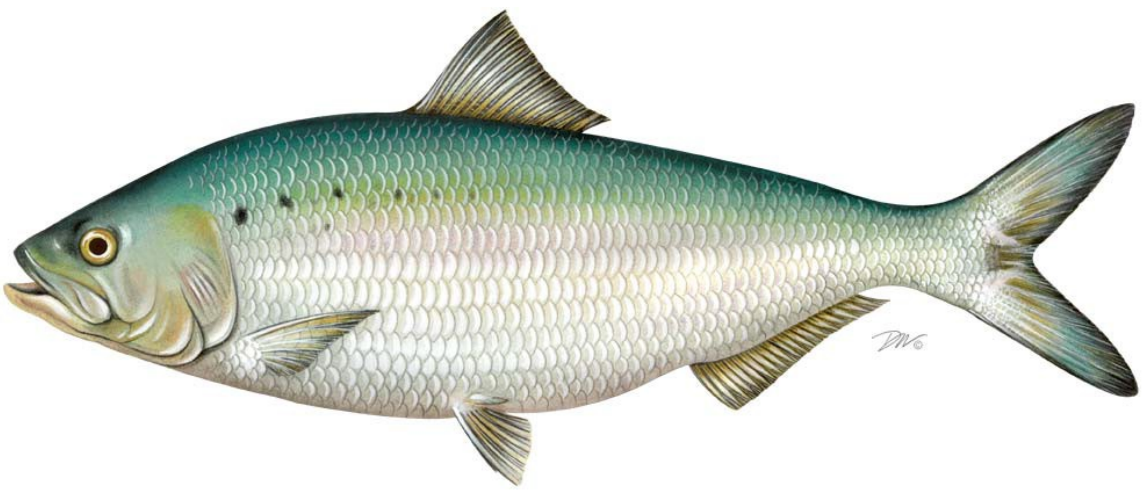
The Delaware River Basin Fish and Wildlife Management Cooperative

American Shad Habitat Plan for the Delaware River



Prepared by:
The Nature Conservancy for the Delaware River Basin Fish and Wildlife Management Cooperative

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 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

January 7, 2021

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Members of the Delaware River Basin Fish and Wildlife Management Cooperative wish to express our deepest gratitude to Mari-Beth DeLucia and Lyndon DeSalvo of The Nature Conservancy. Simply stated, their exemplary contributions to the management of American Shad will form the foundation for the restoration of American Shad to the Delaware River Basin.

Thank you.

Introduction

The Atlantic States Marine Fisheries Commission's (ASMFC) Amendment 3 to the American Shad and River Herring Fishery Management Plan (FMP) requires all states to submit a Habitat Plan for American Shad stocks in their jurisdiction. This report contains specific information for the Delaware River and its tributaries as it relates to habitat for American Shad in New York, Pennsylvania, New Jersey, and Delaware and provides an update to the 2014 American Shad Habitat Plan (Plan) for the Delaware River Watershed.

Recognition of the need to improve water quality and conserve the valuable resources of the Delaware River 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 Delaware 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 (NPS): 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 year 2000, three additional sections of the mainstem river covering a total of 63 km (39 mi.) were designated the Lower Delaware Scenic and Recreational River, also administered by the National Park Service.

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 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 USFWS 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.

Signed into law in December 2016, the Delaware River Basin Conservation Act (Act) recognized the basin as "a natural treasure of great cultural, environmental, ecological, and economic importance" (H.R. 1772). The Act established the Delaware River Basin Restoration Program to support efforts to implement conservation, stewardship, and enhancement projects throughout the Delaware River Basin and has included funding for the conservation and restoration of fish and wildlife habitat. As of fiscal year (FY) 2020, over $20 million have been appropriated for the Delaware River Basin Conservation Act. The Nature Conservancy was awarded funding through this program to develop a restoration roadmap for American Shad and River Herring in the Delaware River Basin. Results from this project will inform future updates to this Plan, with an anticipated final report in 2021.

Background

The 531 kilometer-long (330 mile-long) Delaware River is unique along the Atlantic Coast in that it is free flowing along its entire length. It drains an area of 36,568 km^2 (14,119 mi^2) in four U.S. states: Delaware, New Jersey, New York, and Pennsylvania (Fig. 1). American Shad and other migratory fish have access to the entire mainstem river and far up into its headwaters where in other similar East Coast aquatic systems they have long been extirpated.

Historically, American Shad spawned throughout the main stem freshwater Delaware River and its tributaries as well as tributaries connected to the Delaware Bay (Stevenson 1899) (Fig 1). The location of the salt front would have determined the extent of the potential spawning habitat in the freshwater tidal section of the river in any given year. It was presumed that the principal spawning area prior to 1900 was located south of Philadelphia just above Gloucester, N.J. (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, N.J., kept catch records before 1830s documenting annual American Shad hauls of greater than 130,000 fish at rkm 150 (rm 93) (Harding 1999).

Figure 1: Delaware River and tributaries.

As early as the 1800s, exploitation, pollution, and dams in the upper Delaware River and tributaries were having a significant impact on the shad population in the Delaware. The construction of the extensive canals and locks in the late 1800s along the main stem 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 River at Lackawaxen, PA. by the Delaware and Hudson Canal Company, remaining for approximately 80 years. Until dismantled, this dam decimated the upper river spawning run according to reports in the New York Times (NYT 1889). By the 1820s, fishermen noted the drastic decline in the size of shad and eight-pounders, which were once common, became hard to find by the early 1900s. As a result of exploitation and habitat loss, the shad fishery collapsed and led to the closure of the Gloucester fishery, which had been in existence for 200 years (Harding 1999)

During the 1940s and 1950s, heavy organic loading around Philadelphia caused severe declines in dissolved oxygen (D.O.) from late spring to early fall, blocking fish migrations through this area during this period (Hardy 1999). 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 that arrived earlier in the season migrated farther up the Delaware River 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. During the 1960s, 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, N.Y. (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 and subsequent improvement to water quality in the 1980s.

Main Stem Habitat Assessment

Characterization of the spatial distribution of spawning and nursery habitats for American Shad within the non-tidal Delaware River is poorly understood. Presently, much of the non-tidal river above Trenton, N.J. supports high quality habitats (by current standards) and three quarters of this section of the Delaware River is included in the National Wild and Scenic Rivers System. Annual monitoring of spawning American Shad at Smithfield Beach (rkm 351, rm 218), spanning multiple decades (1996 – present), certainly indicate this reach supportive of spawning adults (DRBFWMC 2017). It is unknown if observations at Smithfield Beach are representative of the entire non-tidal river. Subsequent catches of young-of-the-year American Shad via annual beach seine monitoring throughout the non-tidal reaches suggests, at least, a broad spatial nursery habitat utilization of the non-tidal river reaches (DRBFWMC 2017). American Shad spawn primarily in the middle and upper Delaware mainstem spanning approximately 236 river kilometers (147 river miles) from near Easton, Pa. (rkm 296, rm 184) to Hancock, N.Y. (rkm 532, rm 330) (Chittenden 1976). . American Shad also appear to be using the lower non-tidal reaches and freshwater tidal reaches of the Delaware River with early life stages of shad present in the estuary (PSEG Nuclear, LLC 2018).

The tidal section of the river is densely populated and home to one of the largest freshwater ports in the world. Losses of freshwater tidal wetlands and other riparian habitat in this area are significant (Partnership for the Delaware Estuary 2017). However, overall water quality has been improving in recent years and the near elimination of the D. O. block has prompted initiation of potentially upgrading the Delaware Estuary designated use (DRBC 2015, 2020). Ichthyoplankton surveys completed in 2018 captured larval American Shad in all zones of the estuary from Trenton (rkm 214, rm 133) down to roughly rkm 56 (rm 35) and American Shad eggs from Trenton to the mouth of the Schuylkill River (rkm 149, rm 92) (PSEG Nuclear, LLC 2018).

Tributary Habitat Assessment

Historically, shad utilized many, if not all, medium to large tributaries for spawning in addition to the main stem habitat. Although the main stem Delaware River 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 legacy mill dams, the building of multiple canal systems (Delaware and Raritan, Lehigh Coal and Navigation, etc.) during the 19th century extirpated shad from many main stem tributaries. Many of these canal systems still preclude shad from utilizing historic spawning and nursery grounds.

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 Table 1: beginning in the headwaters and moving downstream. Figure 2 highlights the known spawning runs as of 2020.

