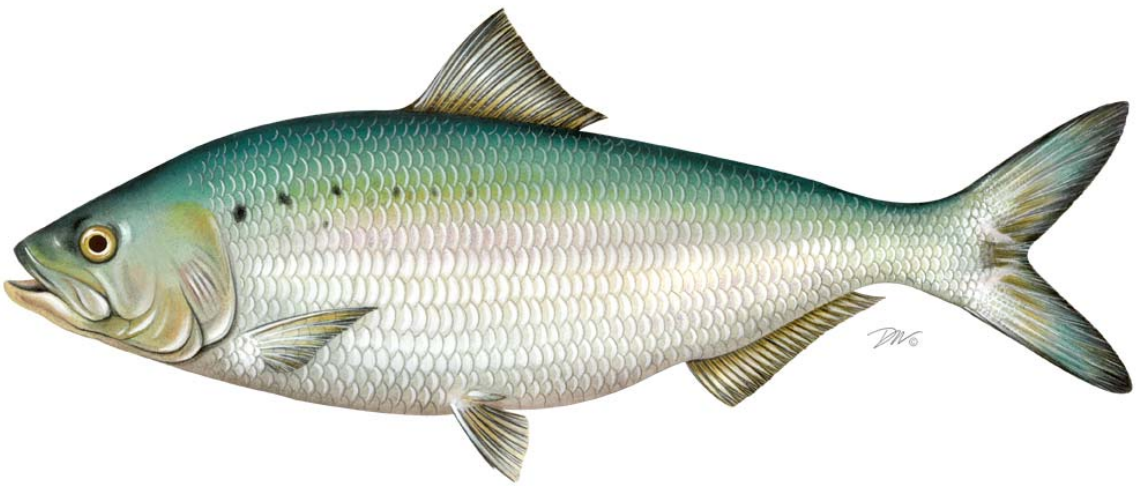
The Delaware River Basin Fish and Wildlife Management Cooperative

American Shad Habitat Plan for the Delaware River



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The Nature Conservancy

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Pennsylvania Fish and Boat Commission
New York State Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources
United States Fish and Wildlife Service
NOAA Fisheries

Submitted to the Atlantic States Marine Fisheries Commission as a requirement of Amendment 3 to the Interstate Management Plan for Shad and River Herring

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Delaware River

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Delaware Division of Fish and Wildlife • New Jersey Division of Fish and Wildlife

Pennsylvania Fish and Boat Commission • New York State Division of Fish, Wildlife and Marine Resources

U. S. Fish and Wildlife Service • National Marine Fisheries Service

For:

The Atlantic States Marine Fisheries Commission

Shad and River Herring Management Board

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1. Overview

The Delaware River begins in Hancock, NY and flows more than 454 kilometers (330 miles) before emptying into Delaware Bay (Fig 1). The tidal portion extends from the head of the bay to near Trenton, NJ (rkm 214, rm 133[1]). The East and West Branches, Lackawaxen, Neversink, Lehigh and Schuylkill rivers are the major tributaries. The 33,038 square kilometer basin includes parts of four States: Pennsylvania (50 percent of the basin), New Jersey (23 percent), New York (19 percent), and Delaware (8 percent). As the drinking water supply for 15 million people (Philadelphia – New York City (NYC) metropolitan area), vast areas of the basin's headwaters have been protected from development and much of the river corridor retains its wild, free flowing character.

The Delaware River is unique along the Atlantic Coast in that it is free-flowing along the entire length of the mainstem, which allows numerous species of migratory fish and freshwater mussel species to persist far up into its headwaters where in similar East coast aquatic systems they've been long extirpated. Since colonial times, however, the basin's resources have been exploited and depleted. By the early 20th century the estuary was considered one of the most polluted waterbodies in the United States and a recurring pollution block in the tidal portion of the upper Delaware Estuary severely hindered migratory fish runs, which were already severely depleted from overfishing and habitat degradation.

The tide began to turn in the late 1960s. The recognition of the need to conserve the valuable resources of the basin led to the formation of the Delaware River Basin Commission (DRBC) in 1961. The passage of the Clean Water Act in 1972, which established water quality standards to reduce municipal and industrial discharges, eventually led to improved water quality and the near elimination of the pollution block on the lower river. In 1978, two sections of the river covering 181 km (113 mi) were designated as National Wild and Scenic Rivers to be administered by the National Park Service: 117 km (73 mi) as the Upper Delaware Scenic and Recreational River, and 64 km (40 mi) as the Middle Delaware National Scenic and Recreational River. In 1992, DRBC adopted the special protection regulations to protect the high water quality of the river sections that had been designated as part of the National Wild and Scenic River system. The special protection regulations do not allow any degradation of "existing water quality" as defined by numeric standards for a number of water quality parameters. Through a series of amendments between 1994 and 2008, the special protection waters designation was expanded to apply to point and non-point discharges along the entire mainstem downstream to Trenton, NJ. In 2000, the U.S House of Representatives passed a measure to include an additional 63 km (39 mi) of mainstem and tributaries in Lower Delaware Scenic and Recreational River. Presently, three-quarters of the non-tidal Delaware River is now included in the National Wild and Scenic Rivers System.

[1] A river mileage excel table and maps can be found on the DRBC website. http://www.nj.gov/drbc/basin/river/

The tidal river, however, is densely populated and home to a large freshwater port (in 2007, handled 167,413 twenty-foot equivalent units). Losses of freshwater tidal wetlands and other riparian habitat in this area are significant. Although the mainstem Delaware is free of physical barriers, many important tributaries that once supported large runs of American shad are blocked or have reduced access and/or degraded habitat. In addition to dams, the building of multiple canal systems including the Delaware and Raritan canals, extirpated shad from many mainstem tributaries.

Within the Delaware River Basin, the Delaware River Basin Fish and Wildlife Management Cooperative (Co-op) is responsible for the management of diadromous fishes inclusive of the American shad. The Co-op was established by Charter in 1973 and primarily develops unified approaches to anadromous fish management. It is comprised of U. S. Fish & Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Delaware Department of Natural Resources and Environmental Control (DNREC), Pennsylvania Fish and Boat Commission (PFBC), Pennsylvania Game Commission (PGC), New York Division of Fish, Wildlife, and Marine Resources (NYDEC), and New Jersey Division of Fish and Wildlife (NJDFW). A Coordinator from the U. S. Fish and Wildlife Service serves as secretary to the Co-op and acts as a liaison and technical specialist primarily on aquatic issues to the National Park Service (NPS), the DRBC, the Delaware Estuary Program, and the USFWS's Delaware Bay Estuary Project.

The Atlantic States Marine Fisheries Commission (ASMFC) has required all states to submit a Habitat Plan (1 August 2013, extended to 15 September 2013) for American shad as part of their Implementation Plan as per Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring. The Habitat Plan was to focus on threats that are deemed most significant to American shad. As such, it is likely that data and/or monetary support may not yet be available to address specific topics. In these cases, this plan identifies the threat and offers potential direction for rectification but indicates the states abilities in those identified directions are limited. In accordance with guidelines provided in Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2010), the Co-op on behest of all members, submits the following Habitat Plan.

2. Mainstem Habitat Assessment

2.1 Historic

Historically American shad spawned throughout the mainstem freshwater Delaware River and its tributaries as well as tributaries connected to the Delaware Bay (Stevenson, 1899). The location of the salt front would have determined the extent of the potential spawning habitat in the freshwater tidal section of the river. Prior to the construction of the NYC reservoirs and subsequent diversions, the salt front was variable seasonally within and among years depending on the total volume of water being discharged from the Delaware River at any given time. Management of reservoir releases was thought to reduce the extreme variation of salinity in the estuary and hence moderate the migration of the salt front (Ketchum 1952). Today the average location of the salt front is at rkm 111 (rm 69). During the drought of record in the 1960's the salt front reached rkm 164 (rm 102) upstream (Fig 2).

During the late 1800's there was evidence indicating that shad were spawning in the freshwater tidal areas of the mainstem as well as several tributaries of the lower Delaware River. It was presumed that the principal spawning area was located south of Philadelphia, PA prior to 1900 just above Gloucester, NJ (rkm 157, rm 97) (U. S. Fish Commissioners, 1887; Cable, 1945; Walford, 1951; Mansueti and Kolb, 1953.) Furthermore, the Howell family fishery, in existence for 200 years at Woodbury, NJ, kept catch records before 1830's documenting annual American shad hauls of greater than 130,000 fish at rkm 150 (rm 93) (Harding 1999).

