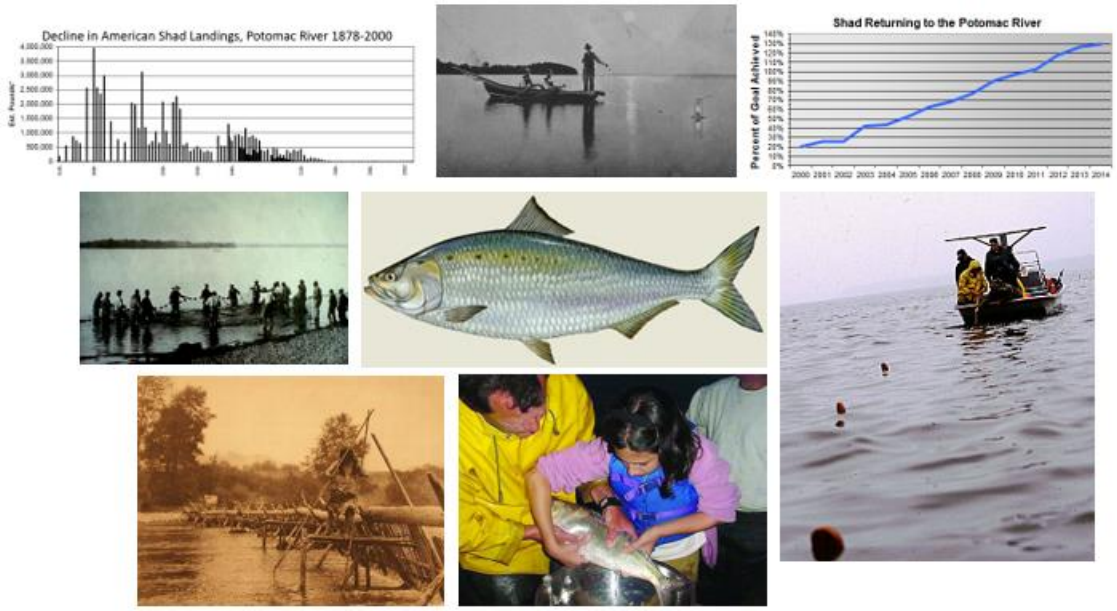

The Return of American Shad to the Potomac River: 20 Years of Restoration

Final Report
July 2016

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[1] Cover Images: the American shad, center, surrounded by, as viewed clockwise from the upper left, precipitous decline in the Potomac River's commercially harvested shad that resulted in a harvest moratorium in 1982 (graph by the Potomac River Fisheries Commission), Watermen deploying a shad net with a lantern marker (image by U.S. Fish Commission, courtesy of NOAA), American shad's recent return to the Potomac River (graph by the Chesapeake Bay Program), Deploying a gillnet to collect shad for the restoration program (image by ICPRB), many students and volunteers helped (image by Sandi Geddes, Westbrook Elementary School), an historical image of a Native American fish weir (image by Edward Curtis, courtesy of the Library of Congress), fishing a haul seine for shad in the Potomac River circa 1890s (image by U.S. Fish Commission, courtesy of NOAA).

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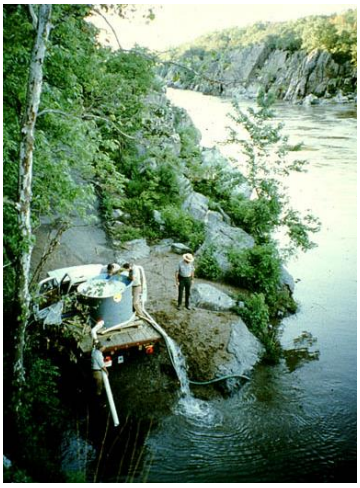

Figure 1: After hatching and marking with oxytetracycline, the American shad fry were stocked by the U.S. Fish and Wildlife Service back into the Potomac River at Mather Gorge. Near Great Falls, this area is the natural upstream boundary to shad migration. It is approximately ten river miles upstream from Little Falls and the District of Columbia. (Image courtesy of ICPRB)

Executive Summary

Figure 2: An American shad caught and released in the Potomac River near Fletcher's Cove, Washington, D.C. (Image courtesy of Fletcher's Cove)

The American shad (*Alosa sapidissima*) was once one of the East Coast's most abundant and economically important fish. By the mid-1970s, water pollution, over-harvesting, and the blocking of spawning habitat by dams led to their decline. In 1982, a harvest moratorium on American shad was put into effect on the Potomac River because their once abundant population had virtually disappeared. A decade later the American shad population was still showing no signs of recovery.

In 1995, the Interstate Commission on the Potomac River Basin (ICPRB) began an American shad restoration program, with the assistance of local watermen and the involvement and support of the U.S. Fish and Wildlife Services' (USFWS) Harrison Lake National Fish Hatchery. In 2000, a new fish-passage was installed in the Brookmont Dam at Little Falls by the U.S. Army Corps of Engineers. By 2002, after stocking approximately 18-million shad fry, the Potomac American shad population had recovered well enough that restoration stocking was concluded. As a measure of success, the Potomac River then became the egg source for Virginia, Maryland and Pennsylvania shad recovery programs in Chesapeake Bay tributaries. From 2003 until 2014, ICPRB worked with the Virginia Department of Game and Inland Fisheries (VDGIF) collecting fertilized shad eggs from the Potomac River to be used for restoration stocking in the Rappahannock River. Through that program more than 48-million shad fry were stocked in the Rappahannock River and an additional 4-million shad fry were put in the Potomac River as "replacement stocking" for the adult shad harvested during egg collections.

The efforts worked. In 2012, the Potomac River American shad population was designated a recovered and sustainable fishery by the Atlantic States Marine Fisheries Commission, the agency with regulatory oversight on migratory marine fishes. In 2014, the Rappahannock River American shad population exceeded the VDGIF restoration goal, which is based on an abundance index derived by the Virginia Institute of Marine Science (Hilton et. al., 2014). These American shad recoveries are encouraging signs that investments made in water quality improvements, harvest management, habitat access, and fisheries restoration are working.

Public involvement was an important component of the program. Thousands of students from dozens of Washington area schools hatched shad fry in their classrooms and released them into the Potomac River and several of its tributaries. Their participation was made possible through a "Schools-in-Schools" partnerships with Living Classrooms of the National Capitol Region, the Anacostia Watershed Society and the Chesapeake Bay Foundation. Hundreds of volunteers, including many teachers and students, helped with adult shad collections and preparation of shad eggs for the hatchery and their classrooms.

Given the Potomac River's current American shad recruitment and spawning numbers, its shad population should continue to increase for at least 5-7 years, which is the foreseeable future based on the shad's average life span, and probably much longer.

While the Potomac and Rappahannock rivers have shown recovery, coast-wide populations of American shad remain in trouble with most at all-time lows (Limburg, 2007). Due to predation and ocean fisheries by-catch issues, both rivers will have difficulties fully recovering until shad are restored coast-wide.

The following is ICPRB's story of the American shad restoration in the Potomac watershed. It includes our role in the restoration process, the lessons we learned, and the methods we used.

Background

The American shad was once one of the Potomac River's most abundant and economically important fish. It is the largest member of the herring family and native to the east coast of North America, from the Saint Johns River, Florida to the Sand Hill River in Labrador, Canada. Like salmon, it is anadromous, at maturity it returns to its natal river to spawn in the fresh water where it hatched. Unlike salmon, shad from mid-Atlantic rivers northward can return from the ocean in subsequent years to spawn. It is a planktivore, whose gill structures form a net to capture small and predominantly animal plankton. Its species name, "sapidissima," means "savory" or "delicious," and for thousands of years their spawning runs were a much anticipated springtime event for humans living on the east coast. A huge industry developed in the Potomac for their harvest, preparation and distribution.

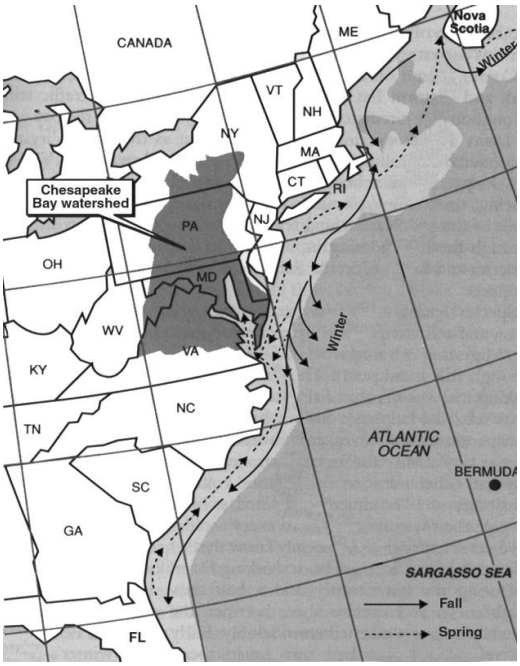

Figure 3: Natural range of American shad.

