Hickory Shad Restoration in Three Maryland Rivers

F-57-R Segment 20 Progress Report
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*****Reporting Timeline*****

This progress report will cover calendar year 2018 sub-projects one, two, three and overall restoration progress. Elements of the project initiated in 2019 will be briefly reported on. A comprehensive progress report for 2019 will be submitted in 2020.

OUTLINE

Need

Hickory Shad *Alosa mediocris* were historically abundant in many Chesapeake Bay tributaries (O'Dell et al. 1975, 1978). Populations declined similar to other Clupeid species during the 1970s (Minkkinen 1999). A moratorium was enacted on all Maryland Hickory Shad harvest in 1981. Recently, some upper Chesapeake Bay tributaries have experienced a mild resurgence in Hickory Shad runs. The increased availability of Hickory Shad broodstock provided the opportunity to culture and stock this species. Few studies have been conducted on Hickory Shad. Funding obtained through Sportfish Restoration Act (F-57-R) has supported the Maryland Department of Natural Resources restoration project since 1999.

Previous work conducted under F-57-R yielded new Hickory Shad spawning strategy and life history information. Many Chesapeake Bay tributaries had historical Hickory Shad runs equal to or greater than that of American Shad *Alosa sapidissima.* Since shad populations indicate evidence of density dependent spawning behavior, self-sustaining shad populations are not likely to return to tributaries without hatchery stocking. Since 1999 the Maryland Department of Natural Resources has been developing spawning, culture, marking and stocking techniques that could restore spawning populations of Hickory Shad to target tributaries. These techniques have been continuously refined, and reintroduction of Hickory Shad to target tributaries has progressed similar to the department's American Shad restoration projects.

Objective

The overall objective for this proposed scope of work is to reintroduce self-sustaining Hickory Shad populations to the Patapsco River. Stocking larval and juvenile hatchery-origin fish should produce adult stock that will return to spawn upon maturity. The depressed native stocks do not optimally utilize the tributary. This tributary has historically supported spawning runs.

Expected Results and Benefits

Hatchery inputs are intended to provide adult spawning stock that will produce self-sustaining populations in the target tributary. These fish have tremendous value for stock assessment purposes at the larval, juvenile and adult life stages, since all stocked shad receive an otolith mark. Larval and early juvenile otolith marking is the primary identification method for hatchery reared Hickory Shad. Natural spawn culture techniques allow for the production of large numbers of larval and juvenile shad for stocking and assessment efforts.

Upper Bay shad populations, specifically the Susquehanna River, currently support Hickory Shad populations that sustain active catch and release recreational fishing. Restoring Hickory Shad stocks to tributaries that historically supported runs will increase fishing opportunities for anglers. An indirect benefit of restoring shad populations to self-sustainable levels is the increased prey availability provided by both juvenile and adult shad for larger, more economically important recreational species such as Striped Bass *Morone saxatilis*, Bluefish *Pomatomus saltatrix*, and Weakfish *Cynoscion regalis*.

Approach

The Maryland Department of Natural Resources American Shad hatchery based restoration project incorporated Hickory Shad into the project in 1996. The project continued over the next three years through various short-term funding sources. In 1998 it was determined that a long term funding source would be required, since it would take years of additional stocking and assessment to successfully support restoration. Federal Aid in Sport Fish Restoration funds were utilized to conduct this long-term effort.

The project consists of three sub-projects:

1. *Produce, mark and stock cultured Hickory Shad.*
2. *A. Assess the contribution of hatchery-produced fish on the resident/pre-migratory stock in the Patapsco River.*
   B. Monitor the abundance and mortality of larval and juvenile shad using marked hatchery-produced fish.
3. *Analyze the contribution of hatchery origin Hickory Shad to the adult spawning population and monitor the recovery of naturally produced stocks.*

Justification to amend approach 2017

Hickory Shad populations in the Patuxent River were deemed restored in 2007, and the Choptank River was deemed self-sustaining in 2014. Both rivers were original target tributary with stocking beginning in 1996. The Patuxent River watershed is heavily urban-impacted, but has been the subject of numerous mitigation efforts due to its designation as a targeted watershed (e.g., sewage treatment upgrades). The Choptank River watershed is rural-impacted by agricultural activities and low urban development. Choptank River efforts included the tributary Tuckahoe Creek. Both rivers will be sampled on a three year rotation in order to maintain trend data. Sampling will be conducted in the spring of 2020.