As early as the 1800's, exploitation, pollution and dams in the Upper Delaware River and tributaries were already having a significant impact on the shad population in the Delaware. The construction of the extensive canals and locks in the late 1800's along the mainstem Delaware, Lehigh, and Schuylkill rivers extirpated American shad from historic spawning and nursery habitats. In 1828, a 16-ft dam was built across the Delaware at Lackawaxen, Pa. by the Delaware and Hudson Canal Company for a period of approximately 50 years. Until dismantled, this dam decimated the upper river spawning run according to reports in the New York Times (NYT 1889). Still on-going to the present, dredging the main channel for navigation has also resulted in major changes to the mainstem channel in the lower basin from Philadelphia, Pa to the ocean. Table 1 illustrates the historic and incurring changes to the width and depth of the channel. These changes to the channel allowed the salt front to reach further upstream. Significant loss of side channel habitat as well as shallow water habitat was lost.

Water pollution since colonial times was severe, culminating in anoxic conditions in the lower Delaware River. During the 1940s and 1950s, heavy organic loading around Philadelphia, Pa. caused severe declines in dissolved oxygen (D.O.). A remnant of the American shad run in the Delaware River survived by migrating upstream early in the season, when water temperatures were low and flows were high, before the D.O. block set up. These fish, because of their early arrival, migrated far up the Delaware to spawn. Out-migrating juveniles survived by moving downriver late in the season during high flows and low temperatures, thus avoiding the low oxygen waters present around Philadelphia earlier in the fall.

By the 1820's, fishermen noted the drastic decline in the size of shad and eight-pounders, which were once common, became hard to find (Harding 1999). By the early 1900's, as a result of exploitation and habitat loss, the shad fishery collapsed and the Gloucester fishery which had been in existence for 200 years ended (Harding 1999).

During the 1960's, the Tri-State Shad Surveys as described by Chittenden (1976) showed that the greatest numbers of adults were captured from Minisink Island near Milford, PA (rkm 392) up to Skinners Falls near Narrowsburg, NY (rkm 475); none were captured downstream from Manunka Chunk (rkm 325). Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. During the 1980's water quality of the Delaware River mainstem began to improve, particularly in the freshwater tidal reaches. Specifically, improvements to sewage treatment plants have also substantially reduced the occurrence of the D. O. block allowing passage of fishes to occur once again between the freshwater river and estuary.

2.2 Current (1990 onward)

Currently, American shad spawning is thought to be primarily in the middle and upper Delaware mainstem spanning an area of approximately 236 river kilometers (147 river miles) from near Easton, Pa. (rkm 296, rm 184) to Hancock, NY (rkm 532, rm 330). Yet, American shad also appear to be using the lower non-tidal reaches and freshwater tidal reaches of the Delaware River. Entrainment of Alosine eggs and larvae in industrial water intakes, suggest the lower freshwater reaches and upper tidal reaches of the Delaware River are nursery grounds. In addition, observed adult shad spawning behaviors support this assumption, however, ichthyoplankton surveys for documenting the occurrence of American shad eggs in this region should be a priority research topic (Maurice et al. 1987).

3. Tributary Habitat Assessment

Historically, shad utilized many, if not all, medium to large tributaries for spawning in addition to the mainstem habitat. Although the mainstem Delaware is free of physical barriers, many important tributaries that once supported large runs of American shad are blocked or have reduced access and/or degraded habitat. In addition to dams, the building of multiple canal systems included the Delaware and Raritan canals extirpated shad from many mainstem tributaries. These canal systems to date still preclude shad from utilizing historic spawning and nursery grounds. Tidal gates in coastal tributaries likely have restricted access as well.

Except for in a few select places, i.e. the Lehigh and Schuylkill, very little information on the size of these tributary spawning runs or their production of young is available. Using historical and current information a brief description of known historic and/or current status of spawning runs in all tributaries, as well as known habitat impacts can be found in Appendix 1 beginning in the headwaters and moving downstream. Figure 3 highlights the known spawning runs as of 2010.

A summary of the habitat status of major shad tributaries by state is below.

3.1 <u>New York</u>

The major spawning tributaries for shad in New York were the East and West Branches of the Delaware and, to a lesser extent, the Neversink River. Most of the East and West Branches of the Delaware no longer support shad spawning runs due to the cold water releases from the NYC reservoirs and direct loss of habitat due to the reservoirs themselves (Chittenden 1976). Shad historically migrated 68 km (42 miles) up the East Branch to former town of Shavertown (Bishop 1936), which is now submerged beneath New York City’s Pepacton Reservoir. There have been reports from fishermen of shad as far as 25 km (15.5 mi) up the East Branch, to the confluence with the Beaver Kill (Saunter 2001). Chittenden (1976) reported that shad ran up 6 km (3.7 mi) up the Beaver Kill, an East Branch tributary, but it is unclear whether they spawn there. Other reports have shad going as far as a mile up into the Little Beaver Kill, a tributary of the Beaver Kill (McPhee 2005).

In the early 1800's the shad run in the Neversink River was large enough to support a seine fishery in the lower part of the river (Gumaer 1890). It is believed that shad went upstream approximately 24k (15 miles) to the Neversink Gorge, which is the natural barrier due to gradient on this river. The Southwest Cuddebackville Dam built in 1904 restricted passage 16km (10 miles) upstream from the mouth until 2004 when the dam was removed. Shad now have access to their full historic habitat in the Neversink River and are not impacted by cold water releases from the Neversink Reservoir due to the large distance from the reservoir; however, it is not clear if shad are utilizing this newly opened habitat (Horwitz et al. 2008).

3.2 Pennsylvania

Two of the largest shad spawning tributaries in the Delaware Basin are wholly located within the Pennsylvania; the Schuylkill River has a drainage area of 5,180 km^2 and the Lehigh River has a drainage area of 3,484 km^2. In the late 1880's shad were extirpated from all waters associated with the Schuylkill and Lehigh basins with the construction of various dam and canal systems. The building of the Delaware Canal on Pennsylvania's shoreline also disconnected many smaller tributaries from the mainstem, precluding shad access. In addition to physical barriers, water quality is also an issue in the Lehigh. Just south of the municipality of Palmerton, PA water quality is poor due to impacts from several large municipalities that have discharges to the drainage and historic inputs from a former metal smelting operation.

The Schuylkill is the largest tributary to the Delaware River and once supported very large numbers of American shad until the construction of dams in the early 1800's. Point of entry of the Schuylkill is at 149 rkm in the upper tidal estuary, in Philadelphia, PA. Shad historically migrated 193 km (120 miles) upstream to Pottsville, Pa. In 1820, the Fairmount Dam was constructed nine miles from the mouth of the Schuylkill; an additional nine other dams were also constructed in the watershed effectively eliminating the shad runs in the Schuylkill system for 150 years.

Located upriver in the non-tidal reach of the Delaware, the Lehigh enters the Delaware River at Easton, Pa at 294 rkm. Prior to the construction of a series of dams for supporting the Lehigh Coal and Navigation Canal system in the early 1800's, shad migrated at least 58 km (36 miles) upriver to Palmerton, Pa where native Lenape Indians annually harvested shad at the confluence of the Aquashicola Creek. Although no written record has been found documenting the occurrence of shad further upriver of Palmerton, PA, it is reasonable to assume they continued their migrations for some distance upriver. Construction of the Easton Dam (0 rkm) in 1829, at the confluence of the Lehigh and Delaware rivers, extirpated shad from the Lehigh basin for 165 years until the subsequent installation of a fishway in 1994.

3.3 New Jersey

In New Jersey, most tributaries that were tidally influenced had runs of shad that could support fisheries. In 1896 the Cohansey River ranked 3rd in New Jersey as a shad producing stream, surpassed only by the Hudson and Delaware (Stevenson 1899). Currently, there is no documented shad run in the Cohansey. Historic water quality issues likely impacted many of the shad streams in New Jersey. Current habitat impacts include dams, canals, tidal gates and water quality.

3.4 Delaware

In the late 1600s, before the first dams were constructed, the Brandywine supported tens of thousands of American shad. But even in the 1700's the Brandywine Lenape Native Americans were complaining to commissioners in PA that dams were preventing the rockfish and shad from "coming up" as formerly and causing great injury to their people (Weslager, 1989, Schutt 2007).

The current status of shad in most of the tributaries that are found in State of Delaware is unknown, but few have been caught in any of these tributaries during the past century and it is unlikely that any of them currently support spawning runs. However, shad were found historically in most tributaries (Mansueti and Kolb 1953, Stevenson 1899). In Wilmington, the Christina watershed (including White Clay Creek and the Brandywine) had a major spawning run of shad before dams and water pollution effectively eliminated the run. The majority of tributaries that once supported shad runs are impacted by dissolved oxygen and nutrient issues (DNREC 2005).