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

Table 1: Delaware River Tributaries with known current and/or historic American Shad spawning runs

Delaware River Tributaries	RKM	Historic (Pre-1950) Shad Run	Current Shad Run	Relevant Barriers	Comments	Data Sources
West Branch Delaware (NY)	532	Y (24km)	N	Cannonsville Dam (NY_119-2889)	Historic runs up to at least Deposit, NY. Cold tailwaters from NYC reservoirs create unsuitable conditions for shad.	Sykes & Lehman 1957; Bishop 1935; Gay 1892; Mansueti & Kolb 1953; Chittenden 1976
East Branch Delaware (NY)	532	Y (68km)	Y	Pepacton Dam (NY_146-1429)	Historic runs as far upstream as Downsville and within 30 miles of headwaters. Am. Shad present in East Branch during 1959-62 surveying and persist present day to East Branch, NY into the Beaver Kill. Cold tailwater from NYC reservoir and distance upstream probably varies with water temperatures.	Sykes & Lehman 1957; Bishop 1935; PA Fisheries Report 1896; PFBC Del River Mgmt Plan 2011;
Beaver Kill (NY)	East Branch Tributary	Y	Y (6km)	None	Chittenden (1976) reported shad 6km up Beaver Kill; and others reported shad 1km up Little Beaver Kill (tributary). Excellent water quality and undammed on its mainstem.	Chittenden 1976; Bishop 1935;
Lackawaxen River (PA)	447	Y	Y	Woolen Mill Dam (PA_64-053); Lake Wallenpaupack Dam (PA_52-051)	Thousands of shad noted in Lackawaxen in 1891 following installation of fishway at Lackawaxen Dam, as far as 25-30 miles above dam. Current fishing log mentions shad throughout Pike County section of Lackawaxen - likely a minor run today. Flow alteration due to releases from Lake Wallenpaupack that create cold tailwaters unsuitable for shad.	Gay 1892; Co-Op Fishways Review 1985; http://www.angelfire.com/pa/pikesportsmen/pcfsc4.1.htm; https://riverreporter.com/stories/loving-the-lackawaxen,18155
Mongaup River (NY)	420	Y	Y (7.5km)	Rio Dam (NY_149-0086); Mongaup Falls Dam (NY_148-0130)	Hydroelectric dams (currently in process of relicensing for 2022). Supports minor run in lower reach below Rio Dam. Mongaup Falls was almost certainly a natural barrier prior to hydroelectric dams. Estimated 237 Am. Shad were counted during American eel surveying in 2018.	Eagle Creek RE relicensing report 2020; National Park Service (Jessica Newbern - pers. comm.)

Neversink River (NY)	408	Y	Y (24km)	None	Small seine fishery in early 1800s. All historic mainstream habitat accessible and shad spawning run confirmed. Cuddebackville Dam removed in 2004 at RKM 16. High quality habitat.	Academy of Natural Sciences 2008 Neversink Shad Study; Gumaer 1890; The Nature Conservancy
Flat Brook (NJ)	362	Y (10km)	?	None	Minor historic run.	NJ Outdoors 1961
Brodhead Creek (PA)	343	?	Y	Brodhead Creek Dam (PA_1195188); Mill Creek Rd Dam in East Stroudsburg; McMichael Creek Mill Dam (PA_45-029)	Current fishing logs mention shad in lower reaches. Brodhead Creek Dam is breached and shad able to pass upstream to Mill Creek Rd Dam in East Stroudsburg. Exceptional water quality; prone to flooding.	http://www.paflyfish.com/forums/Open-Forums/Warm-Water---Salt-Water-Fly-Fishing/Shad-on-the-Brodhead/16,46369.html
Paulins Kill (NJ)	333	Y	Y (16km)	Paulina Lake Dam (NJ_NJ00170); County Line Dam (NJ_21-33)	Historic shad run documented in 1700s prior to damming of river. Current shad run up to Paulina Lake dam following removal of Columbia Lake Dam in 2018. TNC and partners looking to remove next two dams, the Paulina Lake and County Line.	NJ Freshwater Fisheries Report 2019; The Nature Conservancy; Cummings 1964
Pequest River (NJ)	318	?	Y	E.R. Collins & Sons Dam (NJ_24-28); E.R. Collins & Sons Dam (NJ_24-29); No Name Dam (NJ_24-31); Cedar Grove Dam (NJ_24-32)	Shad are in lower Pequest near confluence with Delaware River. Lower dams in Belvidere block shad and cause flooding issues.	https://www.nj.gov/dep/newsrel/2005/05_0061.htm
Lehigh River (PA)	295	Y (58km+)	Y (38km)	Easton Dam (PA_48-012); Chain Dam (PA_48-013); Hamilton Street Dam (PA_39-009); Cementon Dam (PA_39-060); Francis E. Walter Dam (PA_PA00008)	Historic fisheries with large run prior to construction of dams and canals. Current shad distribution possible to Cementon Dam (38km) where there is no fish passage. Lower three dams have fishways, but they are ineffective. Additional habitat impacts include lack of riparian vegetation (lower section); sediment deposition (lower section); metal contaminants. Easton averaged 1,459 shad passing fish ladder from 2004-2018 (Post 2012 data is estimated from electro-fishing below dam). Shad juveniles present.	2012 PFBC Next Steps in American Shad Restoration in PA; 2007 PFBC Lehigh River Management Plan; PFBC

Musconetcong River (NJ)	281	?	Y (9.5km)	Warren Mill Dam (NJ_NJ00765); Bloomsbury Dam (NJ_24-6); Asbury Mill Dam (NJ_NJ00581); Beattys Mill Dam (NJ_24-36)	Five dams removed between 2008-2016 by Musconetcong Watershed Partnership. Support from state and dam owner for removal of Warren Mill Dam, which has been reported as a safety hazard since 1981 and has shad at base. Cost of ~$20M to remove due to sediment buildup behind dam. Upstream designated as Wild and Scenic River.	https://www.state.nj.us/dep/nrr/restoration/bloomsbury-dam.html; USFWS (Danielle Mcculloch - pers. comm.);
Crosswicks Creek (NJ)	206	Y	Y	Gropp Lake Dam (NJ_NJ00235); Walnford Dam (NJ_28-21); Yardville Dam (NJ_28-15)	Crosswicks was clear for fish passage in mainstem in late 1800s. Creek is generally in good condition. Shad run is in lower section of river and confirmed at Route 206 in 2007.	Zich 1978; Fowler 1900; NJDEP 2012;
Blacks Creek (NJ)	206	Y	Y	Dunns Mill Dam (NJ_28-11)	Shad confirmed at West Burlington St in 2007.	NJDEP 2012;
Assiscunk Creek (NJ)	191	Y	Y	None	Water quality generally good and no dams evident in watershed. Shad confirmed at Rt 130 in 2004.	Zich 1978; NJDEP 2005, 2012;
Neshaminy Creek (PA)	186	Y	Y	Hulmeville Park Dam (PA_09-084); Neshaminy Falls Dam (PA_09-003; Spring Garden (PA_09-083); Neshaminy Weir Dam (PA_09-167)	Gay 1892 writes that shad frequent this stream. Shad run up to base of Hulmeville Park Dam and spawn in lower section of river. YOY shad documented in 2014 and 2017. Creek is susceptible to flooding, sewage discharge, and sediment and nutrient loading.	Gay 1892; Coop Fishways Review 1985; PFBC Darby + Neshaminy LMB Survey 2014; PFBC (Tyler Grabowski, John Buzzar - pers. comm.)
Rancocas Creek (NJ)	179	Y (25km+)	Y (2014)	Mill Dam (NJ00540); Smithville Dam (NJ_NJ00043); Cedar Lake Dam (NJ_31-13); Vincentown Mill Dam (NJ_NJ00396); Kirbys Mill Dam (NJ_NJ00634)	Listed as good shad river in 1896 PA Fisheries Report with runs 15-20 miles up. Shad in Rancocas between Centerton and Rancocas Park around 1950. Largest watershed in south central NJ. 2013 and 2014 NJ DEP Freshwater Fisheries seine samples found juvenile shad in Rancocas. Mill Dam at Mt Holly is impassable.	NJDEP; PA Fisheries Report 1896; Mansueti & Kolb 1953;
Pennsauken Creek (NJ)	169	?	Y	Moorestown Dam (NJ_NJ00635)	Small watershed with impacts from nutrients, PCBs.	NJDEP 2012
Cooper River (NJ)	163	Y	Y	Cooper River Parkway (Kaighn Ave) Dam (NJ_NJ00393); Cooper River Lake Dam (Cuthbert Ave); Wallworth Pond Dam (NJ_31-58); Evans Pond Dam (NJ_NJ00394)	Listed as good shad river in 1896 PA Fisheries Report. Fish ladder at Cooper River Lake with confirmed shad.	Zich 1978; NJFW 2012; PA Fisheries Report 1896; NJ F&W (Brian Neilan - pers. comm.)

