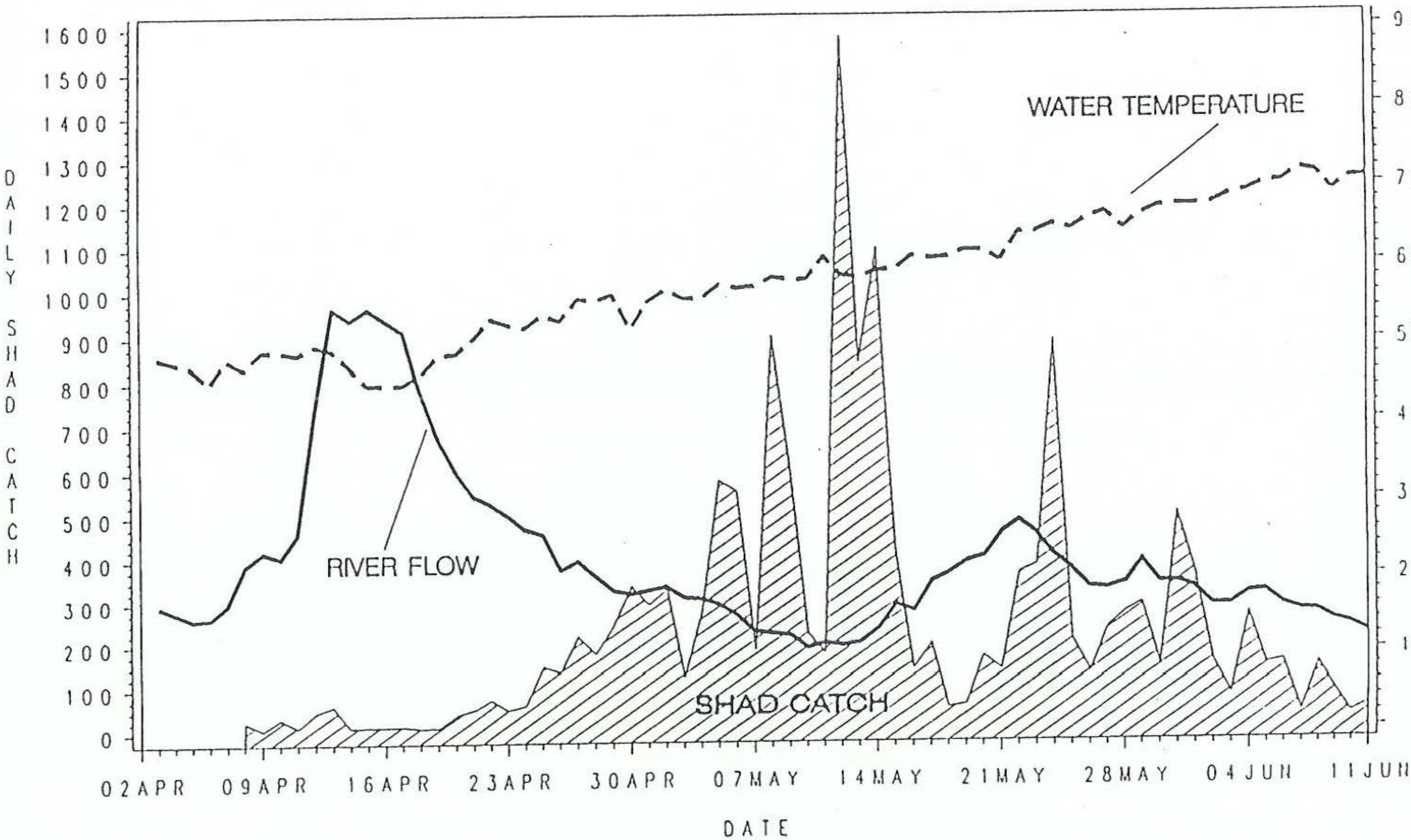


FIGURE 3

A plot of river flow (x 1000 cfs) and water temperature (F) in relation to the daily American shad catch at the Conowingo West Lift, 1995.

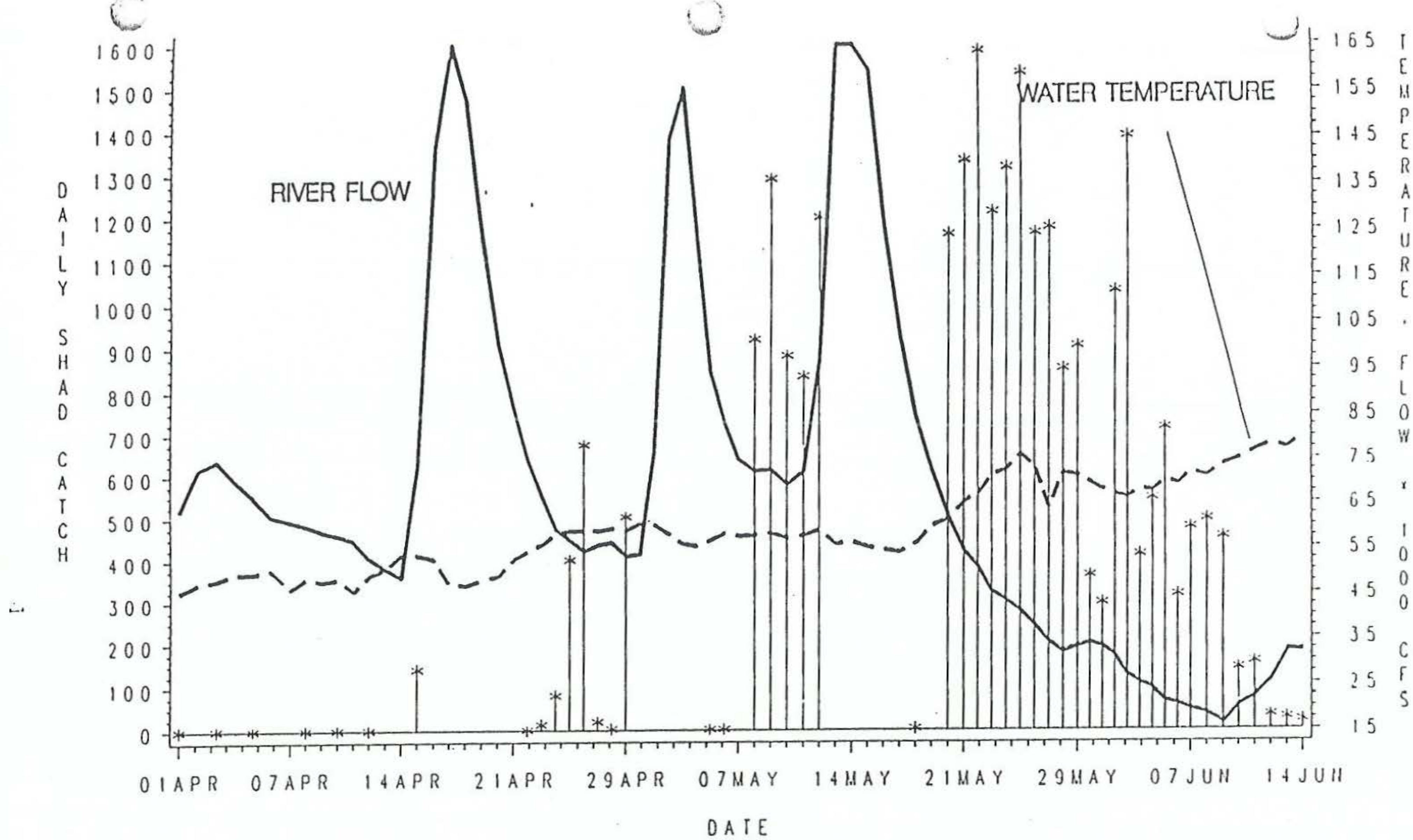


FIGURE 4

A plot of river flow (x 1000 cfs) and water temperature (F) in relation to the daily American shad catch at the Conowingo East Lift, 1996.

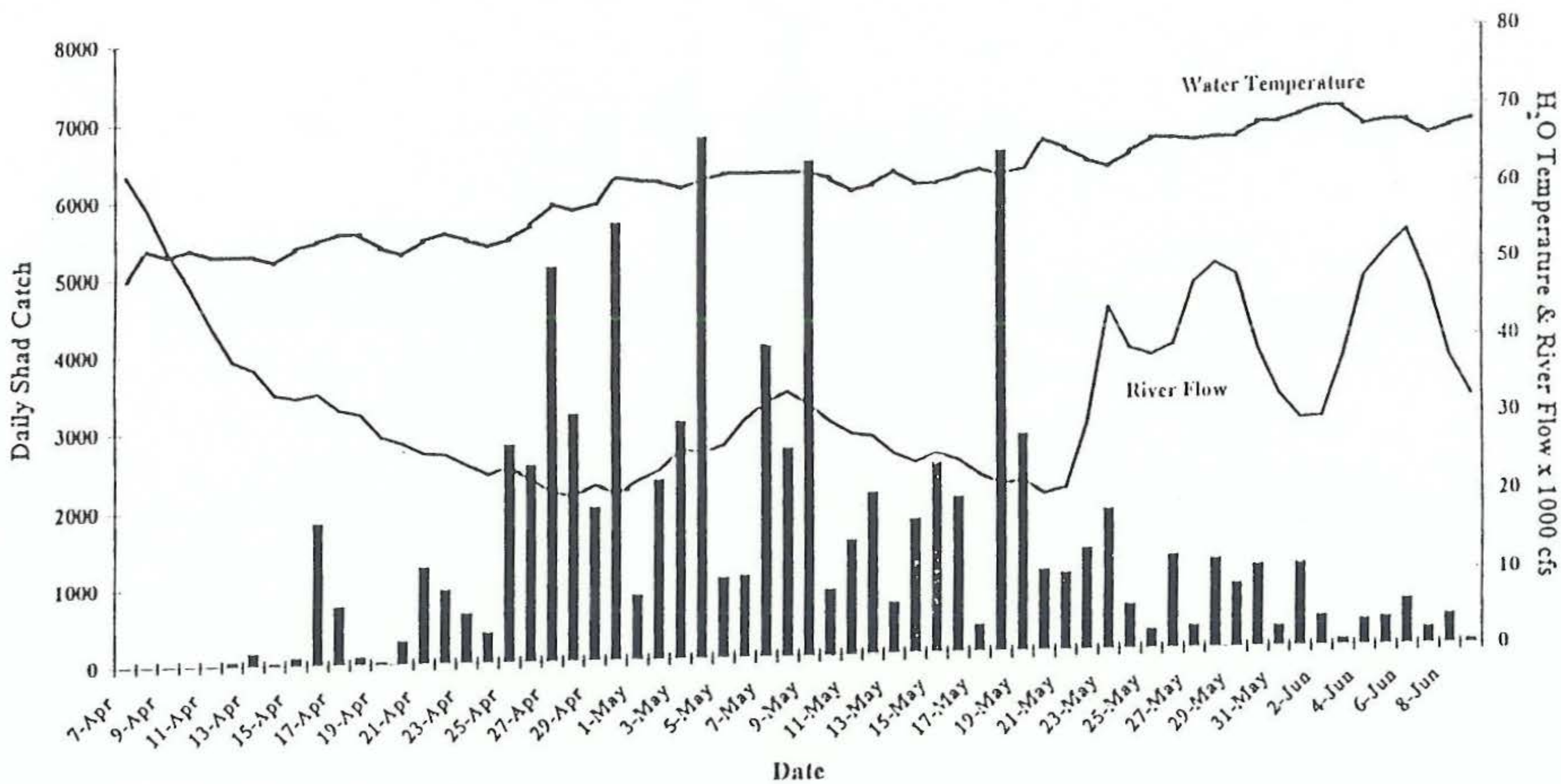


Figure 5

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Conowingo East Fish Lift, spring 1997.