By the mid-1970s, water pollution, over-harvest, and the blocking of spawning habitat by dams resulted in severe population declines in the Potomac and other rivers in the Chesapeake Bay and along the east coast of the United States. That the shad's once huge numbers so declined is similar to what happened to the American bison, but relatively hidden in our waters. This fish has become largely forgotten as well. In 1982, a harvest moratorium for American shad was put into effect in the Potomac River. By the 1990s, the Potomac had become one of the Nation's showcases for successful programs to restore water quality, but even with significant water quality improvements and a river harvest moratorium for more than a decade, the Potomac River's American shad population still had not recovered.

Ecological Roles of American Shad

The American shad and other herrings are important ecologically as well as economically. Shad provide a critical conversion of plankton to food for larger predators. The annual spring spawning runs were once major food sources for many animals, from large predators such as bears, bald eagles (who time the hatching of their young to the spring fish runs), ospreys, striped bass and catfish, to small predators like young fish and minnows (who eat shad eggs and fry), to detritivores such as the blue crabs who consume adult shad who succumbed to spawning stress and, eventually, back again to plankton. When American shad numbers are compromised, the species that rely upon them also are compromised. In this respect, they are similar to salmon.


Figure 4: Throughout their journey, American shad are important to the ecosystem, providing food for many predators.

The shad's ecological importance can be easier to understand if we conceptualize the Potomac River as a machine, a grandfather clock, whose frame is its habitat, i.e., the river bottoms and edges. All of the river's plants and animals make up the various wheels, pulleys, levers, cogs, gears, etc., inside of the clock. The American shad, and other migratory fishes in the herring family, were once major energy sources which powered the river-clock's main spring. After spending years in the ocean maturing into adults, they bring tremendous amounts of ocean-derived energy into this machine when they return to spawn. That energy is made available when they release their eggs, when the adults are preyed upon, and when they succumb to spawning stress. American shad, like their ecological counterparts, the salmon, are a keystone species (Helfield, 2006), and, because they provide important energy and nutrients, are thus also a "clock-spring species" necessary for keeping a river's ecological clockwork running smoothly and correctly. The ecology of the Potomac River, and the entire Chesapeake Bay's, will only function properly when their clock-springs are functioning. To restore the Bay and the Potomac River, we must restore this integral, but largely forgotten, component. In addition, the ecological and economic importance of American shad are both year-round and coast-wide, providing that food conversion to many oceanic species, including the cod (Baird, 1889)[2] and the bottle-nose dolphin (Popper, 2002)[3].

A History of Human Interactions with American Shad in the Potomac River

Shad were important components of native people's diets. Arriving at the time of year when food stocks were at their lowest and people were starving, shad and river herring were more than welcome treats, they were often life savers. Native Americans taught European colonists the various methods to capture shad and herring, using weirs, traps, and nets, as well as how to cook and prepare them, primarily through smoking and drying.

Captain John Smith was the first to report the remarkable quantities of fish in the Potomac which he witnessed in his exploratory journey in June, 1607, to the Great Falls, upstream of what is now the city of Washington D.C. One of Smith's often quoted passages notes that fish were "...lying so thicke with their heads above water, as for want of nets we attempted to catch them with frying pans" (Smith, General Historie of Virginia, 1608). His report was subsequently confirmed by Henry Spelman, Captain Samuel Argoll (Purchas, 1625), Henry Fleet (Neill, 1871), and Father Andrew White, the first chronicler of the Maryland colony (White, 1635). Fleet recorded in his journal of a trip in 1631, that, "This place [the site of Washington] without question is the most pleasant and healthful in all this country. It aboundeth in all manner of fish. The Indians in one night will commonly catch thirty sturgeons in a place where the river is not above twelve fathom broad."

Edward Neill reports, "Though the records of the average weight of shad in those days [colonial period] are lacking, seven pounds is a fair estimate, and it may have been greater. The weights now seldom exceed three or four pounds, because in the more recent years of intensive fishing, shad have been widely caught up as they returned from the ocean to spawn for the first time" (Neill, 1871).

During the mid-1700s, Andrew Burnaby, in speaking of the Potomac River, remarked as follows, "These waters are stored with incredible quantities of fish…shad are in such prodigious numbers that one day…above 5,000 have been caught at one single haul of the seine" (Burnaby, 1798).

During the period 1814-1824, George Chapman, owner of a haul-seine shad fishery on the Potomac's Chapman's Point, Maryland, kept a daily record of the shad and herring caught and sold. Those records

[2] Spencer F. Baird also states in his report, page 203: "…the reduction of cod and other fisheries, so as to become a failure, is due to the decrease off our coast in the quantity, primarily, of alewife, and secondarily of shad…more than any other cause." It is important to appreciate the linkage between cod and herrings (including the shad).

[3] Shad are quite unique fish because they have sound reception skills which key in on the very high frequency sound waves, known as echolocation, emitted by dolphins. The shad's avoidance of these dolphin sounds is interpreted as an evolutionary development due to predator-prey interactions. The use of echolocation d is being employed at fishways to direct shad to certain areas of the dams to avoid entrainment in water intakes. Dolphins are major shad predators and should benefit greatly from shad recovery.

Figure 5: Shad planking, Marshall Hall, MD 1893. (Photo by William Cruikshank, courtesy of the Library of Congress)

Figure 6: Seining for shad on the Potomac, Northern Neck, Va. An 1894 illustration by Charles B. Hudson. (Image courtesy of NOAA)

survived as part of his friend, Thomas Jefferson's, library collection. Examined and analyzed by Virginia biologist William Massman in the mid-1900s, he reported (Massman, 1961):

> Shad catches from Chapman's fishery amounted to 955,615 shad (and 116 million herring) for the 11-year period [1814-1824]. If only 100 fisheries were operating on the Potomac River in the early 1800's and if they were as successful in the capture of shad as George Chapman, prodigious quantities of shad must have been captured. Chapman's catches were equal to about one-third of the catch of shad by all gears from the entire Potomac River during the 11-year period from 1946 through 1956. There is little doubt, if Chapman's records have been interpreted correctly, that the abundance of shad in the early 1800s was considerably greater that at the present time. These reports also suggest that reports by early historians concerning the tremendous quantities of fishes found [in the Potomac] may not have been exaggerated.

Spencer F. Baird, first Director of the U.S. Fish Commission, reported (Baird, 1889):

> No better illustration of the numbers in which anadromous fish enter the rivers can be given.... than a presentation of the case as it relates to the Potomac River in the short distance between its mouth and the Great Falls of the Potomac, only twelve miles above Washington. Although this stretch of water is even now very productive, many years will elapse, if ever, before it gets up to the measure of yield mentioned by [Joseph] Martin in his History of Virginia, a work published in 1835. I give, however, the statement, allowing it to speak for itself:
>
> '...of the Potomac, it may be well to mention that in the spring of the year quantities of shad and herrings are taken which may appear almost incredible. The number of shad frequently obtained at a haul is 4,000 and upwards, and of herrings from 100,000 to 300,000. In the spring of 1832 there were taken in one seine at one draught a few more than 950,000 accurately counted. The shad and herrings of the Potomac are transported by land to all parts of the county to which there is a convenient access from the river, and they are also shipped to various ports in the United States and West Indies (Martin, 1835).'

Baird continues:

> It is proper to say that the accuracy of Martin's figures has been disputed by some recent writers. Even if they are, however, twice as large as the fact would justify, the general argument would not be invalidated…Although the season lasted but about eight weeks, during this time [the 1830s] as many as 22,500,000 shad were taken and 750,000,000 herring. In curing the fish for later

> consumption, 995,000 barrels[4] of salt were used…For the 750,000,000 actually captured we may suppose that this was not more than one-fourth of the total number in the river during the season, which would give 3,000,000,000 for the Potomac River only…The fishery on the Potomac during the period referred to equaled the total yield of the Scottish salmon fisheries in 1873, prosecuted through-out the year, and employing 15,000 boats and 45,594 men, and equaled nearly twice the entire number of barrels of the sea herring put up in Canada in 1876 (Ibid, pg. 167).

In what may have been the first report of gridlock in Washington, D.C., the *Metropolitan*, a Georgetown newspaper, in its April 25, 1836, issue stated (Beitzell, 1968):

> We were not fully aware of the immense importance of the Potomac fisheries and their value, until this spring. Besides the larger supplies shipped daily by the canal[5], every night the long length of Bridge street and High street, besides many other places, is crowded with heavy four and six horse wagons from the most remote parts of Pennsylvania, Maryland and Virginia, even to the confines of Ohio, which exchange the produce they bring down, for the delicious fish which this noble stream affords in an exhaustless abundance, and return with a year's supply of these grateful delicacies to the far-off homestead of the inland farmer.

In the mid-1800s, an important American shad fishery was located in the Anacostia River, just across from the Washington Navy Yard (see Figure 7), which used a human and horse powered winch to gather up the large nets used to capture the fish. This location is near the former village of the river's native namesake, the Nacotchtanks, who were also noted for their fishing, in particular for shad and sturgeon, and for beaver trapping and fur trading.