Big Timber Creek (NJ)	154	Y (25km+)	Y	Blackwood Lake Dam (NJ_NJ00800); Laurel Springs Dam (NJ_NJ00400)	Listed as great shad river in 1896 PA Fisheries Report with runs 15-20 miles up and fisheries.10,400 shad yield in 1896. Historic water quality issues, development, Tidal Gate at Glendora. No dams before split into South and North branches.	Zich 1978; Fowler 1900; NJDEP 2012; PA Fisheries Report 1896; Stevenson 1898; NJDEP (Brian Neilan - pers. comm.)
Schuylkill River (PA)	149	Y (193km+)	Y (120km)	Fairmount Dam (PA_51-002); Flat Rock Dam (PA_PA00896); Norristown Dam (PA_46-001); Black Rock Dam (PA_46_027) - *all have fish passage however passage only currently monitored at Fairmount;* New Kernsville Dam (PA_PA00723); Auburn Dam (PA_PA00670)	Shad historically migrated 193km up the Schuylkill to Pottsville, PA and the river was estimated to support historic runs in the hundreds of thousands. Passage issues at lower four dams with fishways. Documented passage at Fairmount averaged1,460 annually between 2009-2019, with flooding or mechanical breakdowns in certain years serving to lower the average. Invasive species (Flathead Catfish; Northern Snakeheads) prey on migrating Alosines below Fairmount Dam. Single digit passage of shad at Black Rock Dam (2011-18). Juvenile shad present.	2018 Del R Shad & RH Compliance Report; 2012 PFBC Next Steps in American Shad Restoration in PA; 1985 Co-Op Fishways Review; PFBC (Ben Lorson, Josh Tryninewski - pers. comm.); PWD (Joe Perillo - pers. comm.)
Wissahickon Creek (PA)	Schuylkill Tributary	Y (Ambler, PA)	N	Grant Street Dam (PA_51-019); Robeson-Vandaren Mill Upper (PA_51-018)	History of Ambler document notes shad fishing as far as Ambler, PA. Habitat impacts include elevated nutrients, siltation, low DO, oil & grease, pathogens, non-native and invasive riparian species. Two dams right near confluence with Schuylkill. Flooding an issue.	2002 study; 2010 Wissahickon Creek Feasibility Study; Early History of Ambler, 1682-1888
Perkiomen Creek (PA)	Schuylkill Tributary	Y	?	Wetherill Dam (PA_46-050); Indian Head Dam (PA_46-051)	Historic fishery located at mouth of Perkiomen Creek. Wetherill Dam used for water supply and is barrier to passage.	PA Fisheries Report 1896;
Pickering Creek (PA)	Schuylkill Tributary	Y	N	Pickering Creek Dam (PA_1194555)	Fishery at mouth of Pickering Creek in 1730s. Pickering Creek Dam (water supply) completely cuts off watershed.	PA Fisheries Report 1896;
French Creek (PA)	Schuylkill Tributary	Y	?	Phoenixville Dam (PA_15-200)	Shad fishery mentioned in 1896 PA Fisheries report.	PA Fisheries Report 1896;
Woodbury Creek (NJ)	147	Y	N	Woodbury Creek Dam (NJ_NJ00398) - *has fish passage*	Listed as good shad river in 1896 PA Fisheries Report. Lowermost dam has fish ladder. Smaller watershed.	Zich 1978; NJDEP 2012; PA Fisheries Report 1896;
Mantua Creek (NJ)	144	Y	Y	Bethel Lake Dam (NJ_NJ00406)	2,000 shad reported in 1896; Zich confirmed them in Mount Royal in lower section of Mantua Creek. Shad occupy lower part of river.	Zich 1978, Fowler 1900; NJDEP 2012; Stevenson 1898;

Darby Creek (PA)	138	?	Y*	None	Barriers have been removed. Northern Snakeheads present in Darby. Shad found at 84th St Bridge in John Heinz National Wildlife Refuge in 2010. *Likely minor/limited to lower part.	PFBC Darby and Neshaminy Survey 2014; PFBC (Mike Kauffman, John Buzzar - pers. comm.); NOAA 2014;
Chester Creek (PA)	133.5	Y	Y	Rockdale Dam (PA_23-004); Llewellen Mill Dam (PA_23-012); Cotton Mill Dam (PA_1209034); Lenni Dam (PA_1194411)	Shad noted as plentiful in account from 1683. 2007/2008 PFBC Surveys: numerous American Shad fingerlings, one striped bass fingerling, and blue crabs in Chester Creek. American Shad utilize the Chester/Upland portion of Chester Creek as nursery water. Chester Creek had been previously unknown as American Shad nursery water.	PA Fisheries Report 1896; PA Fish and Boast Commission 2007-2008 Fisheries Report: https://pfbc.pa.gov/images/fisheries/afm/2008/6x09_08wwcw.htm
Repaupo Creek (NJ)	132.5	Y	?	Warrington Mill Dam (NJ_NJ00114)	Shown as historic run in 1985 Coop Fishways Report. Flood gate at mouth.	1985 Co-Op Fishways Review;
Raccoon Creek (NJ)	128	Y	Y	Mullica Hill Pond Dam (NJ_NJ00639) - *has fish passage*	Historic shad fishery, with 4,800 shad reported in 1896. American Shad confirmed at Rt 130 in 1994.	Zich 1978, Fowler 1900; NJDEP 2012; PA Fisheries Report 1896; Stevenson 1898;
Oldmans Creek (NJ)	122	Y	N	Harrisonville Dam (NJ_NJ00105)	Listed as good shad river in 1896 PA Fisheries Report. No shad found in recent sampling.	Zich 1978; NJDEP 2012; PA Fisheries Report 1896;
Christina River (DE)	113	Y	Y	Christina Lake Dam (DE_18); *aka Smalleys Pond Dam*; Cooch's Mill Dam (DE_24)	Historic fisheries, with 2,900 shad in 1896. Haul seine sampling in 2019 produced 21 American Shad in Christina River. Dams in key tributaries to Christina, and at Smalleys Pond (though shallow reaches below the spillway are presumed impassable by shad). Juvenile shad present.	DNREC 2019;
Brandywine Creek (DE)	Christina Tributary	Y	Y	Broom Street Dam (DE_13); Dam #3/O'Neill (DE_12); Alapocas Run Park Dam (DE_11); Brandywine Falls Dam (DE_10); DuPont Dam (DE_8/DE_9); Breck's Mill/Walker's Mill Dam (DE_7); Lower Hagley Dam (DE_6); Upper Hagley Dam (DE_emadd02); Eleutherian Dam (DE_5); Brandywine Creek/Rocklands Mill Dam (DE_101)	Historically supported very large shad runs. YOY shad were first found downstream of West St. dam (#1) on Brandywine Creek in 2017, when 386 YOY were sampled. Following West St. dam removal, YOY shad were found below Broom Street Dam (#2) in 2020 sampling. Dam removals and fishways planned for remaining 10 dams. Algal buildup due to dams.	DNREC 2019; Gay 1892; Brandywine Shad 2020 (pers. comm.)

White Clay Creek (DE)	Christina Tributary	Y	Y (6.5km)	Red Mill Dam (DE_23); Karpinski Park Dam (DE_emadd05); Paper Mill Dam (DE_22); Newark Intake Dam (DE_emadd06); Creek Road Dam (DE_emadd07); Deerfield Dam (DE_emadd08); White Clay Creek Preserve (PA_15-377)	Historic shad run. Byrnes Mill Dam removed in 2014 but reports that shallow depths and sediment might still impede fish passage here, especially during low tides. No shad present between removed Byrnes Mill Dam and existing Red Mill Dam in 2016+2017 during sampling. Dam removals and fishways planned for next four dams, with high potential for improving passage. Virtually the entire White Clay Creek watershed (306 km = 190 miles of streams) protected under the Wild & Scenic Rivers Act (since 2000).	DNREC 2019; Shad Restoration White Clay Creek 2010; DNREC (Mike Stangl - pers. comm.)
Salem River (NJ)	94	Y	N?	Flood gates.	Listed as good shad river, with 8,000 shad in 1896. Multiple flood gates near confluence with Delaware.	Zich 1978; NJFW 2012; Stevenson 1898; PA Fisheries Report 1896;
Alloway Creek (NJ)	87	Y	N?	Alloway Lake Dam (NJ_NJ00038), Elkinton Pond Dam (NJ_NJ00102)	300 shad yield in 1896.	Zich 1978; NJDEP 2012; Stevenson 1898;
Appoquinimink River (DE)	82	Y	?	Noxontown Pond Dam (DE_36); Silver Lake Dam (DE_35) - *have fish passage*	350 shad yield in 1896. Two YOY American shad were caught in Appoquinimink in 2017 approximately 1.2 km downriver of the Appoquinimink spillway. No shad reported in fish ladders, but Steeppass design is intended for river herring. Water quality: DO, nutrients.	DNREC 2020; DNREC (Mike Stangl - pers. comm.)
Blackbird Creek (DE)	81	Y	N?	Blackbird Pond Dam (DE_38)	Current status unknown. Water quality: DO, nutrients	
Duck Creek / Smyrna River (DE)	72	Y	N?	Duck Creek Pond (DE_40), Lake Como Dam (DE_41)	Current Status unknown. Fisheries on Duck Creek at Smyrna and Walker in 1896 yielded 1,500 shad. Water quality: DO, nutrients	Stevenson 1899;
Cohansey Creek (NJ)	61	Y	N?	Sunset Lake Dam (NJ_NJ00063) - *has fish passage;* Seeley's Mill Pond Dam (NJ_NJ00065)	Cohansey used to be third largest shad fishery in the state, after Hudson and Delaware. 21,850 shad yield in 1896. No current shad run.	1872 Fish Commissioners Report, Zichs 1978, ASMFC RH Stock Assessment 2017, Stevenson 1898; Brian Neilan (pers. comm.)
Leipsic River (DE)	55	Y	N?	Garrisons Lake Dam (DE_43) - *has fish passage*, Masseys Mill Pond Dam (DE_42)	Current status unknown. Fisheries from mouth to city of Leipsic yielded about 3,000 shad in 1896. Water quality: nutrients DO. No shad recorded at Garrisons Lake Dam, but fish ladder is steeppass designed for river herring.	DNREC 2020; Stevenson 1899;
Little River (DE)	45	Y	?	None	Current status unknown. Considered an important shad stream in 1940s. Undammed.	