4. Nursery Habitat - Historic and Current

Juvenile shad remain in the rearing area of their natal river which is usually located downstream from where they were spawned. Juveniles then move from the nursery areas to the ocean in October and November as water temperatures decrease (Limburg et al. 2003). Historically the tidal Delaware was probably an important nursery area with thousands of acres of saltwater and freshwater tidal marshes of highly productive systems with extensive food and shelter for juvenile shad. More than 145,000 hectares of brackish and salt marshes remain in the Delaware Estuary, roughly half in Delaware and half in New Jersey. However, only five percent of freshwater tidal marshes in the Delaware River Basin remain (Kreeger et al. 2010). Concentrated along the mainstem Delaware River between Wilmington, DE and Trenton, NJ, the condition of these marshes reflects the effects of negative impacts of intensive land conversion and industrial activities in this urban corridor (Simpson et al. 1983). Residential and commercial development has left only fragments of freshwater tidal marsh fringing the Delaware and its tributaries in this section of the basin.

In the upper Delaware River, prior to the construction of NYC reservoirs Chittenden (1969) reported that juvenile shad were repeatedly captured in the West Branch of the Delaware River. In 1964 and 1966, after cold water releases began, Chittenden was unable to document juvenile shad in the West Branch. In other studies Miller (1975) and Chittenden (1972) both demonstrated that juvenile shad are adversely impacted by cold water releases in the West Branch and would abandon the affected areas. The East Branch is utilized as nursery habitat though the extent probably varies with temperature in any given year and warrants further study.

Ross and Johnson (1997) found relatively general habitat use by juvenile shad in the mainstem upper Delaware River with some affinity for riffles and submerged aquatic vegetation (SAV). Chittenden (1976) found the chief nursery in 1966 was apparently located upstream from Dingmans Ferry (rkm 385, rm 239) and was especially centered near Tusten, NY and Lordville, NY. Ross et al. (1997) found no overall effect of habitat type on juvenile American shad relative abundance in the upper Delaware River, indicating that juveniles use a wide variety of habitat types to their advantage.

The hypothesis that young of year (YOY) shad utilize all mainstem habitats is assumed to be true. With the improved water quality, particularly in the freshwater reach of the upper estuary, the presence of YOY shad has been observed throughout the entire mainstem. Furthermore, the presence of YOY shad has been observed in those tributaries in which existing dams were outfitted with fishway passages. However, the utilization of these tributaries by American shad for spawning and subsequent nursery habitat is presumed minimal, given the ineffectiveness of the fishways to facilitate the successful passage of returning shad.

5. Threats Assessment & Habitat Restoration/Mitigation

5.1 Barriers

Although the mainstem Delaware is free of dams, the Northeast Aquatic Connectivity Project evaluated 1,547 dams on 20,320 km of river in the Delaware River Basin (Martin and Apse 2010). This corresponds to a density of one dam for every 13 km of river. A table with information on each dam in the basin can be found in Appendix 2. The Paulinskill, Schuylkill, Lehigh, Brandywine, and White Clay Creek are systems with shad runs that would benefit the most from dam removal. For more information on ranking and results please refer to the report which can be accessed here http://rcngrants.org/content/northeast-aquatic-connectivity.

A continuing challenge in the Delaware system to removing dams is the historic status and values of many of the dams and canals such as the Fairmount Dam on the Schuylkill and the canal system on the Lehigh. This historic status complicates or even precludes the possibility of removal even though the dams no longer serve any significant purpose.

Restoration/Mitigation

The Lehigh River is considered one of the most important tributaries for American shad restoration in the Delaware River Basin. Full utilization of this habitat is prevented by multiple dams and water quality issues. There are five dams impairing or blocking fish movement into and within the Lehigh River. They are Easton Dam (rkm 0), Chain Dam (rkm 5), Hamilton St. Dam (rkm 27), Cementon Dam (rkm 38), and the Francis E. Walter Dam (rkm 125). The Easton (owned by PA Dept. of Conservation and Natural Resources) and Chain (owned by the City of Easton) dams represent legacies from the canal/lock navigation systems from the 1800's. Presently these dams are only used to provide flooding of short sections of canals, principally for aesthetics and for the benefit of concessionaires that operate canal boats as a tourist attraction. The Hamilton St. Dam, owned by the City of Allentown, provides recreation and water supply to Allentown, PA; whereas the Cementon Dam is privately owned by LeFarge Corporation for industrial water supply to their daily operations. The Francis E. Walter Dam, owned and operated by U. S. Army Corps of Engineers, is the political result of devastating flooding from hurricanes in the 1950's. Its primary purpose is flood control but it is secondarily managed for recreational activities, principally whitewater rafting and tailwater trout fishery.

Although there are fishways on the Easton and Chain dams, they have been fairly ineffective at passing American shad. Passage has been documented since their construction, with annual average passage of 1,662 individuals at Easton Dam and 499 individuals at Chain Dam, since 1995. Passage through the Hamilton St. Dam fishway is unknown at this time, but assumed nominal. The Cementon Dam and Francis E. Walter Dam are presently without fish passage facilities.

Recognizing the anticipated return of an annual American shad run into the Lehigh River of at least 160,000 individuals has not materialized, even after significant modification to the fishway structure at the Easton and Chain dams, other options must be explored to improve passage on the Lehigh. A feasibility study was just completed that assessed options for improving fish passage through both the Easton and Chain dams (http://www.google.com/url?sa=t&rct=j&q=easton%20dam%20feasibility%20study%20wildlands%20conservancy&source=web&cd=1&cad=rja&ved=0CDQQFjAA&url=http%3A%2F%2Fwildlandspa.org%2FPDF%2FfishpassageStudy2013.pdf&ei=BWyaUb_IKIfa4AOd7YC4CQ&usg=AFQjCNFF_BG4nHRwvcXMi1vtPqzO_f1ZVA). This study concluded that complete removal of the Easton and Chain dams was the only alternative which was certain to improve fish passage into the Lehigh River. If both Easton and Chain dams were removed or significantly altered to provide improved fish passage, it would provide for nearly 27 km of restored fish habitat up to the base of the Hamilton St. Dam located in Allentown, PA. Any action involving modification/removal of these structures would impact numerous stakeholders, and would be dependent on the willingness of the dam's owners to pursue the goal of complete removal. The Co-op members agree with the conclusions of the study, i.e., that complete removal of both the Easton and Chain dams, is the only alternative which is certain to maximize fish passage into the Lehigh River. To this end Co-op members hope that by speaking as one voice on this issue, that our state-federal partnership will be influential in persuading stakeholders to eventually seek removal of the Easton and Chain dams.

The Cementon Dam has also been identified as a blockage to fish passage, due to the lack of any kind of fish passage device. The DRBC Docket D-1974-189-2, approved May 10, 2012 addresses dam removal and fish passage of the Cementon Dam (www.state.nj.us/drbc/library/documents/dockets/1974-189-2.pdf). The docket, provides for the LeFarge Corp. conducting a dam removal/fish passage feasibility study be completed by 10 May

2017. Improved fish passage at this facility will open an additional 85 rkm up to the base of the Francis E. Walter Dam.

The Schuylkill River is the largest tributary to the Delaware River. The USFWS estimated that the Schuylkill River has habitat to support 700,000 to 800,000 shad (USFWS 1999). However, the numerous dams that have been built for various reasons since colonial days effectively extirpated American shad from the river. During the 1970's shad were detected below the Fairmount Dam on the Schuylkill River. This eventually led to the installation of a fish ladder on this dam; however, it was poorly designed and few shad were successfully passed. The Fairmount Dam fish ladder underwent major renovation in 2008 and the new fish ladder expected to pass 200,000 to 250,000 shad yearly. However, current passage numbers are far lower than the restoration goals, with approximately 3,500 shad passed in 2011. Passage through the Fairmount Dam fishway will continue to be monitored by the Philadelphia Water Department (PWD).

Fish passage on the Schuylkill River is further constrained by the series of dams upriver of the Fairmount Dam. In recent years, fish ladders or dam removal have led to significant improvements in the opportunity for passage through this system, though shad still have to navigate through four fishways. The following list details the recent improvements in passage.

a. Fairmount Dam (rkm 14.5) - Fishway underwent major renovation in 2008 by the owner, City of Philadelphia.
b. Flat Rock Dam (rkm24) - Fishway was completed by the owner, PA Department of Environmental Protection (PA DEP), and became operational in 2006.
c. Plymouth Dam (rkm 29) - Dam was removed in 2010, by the owner, PA DEP.
d. Norristown Dam (rkm 34) - Fishway was completed by Exelon Energy in January, 2008 and opened to fish passage.
e. Black Rock Dam (rkm 59.5) - Fishway went into service on June, 2009 installed by the owner Exelon Energy.
f. Vincent Dam (rkm 67.5) - Dam was removed in 2009, the owner, PA DEP.
g. Felix Dam (rkm 127) - Remnants of this breached dam, owned by PA DEP, was removed in December, 2007.