Shad once were the most important food fish in Maryland. The first report of the Commissioner of Fisheries of Maryland, discusses the fisheries declines, which led to the creation of the Commission, it's "Shad" section begins, "This being the most important of the food fishes of our waters, your Commissioners immediately sought for means of their increase..." (Ferguson, 1876)[6].

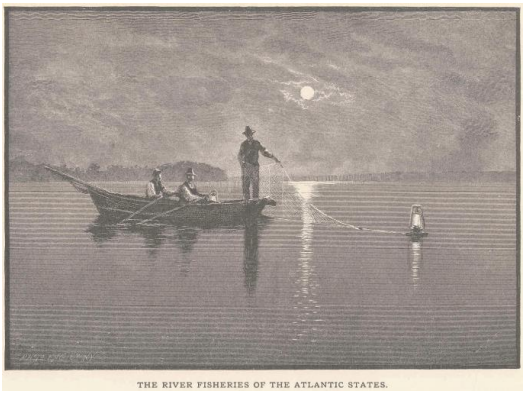

Figure 8: Watermen set lanterns on floats to mark the ends of their nets when fishing at night. (Image courtesy of NOAA)

Figure 7: The Washington Navy Yard, 1861. Shad fishers in the foreground. (Image courtesy of Library of Congress)

[4] These "barrels" are likely British 36 gallon barrels, and 995,000 of them = 5,721,000 ft³, equals a pyramid with a base the size of a football field from goalpost to goalpost and a height of 300', or a city block (300'x300') nearly 200' high.

[5] Between 1845 and 1856, the C&O Canal (Unrau, 2007) reported shipping upstream over 2 million lbs./year of barreled shad and herring. That would be about 10,000 barrels/yr. The C&O Canal was just one conduit for these fish, they were also transported out of the Potomac watershed to Philadelphia, Baltimore, New York City, and the Caribbean.

[6] The MD Fisheries Commission was created in 1874, their first report was in 1876.

The following is a wonderful description of shad fishing on the Potomac River in the early 1900s (Wilstach, 1930):

> But one has not seen the most picturesque feature of the Potomac fisheries who has not seen shad fishing at night. The nets are laid for every run of the tide, by night as well as day. By day the lines of huge corks sustaining the nets across the channel are easily seen and avoided by passing steamers. At night these same reaches of nets would be invisible were it not for the "gillers," as fishermen are called on the Potomac, who have extra-large floaters at both ends of each net and on them make fast lighted lanterns. To look across the broad waters of the river on nights when the shad are running is to mistake the vision for a bit of Venice, a fairy city twinkling in the darkness.

Decline of Shad in the Potomac

The peak of the Potomac River's pollution was from the late 1950s to the early 1970s, when the upper freshwater-tidal Potomac in the Washington metropolitan area was receiving the river's largest wastewater and stormwater inputs, which often was lethal to most fishes. That was particularly true for migratory fishes returning to spawn. The huge migratory fish kills that occurred in the early 1960s, were one of the major reasons that President Lyndon Johnson declared the Potomac River "disgraceful" (Johnson, 1965). Running through our nation's capital, the sad state of the Potomac River was a national embarrassment and helped focus attention on river pollution and the enactment of the Clean Water Act.

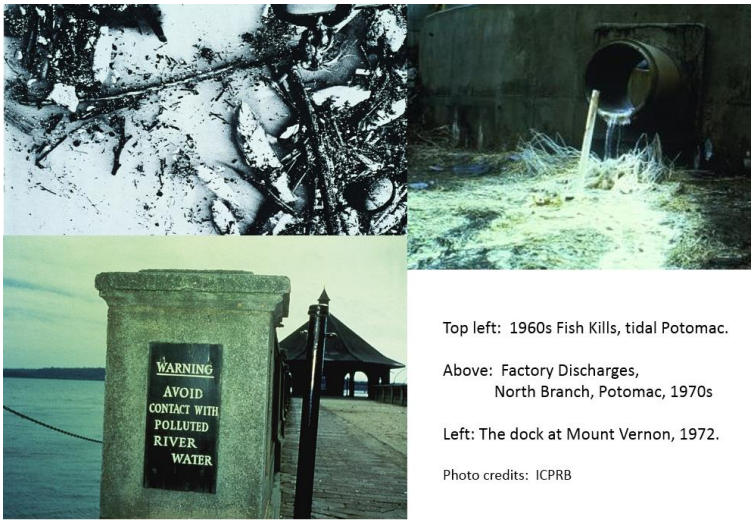

Figure 9: The Potomac River was once synonymous with water pollution.

Migratory fishes also were subject to over-harvest and loss of spawning habitat, the latter principally through the construction of dams. In the 1970s and 1980s, the American shad fishery collapsed on the East Coast. It closed in the state of Maryland in 1980, followed by the entire Potomac watershed in 1982. The remaining fisheries in the state of Virginia did not close until 1993.

Another factor complicating American shad recovery was the effect of predation on the reduced numbers of offspring, particularly their eggs and fry. While the word "predator" usually conjures up the image of something big and toothy, in this case the predators are minnows, schools of satinfin (*Cyprinella analostana)*, and spottail shiners (*Notropis hudsonius*), which prey upon the eggs and larvae of the shad. This is likely the major reason the planktivorous shad, which does not typically eat while spawning, will bite at minnow-like lures. Rather than trying to eat the minnows, their behavior would help keep these predators away from their spawning areas.


Figure 10: Spottailed Shiner (*Notoropis hudsonius*)

Into the mid-1990s, American shad stocks remained depressed in the Potomac River despite significant improvements in water quality made over several decades and a river harvest moratorium which had been

in effect since 1982. From a Letter to the Editor in the May 25, 1995, edition of the *Washington Post*, Jim Fearson of Herndon, Virginia, writes:

> Louis Harley, Fairfax County's last commercial fisherman, is the closing chapter in what was once the largest industry in the area [Netting a Profit on the Muddy Potomac, Washington Post Metro, May 15, 1995)]. Since colonial times landowners have operated fisheries along the Potomac shores, as well as leasing the fishing 'rights.' According to the Gazetteer of Virginia (1835): 'In 1832, there were 158 such fisheries on the local Potomac shoreline requiring a work force of 6,550 laborers at the landings and another 1,350 men on board the 450 vessels engaged in the haul.'
>
> Perhaps the most industrious fisherman on the Potomac at the beginning of the 20th century was Capt. Neitzey, who had fisheries at Freestone Point, Stony Point and Ferry Landing and, as described in an article in the 1991-92 Historical Society of Fairfax yearbook, was owner of the largest fishing net in the world. The net proper was 9,600 feet in length and the hauling ropes at the ends were 22,400 feet long, giving 32,000 feet of total sweep. During fishing season, Neitzey made two hauls with this net every 24 hours, taking seven hours per haul using eight horses and about 100 men. He claimed to have caught as many as 500,000 herring and 10,000 shad in one haul. This is the same waters that now support only Mr. Harley and his two helpers.

By the late 1990s, the momentum was beginning to change. In 1995, a coalition of federal, state, regional and local agencies and nonprofit groups, organized as a Task Force,[7] began to open historic spawning and nursery habitat for native and anadromous fishes in the Potomac River. The U.S. Fish and Wildlife Service's document entitled, "A Strategic Plan for the Restoration of American Shad to the Potomac River Upstream of Little Falls Dam" (Odom, 1995), endorsed and adopted by the Little Falls Task Force, recommended an eight-year restoration stocking effort for American shad as necessary to sufficiently augment and imprint the Potomac River's stocks.

Figure 11: The two dams at Little Falls. The curved dam is Dam #1, a feeder dam for the C&O Canal, the first dam built across the Potomac River. The straight dam is the 1960s Brookmont Dam, used for water supply in Washington, D.C., Arlington and parts of Falls Church, Va. The 2000 fishway is located near the Virginia shore (left to viewer) on the Brookmont Dam. Dam #1 is a rubble dam with enough porosity that it did not completely restrict fish migration. (Image by Curtis Dalpra, ICPRB)

Led by the Interstate Commission on the Potomac River Basin, with significant support and involvement of the U.S. Fish and Wildlife Service (USFWS) and their Harrison Lake National Fish Hatchery. The stocking program was designed for two reasons: 1) to imprint shad to approximately ten miles of their historic spawning and nursery habitat upstream from the Brookmont Dam at Little Falls, a water supply dam for Washington, D.C. and parts of Virginia suburbs, that blocked their migration but was destined to

[7] Members of the Little Falls Fish Passage Task Force, formed in 1992, came from Virginia, Maryland, the District of Columbia, the Interstate Commission on the Potomac River Basin, the Potomac River Fisheries Commission, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the National Biological Survey, the U.S. Environmental Protection Agency, the National Park Service, the National Marine Fisheries Service, Montgomery County, Maryland, the Chesapeake Bay Foundation, and the Potomac Conservancy.

be modified with a new fishway, and 2) to help rebuild Potomac River shad stocks. The program's annual goal was to stock at least one-million shad fry.