east_rpt.xls/Fg 3 - 2/5/98

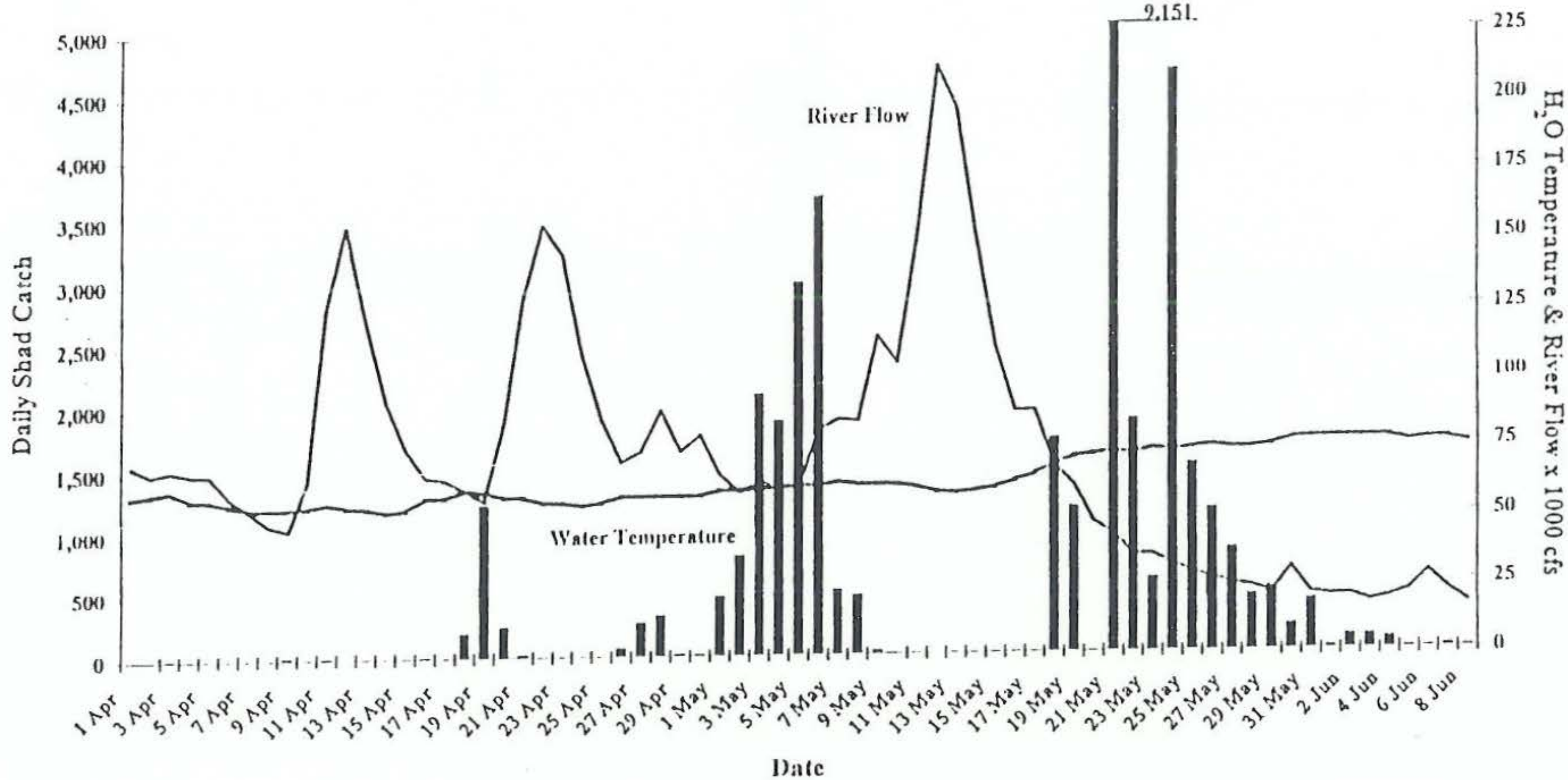


Figure 6

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Conowingo Dam East Fish Passage Facility, spring 1998.

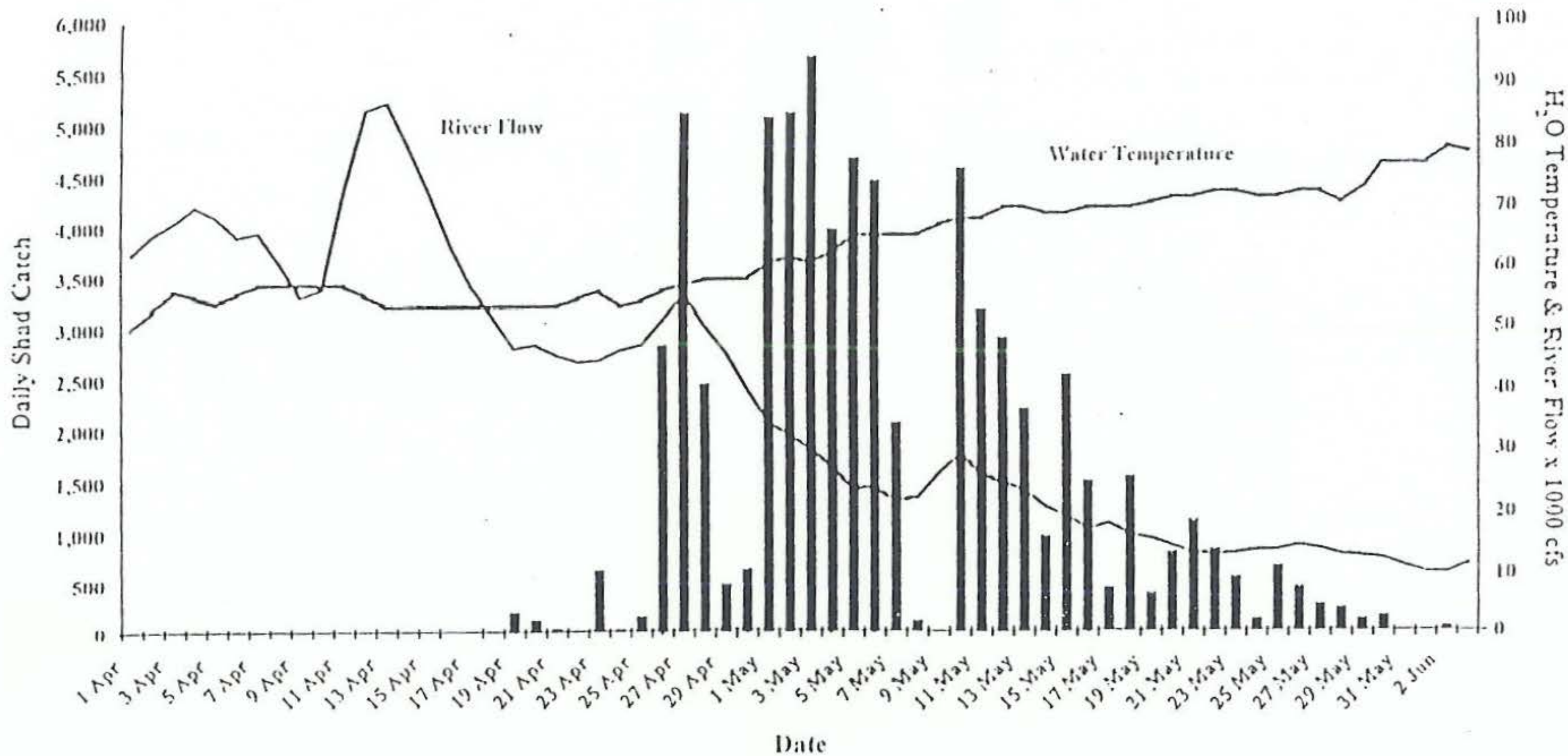


Figure 7

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Conowingo East Fish Lift, spring 1999.

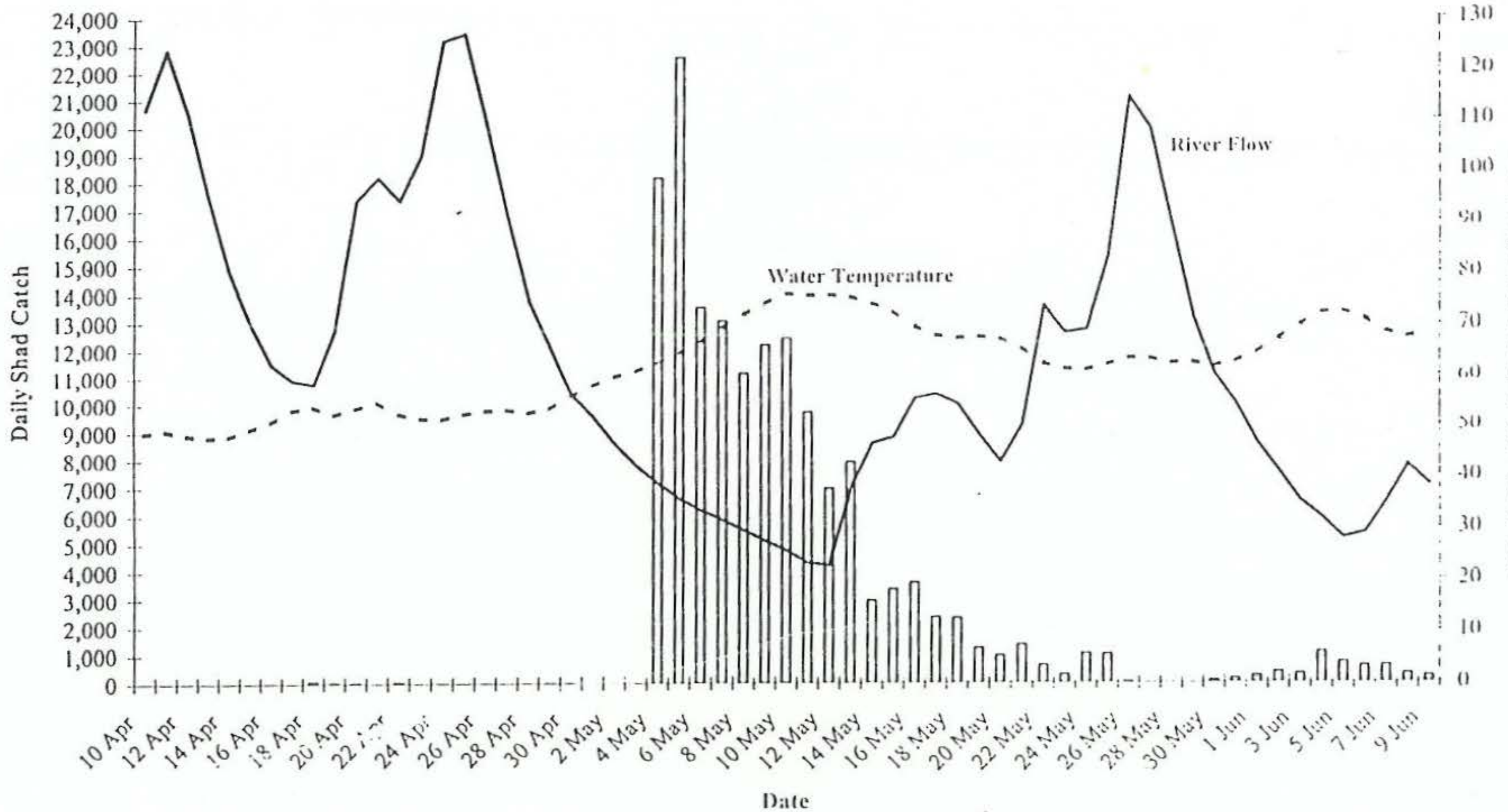


Figure 8

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Conowingo East Fish Lift, spring 2000.