St. Jones River (DE)	38	Y	Y*	Silver Lake Dam (DE_45); Moores Lake Dam (DE_47) - *have fish passage*	Fisheries in 1896 at Lebanon, Cherrytree Landing, and Dover took about 3,000 shad. In 2012, 2 American shad were found in in steeppass fish ladder at Moores Lake, designed for passing river herring. Water quality: nutrients, DO.	DNREC 2020; Stevenson 1899;
Murderkill River (DE)	37	Y	N?	Courseys Pond Dam (DE_54); McColleys Pond Dam (DE_55); McGinnis Pond Dam (DE_51) - *have fish passage*	Fisheries at Fredericka in 1896 yielded 8,700 shad. Current status unknown, but no shad recorded at steeppass fish ladders designed for river herring. Water quality: nutrients, DO.	DNREC 2020; Stevenson 1899;
Maurice River (NJ)	34	Y	Y	Union Lake Dam (NJ_NJ00448); Willow Grove Dam (NJ_NJ00040); Rainbow Lake Dam (NJ_NJ00751) - *have fish passage*	Historically supported extensive shad fisheries. Current status unclear - juveniles caught in seine 2013-15, but none in 2016. Shad believed to be present in lower section of river. Union Lake Dam has fish passage but is ineffective at passing alosines. Approximately 35 miles protected under the Wild & Scenic Rivers act (since 1993).	NJDEP 2012; 2019 Del Riv Basin Shad and RH Compliance Report; NJDEP (Brian Neilan - pers. comm.)
Mispillion River (DE)	19	Y	N?	Silver Lake Dam (DE_61) - *has fish passage;* Haven Lake Dam (DE_60); Marshall Millpond Dam (DE_62)	Current Status Unknown. Shad fishery in 1896 at and around Milford, DE yielded 50,000 shad. Water quality: nutrients, DO. No shad found at Silver Lake, but fish ladder is steeppass designed for river herring..	DNREC 2020; Stevenson 1899;
Broadkill River (DE)	0	Y	Y*	Wagamons Pond Dam (DE_69) - *has fish passage;* Diamond Pond Dam (DE_68); Red Mill Pond Dam (DE_71)	Shad were not present before being stocked here in 1880s (Stevenson 1899). *No shad in recent samples, but anglers reported American shad in Wagamons Pond spillway in 1998. Wagamons Pond fish ladder is steeppass designed for river herring. Water quality: DO, nutrients.	DNREC, 2020; Stevenson 1899; Mansueti & Kolb 1953; Jones 1999

Figure 2. Current American Shad runs in the Delaware River basin (as of 2020).

New York

The major spawning tributaries for shad in New York were the East and West Branches of the Delaware and 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 New York City reservoirs and direct loss of habitat due to the reservoirs themselves (Chittenden 1976). Fishways on these dams were deemed to be impractical due to the limited potential spawning areas above the reservoirs and the anticipated high cost of construction (DRBFWMC 1985). Shad historically migrated 68 km (42 miles) up the East Branch to the 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 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 1800s, the shad run in the Neversink River was large enough to support a seine fishery in the lower part of the river and it is believed that shad went upstream approximately 24km (15 miles) to the Neversink Gorge, which is the natural barrier due to gradient on this river (Gumaer 1890). Following the removal of the Southwest Cuddebackville Dam in 2004, 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.

The lower section of the Mongaup River also supports a current shad run to the base of the Rio Dam. Located 7.4 rkm (4.6 rm) upstream of the confluence with the Delaware River, Rio Dam is the lowermost of three hydroelectric dams owned and operated by Eagle Creek Renewable Energy. Mongaup Falls Dam is approximately 7 rkm (4.5 rm) further upstream and the falls, now submerged, were almost certainly a natural barrier for American Shad prior to the development of the hydroelectric dams in the 1920s.

Pennsylvania

Two of the largest shad spawning tributaries in the Delaware River Basin are wholly located within 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. The Schuylkill River is the largest tributary to the Delaware River with a point of entry at 149 rkm in the upper tidal estuary, in Philadelphia. Shad historically migrated 193 km (120 miles) upstream to Pottsville, Pa. and the runs were estimated to be in the hundreds of thousands. In 1820, the Fairmount Dam was constructed nine miles from the mouth of the Schuylkill River, effectively eliminating shad runs in the tributary for 150 years. In the last two decades, several main stem dams have been removed and others have added fish passage, which has theoretically enabled access to the New Kernsville Dam (rkm 160), though the current run is only estimated to Reading, Pa (rkm 120).

Located upriver in the non-tidal reach of the Delaware River, the Lehigh River enters the Delaware River at Easton, Pa. (rkm 294). Prior to the construction of a series of dams for supporting the Lehigh Coal and Navigation Canal system in the early 1800s, 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 River basin for 165 years until the subsequent installation of a fishway in 1994. Shad currently have access to the Cementon (Northampton) Dam at rkm 38, though ineffective passage at the three downstream dams limits the run size. In addition to physical barriers, water quality is also an issue in the Lehigh River due to impacts from several large municipalities that have discharges to the drainage and historic inputs from a former metal smelting operation.

At rkm 447, the Lackawaxen River was also a historically significant shad tributary and is believed to have a current run, according to anecdotal accounts from fishermen. Presently, Brookfield Energy is required to maintain an experimental trout tailwater via reservoir releases from Lake Wallenpaupack, as per FERC re-license agreement (FERC Proj. # 487, May 19, 2004). The target reach is from Kimbles Road Bridge (rkm 16, rm 10) down river to Rowland Road Bridge (rkm 6.4, rm 4). The program seeks, to prevent maximum instantaneous temperatures from exceeded 23.8 ºC (75 ºF) under most meteorological and hydrological conditions, and to prevent instantaneous stream temperatures from exceeding 25.0 ºC (77 ºF) during more severe meteorological and hydrological events. Annual performance evaluations indicated tailwater temperatures tended to vary but remain more characteristic of a transitional thermal habitat (> 21.1 ºC (70 ºF)) rather than reflective of a well-defined cold-water thermal habitat (< 18.8 ºC (66 ºF)). Efficacy of this program is anticipated to be evaluated in 2023.

Several other tributaries to the Delaware River within Pennsylvania are also known to have American Shad runs. Recent sampling in the Chester and Neshaminy Creeks have confirmed American Shad fingerlings in these tributaries and both are known to support nurseries in their lower reaches. Since American Shad were documented in the Darby Creek (rkm 138) within the John Heinz National Wildlife Refuge at Tinicum in 2010, four dams have been removed in the lower portion of the waterway enabling access to over 10 miles that were previously blocked (John Buzzar, pers. comm.).

New Jersey

In New Jersey, most tributaries that were tidally influenced had runs of American Shad that could support fisheries. In 1896, the Cohansey River (rkm 61) ranked third in New Jersey as a shad-producing stream, surpassed only by the Hudson and Delaware rivers, and shad were known to run 20 miles upstream to Bridgeton (Stevenson 1899). The Maurice River, which discharges into the Delaware Bay at rkm 34, similarly supported extensive shad fisheries until the construction of a dam at the present-day Union Lake in the 1860s. While the current Union Lake Dam does have a fish ladder, no shad have been documented passing here and they are recorded intermittently in the tidal Maurice River below the dam.

Several other tidal tributaries were also noted as supporting extensive shad runs at the end of the 19th century, including the Salem River (rkm 94), Oldmans Creek (rkm 122), Raccoon Creek (rkm 128), Woodbury Creek (rkm 147), Big Timber Creek (rkm 154), Cooper River (rkm 163), and Rancocas Creek (rkm 179) (PA State Commissioners of Fisheries 1896). In the Big Timber and the Rancocas creeks, shad were known to run 15 to 20 miles upstream and extended into the northern and southern branches of both these tributaries (PA State Commissioners of Fisheries

1896). An anadromous clupeid inventory by the New Jersey Division of Fish & Wildlife from 2002-2007 compiled previous run information and confirmed shad in many of these historically significant tributaries, though in large part their numbers and known extent have been greatly reduced. In these systems, shad face many habitat impacts including dams, canals, tidal gates, water quality, and predation by invasive species, particularly Flathead Catfish and Northern Snakeheads.

American Shad have also been confirmed in a few non-tidal New Jersey tributaries in recent years following dam removal and restoration efforts. With the removal of the lowermost barriers on the Paulins Kill and Musconetcong River, shad have begun occupying these systems and accessing newly available habitat. Currently, shad have access to 17 km of the Paulins Kill to the Paulina Lake Dam and 9 km of the Musconetcong River to the Warren Glen Dam. The lower reach of the Pequest River (rkm 318) near its confluence with the Delaware River is also documented to have shad present.

<u>Delaware</u>

In the late 1600s, the Christina watershed, including the White Clay and Brandywine creeks, supported tens of thousands of American Shad. However, as early as the 1700s, the Brandywine Lenape Native Americans were complaining to commissioners in Pennsylvania 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 proliferation of dams and water pollution effectively eliminated the run in the watershed up until recently, when efforts to improve water quality and remove dams have succeeded in reopening previously inaccessible reaches within this system. In July 2020, sampling below Broom Street Dam (Dam #2) in Wilmington confirmed American Shad were spawning in this section that had been opened up with the removal of the West Street Dam in 2019. Shad are also known to access the Christina River beyond its confluence with the White Clay Creek and the White Clay to the former Byrnes Mill Dam site (DNREC 2020).