In addition to the efforts to improve passage on both the Lehigh and Schuylkill rivers, the PFBC has been stocking otolith-marked American shad fry in both rivers since 1985. Shad eggs for the stocking program are collected from Delaware River shad. Since 2000, all Delaware River shad fry have been primarily allocated to the Lehigh and Schuylkill rivers. But occasionally excess production has been stocked back into the Delaware River at Smithfield Beach (2005 – 2008). Since 1985, egg-take operations on the Delaware River have resulted in the use of an average of 765 adult shad brood fish per year. Eggs from these shad are fertilized and transported to the PFBC's Van Dyke Anadromous Research Station, located on the Juniata River at Thompsontown, Pa, where they are hatched and otolith-marked with oxytetracycline (OTC).

The contribution of hatchery-reared fry to the returning populations of the Delaware, Lehigh and Schuylkill Rivers has been estimated by analysis of daily tagging patterns from OTC within the otolith microstructure of adult fish (Hendricks et al. 1991). The total hatchery contribution at Smithfield Beach on the mainstem Delaware, which is located upstream of the confluence of the Lehigh and Schuylkill Rivers, has been low, ranging from 0.0 to 7.8%. In contrast, on the Lehigh River the average contribution of hatchery fish has been 74%. At the Fairmount Dam on the Schuylkill River, about 96% of the fish returning to spawn are of hatchery origin. Hendricks et al. (2002) demonstrated the occurrence of hatchery stocked shad in the Raubsville collections on the Delaware River. Hatchery origin fish favored the west side of the river, presumably homing to the Lehigh River where they were stocked as fry.

The PFBC plans to reevaluate its stocking program in the Delaware River system in the near future relative to the findings of the Lehigh River Fish Passage Feasibility Study mentioned above.

Currently there are 11 dams on Brandywine Creek in the City of Wilmington. The Brandywine Conservancy and partners completed a feasibility study in 2009 to assess migratory fish passage options in this watershed. Initiatives by DNREC and others are working towards removal of multiple dams, while improving passage at other dams.

A feasibility study was completed in 2010 is to assess the possibility of restoring fish passage and habitat on White Clay Creek in the White Clay Creek National Wild and Scenic River watershed (http://www.ipa.udel.edu/publications/ShadRestoration.pdf). In 2012, funding was secured from NOAA/American Rivers to remove the first dam, which will open up 5.5 km of river.

5.2 Dissolved Oxygen

Major strides have been taken to improve dissolved oxygen levels in the Delaware and by the late 1980s, dissolved oxygen began to regularly exceed the 3.5 mg/L water quality criterion set in 1967 for the urban zones of the estuary (PDE 2012). Although water quality in the mainstem has improved dramatically, “D.O.” sags near Philadelphia, PA still occur during summer months. There have been many episodes since 2000 in which dissolved oxygen has dropped below 3.5 mg/L (DRBC 2010b, PDE 2012, USGS-NWIS 2013) creating conditions lethal to some life stages of American shad. Additionally, most of the coastal tributaries that drain into the Delaware River and Bay from the State of Delaware are impaired due to nutrients and/or dissolved oxygen (DNREC 2005). For American shad, Stier and Crance (1985) report that D.O. of at least 4.0 mg/l is necessary in spawning areas and that mortality of eggs and larvae exposed to D.O. concentrations of 2.5 to 2.9 mg/l was about 50% with 100% mortality of eggs at D.O.'s below 1.0 mg/l. Larvae lost equilibrium at a D.O. of 3.0 mg/l; many died at D.O.'s below 2.0 mg/l; and all died at 0.6 mg/l. Juvenile shad seem to prefer high D.O. concentrations when exposed to a gradient but can probably survive low D.O. (0.5 mg/l) for several minutes if they have access to D.O. above 3.0 mg/l. Minimum D.O.s of 2.5 -3.0 mg/l are probably sufficient to allow juvenile migration through polluted waters but severely low D.O. concentrations in rivers can prevent the passage of adult shad to spawning areas upstream.

Recent observations, by Co-op members indicate that shad spawning has returned to the tidal areas of the Delaware. Therefore all life stages of shad may be found in areas of potential D.O. sag. Given the above D.O. requirements, it appears that there is potential for adverse impact to American shad in the Delaware Estuary, especially in juvenile life stages.

Restoration/Mitigation

Any future management actions taken to improve dissolved oxygen and other water quality conditions in the Delaware Estuary and River basin will benefit American shad and the Delaware River ecosystem in general. The DRBC is assessing the feasibility of increasing dissolved oxygen standards in the urbanized corridor to better support aquatic life.

The State of Delaware has either developed or is developing Total Maximum Daily Loads (TMDL's) for nutrients for its impaired coastal tributaries; however, progress on developing strategies to address nutrients and dissolved oxygen has been slow.

5.3 Flow Alteration

River flows on the Delaware River have long been manipulated by the combined outflow from three NYC reservoirs. Management of these reservoirs is linked to a 1954 U. S. Supreme Court Decree, which provides for the supply of up to 800 million gallons per day of water to the NYC metropolitan area. The Decree stipulates the use of reservoir releases for maintaining a river flow objective of 1,750 cfs at Montague, NJ. Over the years since the 1954 Decree, reservoir releases have been managed through a series of evolving programs based on unanimous agreement by the Parties to the Decree (States of New Jersey, New York and Delaware, Commonwealth of Pennsylvania, and New York City). The "Flexible Flow Management Program" (FFMP) is the current framework for managing diversions and releases from NYC's Delaware River Basin reservoirs. This program was designed by the Decree Parties to support multiple flow management objectives, including water supply; drought mitigation; flood mitigation; protection of the tailwater fisheries; a diverse array of habitat needs in the mainstem, estuary and bay; recreational goals; and salinity repulsion in the Delaware Estuary related to maintaining adequate water quality for municipal water supply withdrawals from the estuary. River reaches immediately below the NYC reservoirs are managed as cold-water trout tailwaters, which has been shown to preclude American shad from utilizing these reaches of river.

Restoration/Mitigation

The FFMP was implemented in 2007 and successively modified annually thereafter for the management of the three NYC reservoir releases. The FFMP was designed to provide a more natural flow regime and a more adaptive means than the previous operating regimes for managing releases and diversions from these reservoirs, inclusive of improved modeling tools. Changes to the FFMP involve complex negotiations among Decree Party principals. The long-term goals of the PFBC and NYDEC have been to develop and promote the cold-water trout fishery via releases from the

NYC water supply reservoirs. Extensive modeling studies are needed to explore the potential of managing reservoir releases for the concomitant utilization of the upper Delaware River by both trout and American shad. These types of studies, however, are not a principal focus.

5.4 Emerging Containments

Contaminants of emerging concern (CECs) are chemicals that have entered the environment through human activities. They have been detected in humans or other living organisms and have been found to persist in the environment, but they are not routinely monitored and are currently unregulated. Examples include phthalates, perfluoroalkyl and polyfluoroalkyl substances (PFASs), brominated flame retardants (PBDEs), nanoparticles, pharmaceuticals and personal care products (PPCPs). Many of the CEC's are known endocrine disrupting chemicals (EDCs) and are thought to be especially important at the larval or developmental stages of fish, disrupting sexual development, behavior, and fertility (Pait and Nelson 2002, Vajda et. al. 2008).

<u>Restoration/Mitigation</u>

A number of efforts have been undertaken within the Delaware River Basin to identify, understand, and prioritize CECs, including a three year effort by DRBC to investigate the presence and concentration of PPCPs, PFASs, and PBDEs in the ambient waters of the tidal Delaware River (MacGillivray 2007). Future research and potential legislation regulating these chemicals will be important to understanding their potential impacts to shad and other aquatic life in the urbanized part of the river.

5.5 Natural Gas Development

As shale-gas development is poised to move into the Delaware River Basin (fully 36% of which is underlain by Marcellus Shale), it will bring with it an industrial activity with a risk of environmental consequences. Potential effects may include surface and groundwater contamination related to hydraulic fracturing and disposal of drilling fluids, decreased stream flows resulting from surface water withdrawals, air quality degradation, soil contamination and compaction, forest fragmentation, and increased erosion and sedimentation due to large-scale development and changes in land use. All of these factors can result in additional water quality impacts. The cumulative impact potential of these effects on American shad of the Delaware River is unknown at this time.