In 2014, Hickory Shad were stocked in the Choptank River for the final time and a tributary needed to be identified for stocking efforts. In 2015, the program shifted focus and conducted exploratory surveys on the Pocomoke River, Marshyhope Creek, Chester River, Sassafras River, Elk River, Northeast River, and the Patapsco River for baseline Hickory Shad data in order to assess restoration need. Future target tributaries would be chosen based on historical data, angler access, and suitable Hickory Shad spawning and nursery habitat. Restoration efforts are now directed to the Patapsco River as a result of this assessment. The main-stem Patapsco River is 63 km long and heavily urban impacted. With its origins in Carroll and Howard county farm land, the Patapsco River quickly transitions to urban sprawl and the tidal portion creates the Baltimore Harbor. The river was once impacted by industry and dams. A Baltimore City drinking reservoir is in its north branch. Union Dam and Simkins Dam were removed in 2010 and 2011 respectively, and the lowermost dam, Bloede Dam was removed in 2018. Once the Bloede Dam was removed, anadromous species had access to more than 104 km of the river and its many tributaries. As of 2018 only one dam (Daniels Dam) remains in the main-stem.

From 2012-2017 the Patapsco River was the subject of a separate restoration effort known as the Patapsco River Shad and Herring Restoration Project. American Shad and Hickory Shad were stocked by the Maryland Department of Natural Resources. The United States Fish and Wildlife Service (USFWS) Maryland Fish and Wildlife Conservation Office (MDFWCO) was subcontracted to perform assessments. This project was funded by a six year grant from the Maryland Department of Transportation (MDOT) through the Maryland Port Authority (MPA).

Recent Patapsco River fish passage implementation has reopened historical spawning habitat for anadromous species such as American Shad, Hickory Shad, Blueback Herring *Alosa aestivalis* and Alewife *Alosa pseudoharengus*. This tributary historically supported spawning stocks, and reintroduction through hatchery inputs could indicate positive impacts. Restoring

Hickory Shad populations takes many years, and it was determined by project biologists that it would be advantageous to continue the MPA funded project, given the head start the river had received. Several years of additional inputs would be necessary to determine whether hatchery stockings were successful.

In 2017, the USFWS Wildlife and Sport Fish Restoration F-57-R grant proposal was amended to continue stocking and assessment on the Patapsco River. In 2018, Hickory Shad were stocked as larvae and early juveniles in the Patapsco River, continuing the restoration effort previously funded through the MPA grant. Since stocking in the Choptank and Patuxent rivers ceased, it was an opportunity to continue this worthy effort.

Location

Restoration efforts will focus on the Patapsco River (Figure 1). The Patapsco River watershed is heavily impacted by urban, commercial and industrial development, but has been the subject of numerous mitigation efforts (e.g. sewage treatment upgrades, habit improvements, fish passages, and dam removal).

2018 Sub-Project 1.

Objectives

"Produce, mark and stock cultured Hickory Shad."

In 2018, the Maryland Department of Natural Resources staff produced, marked, and stocked Hickory Shad larvae and juveniles. Hickory Shad larvae were marked and stocked into the Patapsco River (Figure 1). Larval fish were stocked into the target tributary immediately after being marked with a day-1 oxytetracycline (OTC) mark. Early juvenile fish were marked with OTC on day-1 and day-3, then were stocked as larvae into hatchery ponds and later transported to the river at approximately 30 days of age. Hickory Shad were produced through hormone-induced tank spawning utilizing Susquehanna River origin broodstock.

Materials and Methods

Broodstock Collection

Hickory Shad broodstock were collected from the Susquehanna River (Figure 2; Table 1). Since the mid-1990s, Hickory Shad abundance increased in the upper Chesapeake Bay and its tributaries (ASMFC 1999).