Historically, shad were found in most Delaware tributaries, with fisheries established in the Mispillion, Murderkill, St. Jones, Leipsic, and Smyrna Rivers (Mansueti and Kolb 1953, Stevenson 1899). 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 streams during the past century and it is unlikely that many of them currently support spawning runs. An eDNA study is planned for 2021 to assess presence of alosines, including American Shad, below Delaware fish ladders to better understand current distribution and the effectiveness of the steeppass ladders, which were designed to pass river herring. Dissolved oxygen and nutrient issues continue to impact many of these tributaries that once supported shad runs (DNREC 2005).

Nursery Habitat

Juvenile American Shad are presumed to remain in the rearing area of their natal river. It is unknown if juveniles remain fidel to a specific nursery reach or tend to disburse among suitable nursery habitats. 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, N.Y. and Lordville, N.Y. Subsequent annual beach seine monitoring by Co-Op members throughout the Delaware River support greatest catches typically occurring at Milford Beach (rkm 394) and Water Gap (rkm 339), but variation of site specific seine efficacy may also strongly dictate observed catch totals. 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); but no overall effect of habitat type on shad were determined (Ross et al. 1997), indicating that juveniles use a wide variety of habitat types to their advantage. Furthermore, the specific environmental and/or biological ques for outmigration are also poorly understood. Yet, it is generally accepted that juveniles out-migrate from nursery areas to marine waters during fall months as water temperatures decrease (Limburg et al. 2003).

In the upper Delaware River, prior to the construction of the New York City Delaware 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. Juvenile American Shad do not appear to be as tolerant to temperature changes as American Shad eggs and actively avoid temperature extremes, if possible. Laboratory tests suggest that juveniles can tolerate temperature increases between 1° and 4°C above ambient temperature, but beyond that they will avoid changes if given a choice (Moss 1970).

Historically the tidal Delaware River and Estuary were 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 between Wilmington, Del. and Trenton, N.J., 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 freshwater tidal reaches of the Delaware River and its tributaries in this section of the basin.

Very little is known about nursery habitat in tributaries to the Delaware River. The continued extirpation of shad from various tributaries throughout the basin preclude understanding for their importance to American Shad, forcing inferences to be drawn from anecdotal historical references. However, observations upstream of recently removed barriers suggests that shad will return and utilize tributary habitat if unimpeded. For example, young-of-year shad were documented in 2020 upstream of the removed West Street Dam on the Brandywine Creek and are also known to utilize the main stem of the Christina River. In 2019 NJFW biologists documented the return of American Shad to the Paulins Kill after the removal 109-year-old Columbia Lake Dam (NJDEP 2019). In 2008, PFBC biologists have also documented that American Shad utilize the Chester/Upland portion of Chester Creek and lower section of Neshaminy Creek as nursery waters.

Threat Assessment

Despite significant improvements to water quality and fish passage in the Delaware River Basin over the last decade or more, there has been a lack of a corresponding rebound in numbers of American Shad. The 2020 ASMFC Stock Assessment for American Shad determined that adult mortality was unsustainable in the Delaware River population. An assessment of solely the threats to freshwater and brackish habitat is insufficient. A holistic approach to addressing the cumulative impacts of a variety of stressors is needed across all of this species' life cycles.

Barriers to Migration:

Although the Delaware River is free flowing along its mainstem, there are over 1,500 dams and other barriers on its tributaries that greatly impact aquatic connectivity throughout the basin. A list of barriers relevant to American Shad based on current and historic spawning runs is included here in Table 2.

Table 2. Relevant Barriers to American Shad migration in the Delaware River Basin.

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Cannonsville Dam	NY_119-2889	West Branch Delaware River	Cannonsville Reservoir	Complete	
Pepacton Dam	NY_146-1429	East Branch Delaware River	Trout Brook-East Branch Delaware River	Complete	
Woolen Mill Dam	PA_64-053	Lackawaxen River	Belmont Lake-West Branch Lackawaxen River	Complete	
Lake Wallenpaupack	PA_52-051	Wallenpaupack Creek	Lake Wallenpaupack-Wallenpaupack Creek	Complete	
Rio Dam	NY_149-0086	Mongaup River	Rio Reservoir-Mongaup River	Complete	
Mongaup Falls Dam	NY_148-0130	Mongaup River	Rio Reservoir-Mongaup River	Complete	
Brodhead Creek Dam	PA_1195188	Brodhead Creek	Lower Brodhead Creek	Breached	
Mill Creek Road Dam	?	Brodhead Creek	Lower Brodhead Creek	Complete	
McMichael Creek Mill Dam	PA_45-029	McMichael Creek	Lower McMichael Creek	Complete	
Paulina Lake Dam	NJ_NJ00170	Paulins Kill	Middle Paulins Kill River	Complete (to be removed)	
County Line Dam	NJ_21-33	Paulins Kill	Middle Paulins Kill River	Complete (to be removed)	
E.R. Collins & Son Dam	NJ_24-28	Pequest River	Lower Pequest River	Complete	
E.R. Collins & Son Dam	NJ_24-29	Pequest River	Lower Pequest River	Complete	
No Name Dam	NJ_24-31	Pequest River	Lower Pequest River	Complete	
Cedar Grove Dam	NJ_24-32	Pequest River	Lower Pequest River	Complete	
Easton Dam	PA_48-012	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Chain Dam	PA_48-013	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot
Hamilton Street Dam	PA_39-009	Lehigh River	Lehigh River-Delaware River	Fishway	Vertical slot
Cementon Dam	PA_39-060	Lehigh River	Fireline Creek-Lehigh River	Complete	
Warren Mill Dam	NJ_NJ00765	Musconetcong River	Lower Musconetcong River	Complete (to be removed)	
Bloomsbury Graphite Dam	NJ_24-6	Musconetcong River	Lower Musconetcong River	Complete (to be removed)	
Asbury Mill Dam	NJ_NJ00581	Musconetcong River	Lower Musconetcong River	Complete	
Gropps Lake Dam	NJ_NJ00235	Back Brook	Lower Crosswicks Creek	Fishway	Steeppass*
Walnford Dam	NJ_28-21	Crosswicks Creek	Lower Crosswicks Creek	Unknown, assumed complete	
Yardville Dam	NJ_28-15	Doctors Creek	Doctors Creek	Unknown, assumed complete	
Dunns Mill Dam	NJ_28-11	Blacks Creek	Blacks Creek	Unknown, assumed complete	
Hulmeville Dam	PA_09-084	Neshaminy Creek	Core Creek-Neshaminy Creek	Complete	
Neshaminy Falls Dam	PA_09-003	Neshaminy Creek	Core Creek-Neshaminy Creek	Complete	
Spring Garden Dam	PA_09-083	Neshaminy Creek	Mill Creek-Neshaminy Creek	Complete	
Neshaminy Weir	PA_09-167	Neshaminy Creek	Mill Creek-Neshaminy Creek	Complete	
Mill Dam	NJ_NJ00540	North Branch Rancocas Creek	Powells Run-North Branch Rancocas Creek	Complete	
Smithville Dam	NJ_NJ00043	North Branch Rancocas Creek	Powells Run-North Branch Rancocas Creek	Fishway	Steeppass*
Cedar Lake Dam	NJ_31-13	South Branch Rancocas Creek	Jade Run-South Branch Rancocas Creek	Unknown, assumed complete	
Kirbys Mill Dam	NJ_NJ00634	SW Branch South Branch Rancocas Creek	Little Creek-Southwest Branch Rancocas Creek	Complete	
Vincentown Mill Dam	NJ_NJ00396	South Branch Rancocas Creek	Jade Run-South Branch Rancocas Creek	Fishway	Steeppass?
Moorestown Dam	NJ_NJ00635	North Branch Pennsauken Creek	Pennsauken Creek	Complete	
Cooper River Parkway (Kaighn Ave) Dam	NJ_NJ00393	Cooper River	Cooper River	Fishway	Flood gate
Cooper River Lake Dam (Cuthbert Ave)	?	Cooper River	Cooper River	Fishway	Flood gate
Wallworth Pond Dam	NJ_31-58	Cooper River	Cooper River	Fishway	Steeppass*
Evans Pond Dam	NJ_NJ00394	Cooper River	Cooper River	Fishway	Steeppass*
Laurel Springs Dam	NJ_NJ00400	North Branch Big Timber Creek	North Branch Big Timber Creek	Unknown, assumed complete	
Blackwood Lake Dam	NJ_NJ00800	South Branch Big Timber Creek	South Branch Big Timber Creek	Complete	
Fairmount Dam	PA_51-002	Schuylkill River	City of Philadelphia-Schuylkill River	Fishway	Vertical slot
Flat Rock Dam	PA_PA00896	Schuylkill River	Plymouth Creek-Schuylkill River	Fishway	Vertical slot
Norristown Dam	PA_46-001	Schuylkill River	Plymouth Creek-Schuylkill River	Fishway	Denil
Black Rock Dam	PA_46-027	Schuylkill River	Mingo Creek-Schuylkill River	Fishway	Denil
Kernsville Dam	PA_PA00723	Schuylkill River	Pigeon Creek-Schuylkill River	Complete (to be removed)	
Auburn Dam	PA_PA00670	Schuylkill River	Mahannon Creek-Schuylkill River	Complete	
Grant Street	PA_51-019	Wissahickon Creek	Lower Wissahickon Creek	Complete	
Robeson-Vandaren Mill Upper Dam	PA_51-018	Wissahickon Creek	Lower Wissahickon Creek	Complete	
Wetherill Dam	PA_46-050	Perkiomen Creek	Lower Perkiomen Creek	Complete	
Indian Head	PA_46-051	Perkiomen Creek	Lower Perkiomen Creek	Complete	
Pickering Creek Dam	PA_1194555	Pickering Creek	Pickering Creek	Complete	
Phoenixville Dam	PA_15-200	French Creek	Lower French Creek	Complete	
Woodbury Creek Dam	NJ_NJ00398	Woodbury Creek	Woodbury Creek	Fishway	Steeppass*