<u>Restoration/Mitigation</u>

Strict compliance with Best Management Practices, coupled with prioritized protection of forested tracts, adequate site restoration and erosion and sedimentation controls, and sufficiently protective riparian buffers, may help to mitigate some of the threats posed by natural gas development. Currently, development of natural gas wells within the Delaware River Basin is under a DRBC moratorium, pending development of regulations.

5.6 Impingement and Entrainment

The U. S. EPA performed a case study of cumulative impacts from impingement and entrainment (I & E) at numerous industrial intakes in the Delaware Estuary (EPA 2002) and reported that fish losses (all species) were greater than 500 million age-1 equivalents annually and represented an economic loss of between $23.4 to $48.5 million each year (in year 2000 dollars).

The Co-op acquired 316b reports for five companies with cooling water intake structures (CWIS) on the Delaware River or its tributaries as well as annual biological monitoring reports for the Salem Generating Station. The Co-op reviewed the reports for I & E impacts on shad and found that impingement and/or entrainment is very significant at some sites (Fig. 5). In particular, American shad entrainment is very high at the Eddystone and Fairless Hills generating stations. Additional withdrawals exist in the river and estuary, but the Co-op has not reviewed CWIS data on these intakes.

Although there is a significant loss of America shad due to I&E, studies characterizing the loss are infrequent and companies are not required to provide mitigation. Furthermore, studies tend to characterize I&E losses by individual plants and not the cumulative impacts to the entire basin.

Restoration/Mitigation

Losses from I & E constitute a significant threat to American shad in the Delaware River. State fisheries agencies will need to work closely with the regulatory agencies and policy administrators to reduce losses. Cumulative losses and impacts need to be evaluated. The Co-op is determining potential avenues for obtaining mitigation for I & E losses and is working with appropriate agencies to advocate for Best Management Practices.

5.7 American Eel Weirs

In the Delaware and Neversink rivers in New York an American silver eel weir fishery exists. At times in the recent past up to 10 weirs were operating in one year on the Delaware River and two to three weirs on the Neversink. American shad are captured as bycatch in this fishery. The cumulative impact of all the weirs on American shad is unknown at this time.

Restoration/Mitigation

There is no current action to address the threat of eel weirs; however, the eel fishery could possibly be reduced or eliminated depending on how the ASMFC management action related to Addendum III to the ASFMC American Eel Fishery Management Plan is implemented.

5.8 Climate Change

Stream flow and temperature provide significant cues for shad migration and spawning in streams. Changes in the timing of peak spring flow have already been documented in the last 50 years (Frumhoff et al. 2007). Some predictions indicate that by 2040–2069 mean annual temperatures for the Delaware River Basin will be significantly warmer than experienced between 1971 and 2000 (DRBC 2008). This change may have implications for American shad in the basin. Increased flooding frequency and magnitude during critical migratory and spawning times may lead to higher potential for recruitment failure as flood conditions have a greater potential to sweep shad egg and fry out of nursery habitats. Extreme water temperature fluctuations during these times could also decrease productivity.

A recent analysis of flow data in the Upper Delaware by Moberg et al. (2009) found that at the Cooks Falls reference gage on the Beaver Kill the mean annual flow has increased from 532 to 597 cfs (12%) between the pre- and post-reservoir periods[2]. Median monthly flows have increased in summer, fall, and winter months, and have decreased during spring months (March-June). Low and high flows, including 3-, 7-, and 30-day events, have increased by 4 to 54%. In general, the post-reservoir period was wetter than the pre-reservoir period, as represented by both monthly median flows and the magnitude of low and high flow events. This pattern is consistent with long-term climatic trends published by Burns et al (2007).

Over their history, diadromous fish, in general, have shown to be resilient and adaptable to environmental changes and stressors. Large ranges, diverse habitats and extremely abundant populations account for this resilience (McDowall 2001). With the current status of American shad stocks at historic lows, however, changes in flow, temperature and extreme flooding events as a result of climate change are likely a more significant threat to the status of this species than if populations of shad were near historical abundances and if their full range of habitats were available. It is possible that tributary habitat may become important refugia for juveniles in certain years due to mainstem conditions i.e. major flood events. Sea level rise may impact the remaining freshwater tidal marshes in the lower basin and this potential could further degrade nursery habitat in this area.

<u>Restoration/Mitigation</u>

Historically, the notion of climate change has not been a focus of investigation for the Delaware River Basin. Yet, climate change is gaining momentum in the formation of various consortiums, groups, and governmental agencies releasing reports, models, and scenarios demonstrating the occurrence of climate change and potential forecasted impacts. While, there is no specific climate change restoration program aimed at American shad, within the Delaware River Basin, multiple initiatives, such as the current William Penn Watershed Initiative, seeks to protect and restore forests and floodplains to protect water quality in key shad watersheds in the basin could be

[2] The pre- impact period does not represent a natural or unaltered state, as the Upper Basin has a history of logging and land use conversion that have and continue to influence river processes.

important to improving and increasing habitat diversity and potentially provide additional refugia habitat. The DRBC has and is currently participating in panel discussions among peers, and continues exploring funding opportunities to further investigate this topic. The DRBC's State of the Basin Report (2008) includes a feature on climate change (in the hydrology section), which highlights the need for more localized studies, mapping, monitoring, and modeling, as well as for planning initiatives that integrate the reality of a changing climate. State agencies from all Co-op members also maintain programs for addressing climate change (http://www.state.nj.us/drbc/hydrological/climate/). Continued efforts to remove barriers will also allow shad access to tributary habitat that could increase resilience to climate change stressors.

5.9 Altered Trophic Structure

In the past the American shad in the Delaware River co-existed with fewer types of predatory fish than occur today. Since the late 1800's several species of piscivorous fish have been introduced and subsequently naturalized in the Delaware, including: largemouth bass, walleye, smallmouth bass, muskellunge, rainbow trout, and brown trout. Others including flathead catfish, northern snakehead, and Asian swamp eels have only recently begun to invading the lower reaches of the Delaware River Basin. During 2010 fall sampling, PFBC biologists collected numerous YOY and adult flathead catfish at both the Sandts Eddy, Pa (rkm 293) and Point Pleasant, Pa (rkm 251) stations. The PWD has documented flathead catfish inhabiting the fishway in Fairmount Dam, and these fish were likely targeting American shad as a food source during the spring spawning run. In 2008, the NJDFW documented the occurrence of Asian swamp eels in the Cooper River drainage in Silver Lake. Invasions outside of this water have not yet been documented.

In addition, the striped bass population has increased to historic highs coastwide and some studies have shown that river herring and shad can make up a substantial proportion of their diet (Walter *et al*., 2003; Savoy and Crecco 2004). With other prey species at historic lows, such river herring, and others entirely gone from the Delaware River, e.g. rainbow smelt, increased predation by striped bass and other piscivores may be having an adverse impact on the shad population.

Restoration/Mitigation

This type of threat is difficult to address and highlights the importance is ecosystem based management in fisheries. Based on stomach content analysis and direct observation of flathead catfish predation on alosine species, PWD actively targets and removes flathead catfish from the Fairmount Fishway during periods of heavy upstream migration of American shad, hickory shad, and river herring. The NJDFW will continue eradication and monitoring of swamp eels in the Cooper River drainage. Future studies such as stomach analysis on naturalized non-native species and the development of ecosystem level fish population models are critical to understanding if shad populations are being impacted by abundant prey populations. Because the non-native piscivores have themselves become prized by numerous groups of anglers, eradication of them is unlikely.

5.10 Dredging and Other In-Water Construction

The federal navigation channel in the Delaware River is presently 40 foot deep. The Delaware Deepening Project, which is now underway within the existing navigation channel, will deepen it from 40 ft to 45 feet from Philadelphia Harbor, Pa/ Camden, NJ along a 165 km distance into the Delaware Bay. In addition to direct habitat loss due to dredging and blasting, a salinity model completed by the U. S. Army Corp of Engineers indicates that deepening the existing navigation channel will result in salinity increases in the Philadelphia, Pa area in the event of a recurrence of the drought of record. In addition to dredging, there is a threat from the use of shoaling fans. These fans are used to keep water moving around docks to reduce frequency of dredging at docks; however, these fans can also entrain fish.