Prior to 2005, Hickory Shad broodstock were collected by hook and line, either immediately downstream of Deer Creek or at Shure's landing, near the base of Conowingo Dam (Figure 2). In 2005, the Maryland Department of Natural Resources staff transitioned to boat electrofishing to collect Hickory Shad broodstock. The sample area was located along the western shore of the Susquehanna River, from just downstream of Deer Creek at Rock Run Mill down to Lapidum boat ramp in the Susquehanna State Park (Figure 2). Electrofishing was used for its ability to efficiently collect larger numbers of Hickory Shad than could be collected by hook and line. Electrofishing for Hickory Shad broodstock requires less project staff and reduces handling stress. During broodstock collection, immobilized Hickory Shad were netted and placed into the electrofishing boat's live well (220 L). The live well water was flow-thru and oxygenated.

Hormone Induced Ovulation

Injections of Luteinizing Hormone-Releasing Hormone analog (LHRHa), a synthetic analog of gonadotropin-releasing hormone (GnRHa), stimulate pituitary release of endogenous gonadotropin. The use of LHRHa induces gonadal maturation, ovulation and spawning (Mylonas et. al. 1995). In accordance with the Investigational New Animal Drug Permit (INAD #11-375-18-003), the Maryland Department of Natural Resources purchased pre-made 75µg hormone pellets for ovulation induction. The LHRHa pellets are sold under the product name Ovaplant® and produced by Western Chemical Inc. (Ferndale, WA). Hickory Shad were sedated at the boat ramp with the Investigational New Animal Drug Permit Aqui-S 20E® (eugenol; INAD# 741-19-028F) at a rate of 10 mg/L. Males and females received an intramuscular implant of Ovaplant® into the dorsal musculature. Implants were administered through a spring-loaded 11-gauge multiple dose Ralogun® (Intervet/Schering-Plough Animal Health, The Netherlands).

Egg Culture

Fish were placed into circular flow, insulated 3,785 L tanks at 4.0-6.0 ppt salinity and transported to Manning Hatchery (Figure 3). Dissolved oxygen (DO) was continuously monitored and regulated to saturation (approximately 10.0 ppm) with a Point Four oxygen monitoring system (Coquitlam, BC, V3K 6X9, Canada). Adults were netted from the transport tank and into 3.05 m diameter natural spawn tank systems. A sex ratio of approximately 3:2 male: female is preferable in natural spawn systems, but there are times when males are not sufficiently available to meet this ratio. Salinity was maintained at 2.0 ppt. A 25% water exchange was performed each day to maintain adequate water quality. Fish spawned naturally and eggs were automatically transported to an egg collection box through an airlift system.

Eggs were volumetrically measured (ml) and fertilization was determined 24 hours post spawn. Eggs were placed into modified McDonald hatching jars supplied by approximately 2.0 L/min water flow. Prophylactic treatments of formalin were administered in the morning and afternoon to control fungi. Eggs were exposed to a 600:1 treatment of formalin for approximately 17 min. Hickory Shad eggs began hatching at day four. In order to stimulate a simultaneous hatch, jars were removed from the egg bank, placed outdoors in sunlight for ten minutes and stirred occasionally. The rapid temperature change, lower oxygen content, concentrated hormonal influence and agitation stimulated simultaneous hatching. Hatching jars were then placed on benches beside 1.5 m (1,800 L) circular flow-through larval tanks that allowed water and larvae to flow from the hatching jars to the flow-through tanks. Water was supplied at approximately 2.0 L/min.

Hickory Shad feed on rotifers that are difficult to culture in the Maryland Department of Natural Resources hatchery. Therefore, Hickory Shad larvae were marked and stocked into hatchery ponds or target tributaries prior to first feeding (<six days age). Prior to stocking, larvae were enumerated using a volumetric direct proportion procedure in which a columnar sample of water was collected with a 25.0 mm diameter PVC tube at random locations in the larval tank. Larvae were enumerated in this sample and the total number of larvae in the tank was estimated by extrapolation to the total tank volume.