An important milestone for the fish passage restoration program was accomplished in January, 2000, with the completion of the fishway at the Little Falls (Brookmont) Dam by the U.S. Army Corps of Engineers. However, the fishway alone was not enough; migratory fishes had been excluded from the ten-mile area from Little Falls upstream to Great Falls for more than 50 years and they needed to be re-imprinted to that area to help them return.

The fishway was a first-of-its-kind design by the U.S. Geological Survey's Conte Anadromous Fish Research Laboratory, Turners Falls, Ma. It consists of a 2' x 28' x 4' notch which was cut into the 1400' long x 10' high dam and located near the Virginia shoreline due to the proximity of the old river channel. Immediately downstream of the notch there are three associated "W" shaped weirs that reduce water velocity to accommodate multi-species swimming (burst) speeds and provide resting areas (Figure 12). The fishway was designed to allow passage of most resident and migratory fish species in the Potomac but the American shad became the object of the recovery effort because their population had been at historic lows for several decades.

An important component of the program was the involvement of students and teachers from local Washington metropolitan area schools. At the 1999 dedication ceremony for the fishway, the shad restoration program's student involvement was highlighted by "shad student," Ben Symons, then a 5th Grader from Westbrook Elementary School, Montgomery County, Md., who provided remarks at the head table along with Secretary of Interior Bruce Babbitt, Senator Paul Sarbanes (Md.), Maryland Governor Parris Glendening, Congresswoman Connie Morella, USACE Brigadier General Stephen Rhoades and Col. Bruce Berwick (Figure 13).

Importantly, as soon as the program started in 1995, the Interstate Commission on the Potomac River Basin enlisted the help of a fifth-generation local watermen family, the Harleys, from the Mason Neck peninsula of Virginia. They were hired to assist with collection of spawning adult shad and preparation of the fertilized eggs for

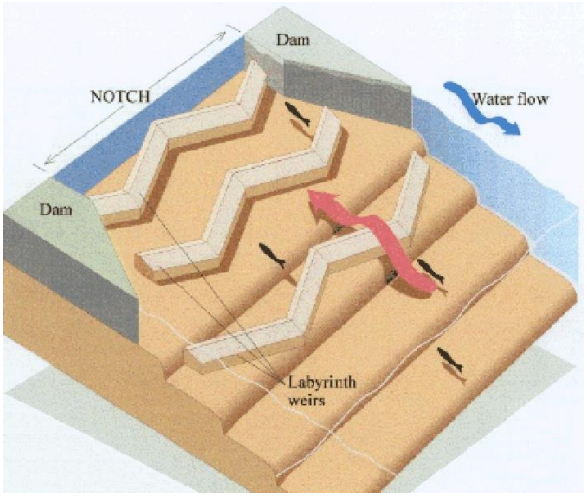

Figure 12: A conceptual design of the notch and "W" shaped weirs of the new fishway at Little Falls. The three weirs slow the water down through the 20' wide notch and provide resting areas for migrating fish. (Image credit: The Washington Post)

Figure 13: The imprinting works, both fish and human fry mature and return. In 2007, then collegian Ben Symons, center, returns to visit our shad-school program at Bethesda Chevy Chase High School. On the left is the author, Jim Cummins, and on the right is environmental writer Sandy Burke. (Image by Sandi Geddes)

delivery to the hatchery. The Harley family's knowledge of shad collection methods was instrumental to the success of the recovery effort, especially Louis Harley, who had fished for shad for more than 30 years before the moratorium went into effect. The Harley expertise saved a lot of trial and error and consistently produced excellent results. Very few of the thousands of people involved in the project had ever met a waterman. As one of the last remaining commercial watermen families in the upper river, they are proud of the profession and their heritage.

Methods

Gillnet Brood-Stock Collections

Mature American shad were collected during their spawn runs at an ecologically and historically important section of their spawning habitat, near Fort Belvoir and Mount Vernon, in the Potomac River. Spawning typically commences near the beginning of April and runs into mid-May. The project's vessel was a 24' Carolina Skiff captained by the Harley watermen. Two drifting gillnets, sequentially deployed, were fished along the river-right side of the main channel (the west or "Virginia side") at the mouth of Dogue Creek and along Fort Belvoir. The nets are fished at evening slack-water, at either the high or low-tidal shift, for a duration of approximately two hours. When fishing a high slack tide, the nets were deployed off shore from the old fishing house at Fort Belvoir one hour prior to the predicted slack. When fishing a low slack tide, the nets were deployed upstream near channel buoy marker #67 starting approximately one half hour before slack tide.

The drift nets are rigged in the traditional manner for this section of the Potomac, a method that has been used since the late 1880s. The nets are approximately 91-meters (300-feet) long, 7-meters (23-feet) deep, 14-centimeters (5 ½-inches) stretch mesh, made of either #69 twine cotton or monofilament equivalent, with top line suspended below the surface approximately 1.5 meters (5 feet) from floating, 16-centimeters (6-inch) diameter corks rigged approximately every 4.5 meters (15 feet). The bottom line is very lightly weighted, rigged with 16-centimeters (6-inch) diameter 9-gauge galvanized metal rings set about 4.8 meters (16 feet) apart. A ring is rigged below each cork. The difference in spacing between the corks and rings is because the bottom line is a little longer than the top line to help provide the necessary slack in the nets. A light, usually a glow-stick, in a 2-liter soda bottle, is attached to the channel side of the net to help other boats see the nets at night and to aid in visual surveillance.

Figure 14: Setting out the gillnet. (Image courtesy of ICPRB)

Continuously tended, fishing is performed roughly between 4:00 p.m. to midnight, depending on the tide, with the best fishing at slack-tides near dusk. It is imperative that collections are made during slack tides so that the nets will drift slowly, hang loosely and shad-fish properly. Otherwise, the currents in the Potomac River will be so strong that the nets will go taught, catch few shad but many non-target fish species (by-catch), drift rapidly and considerable distances, subjecting them to potential snags, damage and, worst of all, loss.

At the end of the drift the corks tend to close up and run together. Then the whole net is taken up, starting at one end, and all fish are removed, culling out the ripe female shad and attempting to keep roughly an equal number of males, during which the net is gathered up and placed into a large tub or bucket. Captured shad are examined when brought on board for sex and maturity, which is tallied on field data sheets. Care is taken to release non-ripe ("green") females, extra males ("bucks"), or any by-catch species. Females judged ripe ("roes") and kept bucks are placed in an oval-shaped 100-gallon stock tank, or equivalent,

which is two-thirds full with river water. The tank has a submerged bilge pump, modified with a large intake filter, that re-circulates and aerates the water while providing a circular current which helps the shad orient correctly in the tank. Typically, any green female shad which does not have eggs running fairly freely from her is released back into the river. However, some of the females are found to produce few eggs at egg-stripping and were noted on datasheets as "Green Females Kept."

During the restoration stocking phase, the collections were performed by the author, the waterman Louis Harley, and volunteers. After a sufficient number of ripe female and male shad have been captured, which depends on the catch rate but generally after the first net has been harvested, we went to shore where we set up tables and tubs to work on collected fish. First, shad eggs are field stripped, i.e., hand-squeezed from the females into large stainless steel mixing bowls. Care is taken to minimize the number of non-viable eggs removed from a female, a skill mostly learned from experience, because such eggs will decay and contaminate the egg batch. After a batch of females, typically 6-8, has been stripped of eggs, the sperm from an equivalent number of males, abundance permitting, is squeezed onto the top of them. A lot of care is taken to minimize water collecting in the bowl by hand drying each fish prior to removing eggs or sperm. We try to keep it a "dry mix" because water activates the sperm, which die about 20 seconds after being activated, and they would not get a chance to fertilize an egg. Once the sperm has been added to the top of the "dry" eggs it is gently mixed with the open fingers of the hand until roughly homogenized, then we add about 1-2 liters of fresh river water to the batch while stirring it gently with the hand for a few seconds. Within 30 seconds the fertilization is complete.

Figure 15: Removing, or stripping, the shad eggs. (Image by Dave Harp)

The batch of mixed fertilized eggs, unviable eggs, errant scales, fish slime and bodily juices must be cleaned. Shad eggs are slightly heavier than water, they settle to the bottom of the bowls within a minute, so the first step is decanting the top layer, which is mostly river water, dead sperm, slime and any floating scales. Depending on the condition of the batch, this usually requires two to three decants, with fresh river water added to the batch between successive decants. The next step is pouring the batch of eggs into a large colander set in an egg hardening box, which is a 100-liter (25-gallon) plastic storage bin that has been modified with metal-screened holes on its sides and foam floatation near the top. The colander's holes are of slightly larger diameter than the fertilized eggs, approximately 5-mm (3/16 of an inch), so shad eggs pass through but errant scales, clumps of clotted blood or mucous and other detritus which were not removed during decanting are now effectively sieved out, thus further cleaning the egg batch.