<u>Restoration/Mitigation</u>

The Co-op works closely with the U. S. Army Corps of Engineers to try and minimize the impacts of dredging and other encroachment activities on aquatic species. Co-op members have developed a document outlining preferred in-river construction activities, to best protect affected species for the Delaware River and Bay (DRBFWMC 2012).

Literature Cited and Sources of Spawning Run Information:

Anonymous. 1961. Big Flat Brook shad. N.J. Outdoors 12(2):28.

Bishop, S. C. 1936. Fisheries investigations in the Delaware and Susquehanna Rivers. N.Y. State Conserv. Dep., 25th Annu. Rep. 1935, Suppl. 10:122-139

Burns, D.A., J. Klaus, M.R. McHale. 2007. Recent climate trends and implication for water resources in the Catskill Mountain region, New York, USA. Journal of Hydrology 336: 155-170

Cable, L. E. 1945. The pollution problem in the Delaware River in relation to the restoration of the shad fishery. U.S. Fish and Wildlife Service. Unpub. MS., 9p.

Chittenden, M. E., Jr. 1976. Present and historical spawning grounds and nurseries of American shad, *Alosa sapidissima*, in the Delaware River. Fishery Bulletin 74: 343-352.

Chittenden, M. E. Jr. 1969. Life history and ecology of the American shad. Phd thesis, Rutgers University. 458p.

Compton K. R. 1963. Angler harvest comparisons on the fly-fishing only and open fishing stretches of the Big Flatbrook. D. J. Job Compl. Rep. State N.J. Proj. F-20-R-1, 37 p.

Cummings, Warren D. Sussex County: A History (Newton, New Jersey: Newton Rotary Club, 1964). Transcribed http://archiver.rootsweb.com/th/read/NJSUSSEX/2002-09/1032918263 accessed Feb 28, 2012

[DNREC] Delaware Department of Natural Resources and Environmental Control. 2005. Delaware Bay and Estuary Assessment Report. 171 pp.

[DRBC] Delaware River Basin Commission.2008. Delaware River State of the Basin Report. Delaware River Basin Commission; West Trenon, NJ. 47pp.

[DRBFWMC] A Review and Recommendations Relating to Fishways within the Delaware Basin, the Delaware River Basin Fish and Wildlife Management Cooperative, 1985, p. 5.

[DRBFWMC] Policy for dredging, blasting and overboard disposal update. the Delaware River Basin Fish and Wildlife Management Cooperative, 2012, p. 57.

[DRBC]Delaware River Basin Commission. 2010. Delaware River and Bay Integrated List Water Quality Assessment report. Delaware River Basin Commission; West Trenon, NJ; 52 pp.

EPA. 2002. Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule. Chapter B2. Technical and Economic Descriptions of In Scope Facilities of the Delaware Estuary Transition Zone. Report EPA-821-R-02-002. U.S. Environmental Protection Agency Office of Science and Technology Engineering and Analysis Division Washington, DC

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast

Gay, J. 1892. The shad streams of Pennsylvania. *In* Report of the State Commissioners of Fisheries for the years 1889-90-91. Harrisburg, Pa., pp. 151-187

Gumaer, P.K. 1890. A History of Deerpark in Orange County, N.Y. Minisink Valley Historical Society.

Harding. Charles. 1999. Fish or Foul: A History of the Delaware River Basin Through the Perspective of the American Shad," *Pennsylvania History* 66:4: 506-534.

Hendricks, M.L., T.R. Bender, and V.A. Mudrak. 1991. Multiple marking of American shad otoliths With tetracycline antibiotics. North American Journal of Fisheries Management. 11: 212-219.

Hendricks, M.L., R.L. Hoopes and D.A. Arnold. 2002. Homing of Hatchery reared American Shad to the Lehigh River, a tributary to the Delaware River. North American Journal of Fisheries Management 22:243-248.

Horwitz, R.J., D. Keller, S. Moser and P. Overbeck. 2008. Neversink Shad Study, Final Report. Submitted to The Nature Conservancy, Patrick Center for Environmental Sciences. The Academy of Natural Sciences. 23pp.

Kauffman, G. 2011. Socioeconomic Value of the Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania: *The Delaware River Basin, an economic engine for over 400 years.* Final Report. Retrieved: 6 Jan 2012. http://www.state.nj.us/drbc/SocioeconomicValueDRB-UDEL-FinalRpt.pdf

Kreeger, D., J. Adkins, P. Cole, R. Najjar, D. Velinsky, P. Conolly, and J. Kraeuter. 2010. Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning. Partnership for the Delaware Estuary, PDE Report No. 10-01.

Limburg, K. E., K. A. Hattala, and A. Kahnle. 2003. American shad in its native range. Pages 125–140 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

MacGillivray, A. R. 2012. Contaminants of Emerging Concern in the Tidal Delaware River a Pilot Monitoring Survey 2007-2009.Delaware River Basin Commission. West Trenton, NJ.

Mansueti I, R., and H. Kolb. 1953. A historical review of the shad fisheries of North America. Chesapeake Bio. Lab. Pub. 97. 293 p.

Martin, E. H. and C. D. Apse. 2011. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy, Eastern Freshwater Program.

Maurice, K.R., R. W. Blye, and P. L. Harmon. 1987. Increased spawning by American shad coincident with improved dissolved oxygen in the tidal Delaware River. American Fisheries Society Symposium 1: 79-88.

McDowall.2001. Anadromy and homing: Two life-history traits with adaptive synergies in salmonid fishes? Fish and Fisheries 2: 78–85.

McPhee, J. 2002. The Founding Fish. Farra, Staus and Giroux, New York, NY.

MacGillivray, R.A. 2007. Emerging Contaminants of Concern in the Delaware River Basin Vulnerability Assessment Preliminary Report. A Report to the Delaware River Basin Commission.

Miller, J.P., J.W. Friedersdorff, H.C. Mears and C.W. Billingsley. 1972. Annual progress report, Delaware River Anadromous Fish Project, AFS-2-5; July, 1971-June, 1972. U.S. Fish and Wildlife Service 88p.

Moberg, T., C. Apse, and M. DePhilip. 2010. Flow alteration in the Upper Delaware River Basin: a historical analysis of water supply reservoir management impacts (1954-2009). The Nature Conservancy, Harrisburg, PA.

[NYT] New York Times. 1889. Shad in the Delaware: Fishways constructing to enable them to pass a dam. Published: September 15, 1889

Pait, A.S. and J. O. Nelson. 2002. Endocrine Disruption in Fish: An Assessment of Recent Research and Results. NOAA Tech. Memo. NOS NCCOS CCMA 149. Silver Spring, MD: NOAA, NOS, Center for Coastal Monitoring and Assessment 55pp

[PDE] Partnership for the Delaware Estuary. 2012. Technical Report for the Delaware Estuary and River Basin. Partnership for the Delaware Estuary Report No. 12-01. 255 pp. http://www.delawareestuary.org/science_reports_partnership.asp

[PFBC] Pennsylvania Fish and Boat Commission. 2011. Draft Delaware River Management Plan: A management plan focusing on the large river habitats of the West Branch Delaware River and non-tidal reach of the Delaware River of Pennsylvania. Pennsylvania Fish and Boat Commission, Bureau of Fisheries, Division of Fisheries Management. Harrisburg, PA.

Ross, R. M., R. M. Bennett, and J. H. Johnson. 1997. Habitat use and feeding ecology of riverine Juvenile American shad. North American Journal of Fisheries Management 17:964–974

Savoy T.F., Crecco V.A. Factors affecting the recent decline of Blueback herring and American shad in the Connecticut River. American Fisheries Society Monograph 2004;9:361-377.

Schutt, A. 2007. Peoples of the River Valleys: The Odyssey of the Delaware Indians. University of Pennsylvania Press. 264 p.

Simpson, R. L., R. E. Good, M. A. Leck, and D. F. Whigham. 1983. The ecology of freshwater tidal wetlands. BioScience 33(4): 255-259.

Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. Pages 101-269 *in* G.M. Bowers. Report of the U.S. Commission of Fish and Fisheries, part 24. U.S. Commission of Fish and Fisheries, Washington, D.C

Stier, D.J. and J.H. Crance. 1985. Habitat suitability index models: American shad. U.S. Fish Wildlife Service. Biological Report 82 (10.88). Washington, DC

U.S. Fisheries Commissioners Annual Reports. 1887-88

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

[USGS-NWIS] U.S. Geological Survey, National Water Information System data available on the internet; accessed January 7, 2013, at URL http://waterdata.usgs.gov/nwis (see Station ID #01467200 and # 01477050).