Marking

All fish stocked into the target tributary were given an OTC mark to identify recaptured fish as hatchery origin. OTC marks applied to larvae or juveniles will still be visible as adults. Larval marks were produced by immersion in a 300 ppm buffered OTC bath for six hours. Dissolved oxygen content was monitored and regulated (>5.0 ppm) by a carbon air stone connected to a liquid oxygen delivery system. All water used at Manning Hatchery for OTC marking was softened before use (Culligan ion exchange system). Reliable marking can only take place in water with hardness below 20 mg/L and water hardness at Manning Hatchery routinely exceeds 200 mg/L. Samples analyzed from each group of OTC marked fish indicated that all fish stocked were successfully marked. Marks were verified by viewing larval otoliths with an ultraviolet microscope (Zeiss Axioskop 20).

Larval Stocking

Fish intended for larval stocking were given a larval immersion OTC mark at day-1 after hatch. Larval stocking was accomplished by placing marked larvae into boxes originally designed for shipping tropical fish. These containers consisted of a cardboard box outer shell, an inner insulating foam box, a black plastic trash bag to reduce stress of bright sunlight and a double thickness plastic fish transport bag. Larval culture tanks were drawn down to crowd the fish. Larvae were scooped out of the tanks and placed in the shipping bags/boxes, which were supplemented with salt (1.0 ppt) to mitigate stress. Each bag was filled with pure oxygen and sealed with electrician’s tape. Boxes were transported to the Patapsco River and the bags were placed into the water to temperature acclimate. Once acclimated, the bags were opened and river water was slowly introduced to further acclimate larvae to river water chemistry. Bags were then emptied into flowing water to minimize predation.

Early Juvenile Stocking

Fish intended for early juvenile stocking were given OTC immersion marks at day-1 and day-3 after hatch. After the second mark was administered, larvae were stocked into hatchery ponds and cultured for approximately thirty days. Manning Hatchery, GenOn Energy, and the University of Maryland Center for Environmental Science (UMCES) Aquaculture and Restoration Ecology Laboratory (AREL) Horn Point provided grow out ponds to hold fish for the restoration effort (Figure 3). The decision to take juveniles out of the pond was based on zooplankton density. Food availability was evaluated with a plankton net. Early juveniles were removed from culture ponds when food availability declined substantially.

Juvenile fish tend to stress easily and direct netting from hatchery ponds into transport tanks results in unnecessary mortality. To prevent losses, juvenile fish were concentrated within the grow out ponds, using a seine net 61.0 m long, 3.1 m deep, with 6.4 mm stretch mesh. They were then effectively removed by scooping the concentrated schools of fish out with buckets and were poured into the transport tanks. A small one-horsepower water pump was used to create current within the seine net to orient shad into the water flow. This current serves two purposes. Shad concentrate into dense schools at the water's surface, which allows them to be easily bucketed, and it separates the fish from algae and detritus. The use of the pump has resulted in high early juvenile survival rates, due to the reduction of algae and detritus in the transport tanks. Early juveniles were transported in fish hauling tanks at 3.0-5.0 ppt. salinity and saturated DO to mitigate stress. Ponds at GenOn Energy and UMCES-AREL already have natural salinity of 6.0-8.0 ppt.

A one-horsepower trash pump was also carried on the stocking truck to temper juvenile shad before stocking. Fish were tempered until temperature and salinity in the tank were within one degree Celsius and 1.0 ppt salinity of the river value. Although this adds a considerable amount of time that fish are aboard the transport truck, it is assumed this procedure increases the survival of early juvenile stocked shad by reducing stress. Juvenile stocking was accomplished by quick-dumping marked juveniles through a quick release drain hose, with a diameter of 15.0 cm, directly from the transport vehicle into the river.

Stocking Goals

The project developed stocking goals (Table 2) based on previous experience with larval survival. Stocking multiple life stages gives fisheries managers the ability to assess larval survival and estimate juvenile mortality and abundance of each life stage. Larval stocked fish can efficiently contribute large numbers of juveniles if survival is high. The stocking goal for the Patapsco River was set at 500,000 larvae.