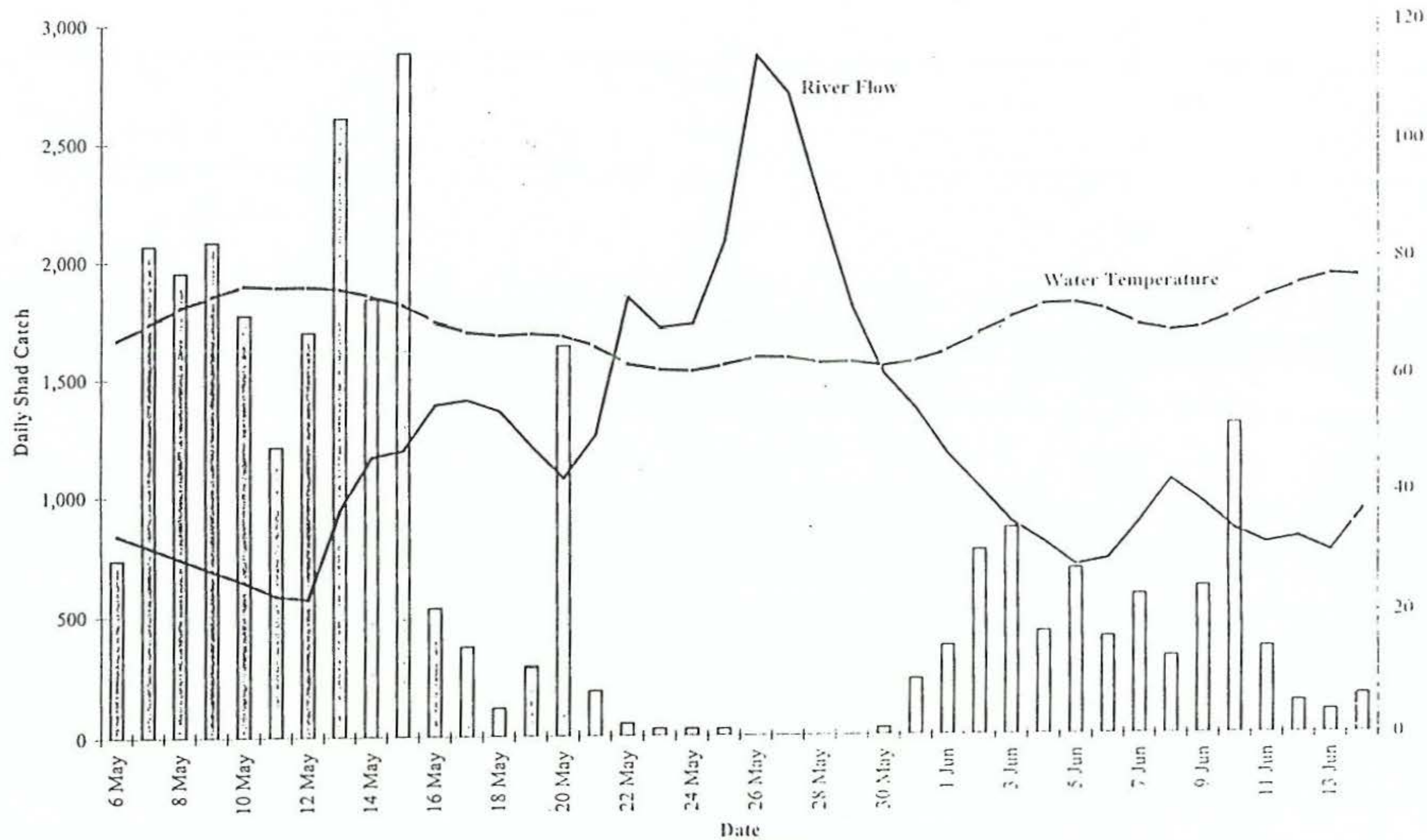


Figure 9

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Holtwood fish lift, spring 2000.

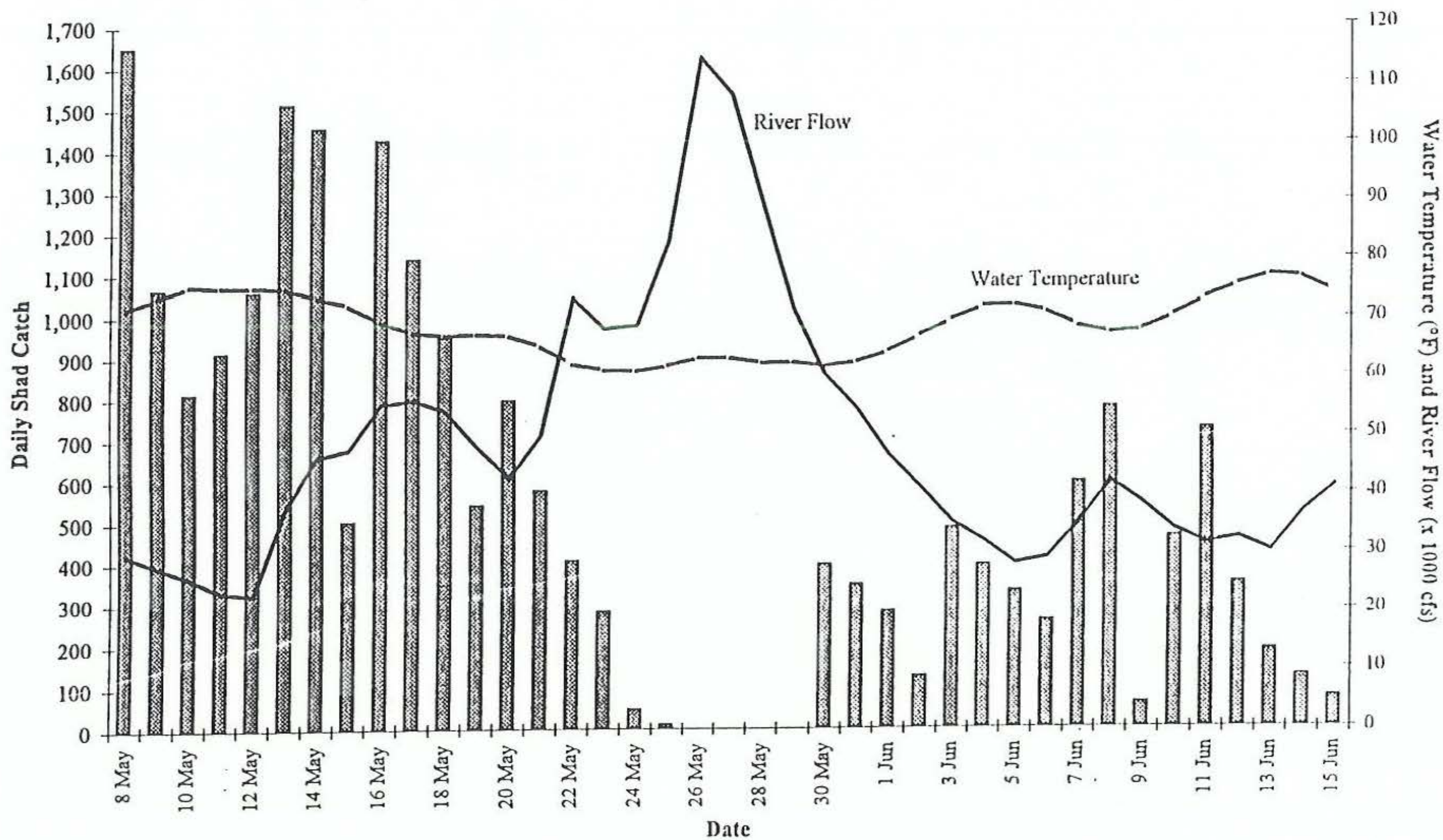
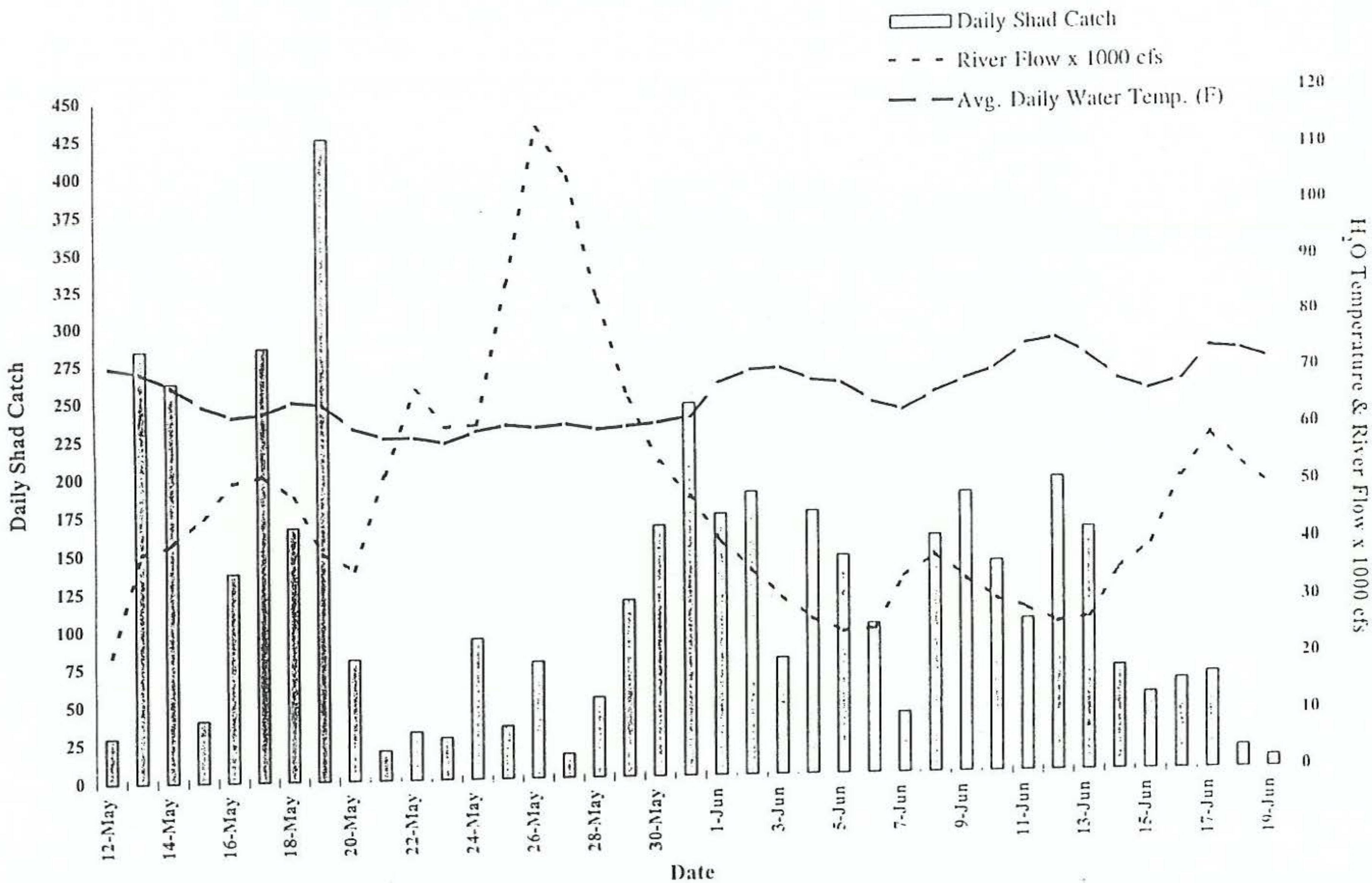


Figure 10

A plot of river flow (x 1000 cfs) and water temperature (°F) in relation to the daily American shad catch at the Safe Harbor fish lift, spring 2000.