The box of delicate newly fertilized eggs is then left undisturbed to float in river water for one hour while the eggs absorb water, enlarge, and their cell walls become "hardened." During this time the processed shad are measured for fork length and maximum total length, with every tenth fish's scales and head collected for aging and otolith hatchery mark evaluations. After the eggs are hardened they can be handled and transferred. Approximately 2 liters (1/2 gallon) of eggs go into a 20-liter (5-gallon) bag that contains 8 liters (2 gallons) of fresh river water. The bagged eggs are placed into insulated boxes, oxygen is added, then the bags are sealed with strong rubber bands. They were then transported to the U.S. Fish and Wildlife Service's Harrison Lake National Fish Hatchery, near Hopewell, Va. The eggs are incubated and hatch in approximately 5-7 days, marked with tetracycline, then transported to, and stocked in, the Potomac River at Mather Gorge, upstream of Brookmont Dam.

Monitoring Surveys for American Shad at Great Falls, Potomac River

Direct monitoring of the new fishway on the Brookmont Dam at Little Falls, Potomac River, was not feasible due to dangerous river currents during spring flows and the remote location of the structure. There is no boat access except by portaged canoe. The notch is approximately 50 feet from the Virginia shoreline but there is no feasible legal access on that side of the river. Access for monitoring was from the Maryland side, the shore of which is in the C&O Canal National Historical Park, a distance of approximately 1,400 feet from the fishway. Immediately downstream from the dam is a mile-long steep grade of rock outcrops and ledges. There is about 11,000 square miles of drainage above the dam, and springtime flows are typically very dangerous at the site. A simple mistake or misstep at the dam could easily risk death or injury. Therefore, several methods of indirect monitoring of the fishway were conducted at Great Falls, the upper limit to natural migration of anadromous fishes, approximately 10 river miles upstream from the fishway. It should be noted that the Great Falls location is also a high-risk area due to currents and the rocky, gorge environment. However, access there is much easier and, with great attention to safety procedures, the degree of risk was judged low enough to merit monitoring. No adult-shad monitoring sites were identified between Great Falls and Little Falls due to very poor access and dangerous conditions in that reach.

Figure 16: Mike Odom, USFWS, with one of the first American shad captured at Great Falls after the fishway was opened in 2000. Mike is standing on "Shad Rock," so-named in the late 1800s. (Image courtesy of ICPRB)

Initially, from 1999 to 2002, boat-electrofishing collections were performed in the Mather Gorge, which is approximately 1,200 meters (4,000 feet) downstream of the base of Great Falls, where there is an emergency rescue boat ramp on the Virginia (Great Falls Park) side. These electrofishing surveys were discontinued after 2002, due to budgetary constraints, concerns that this stretch of the river was not a good location to capture shad (i.e., the Gorge has strong currents with limited fish resting areas and is open to full sun), use of the boat ramp was difficult during low-flows (the apron was not deep or long enough), and the section became very dangerous at higher flows.

In 2001, the use of gillnets deployed by canoes was explored in the first eddy below Great Falls on the Maryland side. The results were disappointing and the method was abandoned.

The use of long handled dip-net monitoring, developed by Mike Odom of the U.S. Fish and Wildlife Service in 2000, became the primary method of monitoring the effectiveness of fish passage at Little Falls. The dip net was constructed of 2-inch wire mesh net with a 36-inch mouth and 30-inch depth fastened to an 8-foot fiberglass pole. The net was positioned with its top approximately 4 inches in the water next to the rock faced shoreline, a task that took a good amount of skill and dexterity. The net's basket faced upstream so that migrating fish moving upstream would swim into the mouth of the net. Upon felt contact, the net was raised to capture the fish. This method also partially replicates bow and dip-net methods traditionally used at this location a century earlier.[8]

[8] U.S. Fish Commission scientist and shad expert, Charles H. Stevenson, related the following in his 1898 annual

Sampling intensity was scheduled for twice a week from mid-April to late June, but that varied primarily due to flow. Dip-netting could not be performed effectively much above the spawning season's median flow (10,000 cubic foot per second). Secondarily, effort varied due to availability of personnel. The best time for dip-netting was the 2-4 hours during dusk or dawn. Night sampling is not feasible due to a requirement to have National Park personnel on hand and the park closes at dark.

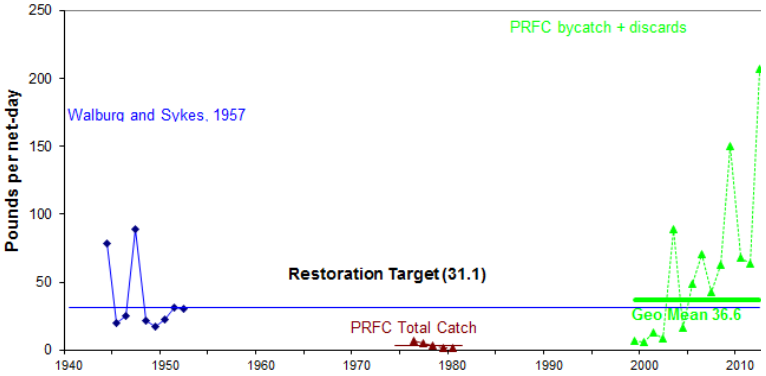

Figure 17: Potomac River American shad commercial pound net by-catch. (Graph by the Potomac River Fisheries Commission)

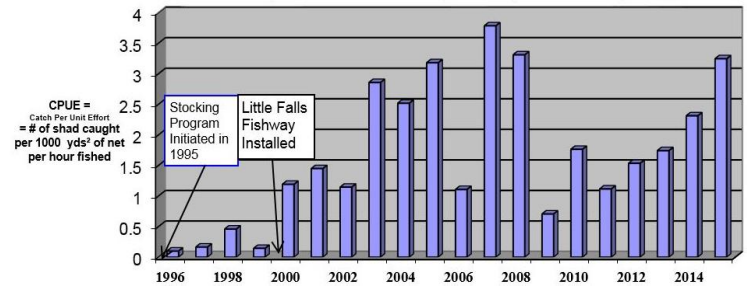

Figure 18: MD DNR Potomac River American shad captured during MD's striped bass spawning stock survey (1996-2015). (Data from MD DNR, Eric Durell, 2015. Chart by ICPRB)

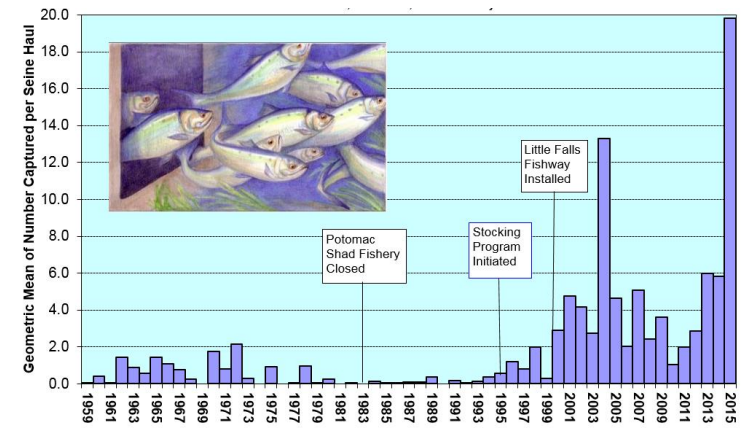

Figure 19: Juvenile American shad captured in the Potomac River by the Maryland Shore Haul Seine Survey (1959-2015). (Data from MD DNR, Eric Durell, 2015. Chart by ICPRB)

Results

In addition to ICPRB, other organizations such as USFWS, MD DNR, VDGIF, and PRFC monitor the progress of the Potomac American shad restoration. By 2002, after the eight-year stocking program had placed 18-million shad fry into the Potomac River at Great Falls, the river's American shad population was judged strong enough that restoration stocking was successfully concluded. In 2003, as an early measure of that success, the Potomac River became the egg source for Virginia, Maryland, and Pennsylvania shad recovery programs in the Chesapeake Bay. From 2003 until 2014, ICPRB worked with VDGIF, collecting fertilized shad eggs from the Potomac River to be used for restoration stocking in the Rappahannock River.[9] Through that

report (Stevenson, 1898): "At Great Falls there are a few bow nets used each spring from the last week in April to the first or second week of June. These nets are operated from a point known as 'Shad Rock,' which projects into the water on the Virginia shore just below the principal falls." This mentioned rock is the same rock upon which Mike Odom is standing. We found it to be an ideal site for our dip-net surveys used for this project. Therefore, upon discovering Stevenson's report, we found that not only had the project brought back American shad to Great Falls, it also once again revealed the historic land feature: "Shad Rock."

[9] From 2003 until 2014, over 48-million Potomac-origin shad fry were stocked in the Rappahannock River. In 2014, the Rappahannock River American Shad Abundance Index derived by the Virginia Institute of Marine Science (Hilton et al., 2014), was 8.66 which exceeded the VDGIF restoration goal of 7.85 for the first time since the survey was initiated in 1998. Restoration stocking of the Rappahannock, with help from the Potomac River stock, was also successfully concluded.

program, an additional 4-million shad fry were stocked into the Potomac River to replace adult shad harvested during egg collections.

By-catch data assembled by the Potomac River Fisheries Commission from commercial pound-net fisheries indicates the population has exceeded 1940s-50s era levels (Figure 17).