Fish stocked as early juveniles survive extremely well and are young enough to successfully imprint to the target tributary. Stocking early juveniles can also mitigate the impacts of poor larval survival since post-stocking survival of this life stage is high. In 2018, Hickory Shad early juveniles were stocked into the Patapsco River. The project developed stocking goals, which were based on past experience with juvenile survival. The stocking goal for the Patapsco River was set at 75,000 early juveniles.

Results and Discussion

Hickory Shad Tank Spawn Production Summary

Hickory Shad overall fertilization was 41.8% in 2018 (Table 3). From the time of the program's inception, Hickory Shad fertilization rates have decreased at a linear rate ($F_{1,20} = 6.84$, $p = 0.017$), with an R^2 of 0.2592 (Figure 4). 2018 fertilization rate was above the linear average. Hickory Shad egg fertilization rates (Figure 4) fluctuate from year to year and it remains difficult to pinpoint an exact cause for the overall trend of declining fertilization success.

Egg clumping in hatching jars has always been an issue and primary concern, but may not explain the decreasing fertility trend. Hickory Shad eggs are adhesive and will attach to anything they come in contact with, including other eggs. Egg clumping increases larval entrapment within hatching jars, which reduces hatching success and lowers overall larval survival. Egg de-adhesion techniques were investigated extensively, and one technique has proved to be moderately effective, but no perfect solution has been found. Egg de-adhesion techniques were adapted from methods described for Atlantic Sturgeon (Mohler 2003). Eggs were treated with solutions containing fuller's earth and tannic acid. De-adhesion solutions containing 100-200 g of fuller's earth and 50-75 mg of tannic acid per gallon of water were used. Eggs were gently mixed in the de-adhesion solution for 20 minutes with a large feather. The egg de-adhesion solutions were effective one to two days after treatment, then eggs would clump together again. The agitation of eggs with a large feather in the hatching jars several times per day helped to minimize the clumping and caking of eggs prior to hatching. Excess iron in the hatchery water may be a contributing factor as well.

Stocking Summary

A summary of 1996-2018 Hickory Shad stocking production appears in Figure 5. In the early years of restoration efforts, larvae and late juveniles were the only life stages stocked into the target tributaries. In 2001, early juveniles were cultured in hatchery ponds and stocked 30 days later into the Patuxent River. In 2002, juveniles were cultured and stocked into the Patuxent River, Choptank River and Marshyhope Creek. Hickory Shad stocking was suspended in the Patuxent River in 2008 and Marshyhope Creek in 2010 to focus project resources towards stocking the Choptank River. In 2014, Hickory Shad stocking concluded on the Choptank River. The stocking effort resulted in the formation of a stable population. Surveys were conducted in 2016 and 2017 on the Pocomoke River, Marshyhope Creek, Chester River, Sassafras River, Elk River, Northeast River, and the Patapsco River for baseline Hickory Shad data in order to determine restoration opportunities. In 2018 after two years of surveying possible target tributaries, it was determined that stocking would focus on the Patapsco River. The decision was partially based on survey results, historical data, angler access, nursery habitat and suitable habitat for Hickory Shad spawning.

The Patapsco River also had two other factors that were taken into consideration. The removal of Bloede Dam, the lowest dam on the Patapsco River, was scheduled to be completed by 2019. The removal of the Bloede Dam would open up miles of potential spawning habitat for returning Hickory Shad adults. Secondly, the Patapsco River Shad and Herring Restoration Project grant funded by the MPA ended when funding expired. The Maryland Department of Natural Resources had been providing juvenile Hickory Shad for this short term project since 2013 (Table 4). Restoring Hickory Shad populations takes many years, and it was determined that it would be advantageous to continue the project efforts, given the head start the river had received.