Figure 11. A Plot of River Flow (x 1000 cfs) & Water Temperature (F) in Relation to the Daily American Shad Catch at the York Haven Fishway in Spring 2000



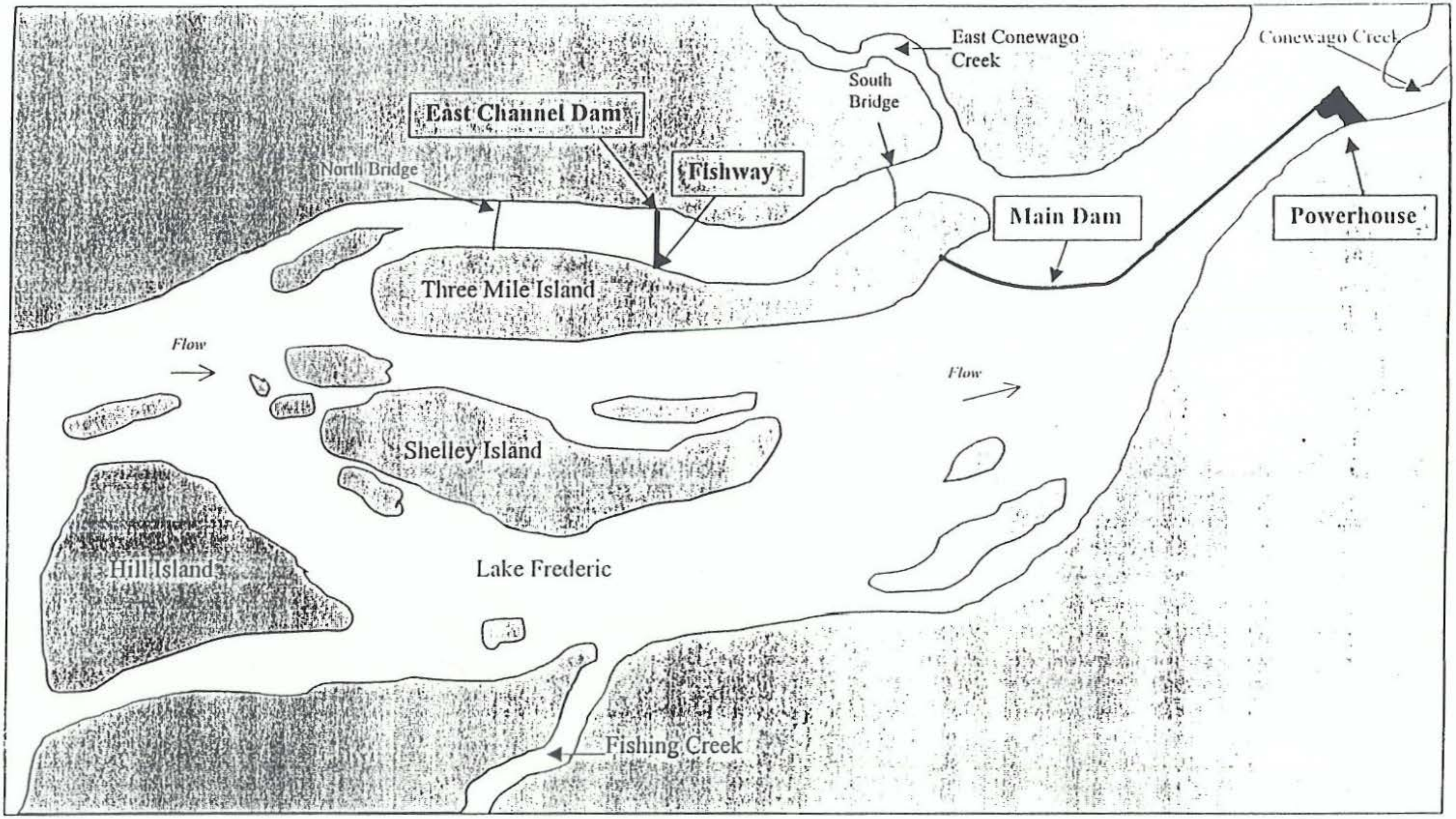


Figure 12. General Layout of the York Haven Hydroelectric Project Showing the Location of the Fishway.

APPENDIX I

Summary of American shad chemoattraction study

After the first year (1999) of this research, we modified the design for the 2000 study so that single test fish were used during testing instead of eight test fish per test. Second, we eliminated the need to move attraction fish from one side to the other by keeping the attraction side stationary in each raceway (this modification was validated using ANOVA, which indicated that there were no significant raceway or attraction side effects). The results of the 2000 study indicated that males were significantly attracted to males, males to females, and females to females (Wilcoxon's sign rank test, $P<0.05$), however, females were not significantly attracted to males ($P>0.05$). The later result may indicate that chemoattraction is gender-mediated. The controls (tests without attraction fish) used in the 2000 study showed no significant difference in the choice of side. Given the modifications made to the experimental design from the first year of this study, We concluded that chemoattraction does in fact exist among American shad. With respect to female shad not exhibiting significant attraction to males, we believe that this result is reasonable. Specifically, female shad may not have biological incentive to seek out males. In essence, if males were attracted to females, then the energetic costs of females seeking males would be unproductive in the literal and figurative sense. The species would benefit more by the females conserving their energy for their reproductive role. Further, the isolation of this chemical or chemicals would seem to be the appropriate next step. However, we also believe that detailed research into the reproductive behavior and the physiological processes involved in olfaction would greatly aid in understanding how chemoattraction is utilized by American shad.

With the advent of fish ladders, much attention has focused on improving ladder design and the importance of flow characteristics in attracting and inducing the desired species to pass (Monk et al. 1989). The American shad *Alosa sapidissima* has been the subject of an ongoing effort to return this species to its original numbers in the Susquehanna River. Little attention has been given to olfaction as a possible means of inducing fish through ladders; however, chemical cues from conspecifics might induce migratory movements (Northcote, 1984; Kleeekoper, 1969; Hara, 1975; Teeter, 1980; Miles, 1968). A significant amount of research has been done on chemical cues in homing/migration with emphasis on odors that emanate from natal streams, from mucus, or from specific bile acids (Sola, 1995; Northcote, 1984; Hara et al. 1976; Doving et al.1974; Liley, 1982). Nordeng (1977) has hypothesized that pheromones released from salmon smolt may also be an attractant to homing conspecifics. Much research has also focused on attraction of conspecifics outside of migration (Kruzhalov, 1990; Cole et al., 1992), however, this information may provide significant clues as to how olfactory response could induce American shad through fish ladders where previous problems have occurred. Chemical attraction may be a new means of increasing the success rate of migratory species that pass through fish ladders.

Upon completion of the first season of experiments, two conclusions were reached. First, the results of the 38 replicates appear to validate the expectation that a chemical cue from conspecifics elicits a behavioral response in American shad *Alosa sapidissima* despite potential complicating factors such as difference in water temperature from river to raceway, being held in tanks overnight before delivery (handling stress), and potential attraction to other test fish as may have been the case when multiple test fish were used in this previous year's study. Of the 38 replicates, data analysis yielded a rejection of the null in 30 (the null hypotheses stating that there would be no difference in choice of subsection – attraction or control side). Analysis of the remaining replicates produced results of no statistical significance in choice of raceway subsection. Of the 30 replicates where analysis yielded rejection of the null, 22 were rejected in favor of the assumption that test fish would choose to migrate towards the subsections where the attraction fish were located. In addition to test results from this study, previous studies indicate that there is chemoattraction among both anadromous and non-migrating conspecifics (Bjerselius et al. *in press*, Cole et al. 1992, Hara et al. 1976, Nordeng 1977, Teeter 1980,). Initial results of this study suggest that American shad fall into this group of fishes. Thus, furthering this study would appear a valid conclusion. These replicates included the use of both multiple and single test fish (**See Appendix I** ***for*** Results and Summary). However, because the results were not as conclusive as expected due to the previously mentioned complicating factors (*in* **Appendix I**), we suggest certain modifications in the experimental design be implemented.

The primary modification to the experimental design will be the use of single test fish. The expectation being that single test fish will be influenced by pheromones from attraction fish only and not by noise produced by other test fish in close proximity. Secondarily, use of single test fish will enable us to increase the number of replications, which may help elucidate test results. Other minor modifications are noted in the methods section.

Methods

American shad *A. sapidissima* in breeding condition will be captured from the west fish lift at the Conowingo dam and transported to the testing facility (Benner Spring Fish Culture Station) where they will be sorted by sex and acclimated a minimum of 12 hours. Weak or stressed fish will be removed from the pool and an attraction group will be randomly selected from the stock (by sex). The remaining stock will be utilized as the test fish for the experiment.

Two modified raceways will be used to determine if American shad will be induced to move towards conspecifics based on chemical cues that attraction fish emit. Each raceway will be designed with four sections. Section E1 will be divided (left and right) with one area holding the attraction fish and the other holding no fish with screens at either end of the 7.9 meter subsections **(See Figure 1 *for*** raceway design). Section E2 will also be divided in two and further subdivided in two at right angles to the other division by screens (a total of four subsections). The two uppermost subsections of E2 will hold no fish (length-6.4m) and the two lower sections will be designated as the test area (length-6.0m). Section E3 will be 14.9m. and designated as the acclimation area with screens at the lower and upper ends. This section will have no subdivisions. Section E4, also 14.9m in length, will be divided in two with one side for male test fish and the other side for female test fish. Section one will be at the upstream end and section four at the downstream end of the raceway.

Attraction fish will be placed in one side of the subdivision (E1). Because of prior statistical analysis (ANOVA) indicating no significant raceway or side effect, attraction fish will only be placed on side A for one raceway and side B for the other, for all replications. Test fish will be placed in section E4 based on sex, male on one side, female on the other. Single test fish (male or female) will be released from the test fish holding area (E4) into the acclimation area (E3). From the acclimation area, the fish will be free to move to either side of the test area (E2)(the screens at the lower end of the test area will be removed) or stay in the acclimation area. Each replication will last 30 minutes **(See Appendix II *for*** original protocol) and the subsequent behavior of the individuals recorded by a digital video camera mounted above the raceway. After each test, the water will be flushed and the raceway cleansed to assure that no chemical cues are left that may bias the results of subsequent testing.

Data will be reported as both counts at 30 second intervals and as total time for side a or b in both raceways. Statistical analysis will be as per the previous year (Wilcoxons sign rank test) with changes as deemed necessary.

Experiment I (a and b)

In Experiment Ia, 12 adult males will be placed in attraction fish holding area A for raceway I and raceway II. Subsequently, 1 female will be released from the appropriate test fish holding area into the acclimation area **(See Figure 1)** for each of 20 trials (10 in raceway I and 10 in raceway II). The consequent behavior will be recorded with digital video cameras for each 30 minute trial.

Experiment Ib will be identical to Experiment Ia with the exception that 1 male will be released from the test fish holding area in experiment Ib. Thus, there will be a total of 20 trials in Ia and 20 in Ib for a total of 40 trials in Experiment I.

Experiment II (a and b)

Experiment II will be identical to Experiment I for all parts with the exception that 12 females instead of 12 males will be placed into the attraction fish holding area. The sequence, number of trials, sex, and number of fish released (one) from the test fish holding area will be identical to Experiment Ia and b.

Controls (all experiments)

Ten controls will be run in both raceways upon shipment and prior to the above tests (a total of 20 control trials). The control trials will consist of using 10 single female and 10 single male test fish with no attraction fish. The above controls will be done for the first two shipments (a total of 40 control trials – 20 female and 20 male). The results of these tests will be analyzed immediately to determine if controls are needed in subsequent trials.