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Bethel Lake Dam	NJ_NJ00406	Mantua Creek	Mantua Creek	Complete	
Rockdale Dam	PA_23-004	Chester Creek	Chester Creek	Complete	
Cotton Mill Dam	PA_1209034	Chester Creek	Chester Creek	Unknown, assumed complete	
Lenni Dam	PA_1194411	Chester Creek	Chester Creek	Unknown, assumed complete	
Warrington Mill Dam	NJ_NJ00114	Repaupo Creek	Repaupo Creek-Delaware River	Complete	
Mullica Hill Pond Dam	NJ_NJ00639	Raccoon Creek	Raccoon Creek	Fishway	Steeppass*
Harrisonville Dam	NJ_NJ00105	Oldmans Creek	Oldmans Creek-Delaware River	Complete	
Christiana Lake Dam	DE_18	Christina River	Middle Christina River	Complete	
Coochs Mill Dam	DE_24	Christina River	Upper Christina River	Unknown, assumed complete	
Broom Street Dam	DE_13	Brandywine Creek	Lower Brandywine Creek	Complete	
Dam #3 (O'Neill)	DE_12	Brandywine Creek	Lower Brandywine Creek	Breached	
Alapocas Run Park Dam	DE_11	Brandywine Creek	Lower Brandywine Creek	Breached	
Brandywine Falls Dam	DE_10	Brandywine Creek	Lower Brandywine Creek	Complete	
DuPont Dam	DE_9	Brandywine Creek	Lower Brandywine Creek	Breached	
DuPont Dam	DE_8	Brandywine Creek	Lower Brandywine Creek	Breached	
Breck's Mill/Walker's Mill Dam	DE_7	Brandywine Creek	Lower Brandywine Creek	Complete	
Lower Hagley Dam	DE_6	Brandywine Creek	Lower Brandywine Creek	Complete	
Upper Hagley Dam	DE_emadd02	Brandywine Creek	Lower Brandywine Creek	Breached	
Eleutherian Dam	DE_5	Brandywine Creek	Lower Brandywine Creek	Complete	
Brandywine Creek Dam	DE_101	Brandywine Creek	Middle Brandywine Creek	Breached	
Red Mill Dam	DE_23	White Clay Creek	Upper White Clay Creek	Complete (to be removed)	
Karpinski Park Dam	DE_emadd05	White Clay Creek	Upper White Clay Creek	Complete	
Paper Mill Dam	DE_22	White Clay Creek	Upper White Clay Creek	Complete (to be removed)	
Newark Intake Dam	DE_emadd06	White Clay Creek	Upper White Clay Creek	Complete	
Creek Road Dam	DE_emadd07	White Clay Creek	Upper White Clay Creek	Complete	
Deerfield Dam	DE_emadd08	White Clay Creek	Upper White Clay Creek	Complete	
White Clay Creek Preserve	PA_15-377	White Clay Creek	Upper White Clay Creek	Complete	
Alloway Lake Dam	NJ_NJ00038	Alloway Creek	Upper Alloway Creek	Fishway	Steeppass*
Elkinton Pond Dam	NJ_NJ00102	Deep Run	Upper Alloway Creek	Complete	
Noxontown Pond Dam	DE_36	Appoquinimink River	Drawyer Creek-Appoquinimink River	Fishway	Steeppass*
Silver Lake Dam	DE_35	Deep Creek	Drawyer Creek-Appoquinimink River	Fishway	Steeppass*
Blackbird Pond Dam	DE_38	Blackbird Creek	Blackbird Creek	Complete	
Duck Creek Pond Dam	DE_40	Smyrna River	Duck Creek	Complete	
Lake Como Dam	DE_41	Mill Creek	Duck Creek	Complete	
Sunset Lake Dam	NJ_NJ00063	Cohansey River	Middle Cohansey River	Fishway	Steeppass*
Seeleys Mill Pond Dam	NJ_NJ00065	Cohansey River	Upper Cohansey River	Unknown, assumed complete	
Garrisons Lake Dam	DE_43	Leipsic River	Upper Leipsic River	Fishway	Steeppass*
Masseys Mill Pond Dam	DE_42	Leipsic River	Upper Leipsic River	Complete	
Silver Lake Dam - Dover	DE_45	Saint Jones River	Upper Saint Jones River	Fishway	Steeppass*
Moores Lake Dam	DE_47	Isaac Branch	Isaac Branch	Fishway	Steeppass*
Courseys Pond Dam	DE_54	Murderkill River	Spring Branch-Murderkill River	Fishway	Steeppass*
McColleys Pond Dam	DE_55	Browns Branch	Browns Branch	Fishway	Steeppass*
McGinnis Pond Dam	DE_51	Hudson Branch	Spring Creek	Fishway	Steeppass*

Dam Name	Dam ID	Stream Name (NHD)	HUC-12 Name	Barrier Status	Fishway Type
Union Lake Dam	NJ_NJ00448	Maurice River	Union Lake-Maurice River	Fishway	Denil
Willow Grove Dam	NJ_NJ00040	Maurice River	Burnt Mill Branch-Maurice River	Fishway	Steeppass*
Rainbow Lake Dam	NJ_NJ00751	Muddy Run	Lower Muddy Run	Unknown, assumed complete	
Silver Lake Dam - Milford	DE_61	Mispillion River	Upper Mispillion River	Fishway	Steeppass*
Haven Lake Dam	DE_60	Mispillion River	Upper Mispillion River	Complete	
Marshall Millpond Dam	DE_62	Mispillion River	Middle Mispillion River	Complete	
Wagamons Pond Dam	DE_69	Broadkill River	Round Pole Branch-Broadkill River	Fishway	Steeppass*
Diamond Pond Dam	DE_68	Ingram Branch	Round Pole Branch-Broadkill River	Complete	
Red Mill Pond Dam	DE_71	Old Mill Creek/Martin Branch	Canary Creek-Broadkill River	Complete	

* Steeppass fish ladders in the State of Delaware are designed to pass river herring and not American Shad. American Shad are not able to effectively pass steeppass fishways greater than 20 m in length with a 27.3% slope (Slatick and Basham 1985)