The number of spawning adult American shad captured by MD DNR has increased tenfold (Figure 18).

Since the project started in 1995, juvenile shad in the Potomac have become substantially more numerous (Figure 19), eclipsing records for 11 of the last 13 years in Maryland's shore monitoring surveys conducted since 1959.

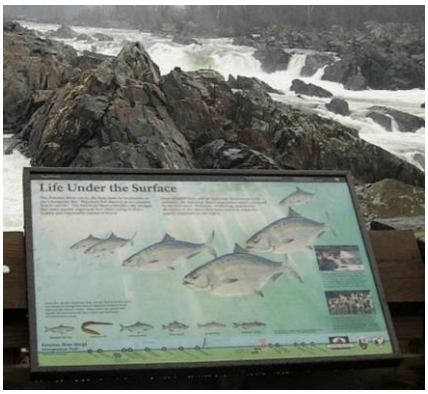

Figure 20: Informational kiosk featuring the American shad at the most upstream visitor overlook at Great Falls Park, Va. (Image courtesy of ICPRB)

In 2007, the Atlantic States Marine Fisheries Commission (ASMFC), the agency with regulatory oversight on migratory marine fishes, set the Potomac River's shad recovery benchmark to be a 10-year geometric mean (average) of 31.1 lbs./net-day (straight blue line in Figure 19). In 2012, the geometric mean (green line) was 36.6 lbs./net-day and ASMFC designated the Potomac River American shad population a sustainable fishery.

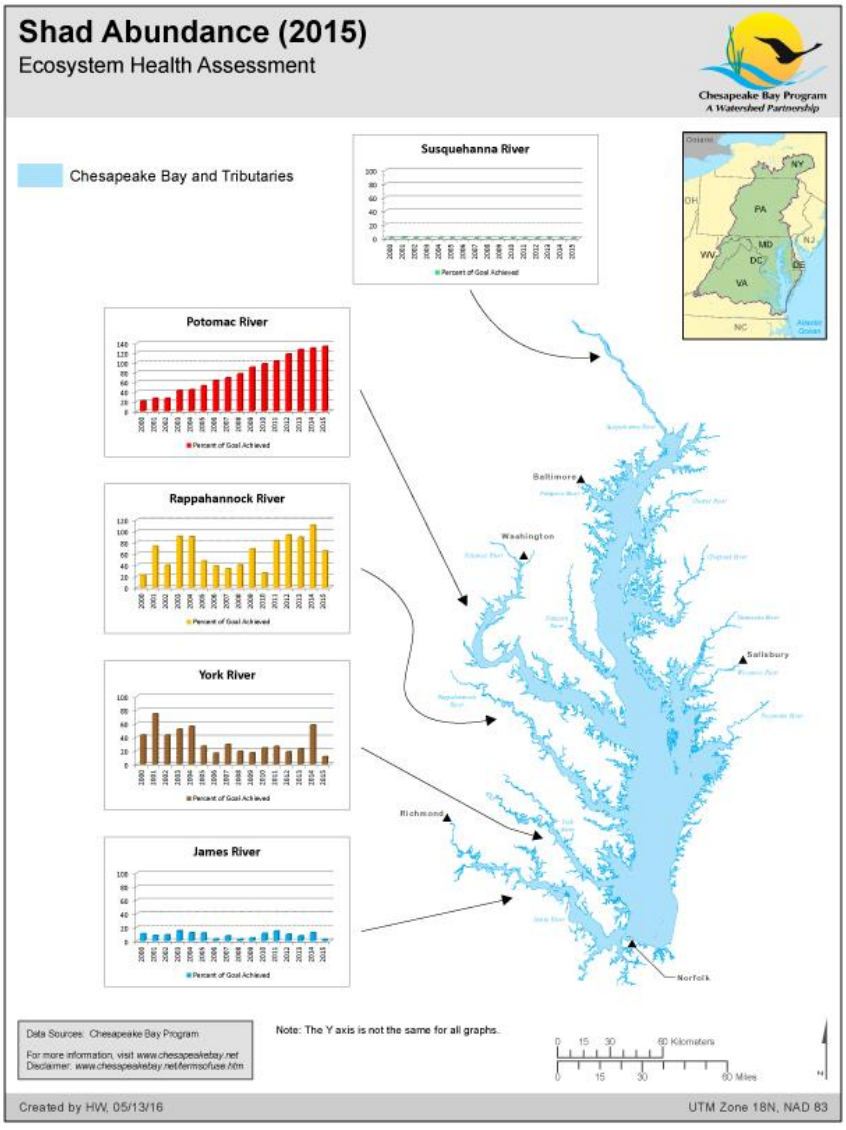

Figure 21: River specific trends in American shad abundance used for the Chesapeake Bay American Shad Indicator. (Graphics by Howard Weinberg for the Chesapeake Bay Program)

The Potomac's American shad recovery is a good sign that investments made in water quality improvements, habitat access, and fisheries restoration are working. The recovery is particularly important because of its ecological linkages: "In the 21st century, American shad could become a bellwether of ecosystem health, managed not only for fisheries, but also to indicate the status of the connectivity and environmental quality of watersheds and coastal oceans" (Limburg, 2007).

During the first three years of the dip-net survey at Great Falls an increasing

trend developed; in 2000 (the first year that the fishway was opened), we captured three American shad, then 12 in 2001, followed by 43 in 2002. This was good evidence the fishway was working. The subsequent years of 2003-2005 were problematic due to exceptionally wet years coupled with staffing issues for USFWS staff. The return of American shad, their spawning actions in the river, and the elevated level of predatory birds such as herons and eagles brought so much visitor attention and questions at Great Falls that a special kiosk on shad was installed by the National Park Service in 2006 (Figure 20).

American Shad Populations

As of 2014, the last year of bay-wide available data, the Chesapeake Bay shad population was at 41% of the 100% recovery goal, and continues to increase. The Potomac's shad population has reached nearly 130% of its goal and is a strong driver in this trend.

River specific components of the Chesapeake Bay's American shad indicator can be seen in Figure 21.[10] Five rivers are currently used to calculate the American Shad Indicator. Collectively they account for an estimated 90% of the Chesapeake Bay's total shad population. The Potomac River trend can be seen in red at the upper left. Individual river indices are proportionally weighted, based on each river's watershed flow, and summed to calculate the indicator value for the Chesapeake Bay.

The team intends to add remaining river systems when their data becomes sufficiently robust. More information on the Chesapeake Bay's American Shad Indicator, including details of how the metrics were derived and each river's restoration efforts can be found at: www.chesapeakebay.net/indicators/indicator/american_shad_abundance.

Figure 22: Center: shad pals (see Figure 22). Clockwise from the upper left: students help remove the adult shad from nets, learning to squeeze the eggs, the scaled down classroom hatchery, bidding fair well, and releasing the fry.

[10] The Potomac River's shad recovery does not occur in so smooth a line as this figure suggest, it also has natural variability from year to year, as can be seen in previous Figures 17-19. The index used for the Potomac recovery is calculated as a multi-year mean which smooths out natural variability.

Public Participation and Publicity

ICPRB's American Shad Restoration Program reached out to the public in significant ways and has been fortunate to have much public support. Hundreds of volunteers have helped during the late-night hours of spring brood-stock collections. Tens of thousands of students and many dozens of Washington area schools have participated, both on the river and raising shad fry in the classroom through a "Schools-in-Schools" partnership with Living Classrooms of the National Capitol Region, the Anacostia Watershed Society, and the Chesapeake Bay Foundation. A school-room sized shad hatchery was developed and each class received approximately 3000 shad eggs to hatch and release. Through the student's efforts, an estimated 380,000 additional shad fry also have been released. Interest in angling for American shad is growing rapidly thanks in large part to this strong public outreach and participation component.

Figure 23: Shad students in the news.

What started with a few students in 1996, grew to involve more than 50 schools in the Washington metropolitan area. They were captivated by how rapidly shad eggs develop, going from a simple fertilized egg to a hatched free swimming fish in only 4-5 days. On the day the shad hatch, sometimes hundreds or thousands of fry appear right before their eyes and the students go wild!

Teachers were thrilled by the cross-curricular nature of the project. Students gobble up the science but were also motivated to research and write about shad, from poems to history stories. They performed math with a passion, estimating how many eggs and how many hatched. They created shad artworks. In most schools, students prepared electronic-format presentations for students in younger grades. The students, fry raising fry, became teachers. Their teaching does not stop at the school doors. They taught their parents and siblings, they involved their neighbors, and they helped educate a community.

The student component has been covered by a variety of publications, perhaps most notably, it was a featured article in the July, 2013, issue of "Impact," the newsletter of the *Journal of the American Water Resources Association* (Volume 15, Number 4) as seen in Figure 23.

Conclusion

The Potomac's American shad population is rebounding well. Unfortunately, most American shad stocks along the entire east-coast "are currently at all-time lows and do not appear to be recovering" (Limburg, 2007). What are the possible reasons for the difference with the Potomac River's population? As with most trends in the natural world, the reasons for the Potomac shad's rebound are multiple and part of a larger story. The following are some possible influences.