Appendix I

Results

In order to elucidate the analysis, results are given as either attraction, avoidance, or no significance. For attraction and avoidance, the null is rejected, however, ***attraction*** implies that test fish exhibited significant rheotaxis toward attraction fish and ***avoidance*** implies that test fish exhibited significant avoidance of attraction side (primarily by choice of control side). ***No significance*** implies that the null hypothesis is neither accepted nor rejected.

Given the above, for multiple male attraction fish on multiple male test fish (MMMM) replicates, analysis yielded attraction for 6 replicates, avoidance for 1 and no significance for 5 replicates. Analysis of multiple male attraction fish on multiple female test fish (MMMF) replicates returned attraction for 7 and avoidance for 5 replicates. Analysis of multiple female attraction fish on multiple female test fish (MFMF) replicates yielded attraction for 2 replicates and 1 no significance (**See Table 1. *Results for replicates with multiple test fish***). Overall, analysis of 15 replicates where multiple test fish were utilized yielded attraction, 6 yielded avoidance, and 6 returned no significance.

Table 1. ***Results for replicates with multiple test fish***

Multiple Male Attraction on Multiple Male Test Fish				$\alpha = 0.05$		
Test ID	*Attraction Side*	*Sign Rank*	*P value*	*Attraction*	*Avoidance*	*No Significance*
MMMM1	A	3231.5	0.0001	X		
MMMM2	B	-139	0.0001	X		
MMMM3	B	-27.5	0.0107	X		
MMMM4*	B	0	0			X
MMMM5	A	-12	0.3916			X
MMMM6	B	-1.5	0.5			X

Test ID	Attraction Side	Sign Rank	P value	Attraction	Avoidance	No Significance
MMMM7	B	-5	0.125			X
MMMM8	A	740	0.0103	X		
MMMM9	B	-613	0.0001	X		
MMMM10	A	69	0.0374	X		
MMMM11	A	-1397	0.0001		X	
MMMM12	A	-40	0.4268			X
Multiple Male Attraction on Multiple Female Test Fish					**α = 0.05**	
Test ID	***Attraction Side***	***Sign Rank***	***P value***	***Attraction***	***Avoidance***	***No Significance***
MMMF1	A	435.5	0.0047	X		
MMMF2	A	1532.5	0.0001	X		
MMMF3	A	1501.5	0.0001	X		
MMMF4	B	1332	0.0001		X	
MMMF5	B	-3018	0.0001	X		
MMMF6	B	2586.5	0.0001		X	
MMMF7	A	1464	0.0001	X		
MMMF8	A	-573	0.0003		X	
MMMF9	B	2204.5	0.0001		X	
MMMF10	B	-3220.5	0.0001	X		
MMMF11	B	-1871	0.0001	X		
MMMF12	A	-1054	0.0001		X	
Multiple Female Attraction on Multiple Female Test Fish					**α = 0.05**	
Test ID	***Attraction Side***	***Sign Rank***	***P value***	***Attraction***	***Avoidance***	***No Significance***
MFMF1	A	126.5	0.0001	X		
MFMF2	B	-336.5	0.0416	X		
MFMF3	B	4.5	0.7266			X

Table 1. Continued from previous page

For replicates where single test fish were utilized, analysis of multiple juvenile attraction fish on single male test fish (JUVSM) replicates yielded attraction for all 3 replicates and avoidance for both replicates of multiple male attraction fish on single male test fish (MMSM). Analysis of multiple male attraction fish on single female test fish (MMSF) replicates yielded attraction for 1 and no significance for 2 replicates. For multiple female attraction fish on single female test fish (MFSF) replicates, analysis yielded attraction for 2 replicates and no significance for the remaining replicate (**See Table 2. *Results for replicates with single test fish***). Analysis of the above 11 replicates yielded attraction for 6 replicates, avoidance of 2, and no significance for 3 replicates.

Table 2. ***Results for replicates with single test fish***

Multiple Juvenile Attraction on Single Male Test Fish					$\alpha = 0.05$	
Test ID	*Attraction Side*	*Sign Rank*	*P value*	*Attraction*	*Avoidance*	*No Significance*
JUVSM1	A	1826	0.0001	X		
JUVSM2	A	4012.5	0.0001	X		
JUVSM3	A	2779.5	0.0001	X		

Multiple Male Attraction on Single Male Test Fish					$\alpha = 0.05$	
Test ID	*Attraction Side*	*Sign Rank*	*P value*	*Attraction*	*Avoidance*	*No Significance*
MMSM1	B	198	0.0001		X	
MMSM2	B	799.5	0.0001		X	

Multiple Male Attraction on Single Female Test Fish				$\alpha = 0.05$		
Test ID	*Attraction Side*	*Sign Rank*	*P value*	*Attraction*	*Avoidance*	*No Significance*
MFSF1	B	214.5	0.2121			X
MFSF2	B	1287.5	0.0001	X		
MFSF3	B	-119	0.3965			X
Multiple Female Attraction on Single Female Test Fish				$\alpha = 0.05$		
Test ID	*Attraction Side*	*Sign Rank*	*P value*	*Attraction*	*Avoidance*	*No Significance*
MFSF1	A	3272.5	0.0001	X		
MFSF2	A	1039.5	0.0001	X		
MFSF3	A	186	0.4072			X

Table 2. Continued from previous page

Summary

Analysis of the above replicates yielded results that appear to indicate an attraction of test fish to conspecifics, however, a portion of the replicates resulted in findings of no significance ($P > 0.05$) or rejection. In essence, American shad appear to show no behavioral response to conspecifics from which they were visually obstructed for a portion of the replicates. In lieu of the above, certain assumptions have been made based on observation and a limited understanding of the physiology of American shad with respect to migration. First, one sex may be attracted to the other dependent on cues such as temperature. Temperature may physiologically influence the timing of one sex being attracted to another (females to males or males to females). When considering the previous possibility, American shad were taken from the Susquehanna at Conowingo Dam where water temperatures were 65-68° F and placed into raceways (after acclimation) were water temperatures ranged from 54-56° F. Thus the possibility that one sex may not have been attracted to the other due to physiological timing being affected by temperature. Additionally, the above reasoning might have heightened attraction to conspecifics of the same sex in close proximity; given that shad are a schooling fish. Second, for the multiple test fish replicates, conspecifics in close proximity may have created enough noise to reduce or eliminate rheotaxis to attraction fish upstream (even for replicates where analysis yielded acceptance). In simpler terms, the pheromone concentration from the attraction fish may have been weaker than the concentration from test fish in close proximity. Although this reasoning may seem contradictory to American shad behavior in the wild and despite attempts to mimic the natural setting in the raceway, the previously mentioned temperature differences, flow limitations, and handling stress may have significantly altered the behavior of the American shad (test fish). For these reasons, we have proposed changes in the experimental design to either greatly reduce or eliminate the above complications. Primarily, taking American shad from the Susquehanna earlier in the year when the temperature of the river is within 2-3° F of the water temperature in the raceway, reducing holding time before delivery, and using single test fish only.

With respect to replicates where single test fish were utilized, the above complications may have again influenced the behavior of the test fish (although using single test fish should certainly eliminate some of the noise created by conspecifics) and the initial number of replicates in each test were not enough to accurately or confidently portray American shad behavior.

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Appendix II

Materials and Methods

American shad in breeding condition will be captured from the fish ladder at the Conowingo Dam and transported to holding facilities where they will be acclimated. Weak or stressed fish will be removed from the pool and an attraction group will be randomly selected from the stock. The remaining stock will be graded by sex and utilized as the test fish for the experiment. The Pennsylvania Fish and Boat Commission will provide the aforementioned fish.

Two modified raceways will be used to see if American shad will be induced to move towards conspecifics based on chemical cues that attraction fish emit. Each raceway will be designed with four sections. Section E1 will be divided (left and right) with one area holding the attraction fish and the other holding no fish with screens at either end of the 7.9 meter subsections (See figure 1). Section E2 will also be divided in two and further subdivided at right angles to the other division by screens (a total of four subsections). The two uppermost subsections will hold no fish (length-6.4m) and the two lower sections will be designated as the test area (length-6.0m). Section E3 will be 14.9m and designated as the acclimation area with screens at the lower and upper ends. This section will have no subdivisions. Section E4, also 14.9m in length, will be divided in two with one side for male test fish and the other side for female test fish. Section E1 will be at the upstream end and section E4 at the downstream end of the raceway. The flow rate will be set to mimic that of the fish ladder as closely as possible.

Attraction fish will be placed in one side of the subdivision (E1). Test fish will be placed in section E4 based on sex, male on one side, female on the other. Test fish (male or female) will be released from the test fish holding area (E2) into the acclimation area for a period of 10 minutes (E3). From the acclimation area, the fish will be free to move to either side of the test area (the screens at the lower end of the test area will be removed) or stay in the acclimation area. The test fish will be recorded on video for 60 minutes. These tests will be conducted several times with the attraction fish being moved from one side to the other and either male or female test fish being released. After each test, the water will be flushed and the raceway cleansed to assure that no chemical cues are left that may bias the results of the subsequent testing.

The number of shad in either acclimation area or test areas will be reported at one minute intervals from the video. In the subsequent analysis chi square will be utilized to test the significance of the data. Note that this method of analysis may change dependent on the distribution of actual data and any changes in experimental design including raceway design.

Experiment I (a, b, and c)

In Experiment I*a*, 8 adult males will be placed in attraction fish holding area A for raceway I and raceway II. Subsequently, 12 females will be released from the appropriate test fish holding area into the acclimation area (See figure 1) for each of 6 repetitions (3 in raceway I and 3 in raceway II). The consequent behavior will be reported for each repetition. Then the 8 adult males will be moved to attraction fish holding area B in both raceways and 3 repetitions will be done again with 12 females released into the acclimation area (a total of 12 repetitions between the two raceways). If the 12 fish released from the test fish holding area school without showing preference to either test area then individual fish will be tested in accordance with the above protocol.

Experiment I*b* and *c* will be identical to Experiment I*a* with the exception that 12 males will be released from the test fish holding area in experiment I*b*. In Experiment I*c*, 6 males and 6 females will be released from the test fish holding areas. Thus, there will be a total of 12 repetitions in I*a*, 12 in I*b*, and 12 repetitions in I*c* for a total of 36 repetitions in Experiment I.

Experiment II (a, b, and c)

Experiment II will be identical to Experiment I for parts *a*, *b*, and *c* with the exception that 12 females instead of 12 males will be placed into the attraction fish holding area. The sequence, number of repetitions, sex, and numbers of fish released from the test fish holding area will be identical to Experiment I*a*, *b*, and *c*.

Experiment III (a, b, and c)

Experiment III will be identical to Experiment I with the exception that 4 females and 4 males will be placed in the attraction fish holding area as per the protocol of Experiment I.

Experiment IV

Experiment IV will also be identical to Experiment I with the exception that an unspecified number of smolt, approximating the biomass of 8 adult shad, (the number of fish used in the attraction fish holding area for Experiments I, II, and III) will be placed in the attraction fish holding area. As previously mentioned, Nordeng (1977) hypothesized that pheremones from salmon smolt may be an attractant to migrating adult salmon Again, there will be a total of 36 repetitions as per the protocol from Experiment I.