Vajda A .M., Barber, L. B., James L.G, Lopez, E.M., Woodling, J.D. and D. O. Norris. 2008. 1. Reproductive Disruption in Fish Downstream from an Estrogenic Wastewater Effluent Environmental Science & Technology *42*:9: 3407-3414

Walford, L. A. 1951. Federal Power Commission Project No. 2039, Delaware River. (Memorandum On the restoration of shad in the Delaware River to the Atlantic States Marine Fisheries Commission, from the U. S. Fish and Wildlife Service). Jan. 24: 1-5

Walter, III, J. F.; Overton, A. S.; Ferry, K. H and M. E Mather. 2003. Atlantic coast feeding habits of striped bass: A synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology, 10: 349 - 360

Weslager C. A. 1989. “The Delaware Indians: A History” Rutgers University Press, New Brunswick, NJ 546 pp.

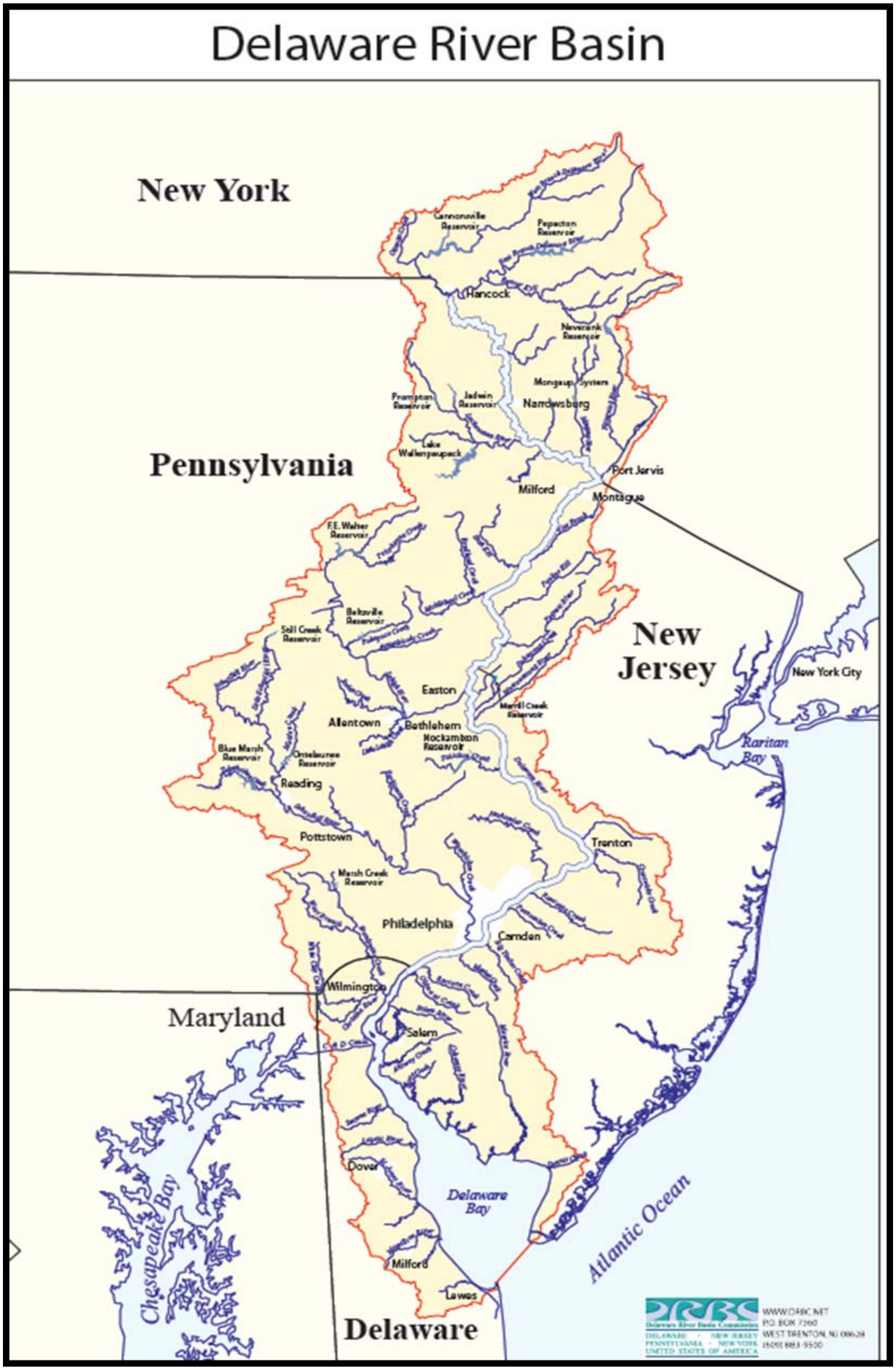

Figure 1: Delaware River Basin

Table 1: Historic and Contemporary Channel Deeping and Widening. Source: http://www.nap.usace.army.mil/Missions/CivilWorks/DelawareRiverMainChannelDeepening.aspx			
Delaware River, Philadelphia to the Sea			
Authorization	Depth (Ft)	Width (Ft)	Complete
NATURAL CONDITIONS (pre-1885)	17'-24'	175'-600'	n/a
January 1885 Board of Engineers recommendation	26'	600'	1898
March 1899 improvement plan	30'	600'	1905
June 1910 River and Harbor Act	35'	800'	1934
June 1938 River and Harbor Act	40'	800'-1000'	1942
Water Resources Development Act 1992	45'	400'-1000'	est. 2017

Figure 2: Historical and present day generalized location of the salt front. During the drought of record in the mid-1960's, the salt front reached river mile 102, just upriver from the Ben Franklin Bridge (rm 100). The present day location of the salt front is located at river mile 69.

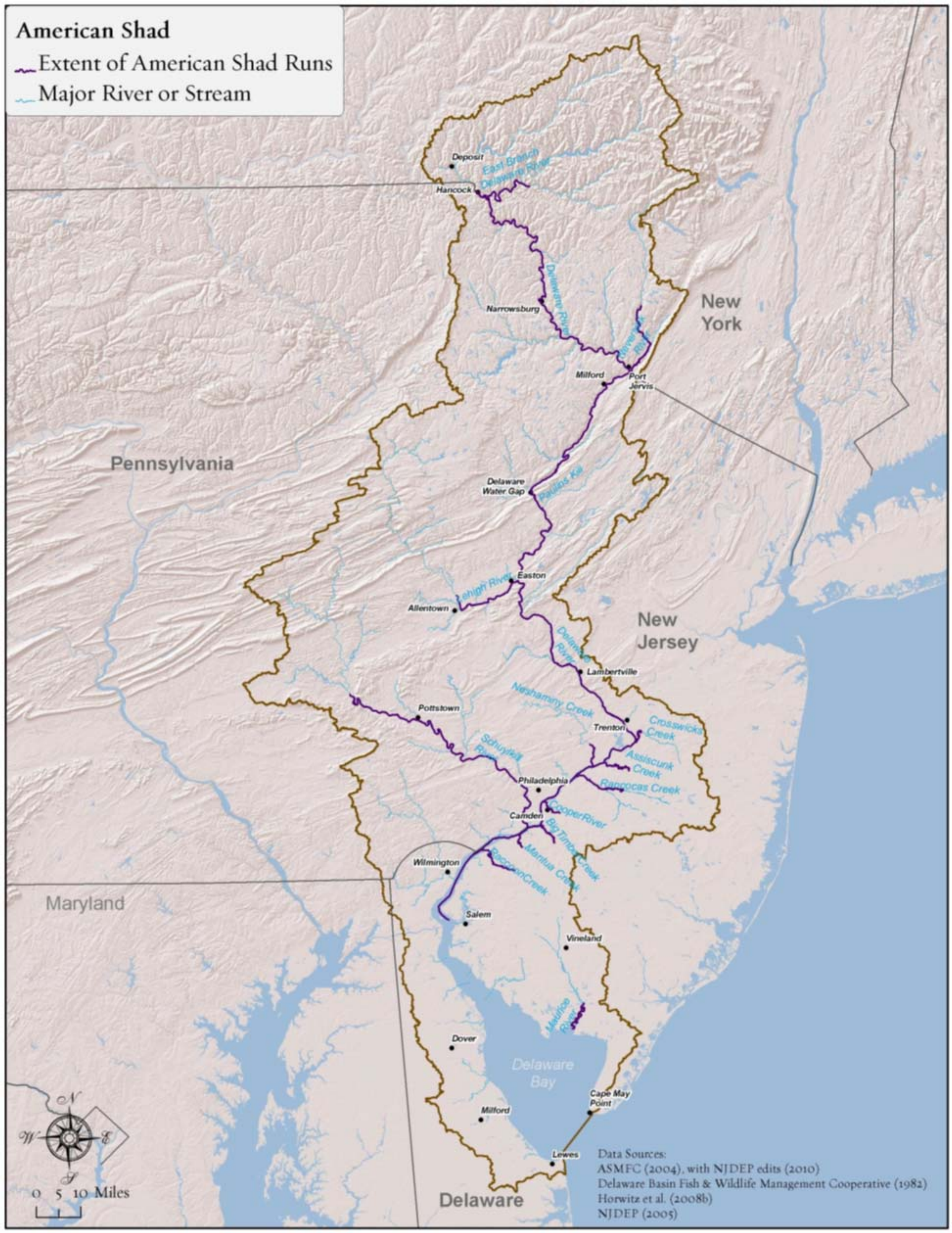

Figure 3: Shad runs (as of 2010).