First, the Potomac's potential for producing shad is extremely high because it was, and is, a remarkably productive river. This is an important point which deserves recognition. Many of the historic descriptions of shad abundance cited in this document seem almost unbelievable compared to other rivers. Yet Captain John Smith, a man who had sailed into many pristine rivers of Africa and the Americas, wrote "neither better fish, more plenty, nor more variety for smal fish, had any of us ever seene in any place." (Smith,

General Historie of Virginia, 1608). In addition, the accuracy of the astounding catch reports from the early 1800s were confirmed with evaluations of Charles Chapman's 1814-1824 catch reports (Massman, 1961). Much of the Potomac's innate productivity remains.

Second, water quality improvements over the last several decades reset the Potomac's ecological functioning. The clean-up of the Potomac River is a national showcase for successful programs to restore highly polluted waters. The river, once called "disgraceful" by President Johnson, now hosts national bass fishing tournaments and has been rated as one of the best areas to fish for bass and catfish in the United States.

Third, the resultant return of submerged aquatic grasses (SAV) to the Potomac River led to a huge ecological reset (Rybicki & Landwehr, 2007), strengthening the chain reaction of water quality and habitat improvements tremendously. However, SAV beds were thick in the Potomac since the early 1980s, but the shad had still not rebounded by the mid-1990s, when restoration stocking was initiated. SAV increases alone were not enough, but shad would not be doing as well in the Potomac without these grass beds.

Fourth, the shad harvest moratoriums, in both our rivers and ocean, were necessary. We over-harvested what we did not kill with pollution. However, Potomac River shad harvest moratoriums had been in place for 15 years and the stock had not recovered. Again, none of these factors alone are enough. Unfortunately, shad recovery is still hampered by by-catch in several Atlantic coastal fisheries.

Fifth, the installation of the fishway at Little Falls. This structure restored roughly ten miles of important spawning habitat. That habitat is important because the gorge area upstream from Little Falls is a zone of high energy which does not support high numbers of minnow predators such as those found in the Potomac's tidal mainstem. This was true in the 1800s, as well as today. The low numbers of predators (i.e., minnows) are what makes the area an excellent nursery for shad, providing time for the eggs and larvae to develop in a predator-reduced environment.

Sixth, the ICPRB/USFWS's shad stocking program. While the stocking effort was designed primarily to restore shad to the river between Little Falls and Great Falls, it also gave an extra shove, a jump-start, to a shad population that was reduced to such low numbers that they were marginally self-sustaining. The jump-start analogy is an apt one. A battery that won't start a vehicle usually has some juice, often quite a bit, just not enough to start the engine, so we jump-start it with some extra power. The stocking effort provided a jump-start to the shad recovery.

Figure 24: American shad populations are strong in the Potomac River. Fishing for them is growing increasingly popular, but they must be released unless harvest moratoriums can be lifted. (Image by Mike Bailey featuring Greg Wilson with shad caught near Fletcher's Cove, D.C.)

Many other American shad restoration programs have the same, or some subset, of these factors. What sets the Potomac apart? There are two major differences. The first, which is likely the most significant, is that the majority of the Potomac's juvenile habitat is in tidal freshwater—where there is plenty of food and strong SAV beds which provide protective habitat. The second reason is that the fish passage installed at Little Falls opened a relatively short stretch (10 river miles) of non-tidal spawning habitat. That enabled a weak population to remain concentrated, thus contributing to spawning success. In rivers where fish passage programs open up long stretches of river, the remnant population can become more dispersed and diluted, impacting spawning and increasing predation on eggs and young, mostly by minnows.

Attributing the shad's recovery in the Potomac to any one factor is a mistake. They all worked together. We initiated a shad stocking program because the Potomac population showed no signs of recovery after harvest moratoriums had been in effect for 13 years and SAV had been doing well in the upper-freshwater tidal Potomac for more than a decade. But the stocking effort itself could not have restored the shad. The other improvements set the stage, the stocking program merely entered it on cue.

What is next?

It is important to continue monitoring to maintain our knowledge of the pulse of this recovery. In addition to the Potomac River Fisheries Commission's commercial harvest information, the fisheries independent data from both Maryland's Bay-wide Shore Haul Seine Survey and their spring gillnet survey (primarily performed to document striped bass population levels) are critical and should be continued.

An important but subtle issue to consider is that restoring this fishery is a different task from restoring the fish. As stated earlier, the fishery was closed in the Potomac in 1982, and in Maryland since 1980, so interest in the fish dwindled and was lost for more than a generation. They had become not only a rare fish, but a forgotten fish. Just about the only people with a memory of shad were more than 70 years old. This is one of the reasons that the school stocking component of this program was critical in that it imprints both fry: shad fry and human fry. These young people, and their families, got to know the American shad once again. All thanks to partnerships between ICPRB, Living Classrooms of the National Capitol Region, the Anacostia Watershed Society, and the Chesapeake Bay Foundation. Interest in angling for American shad is growing rapidly thanks to the strong public outreach and participation component of this project.

It is great news that the American shad population in the Potomac is once again strong. For the foreseeable future (at least the next seven years), there should be enough shad in the Potomac to finally permit a small directed harvest. While we do not want to repeat past problems with over-harvest, it is time to begin permitting and encouraging additional limited-entry commercial and recreational harvest.

In the interim, anglers can practice catch-and-release fishing for shad. This is a good way to re-learn about the shad; how much fun and a challenge they can be to catch on hook and line, how pretty they are, and how important they are to the ecosystem. Perhaps the most spectacular settings for this is the stretch of river from Great Falls down to Little Falls, the area that was re-opened to shad migration in 2000 with the construction of the fishway at the Brookmont Dam. Hopefully, in the not-too-distant future, anglers can once again take a shad home and enjoy the fish on the table as well as at the end of a line.

Figure 25: Hanbin Lee, a student from Waples Mill Elementary, Va., and a shad pal. (Image courtesy of ICPRB)

Unfortunately, with most coast-wide populations of the American shad at all-time lows, the Potomac River will have difficulties fully recovering until coastal stocks are also restored. That is because predation and ocean fisheries by-catch is occurring at higher rates upon Potomac origin shad, which make up a disproportionally high percentage of that population.

"Just as the sacred cod of Massachusetts is the accepted emblem of the Bay State, so the shad may rightly be considered the piscatorial representative of the states bordering the Chesapeake," stated Rachel Carson in the *Baltimore Sun*, 1936 (Carson, 1936). There is currently an effort to make the American shad the District of Columbia's official "state" fish. It would be a very fitting distinction for this nation's founding fish.

Appendices

Appendix I: Dedication and Acknowledgements

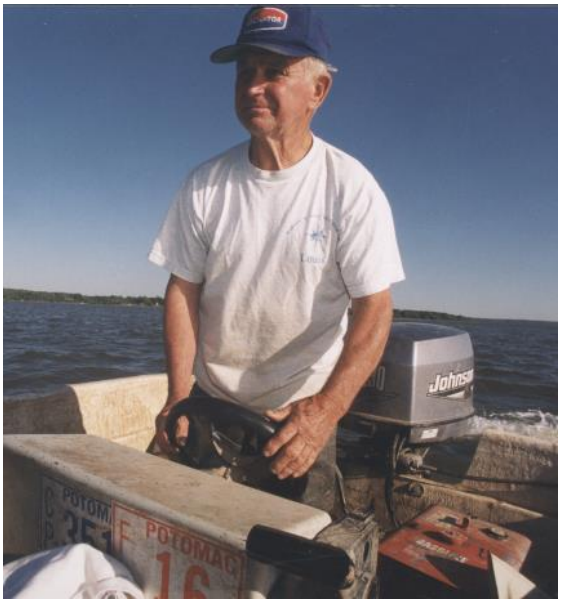

Figure 26: Marvin Louis Harley at the helm. (Image by Jim Cummins)

This report is dedicated to Potomac River waterman, Marvin Louis Harley (9/22/1930 – 3/18/2009), who worked on this project from 1995 until his death from cancer in 2009.

Louis Harley was always ready to do whatever he could to help restore the shad or the Potomac. If it meant spending long, chilly nights out on the river, he would do it. His polite demeanor always inspired admiration from scientists, the hundreds of volunteers, thousands of students and their teachers, and all involved in the project. Louis was glad that more and more people, especially the young, are becoming aware of the American shad, its importance to the economy, history and ecological vibrancy of the Potomac River, the Chesapeake Bay, the entire east coast. He was especially proud to see a renewed interest in shad fishing heritage near his home on Mason Neck, Virginia. At one-time these areas were home to the most active American shad runs along the entire Potomac River: Sandy Point, Stoney Point, Sycamore Landing, Barn Landing, and Hallowing Point.

The success of the program brought regional and national attention, not only to the shad, but to the value of protecting and restoring our rivers. This would not have been possible without Louis' efforts, experience, and his grand, and paternal, presence. He laid out nets. He was a fisherman.