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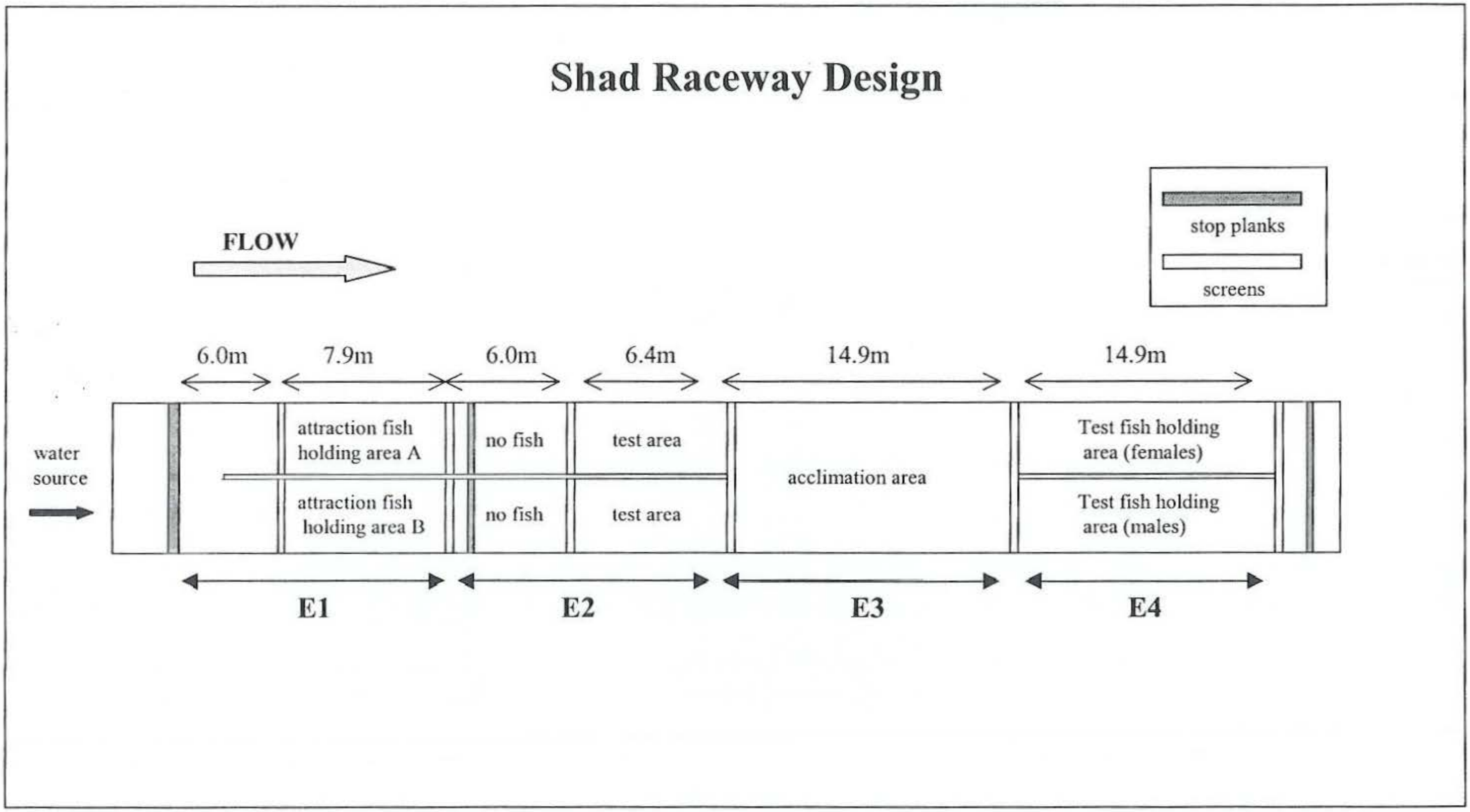

Figure 1. Figure 1 depicts the preliminary design of the raceway. Section E1 contains the attraction fish holding area with a 6m section upstream for intake of water. Section E2 is divided into 2 sections with no fish and two sections designated as the test area. E3 at 14.9m is designated as the acclimation area and section E4 contains the test fish holding area with a section for females and for males.

APPENDIX II

Appendix 1

Survival of American shad larvae released at various sites in the Susquehanna River drainage, 2000.

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Introduction

Development of tetracycline marking has permitted evaluation of the relative success of the hatchery component of the American shad restoration program (Hendricks et al., 1991). Larvae are marked by 4h immersion in 256ppm oxytetracycline hydrochloride. Detectable fluorophore from these marks is visible in the one otolith increment produced on the day of marking. Multiple marks, 3 or 4d apart, have been used to evaluate the relative survival of groups uniquely marked according to release site, egg source river, release time of day, or release habitat (Hendricks et al., 1992, Hendricks et al., 1993).

From 1976 to 1992, American shad larvae reared at the Van Dyke Research Station for Anadromous Fish were stocked into the Juniata River at 18-21d of age. The that larvae released at 7 days of age may not survive any better than those released later. One explanation for this is that multiple releases at any one site may be attracting predators to that site, resulting in reduced survival. It was theorized that spreading larvae out by stocking at a number of sites may result in improved survival.

A study was designed in 1997 to test this hypothesis, however, logistical considerations forced us to deviate from the plan and no conclusions could be drawn regarding the benefit of spreading larvae out to various stocking sites (Hendricks, 1998). Due to insufficient unique marks, we have never been able to conduct a controlled experiment to test the benefits of stocking larvae at various sites. Results in 1997, 1998 and 1999 suggested that small groups of larvae stocked in tributaries at older ages can survive as well as those stocked in the Juniata River at 7-10 days of age.

In 1998, we altered our stocking protocol, spreading larvae out by stocking at various sites with minimal stocking at repeat sites. This paper reports the results of stocking uniquely marked American shad larvae at various sites in 2000 and summarizes results from 1995 to 2000.

Materials and Methods

The majority (63%) of production larvae stocked in 2000 was marked at three days of age and stocked at various sites in the Juniata River and the middle Susquehanna River near Montgomery Ferry. Susquehanna River sites were stocked when high, turbid water prevented stocking in the Juniata River. Sites were generally stocked in succession, moving upriver. Repeated stockings at one site, within a short time interval, were avoided. Smaller numbers of uniquely marked larvae were stocked at other sites, The overall recovery rate for 2000 (0.45) was second only to 1997 (0.57).

Larvae stocked in the North Branch did extremely well in previous years, but only average in 2000. Larvae stocked in the West Branch have not done well, exhibiting relative survival of 0.00 to 0.38 during the period 1996 to 2000.

Larvae stocked in smaller tributaries did well in some years and poorly in others, for example, Conestoga R. larvae exhibited the best survival in 1995 and 1999, poor relative survival in 1997 (0.35) and 2000 (0.24) and were not detected in 1996 and 1998. The high survival, 1995 and 1999 releases were at the Rt. 322 bridge near Ephrata (river mile 38), as was the low survival release in 2000. The other low survival releases were at Conestoga Pines Park in Lancaster (river mile 22). Larvae stocked in Conodoguinet Creek larvae exhibited good relative survival in 1999 (0.77) fair relative survival in 1996 and 2000(0.50 and 0.51), but poor relative survival in other years (0.18 to 0.25; 1995, 1997 and 1998). Water quality in Conodoguinet Creek is good at the larval stocking site, but low dissolved oxygen may be problematic in the lower reaches of the stream. Larvae stocked in Swatara Cr. did well in 1998 and 1999(relative survival 0.93 and 0.81, respectively), but were not detected in 2000, probably due to the low number stocked (33,000). In Conewago Cr., larvae did well in 1998, poorly in 1999, and well in 2000 (relative survival 1.00 , 0.15, and 0.86 respectively), despite release at the same site. Thus, recovery rate of shad larvae at each stocking site fluctuates from year to year with no one site consistently better than the others. The exception is that the West Branch Susquehanna River exhibits consistently low recovery rates, possibly due low fertility.

Crecco and Savoy (1985) found that survival of 5 day cohorts of American shad larvae in the Connecticut River was highest at low river flow, high water temperature and

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Table 1-1. Relative survival of American shad fry stocked at various sites in the Susquehanna River basin, as determined by tetracycline marking of juveniles collected at Holtwood, Peach Bottom and Conowingo, 1995.

Stocking Site	Age at Release (days)	Release Dates	Fry Released N	Fry Released %	Juveniles Recovered N	Juveniles Recovered %	Recovery Rate	Relative Survival
Juniata R./ Susq. R. @ Mont. Ferry	7-9	5/19-6/16	9,070,000	91%	308	87	0.34	0.27
Conodoguinet Cr.	19	6/6	220,000	2%	5	1	0.23	0.18
mouth of Conodoguinet Cr.	19	6/6	230,000	2%	9	3	0.39	0.31
Conestoga R.	22	6/15	198,000	2%	25	7	1.26	1.00
mouth of Conestoga R.	22	6/15	190,000	2%	8	2	0.42	0.33
Muddy Cr.	22	6/19	93,000	1%	0	0	0.00	0.00
		Total	10,001,000		355		0.35	

*Note: Fry released in Muddy Cr. could only have been recaptured at Peach bottom.

Table 1-2. Relative survival of American shad fry stocked at various sites in the Susquehanna River basin, as determined by tetracycline marking of juveniles collected at Holtwood, Peach Bottom and Conowingo, 1996.

Stocking Site	Age at Release (days)	Release Dates	Fry Released N	Fry Released %	Juveniles Recovered N	Juveniles Recovered %	Recovery Rate	Relative Survival
Juniata R./ Susq. R. @ Mont. Ferry	6-8	5/24-6/24	5,730,200	77%	45	66	0.08	0.33
Conodoguinet Cr.	16	6/14	171,700	2%	2	3	0.12	0.50
Conestoga R.	17	6/17	277,100	4%	0	0	0.00	0.00
Standing Stone Cr.	21	7/2	42,900	1%	0	0	0.00	0.00
W. Br. Susq. R.	17	6/15	561,100	8%	5	7	0.09	0.38
N. Br. Susq. R.	13	6/19	682,500	9%	16	24	0.23	1.00
		Total	7,465,500		68		0.09	

Table 1-5. Relative survival of American shad fry stocked at various sites in the Susquehanna River basin, as determined by tetracycline marking of juveniles collected at Holtwood, Peach Bottom and Conowingo, 1999.

Stocking Site	Age at Release (days)	Release Dates	Fry Released N	Fry Released %	Juveniles Recovered N	Juveniles Recovered %	Recovery Rate	Relative Survival
Juniata R./	5-10	5/17-6/1	10.229.000	87%	456	100	0.45	0.75
Juniata R./ Susq. egg source	-	-	0	0%		0	0.00	0.00
Conodoguinet Cr.	14	6/11	373.000	3%	17	4	0.46	0.77
Conestoga R.	20	6/10	236.000	2%	14	3	0.59	1.00
Conewago Cr.	19	6/8	219000	2%	2	0	0.09	0.15
Swatara Cr.	20	6/10	249000	2%	12	3	0.48	0.81
W. Br. Susq. R.	17-22	6/21	984.000	8%	0	0	0.00	0.00
N. Br. Susq. R.	19	6/4	1.211.000	10%	16	3	0.13	0.22
		Total	13.501.000		517		0.38	

Table 1-6. Relative survival of American shad fry stocked at various sites in the Susquehanna River basin, as determined by tetracycline marking of juveniles collected at Holtwood, Peach Bottom and Conowingo, 2000.