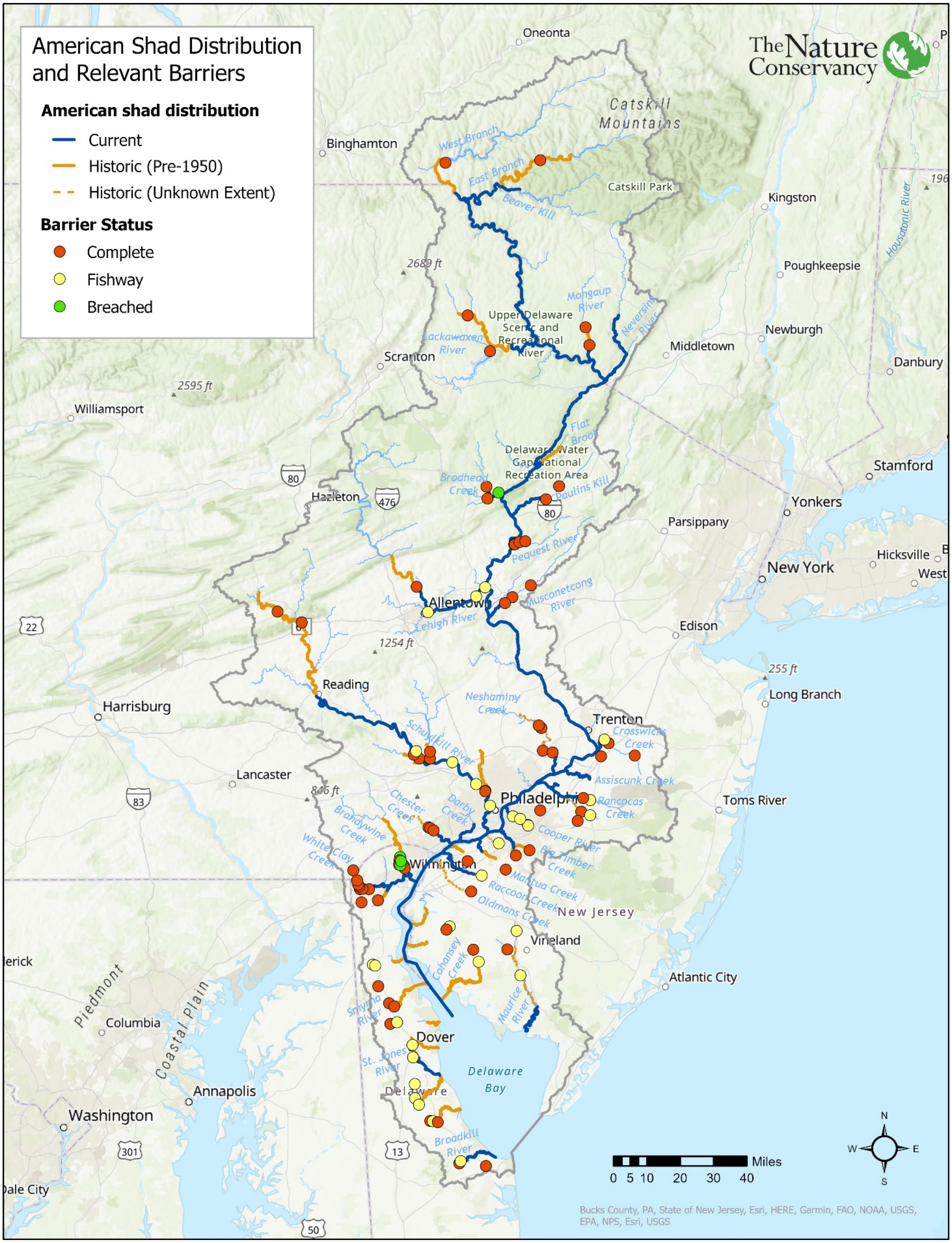

Figure 3. American Shad distribution and relevant barriers to migration in the Delaware River Basin.

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). A recent analysis of flow data in the upper Delaware River by Moberg et al. (2009) found that, at the Cooks Falls reference gauge on the Beaver Kill, the mean annual flow has increased from 532 to 597 cfs (12%) between the pre- and post-reservoir periods. 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, changes in flow, temperature, and extreme flooding 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. In the Delaware River Basin, the shad population should be managed in a way that promotes and protects a diverse age structure and habitat utilization. A population that utilizes the full extent of the main stem as well as numerous tributaries of different size classes may have greater reproductive potential to protect against negative impacts from environmental disturbances (Hillborn et al. 2003, Schindler et al. 2010). A diverse age structure and behavioral patterns within a population of migratory fish can help mitigate against stochastic or anthropomorphic effects and take advantage of ideal conditions for population recruitment (Kerr et al. 2010, Secor 2007).

Tropic dynamics/Invasive species

In the past, the American Shad in the Delaware River Basin coexisted with fewer types of predatory fish than occur today. Since the late 1800s, several species of piscivorous fish have been introduced and subsequently naturalized in the Delaware River Basin, including: Largemouth Bass, Walleye, Smallmouth Bass, Channel Catfish, Muskellunge, Rainbow Trout, and Brown Trout representing some of the most desirable present-day gamefishes. Others including Flathead Catfish, Northern Snakehead, and Asian Swamp Eels have also become established in parts of the watershed. Furthermore, confirmed separate angler catches of Blue Catfish (N = 1 in NJ; N = 1 in PA) in the freshwater reaches of the Delaware Estuary in 2020 is suggestive of their presence likely as initial migrants into the Delaware River Basin via the C&D Canal.

Presumed increased predation by the indigenous (e.g., Striped Bass, White Perch) and naturalized invasive piscivores may be having an adverse impact on the shad population. American Shad are broadcast spawners, using a predator saturation strategy for survival of eggs, larval and juveniles. The increased predation coupled with severely reduced habitat range, potentially reduce survivability to adults. While unquantifiable, as an interesting speculation, would an average year-class production observed in present day, have been considered poor production in pre-colonial times, prior to the introduction of invasive species and imposed habitat limitations? By extension, would present day exceptional juvenile production, have been considered average in pre-colonial times? The converse, however, is of paramount importance, to what extent of juvenile production is needed to surpass present day predator saturation to enable shad population growth? And can it be expected present day habitat availability be able to support the necessary numbers of juvenile shad?

This type of threat is difficult to address and highlights the importance in ecosystem-based management in fisheries. 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 predator populations. Because the non-native piscivores have become widely established in the river system and prized by numerous groups of anglers, eradication of these species is unlikely.

Flow Alteration

River flows on the Delaware River have long been manipulated by the combined outflow from three New York City Delaware 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 New York City metropolitan area (283 U.S. 805, 1954). 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 New York City’s Delaware Reservoirs. This program was designed by the Parties to the Decree 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. Additionally, the FFMP was structured, in part, 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.

Insight relative to the Delaware River Basin water management practices to aquatic community processes have been previously evaluated (DePhilip and Moberg 2013, TNC 2017). Findings were suggestive water management strongly influenced aquatic communities by mitigating seasonal flow regimes. The 2017 Flexible Flow Management Plan structure, in part, attempts to retain natural flow regimes to the greatest extent practical, while being supportive of recognized down basin objectives (FFMP 2017). The recent changes include a thermal mitigation protocol to allow for additional reservoir releases during periods of thermal stress, which has been instituted during the summers of 2019 and 2020. Yet, significant alteration of basin water supply sources usage has high likelihood capacity to diminish resiliency of ecological meso-habitat functionality. Over management of flowing systems can reduce or eliminate natural cues/habitat that aquatic organisms rely upon to complete various stages of their life cycles.

Within the upper Delaware River Basin, the New York City Delaware Reservoirs tailwaters are specifically managed for sustaining cold-water aquatic community. Managed tailwaters encompass the East and West Branches and the Delaware River down river to Callicoon, NY (rkm 487). Thus, American Shad are considered extirpated from the West Branch and upper reaches of the East Branch (above the Beaver Kill). Yet the Delaware River main stem reach, Hancock, NY (rkm 531) to Callicoon, NY, is considered transitional to warm-water aquatic communities. This designation is presumed to support the continuance of connectivity for American Shad spawning adults and YOY access to the lower reaches of the East Branch Delaware River where they are presently known to occur. The influences of the FFMP release management upon American Shad is encapsulated in the Decision Support System (DSS) and its successor the Riverine Environmental Flow Decision Support System (REFDSS) (Bovee et al. 2007). These are Habitat Suitability Index (HSI) models coupled with Instream Flow Incremental Methodology for evaluating flow regimes upon habitat availability in the upper Delaware River. This type of modeling capability has not been extended further down river for the remainder of the Delaware River.

Impingement and Entrainment

Nearly 10 percent of Americans rely on the waters of the Delaware River Basin for drinking and industrial use (DRBC 1998). Power generating facilities, refineries, and other industries rely on withdrawal of surface water from the Delaware River to cool their industrial processes, with most industrial water withdrawals requiring continuous once-through use of water. This withdrawal results in fish and other aquatic organisms either becoming trapped against the intake screens (impingement – I) or taken further into the cooling system (entrainment – E). Both I&E can result in the death of fish and other organisms. Larger individuals typically become impinged and smaller organisms such as eggs and larvae typically become entrained. Impingement does not necessarily result in 100% mortality of affected organisms, but entrainment is considered 100% lethal. When fish spawn in spring and early summer in the Delaware River, the resulting eggs and larvae are vulnerable to entrainment; as fish grow larger during the balance of the year, they become susceptible to impingement. Therefore, losses to I&E are ongoing throughout the calendar year.

There are several large water intake systems at energy projects on the Delaware River. The Co-Op acquired 316b reports for five companies with cooling water intake structures (CWIS) on the Delaware River or its tributaries plus Annual Biological Monitoring Reports for the Salem Generating Station. These reports indicated that individual projects can entrain millions of American Shad eggs and larvae annually and impinge tens of thousands of juveniles (J. Mohler pers. comm.). In a river system with numerous intake facilities that occur in spawning and nursery grounds for American Shad, the cumulative impacts to the population could be substantial.

Impingement data for other important fisheries suggest that impacts may be occurring on Striped Bass and Weakfish populations, reducing the number of fish that would later be available for recreational and commercial fishing. Recent estimates derived by staff from the DNREC, Division of Fish & Wildlife (DFW) suggest that losses of early life stages of Striped Bass translate into losses of Adult Equivalents that rivals or even exceeds current commercial and recreational harvest in Delaware (Ed Hale, DFW, pers. comm.). Losses of large numbers of forage species also reduce the food resources available in the river, further impacting fish communities in the Delaware

River. Reporting of I&E losses are inconsistent. Consistent periodical assessments would aid in providing a better characterization of loss to this type of mortality.

Restoration

Over the last decade, there have been increased efforts to restore access to historic habitat for American Shad via dam removal and improved fish passage throughout the Delaware River Basin. Multiple partnerships are actively seeking to address barriers in key tributaries, and, in some instances, shad have returned to newly accessible reaches of river within the first year. While the Delaware River population has not come close to previously set restoration targets, it is clear that shad will return to restored habitat if given the opportunity. This section offers a brief overview of recent restoration efforts across the basin and highlights upcoming dam removal projects (also noted in Table 2).