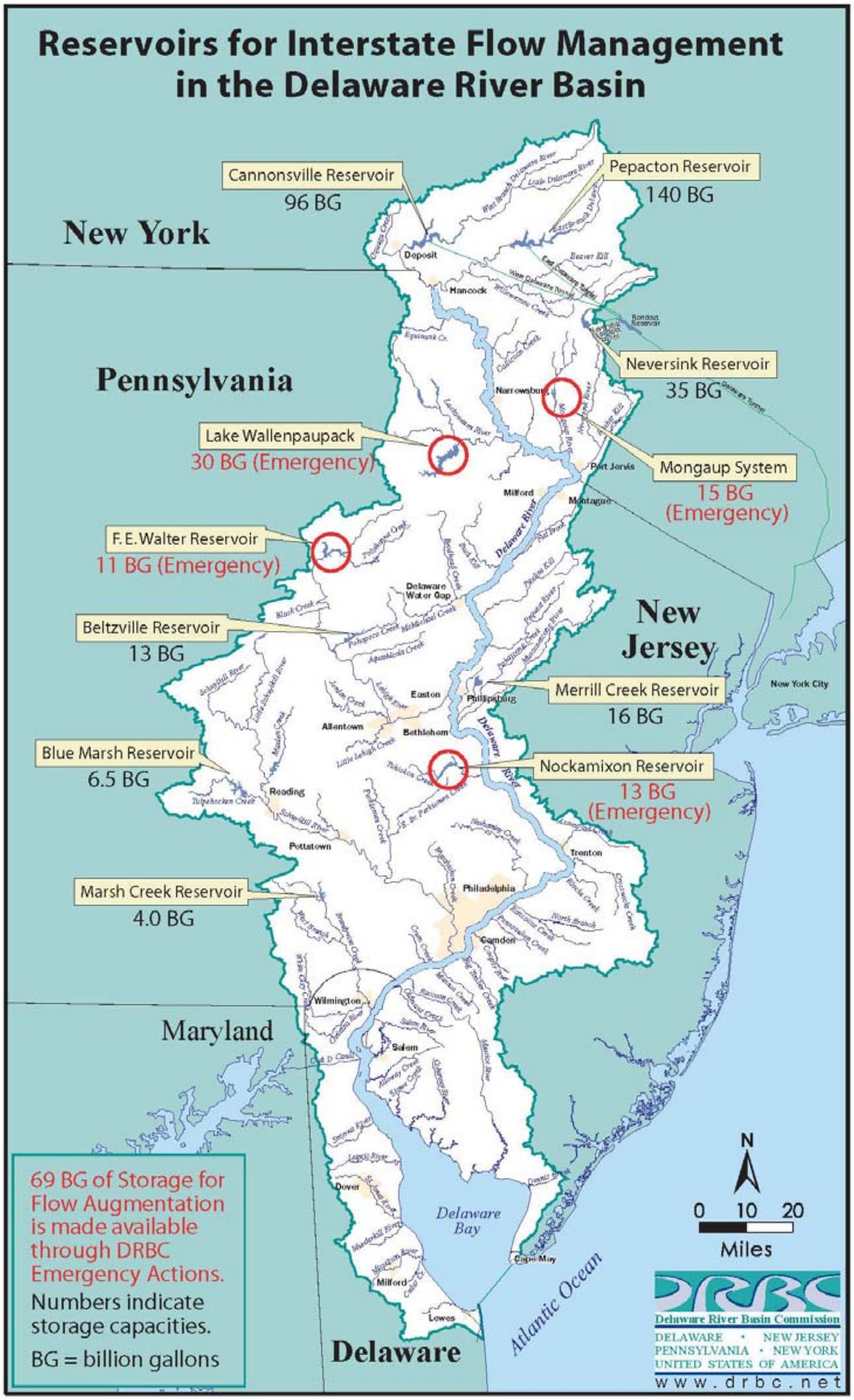

Figure 4: Delaware Basin Regulated Reservoirs.

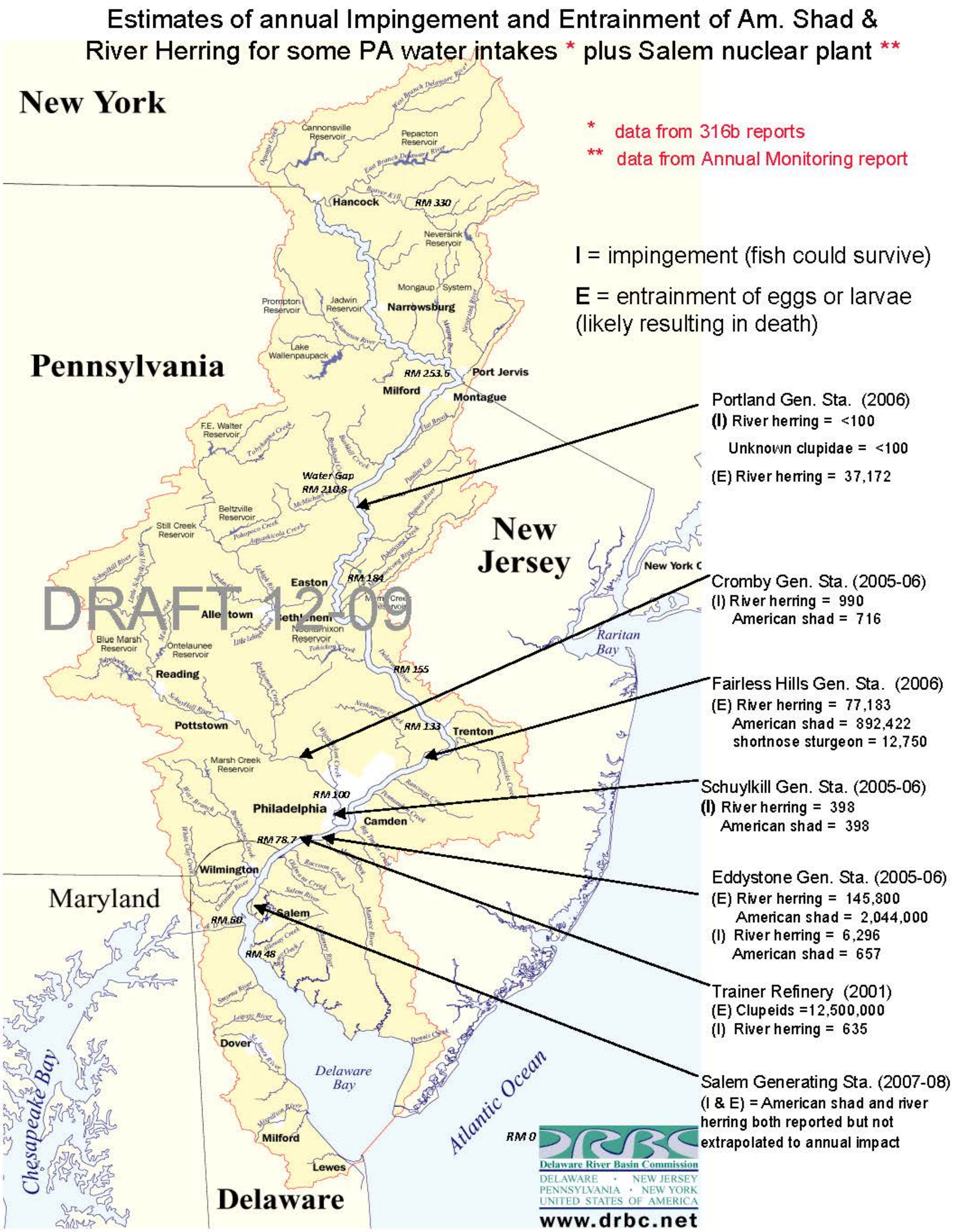

Figure 5: I&E losses.