Stocking Site	Age at Release (days)	Release Dates	Fry Released N	Fry Released %	Juveniles Recovered N	Juveniles Recovered %	Recovery Rate	Relative Survival
Juniata R./ middle Susq. R. near Mont. Ferry	7-15	5/19-6/1	7,368.860	63%	393	86	0.53	1.00
Conodoguinet Cr.	15	6/5	111,017	1%	3	1	0.27	0.51
Conestoga R.	23	6/12	231.178	2%	3	1	0.13	0.24
Conewago Cr.	18	6/5	109.352	1%	5	1	0.46	0.86
Swatara Cr.	25	6/12	33.321	0%	0	0	0.00	0.00
W. Br. Susq. R.	21	6/26	960.982	8%	10	2	0.10	0.20
N. Br. Susq. R.	16-19	6/2-6/29	974.614	8%	25	5	0.26	0.48
		Total	9,789.324		439		0.45	

APPENDIX III

Job V., Task 2. Analysis of adult American shad otoliths, 2000

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Abstract

A total of 197 adult American shad otoliths were processed from adult shad sacrificed at the Conowingo Dam West Fish Lift in 2000. Based on tetracycline marking and otolith microstructure, 54% of the 193 readable otoliths were identified as wild and 46% hatchery. Double marked fish (released below Conowingo Dam) represented 12.4% of the marked fish in the Conowingo West Lift samples.

Using age composition and otolith marking data, the lift catch was partitioned into its component year classes for both hatchery and wild fish. Results indicated that for the 1986-1995 year classes, stocking of approximately 318 hatchery larvae was required to return one adult to the lifts. For fingerlings, stocking of 134 fingerlings was required to return one adult to the lifts. For wild fish, transport of 0.86 adults to upstream areas was required to return one wild fish to the lifts. These numbers are maximum estimates, because the 1994 and 1995 year classes are not fully recruited. Actual survival is even higher since not all surviving adults enter the lifts.

1986, 97.8% tag retention was achieved (Hendricks, et al., 1987) and analysis of outmigrants indicated that 84% of the upstream production (above Conowingo Dam) was of hatchery origin vs 17% wild (Young, 1987). Similar data has been collected in subsequent years.

The contribution to the overall adult population below Conowingo of hatchery-reared and wild fish resulting from restoration efforts was more complicated. The adult population of shad below Conowingo Dam includes: 1) wild upper bay spawning stocks which are a remnant of the formerly abundant Susquehanna River stock; 2) wild fish of upstream origin which are progeny of adults from out-of-basin or Conowingo trap and transfer efforts, 3) hatchery-reared fish originating from stockings in main stem or tributary areas upstream from Conowingo Dam and 4) hatchery-reared fish originating from stockings below the Conowingo Dam. The latter group were fish which received a "double" tetracycline mark and were first planted below Conowingo Dam in 1986.

Since mark retention did not approach 100% until 1987, adult hatchery shad from cohorts produced before 1987 did not exhibit 100% marking. For the years in which these fish were recruited into the fishery, marking rates could therefore be used only to determine minimum contribution of hatchery-reared fish. For fish which did not exhibit a mark, otolith microstructure (Hendricks et al., 1994) was used to distinguish optic light. The best contrast was obtained by directing the light from the side, parallel to the sagittal plane of the otolith. Ageing was done by a single researcher. After initial ageing, length at age was analyzed and apparent outliers were re-examined. We have assembled a collection of approximately 195 otoliths whose age is known based on the presence of a unique tetracycline mark. These were used as reference material.

Historical fish lift catch data was compiled from SRAFRC Annual Progress Reports for the years 1972 through 1999. Age composition data was gathered as follows: for 1996 to 2000, age composition data was collected from the otolith analysis above. For 1991-1995, age composition data was taken from scale samples collected from the fish used for otolith analysis. These samples were collected by sacrificing every 100th fish collected in the lifts, and as such, represent a truly random sample. For 1989 and 1990, age composition data was determined from the overall fish lift database as reported in SRAFRC Annual Progress Reports by RMC Environmental Services. This database includes holding and transport mortalities which skew the data slightly toward females and older fish (Hendricks, Backman, and Torsello, 1991).

Recruitment to the lifts by year class was determined for hatchery and wild origin fish by partitioning the lift catch for each year into its component year classes based upon age composition and otolith marking data. Total recruitment by year class was collections was low prior to 1996, the numbers of wild fish have been increasing since 1993 (Figure 2).

Age frequencies for Susquehanna River fish were analyzed using otolith age data (Table 3). Overall mean age was 4.1 years for males and 5.1 years for females. For wild fish, mean ages were 4.0 for males and 4.8 for females (Table 4). For hatchery fish, mean age was 4.3 for males and 5.4 for females. Overall sex ratio was 2.3 to 1, males to females. Length frequencies and mean length at age are tabulated in Tables 5 to 8. As expected, females were larger than males. No consistent difference in length at age is apparent between wild and hatchery fish.

Fish lift catch, age composition and origin of sacrificed shad are presented in Table 9. The catch of adult shad at the lifts was partitioned into year classes using scale or otolith age data and tabulated according to origin based on otolith analysis (Tables 10-12). Analysis of otoliths to assess hatchery contribution was not conducted prior to 1989. As a result, data for year classes prior to 1986 could not be partitioned into hatchery and wild and are not presented. Year classes after 1994 are not fully recruited, however, recruitment from the 1994 and 1995 year classes were above the long term average, and are included in the analysis. For the period 1986-1995, the number of hatchery larvae required to produce one returning adult ranged from 151 to

1995, transport of an average of 0.86 adults was required to produce one returning adult, above replacement. The actual stock/recruitment ratio of wild fish is unknown since some of the wild fish which entered the lifts would have been of Upper Bay origin and not all recruited fish entered the lifts. These factors may act to cancel each other out, but the magnitude of each is not known.

Stress during trucking may account for reduced performance of transported spawners. The high fecundity of the species has the potential to overcome this, since just a few successful spawners can produce huge numbers of offspring. Another possible explanation is that there may be some threshold number of spawners required to ensure successful spawning. Whatever the cause. stock/recruitment ratios are improving for recent years and must continue to do so to allow for successful restoration.

From 1988 to 1994 American shad larvae reared at the Van Dyke Hatchery were uniquely marked according to egg source river. Since the majority of the fish returning to Conowingo Dam are ages 4 to 6, those cohorts are now fully recruited, and we can analyze adult returns based on egg source river. Prior to 1995, aging of adult American shad collected at Conowingo Dam was done using scale ages. Comparison of scale age vs. tetracycline mark revealed many cases where the age was not possible, given therefore not enter the Conowingo lifts. If this were true, we might expect recovery rates of Hudson River origin fish to be higher than Delaware river origin fish in upper Chesapeake Bay. Table 17 (1995-2000 summary) provides no evidence for this, in fact, recovery rates for Delaware River origin fish in upper Chesapeake Bay are higher (43.8) than Hudson River origin fish (26.8).

Table 17 provides a detailed look at recoveries of marked American shad, by cohort, which were captured at Conowingo Dam and the upper Chesapeake Bay pound nets. The reader should keep in mind that this analysis relies heavily on accurate aging of otoliths, a science/art in which the writer has limited confidence. Recovery rates ranged from 0 for the 1994 cohort from the Connecticut River source to 2,286 for the 1991 cohort from the Connecticut River. The unusually high survival of the 1991 Connecticut River cohort is puzzling, given the overall poor performance of the Connecticut River source as a whole. It is tempting to explain this away based on mis-aging, however that is not likely. The 5,9,13,17,21 day mark applied to this cohort was first used in 1991, eliminating the possibility of over-aging these fish. Under-aging would have been possible, thereby assigning them to the 1992 cohort. Even if 50% were under-aged, the recovery rate would still have been 1143 $\times 10^{-7}$, or 1.4 times the next highest rate.

Connecticut River larvae(144×10^{-7} vs 168×10^{-7}). Recovery rates for juveniles (Hendricks and Bender 1993) were higher for larvae released nearshore for both egg sources (Hudson, nearshore- 264×10^{-6}, Hudson midstream- 174×10^{-6}, Conn., nearshore- 34×10^{-6}, Conn., midstream- 21×10^{-6}). Again, these results support our decision to continue to stock shad larvae at nearshore locations.

In 1993, two tanks of Connecticut River larvae were marked at 5 days of age and stocked at 7 days of age to avoid heavy mortalities which were occurring after 9 days of age. Juvenile recovery rate for this group was 13×10^{-6}, compared to 4×10^{-6} for Connecticut River larvae stocked between 22 and 26 days of age (Hendricks and Bender, 1995). In a follow-up study in 1994, recovery rate of Hudson River larvae stocked at 7 days of age was 123×10^{-6} vs a recovery rate of 17×10^{-6} for larvae stocked at 20 days of age (Hendricks and Bender, 1995). Recovery rates for adults from these groups exhibited similar trends; a 10-fold increase in recovery rate for larvae stocked at 7 days of age compared to those stocked at 20-26 days of age (Table 17). These results do not necessarily agree with our more recent experience in stocking larvae in tributaries. Larvae stocked in tributaries at 13 to 22 days of age have often exhibited higher recovery rates than those stocked in the Juniata River or Susquehanna River at Montgomery Ferry at 7-10 days of age (see this report, job III, Appendix 1, discussion

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Figure 2. Catch of American shad in the Conowingo Dam Fish Lifts

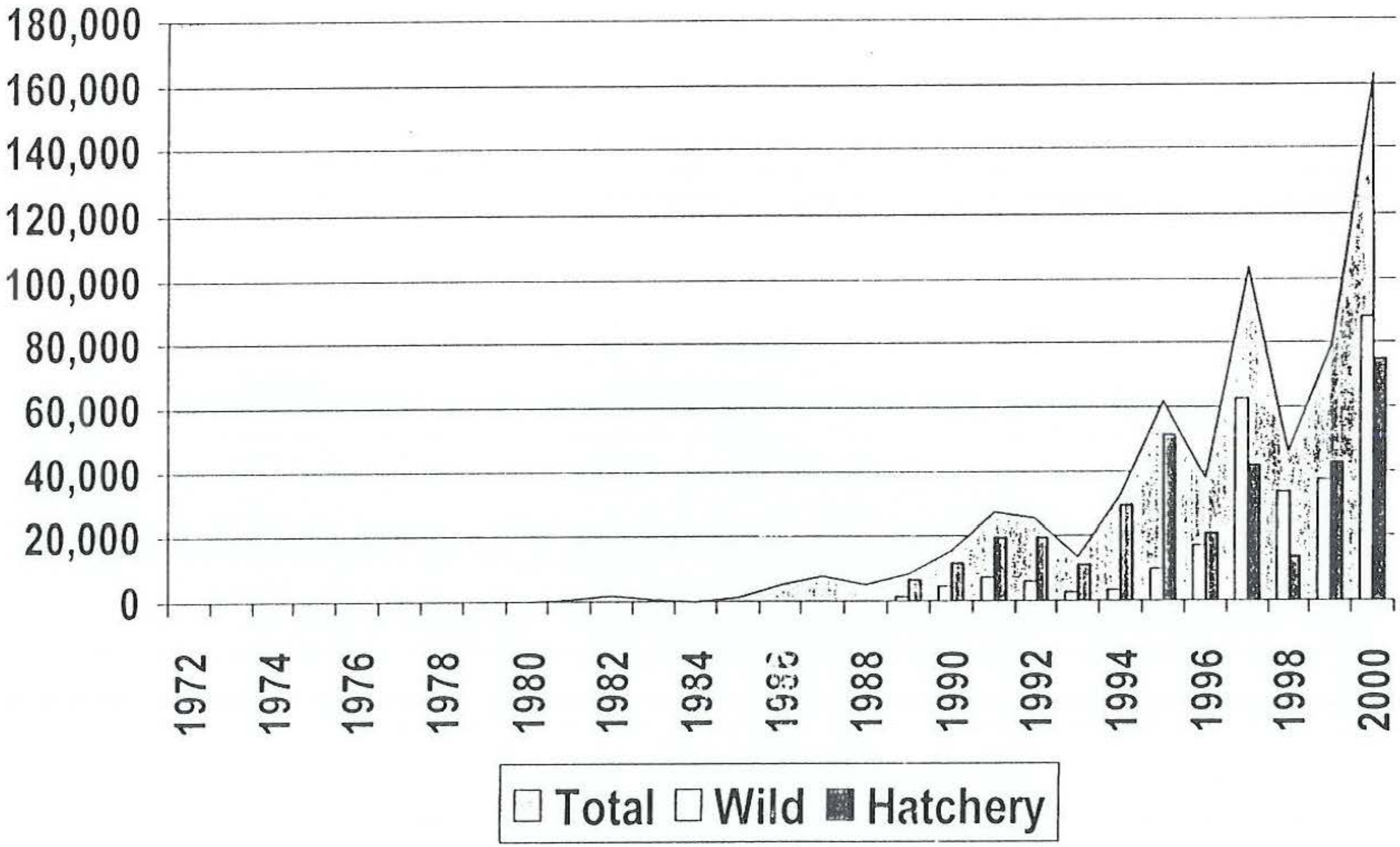

Table 2. Origin of adult American shad collected at Conowingo Dam Fish Lifts, based on otolith analysis. Every 50th or 100th fish to enter the lifts was sacrificed for analysis.