The PFBC has maintained an American Shad Restoration Program since 1985. The original intent of the program envisioned returning an annual self-sustaining, wild adult spawning runs into the Lehigh and Schuylkill rivers. After 35 years of restoration efforts, including improved fish passage and hatchery stocking programs, this has not materialized as expected, and the current runs are far below previous restoration targets. The Lehigh River shad spawning runs remain well below the original expectations of successfully passing 165,000 – 465,000 wild shad annually (PFBC 1988). Similarly, annual spawning runs into the Schuylkill River also fall well short of original restoration goal of an annual run size of 300,000 – 850,000 wild shad (PFBC 1988). It is important to note, however, that these estimates are based on historic runs and available habitat within each basin and do not account for the depressed American shad population across the Delaware River basin and along the entire Atlantic Coast.

Within the Lehigh River, the wild component has been increasing, best represented in 2015, with wild shad composed over two-thirds of the Lehigh River spawning run; whereas, returning shad into the Schuylkill River are mostly (> 95%) originating from hatchery stocked shad fry. Thus, the hatchery component remains integral to both river spawning runs.

It is the conclusion of PFBC, American Shad passage into the Lehigh and Schuylkill rivers are inefficient and inadequate to support the restoration of a self-sustaining population. Yet without maintenance fry shad stockings, any future spawning run into either tributary would most likely be nominal. The PFBC will continue maintenance shad fry stockings to encourage annual spawning runs in both tributaries. Yet, PFBC will also investigate the feasibility of alternative methodology for possibly increasing the magnitude of annual hatchery stockings.

The Schuylkill River is the largest tributary to the Delaware River and historically supported American Shad runs in the hundreds of thousands. However, the numerous dams that have been built for various reasons since colonial days effectively extirpated American Shad from the river until recent times. The Fairmount Dam fish ladder, initially installed in the 1970s, underwent major renovation in 2008 and the new fish ladder has the capacity to pass 200,000 to 250,000 shad yearly, according to USFWS, but reaching these numbers would require a significant increase in the overall Delaware River Basin shad population. Between 2009 and 2018, approximately 1,500 shad have been observed passing annually, a significant improvement over the few shad that passed prior to the renovation, but still far below expectations.

Fish passage at the lower four remaining dams on the Schuylkill River could be significantly improved. In addition to depressed basin-wide population, lower than expected passage counts at the Fairmount fish ladder are likely due to issues with the attraction flow, turbulence between pools and at the observation window, and observed predation at the entrance and within the fishway. Passage through the Fairmount Dam fishway will continue to be monitored by the Philadelphia Water Department (PWD). Upstream of Fairmount, many of the dams on the mainstem of the Schuylkill River are either breached or have been removed in the last couple decades. Figure 2 depicts the remaining six dams on the Schuylkill River and whether they have fish passage. The Flat Rock, Norristown (Swede Street), and Black Rock dams all have had fishways added, but technical issues, limited maintenance, and lack of monitoring means that these dams still serve as significant barriers to upstream migration. The New Kernsville Dam, owned by Pennsylvaina Department of Environmental Protection (PA DEP) and located in Hamburg, Pa. at rkm 161, is slated for removal with an estimated completion date in 2022.

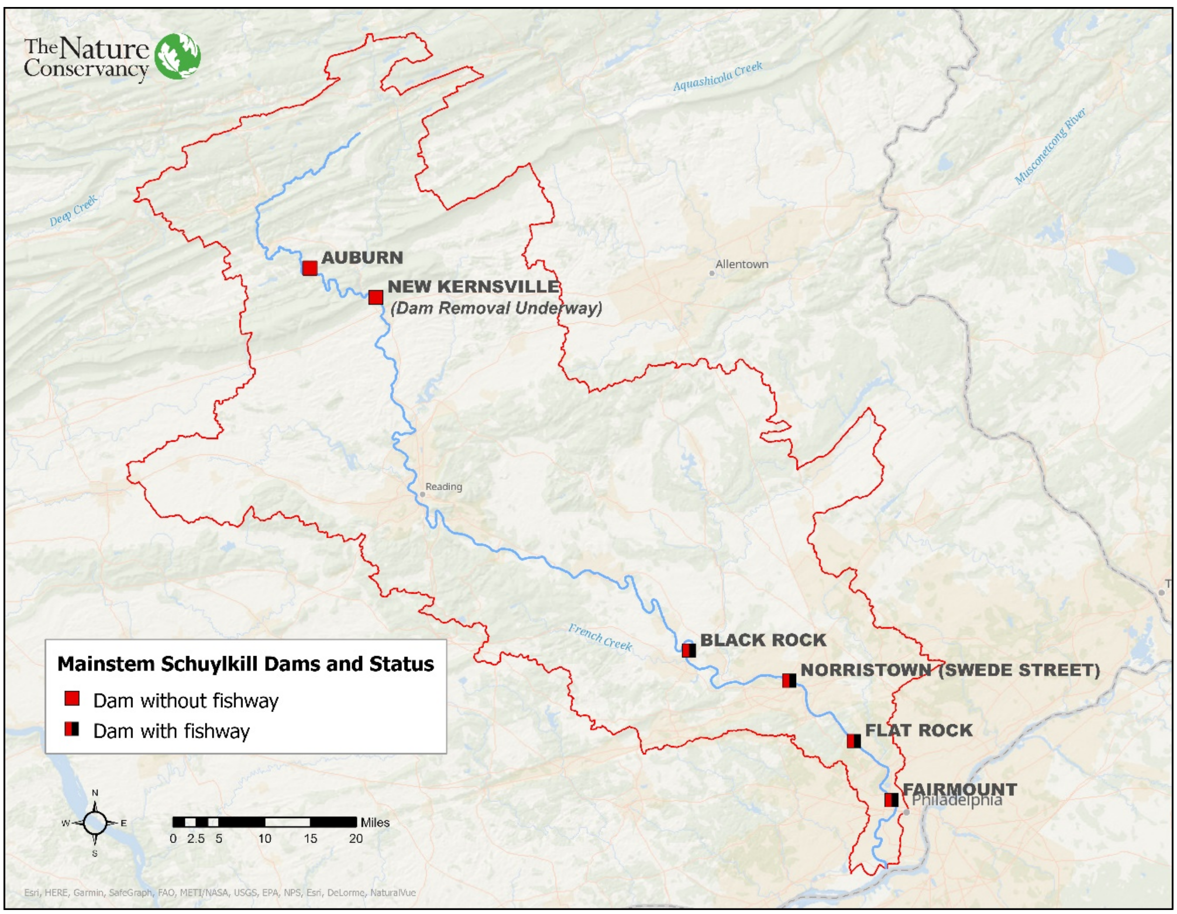

Figure 4: Schuylkill River Dams and Current Status. The map does not show several dams that are either breached or were removed in the last two decades.

Multiple partners are working to restore migratory fish passage within the Brandywine-Christina Basin. In 2014 the Byrnes Mill Dam, also known as White Clay Creek Dam No.1, was removed and planning is underway for the removal of additional dams on White Clay Creek, including the Red Mill and Paper Mill Dams. An active partnership led by Brandywine Shad 2020 is looking to modify or remove each of the 10 remaining dams on the Brandywine that are located along a 5-mile stretch of river from Broom Street in the City of Wilmington to Brandywine State Park and the adjoining portion of New Castle County. In 2017, young-of-year (YOY) American shad were found downstream of the West Street Dam, when 386 YOY were sampled prior to the removal of the dam by the City of Wilmington in 2019. Sampling completed in the summer of 2020 confirmed that shad were spawning in the newly opened section of river upstream of the former West Street Dam and plans are underway for the modification of the next five dams.

Recent restoration efforts in non-tidal New Jersey tributaries have also expanded shad habitat within the Delaware River Basin. Between 2008 and 2016, the Musconetcong River Restoration Partnership removed five dams along the lower portion of the Musconetcong River (rkm 281). In 2017, American Shad were observed at the base of the Warren Mill Dam following the removal of the downstream Hughesville Dam in 2016. The Warren Mill Dam is a 37.5-foot High Hazard Class I Dam vulnerable to a “Sunny Day” breach and its removal will open up an additional three miles of habitat in addition to eliminating a hazard to downstream residents.

Along the Paulins Kill, The Nature Conservancy has been leading efforts to remove a series of dams and reconnect aquatic habitat. In 2018, the Columbia Lake Dam was removed near the mouth of the Paulins Kill and already American Shad have been found 17 kilometers upstream near the base of the Paulina Lake Dam, which is also slated for removal (NJDEP 2019). The Pequest River (rkm 318) is also known to have shad in its lower section and efforts are also underway to remove the two lowermost dams in Belvidere.

Conclusion

The American Shad Habitat Plan for the Delaware River Basin will continue to be updated in future years to reassess restoration efforts and key threats to restoring the shad population within the basin. According to the 2020 ASMFC Stock Assessment for American Shad, the adult mortality for the Delaware River population is currently unsustainable and habitat loss due to barriers is likely restricting positive responses in the coastwide metapopulation abundance (ASMFC 2020). With funding from National Fish and Wildlife Foundation (NFWF), The Nature Conservancy is currently developing a restoration roadmap for American Shad and River Herring in the Delaware River Basin that will lay out a basin-wide strategy for addressing key barriers to migration and improving access to historically significant spawning and rearing habitat. Several partners are already addressing some of these key barriers with recent dam removals or planned removals along major tributaries to the Delaware River, including the Schuylkill River, Brandywine and White Clay creeks, Paulins Kill, and Musconetcong River. Results from the restoration roadmap project will inform future updates to this Plan, with an anticipated final report in 2021.

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