Special thanks is extended to the Potomac River Fisheries Commission, the Virginia Department of Game and Inland Fisheries, the District of Columbia's Department of Energy and the Environment, and the Maryland Department of Natural Resources.

I would be remiss if I didn't recognize the valuable help provided by the hundreds of volunteers who contributed so much of their time and energy.

Since the program's inception in 1995, it has been supported by a number of collaborating agencies and organizations including the Virginia Chesapeake Bay Restoration Fund, the Maryland Chesapeake Bay Trust, the Potomac River Fisheries Commission, the National Fish and Wildlife Foundation, the U.S. Fish & Wildlife Service, the U.S. Army Corps of Engineers, the U.S. EPA's Chesapeake Bay Program, and private donations from members of the Congressional Sportsmen's Caucus.

Thanks to my colleagues Renee Bourassa, Claire Buchanan, Curtis Dalpra, and Carlton Haywood for their help editing of this report.

Penultimate, yet second to none, thank you "Shad Teachers," for opening so many "fish-passages" to your students through this project. Your collective creativity and dedication to your work always inspire.

Last but not least, never underestimate the benefits of good net-working.

Appendix II: Program Recognition

The project received the 2006 "Future of Fishing" award from the American Sportfishing Association. In that same year, it was one of Field and Stream Magazine's top six "Heroes of Conservation" projects.

A book by environmental author, Sandy Burk, on the project's educational component entitled "Let the River Run Silver Again" was awarded the Izaak Walton League's Conservation Book of the Year for 2005, and the Green Earth Book Award for 2006.

From 2000 to 2006, the project was part of the Jim Range National Casting Call held at the Boat House at Fletcher's Cove. Beginning in 2006, this event served as a template for the National Fish Habitat Action Plan of the U.S. Fish and Wildlife Service (USFWS) and a host of its partners. This initiative enhanced large-landscape scale efforts to restore and improve fish populations and habitat through partnerships at the federal, state, local and private levels. The Potomac's shad restoration partnership, under the leadership of ICPRB, was cited as a great example of the type of partnership the USFWS would like to see established across the country.

Appendix III: Summary of the number of American shad captured[11], eggs collected, fry released, and Catch-Per-Unit-Effort (CPUE) for the project period 1995-2014, including estimates of shad returns[12]

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003[13]**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	Totals	Avg.
# Ripe females	135	166	245	105	119	373	338	245	240	387	246	316	441	349	183	379	244	418	239	275	5,443	272
# Green (unripe) Females	78	51	92	50	44	93	135	141	120	127	49	72	93	150	48	226	122	418	212	320	2,641	132
# Post-spawn (spent) Females	3	1	0	8	10	9	27	25	15	27	2	11	118	43	29	31	31	47	21	40	498	25
# Males	78	157	207	153	116	282	235	247	240	435	209	283	397	191	102	460	235	249	239	302	4,817	241
# Total Shad (Used)	**294**	**375**	**544**	**316**	**289**	**757**	**735**	**658**	**615**	**976**	**506**	**682**	**1049**	**733**	**333**	**890**	**409**	**858**	**556**	**482**	**12,057**	**603**
# Total Shad (Captured)								1801	1494	1852	1101	1010	1858	903	444	1096	789	1129	711	987	15,175	1168
# Shad Released								1143	879	896	595	328	809	170	111	206	380	271	155	505	6,448	496
# Eggs Collected x 1000	2,405	4,353	5,744	2,626	2,594	6,383	6,565	5,943	5,327	5,773	8,129	NA[14]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
# Collections/# nets set	11/27	11/22	12/24	14/28	15/30	11/22	16/32	18/36	10/16	14/25	13/25	16/32	17/34	16/31	16/32	16/32	17/35	19/38	18/36	18/36	298/593	15/30
Shad Used/net-set CPUE[15]	**10.9**	**17.0**	**22.7**	**11.3**	**9.6**	**34.4**	**22.9**	**18.3**	**35.9**	**39.0**	**20.2**	**21.3**	**30.9**	**23.6**	**10.4**	**27.8**	**11.7**	**22.6**	**15.4**	**13.4**	**419.4**	**21.0**
Total shad/net-set CPUE								**50.0**	**93.4**	**74.1**	**44.0**	**31.6**	**54.6**	**29.1**	**13.9**	**34.3**	**22.5**	**29.7**	**19.8**	**27.4**	**524.4**	**40.3**
# Eggs/Ripe-female	**17,800**	**26,200**	**23,400**	**25,000**	**24,400**	**17,100**	**19,400**	**24,260**	**22,195**	**14,917**	**24,783**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	21,769
# Fry Stocked Pot. R.	1,175	1,989	1,535	1,589	1,304	3,176	3,336	1,531	200	400	919	1,158	728	884	528	510	488	537	406	350	22,743	1,137
# Fry stocked Rapp. R. **(x**									1,200	3,100	3,400	6,265	4,453	4,832	2,718	3,943	4,116	5,995	4,265	4,156	48,443	2,422
Total # Fry Stocked (x 1000)	**1,175**	**1,989**	**1,535**	**1,589**	**1,304**	**3,176**	**3,336**	**1,531**	**1,400**	**3,500**	**4,319**	**7,423**	**5,181**	**5,716**	**3,246**	**4,453**	**4,604**	**6,532**	**4,671**	**4,506**	**71,186**	**3,559**
# Fry Stocked Each Shad Collected	4,000	5,300	2,800	5,000	4,500	4,200	4,500	2,326	2,435	3,586	5,690	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4031
Est. # of Shad Returning[1]	**3,487**	**5,902**	**4,555**	**4,715**	**3,869**	**9,424**	**9,674**	**4,444**	**4,060**	**10,150**	**11,300**	**22,027**	**15,430**	**16,961**	**9,632**	**13,215**	**14,080**	**19,383**	**13,861**	**13,371**	**209,540**	**10,477**
Est. # Shad Returning Each Shad Collected	11.9	15.7	8.4	14.9	13.4	12.4	13.5	6	5.9	10.6	14.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	11.6

[11] While this data reflects the strength of the yearly shad runs, neither the number nor catch-per-unit-effort of American shad captured during the egg collections proved to be a good indicator of the shad population strength. It did not track well with other indicators. This is most likely due to the way we would "tend the net," removing shad during the net's deployment in order to keep them alive and healthy, and in so doing we disrupted the normal catching ability of the net and created a sampling bias.

[12]Monitoring at the Conowingo Dam fish lifts (Hendricks 2000) found, on average, that it takes 337 hatchery fry stocked in the Susquehanna River to get one returning adult shad. Subsequent results have modified that number slightly, but in order to have a consistent estimate the 1 shad returning per 337 stocked fry ratio has been used since 2001 as an assumed Potomac return rate.

[13]The Potomac Restoration Stocking Program for American Shad was conducted from 1995 until 2002, at which time recovery was considered sufficient for natural reproduction. In 2003, restoration stocking of the Rappahannock River began, using Potomac River origin shad eggs through a partnership between ICPRB, the Virginia Department of Game and Inland Fisheries, and the U.S. Fish and Wildlife Service's Harrison Lake National Fish Hatchery. Stocking of the Potomac continues, but now as a "replacement stocking" to account for the Potomac shad harvested for another river system. In 2014 we stocked approximately 4,506,000 shad fry. About 350,000 of those were stocked into the Potomac to replace harvested adult shad, which roughly 8% of our total shad fry stocked (10% replacement is the goal). Since 2003, we have used 8,089 shad.

[14] NA, for Not Applicable, is used after 2005 because these values could no longer be derived. Starting in 2006, we switched from using 1 boat to 2-3 boats for our collections The Watermen involved were Louis Harley (1995-2008), Mike Harley (starting in 2006), Brad Harley (starting in 2008), and Randy Kirby (2006-2007). Since 2005, shad from all boats are pooled together during the collection process, and it became too difficult to separate or accurately estimate egg or fry production for each individual boat. This table only reports shad caught in the ICPRB boat.

[15]CPUE, or Catch-Per-Unit-Effort, is calculated by two methods in this project. The first CPUE (shad used/net-set) is based upon the number of shad used for egg collections and re-stocking of the Potomac and, starting in 2003, the Rappahannock Rivers. It does not include shad which were netted but released, i.e., the unripe or green females, spent females no longer spawning, or surplus males (we try to keep a 1/1 ratio of males to females). Starting in 2002, all shad netted were counted and a second CPUE (Total shad/net-set) has been calculated this time using all shad brought to the boat, even those released.

Appendix IV: Glossary of Abbreviations and Acronyms

ASMFC…….. Atlantic States Marine Fisheries Commission

CPUE……. Catch-Per-Unit-Effort

ICPRB…… Interstate Commission on the Potomac River Basin

MD DNR.....Maryland Department of Natural Resources

NOAA…… National Oceanic and Atmospheric Administration

PRFC……. Potomac River Fisheries Commission

SAV……... Submerged Aquatic Vegetation

USFWS……. United States Fish and Wildlife Service

USACE…….. United States Army Corps of Engineers

U.S. EPA…… United States Environmental Protection Administration

VDGIF…….. Virginia Department of Game and Inland Fisheries

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