	Hatchery							Naturally reproduced		Total sample size
	Larvae									
	Susquehanna		below Conowingo Dam		Fingerling		Unmarked**			
Year	N	%*	N	%*	N	%*	N	N	%	size
1989	36	82	-		-		94	29	18	159
1990	49	73	1	1	-		42	32	26	124
1991	111	67	8	5	3	2	63	68	27	253
1992	154	73	8	4	2	1	19	54	23	237
1993	76	64	21	18	2	2	4	21	17	124
1994	217	81	22	8	3	1	17	28	10	287
1995	255	77	19	6	4	1	1	52	16	331
1996	180	48	22	6	4	1	1	172	45	379
1997	84	34	12	5	4	2	0	150	60	250
1998	29	22	7	5	2	2	0	92	71	130
1999	90	48	9	5	1	1	0	88	47	188
2000	78	40	11	6	0	0	0	104	54	193
Totals	1.359	59	140	6	25	1	241	890	34	2,655

*Unmarked hatchery fish distributed among groups based on annual percentage.

**Distinguished from naturally-reproduced fish by otolith microstructure.

Table 5. Length frequency by sex of adult American shad sacrificed for otolith analysis, Conowingo West Fish Lift, 2000.

Sex	301-325	326-350	351-375	376-400	401-425	426-450	451-475	476-500	501-525	526-550	551-575	576-600	Total
Male			9	42	51	29	5						136
Female					6	16	18	14	7				61
Unknown													0
Totals	0	0	9	42	57	45	23	14	7	0	0	0	197

Table 6. Length frequency by sex and origin of adult American shad sacrificed for otolith analysis, Conowingo West Fish Lift, 2000.

Sex	301-325	326-350	351-375	376-400	401-425	426-450	451-475	476-500	501-525	526-550	551-575	576-600	Total
Male-Wild			6	29	22	10	3						70
Male-Hatc.			3	13	29	19	2						66
Female-Wild					3	8	9	9	5				34
Female-Hatc.					3	8	9	5	2				27
Totals	0	0	9	42	57	45	23	14	7	0	0	0	197

Table 9. Age composition and origin of American shad collected at the Conowingo Dam Fish Lifts, 1988-2000.

									Hatchery Release Site			Wild
									Above Dams		Below Dams	
	Fish lift	% Age composition							larvae	fingerlings		
Year	catch	8	7	6	5	4	3	2	%	%	%	%
1988	5.146	0.0	4.0	31.7	38.1	21.2	4.7	0.4	71% *		6% *	23%
1989	8.218	0.0	4.3	18.1	41.5	30.2	5.6	0.2	82%			18%
1990	15.719	0.1	5.5	32.7	45.2	15.0	1.5	0.0	73%		1%	26%
1991	27.227	0.0	10.7	36.7	38.4	12.4	1.7	0.0	67%	2%	5%	27%
1992	25.721	0.6	12.3	35.7	36.8	11.7	2.9	0.0	73%	1%	4%	23%
1993	13.546	0.0	3.2	21.6	52.8	21.6	0.8	0.0	64%	2%	18%	17%
1994	32.330	0.0	3.3	22.6	54.7	19.3	0.0	0.0	81%	1%	8%	10%
1995	61.650	0.0	3.2	12.4	51.9	28.5	4.0	0.0	77%	1%	6%	16%
1996	37.513	0.0	0.8	16.1	41.5	33.6	7.6	0.3	48%	1%	6%	45%
1997	103.945	0.0	0.0	10.5	18.1	44.8	26.2	0.4	34%	2%	5%	60%
1998	46.481	0.0	0.8	10.9	48.1	37.2	3.1	0.0	22%	2%	5%	71%
1999	79.370	0.5	1.1	7.89	32.6	45.3	10.0	0.0	48%	1%	5%	47%
2000	163.331	0.0	1.0	9.90	27.6	51.0	10.4	0.0	40%	0%	6%	54%

*No estimate of hatchery contribution available, used mean of 1989-1996.

Table 11. Recruitment of hatchery fingerlings, stocked above dams, to the Conowingo Fish Lifts, 1986- 1995.

	Cohort										
Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1988	3 [x]										
1989	0	0									
1990	0	0	0								
1991	188	61	8	0							
1992	86	89	28	7	0						
1993	7	49	120	49	2	0					
1994	0	12	82	198	70	0	0				
1995		0	24	93	388	213	30	0			
1996			0	3	64	165	134	30	1		
1997				0	0	174	302	744	436	7	
1998					0	6	78	344	266	22	0
1999						2	4	33	138	191	42
2000							0	0	0	0	0
Total recruits to lifts:	285	211	262	350	524	560	548	1,152	841	220	42
Fingerlings stocked/10,000:	7.25	8.15	6.40	6.04	9.00	5.44	2.18	7.94	13.95	0.00	0.00
Number of fingerlings to return 1 adult:	255	386	244	172	172	97	40	69	166	0	0
Mean number of fingerlings to return 1 adult (1986-1995):				134							

Table 13. Tetracycline marked. Delaware River egg source American shad captured at Conowingo Dam, 1995-2000.

Year	Fish lift catch	Return at age 8	7	6	5	4	3	2	No. Otoliths Processed	Cohort 1991	1992	1993	1994
1995	61.650					7			331	1.304	0	0	
1996	37.513				25	28	14		379	2.474	2.771	1,386	0
1997	103,945			4	10	14	6		250	1,663	4.158	5,821	2,495
1998	46.481			3	13	4			130	0	1.073	4,648	1,430
1999	79,370		1	4	10				188	0	422	1,689	4,222
2000	163.331		1	2					193		0	846	1.693
										5,441	8.424	14,390	9,839
									Number Stocked (millions)	1.09	0.80	2.50	0.79
									Number of larvae to return 1 adult:	199	95	174	80
									Mean number of larvae to return 1 adult (1991-19				136

Table 14. Tetracycline marked. Hudson River egg source American shad captured at Conowingo Dam, 1995-2000.

Year	Fish lift catch	Return at age 8	7	6	5	4	3	2	No. Otoliths Processed	Cohort 1991	1992	1993	1994
1995	61,650					47	1		331	8,754	186	0	
1996	37,513				54	21	4	1	379	5,345	2,079	396	99
1997	103,945			6	9	8	17		250	2,495	3,742	3,326	7,068
1998	46,481			1		3			130	0	358	0	1,073
1999	79,370	1		1	21				188	422	0	422	8,866
2000	163.331			7					193		0	0	5.924
										17,016	6,364	4,144	23,030
									Number Stocked (millions)	6.10	0.57	1.10	3.78
									Number of larvae to return 1 adult:	358	89	266	164
									Mean number of larvae to return 1 adult (1991-19				228

Table 15. Tetracycline marked. Connecticut River egg source American shad captured at Conowingo Dam, 1995-2000.

Year	Fish lift catch	Return at age 8	7	6	5	4	3	2	No. Otoliths Processed	Cohort 1991	1992	1993	1994
1995	61.650					4	7		331	745	1.304	0	
1996	37,513				4	10	2		379	396	990	198	0
1997	103,945				1	3			250	0	416	1,247	0
1998	46,481				2				130	0	0	715	0
1999	79,370			2					188	0	0	844	0
2000	163.331		1						193		0	846	0
										1,141	2,709	3,851	0
									Number Stocked (millions)	0.04	1.67	2.93	1.86
									Number of larvae to return 1 adult:	31	617	761	
									Mean number of larvae to return 1 adult (1991-19				843

Table 17. Recapture of marked adult American shad stocked as larvae in the Juniata and middle Susquehanna River and recaptured at Conowingo Dam or the upper Chesapeake Bay.

Egg Source	Cohort	Mark (days)	Number Stocked	Number recaptured Conowingo lifts 1995	1996	1997	1998	1999	2000	Total	Recovery Rate (1/Exp7)	Number recaptured Upper Bay 1996	1997	1998	1999	Total	Recovery Rate (1/Exp7)
Delaware	1991	3,13,17	1,085,000	7	25	4				36	332	3	3			6	55
Hudson	1991	5,9,13	1,911,000	23	32	5		1		61	319	3	2			5	26
Hudson (day)	1991	5	2,081,000	11	13					24	115	2				2	
Hudson (night)	1991	18	2,106,000	13	9	1				23	109					0	-
Connecticut	1991	5,9,13,17,21	35,000	4	4					8	2,286		1			1	286
Total	1991		7,218,000	58	83	10	-	1	-	152	211	8	6	-	-	14	19
Delaware	1992	3,13,17	798,700		28	10	3	1		42	526	3	3			6	75
Hudson	1992	5,9,13	378,500	1	14	4	1			20	528	3	1			4	106
Hudson- (nearshore)	1992	5	109,700		4	5				9	820	1				1	91
Hudson- (midstream)	1992	18	80,500		3					3	373	2			1	3	373
Connecticut	1992	5,9,13,17,21	514,100							-	-					0	-
Connecticut- (nearshore)	1992	3,13,17,21	623,000	5	3	1				9	144					0	-
Connecticut-(midstream)	1992	3,7,11,21	534,900	2	7					9	168					0	-
Total	1992		3,039,400	8	59	20	4	1	-	92	303	9	4	-	1	14	46
Delaware	1993	3,13,17	2,499,400		14	14	13	4	1	46	184		5	1	4	10	40
Hudson	1993	5,9,13	1,104,200		4	8		1		13	118		3			3	27
Connecticut	1993	5,9,13,17,21	2,037,900					1		1	5					0	-
Connecticut	1993	5	891,700		2	3	2	1	1	9	101	1	2	1	2	6	67
Total	1993		6,533,200	-	20	25	15	7	2	69	106	1	10	2	6	19	29
Delaware	1994	3,13,17	785,000			6	4	10	2	22	280	1			5	6	76
Hudson	1994	5,9,13	2,004,000			6		10	2	18	90				1	1	5
Hudson (7-day)	1994	5	996,000		1	11	3	9	5	29	291		3	1	8	12	120
Hudson (20-day)	1994	18	779,000					2		2	26					0	-
Connecticut	1994	5,9,13,17,21	1,855,000							-	-					0	-
Total	1994		6,419,000	-	1	23	7	31	9	71	111	1	3	1	14	19	30
Summary 1995-2000																	
Delaware			6,387,100	7	67	34	20	15	3	146	229	7	11	1	9	28	44
Hudson			11,549,900	48	80	40	4	23	7	202	175	11	9	1	10	31	27
Connecticut			6,491,600	11	16	4	2	2	1	36	55	1	3	1	2	7	11
Total			24,428,600	66	163	78	26	40	11	384	157	19	23	3	21	66	27