The Patapsco River Shad and Herring Restoration Project was part of a compensatory mitigation package designed around the Masonville Project. The Masonville Project is a Dredged Material Containment Facility (DMCF) located in Baltimore Harbor. The Masonville Cove Environmental Education Center and a 22-hectare Conservation Area was constructed adjacent to the DMCF in 2009 as part of the mitigation. As a component of the DMCF project, the MPA was required to develop a mitigation project to offset impacts associated with filling approximately 53 hectares of open water in the Patapsco River. The USFWS MDFWCO was subcontracted to perform monitoring activities of stocking efforts, including field sampling and collections, laboratory sample preparation and interpretation, data analysis, and report writing. Hickory Shad broodstock collection for Patapsco River shad production was conducted on the

Susquehanna River in conjunction with broodstock collection for Choptank River stockings under the F-57-R grant. Grant costs were appropriately accounted for by project to ensure that charges were apportioned between the two funding sources.

In 2018, Hickory Shad larvae (915,000) were stocked at the Rt. 648 Bridge location on the Patapsco River. Hickory Shad early juveniles (85,000) were stocked at the Southwest Area Park (SWAP) boat ramp on the Patapsco River (Figure 6, Table 2). 2018 stockings are separated by event in Table 5. Historical Hickory Shad stocking production for all years by tributary is contained in Tables 6 through 10. Some larvae were previously stocked into the Patapsco River (1998-2001) to investigate fish passage issues. Additionally, excess marked larvae were stocked into the Chester River in years when the timing of culture and marking activities precluded stocking into the target tributaries. All Hickory Shad cultured and stocked since the inception of the program can be viewed in Tables 6 through 10.

Hickory Shad larval stocking numbers and early juvenile stocking numbers met project goals in 2018 (Table 2; Table 4).

2019 Sub-Project 1 – Preliminary Results – Work in Progress

Analysis of the data for 2019 is currently in progress. Adult Hickory Shad were caught by electroshocking boat on the Susquehanna River on 22 April and 24 April 2019 for broodstock collection. A total of 168 Hickory Shad were used in spawning culture tanks at Manning Hatchery. Approximately 9.54 million eggs were produced, with a fertilization rate of 46.09%, and 1,725,000 larvae and 5,000 early juveniles were stocked.

The complete analyses and summary of the data collected in 2019 to produce, mark and stock cultured Hickory Shad in the Patapsco River will appear in the next F-57-R Segment 21 Progress Report.

2018 Sub-Project 2

Objectives

Restoration stocking of Hickory Shad in the Choptank and Patapsco rivers began in 1994 and 2012, respectively. Choptank River summer juvenile seine survey commenced in 1996 and the Patapsco River summer seine surveys began in 2013. Both surveys had a goal to collect juvenile Hickory Shad to determine the success of the stocking program in each river. From 2013 to 2017, and MPA funded grant supported restoration activities in the Patapsco River and all fisheries monitoring was conducted by USFWS Maryland Fish and Wildlife Conservation Office (MDFWCO). In 2018, the Patapsco River was added to the Maryland Department of Natural Resources' Wildlife and Sport Fish Restoration grant to continue the project for stocking and assessment

Two quantifiable population variables were identified to evaluate restoration progression of juvenile Hickory Shad in the targeted rivers.

A. "Assess the contribution of hatchery-produced fish to the resident/pre-migratory stock in the Choptank River and Patapsco River."

B. "Monitor the abundance and mortality of larval and juvenile shad using marked hatchery-produced fish".

Materials and Methods

The Patapsco River was sampled with a seine 30.5 meters long, 1.2 meters deep, with 6.4mm stretch mesh. The net was deployed by hand from shore into deep water and back to shore at established seine sites. Any juvenile Hickory Shad collected from the seine were placed into plastic bags, labeled, and stored on ice. Upon return to the lab, the samples were frozen to -9°C. All bycatch species data was recorded.

Sagittal otoliths are removed from each Hickory Shad captured from the Patapsco River. Otoliths are mounted on 76.2 mm x 25.4 mm glass slides with Crystalbond 509 (Aremco Products, Ossining, NY).

Mounted otoliths are lightly ground on 600 grit silicon carbide wet sandpaper and viewed under an LED epifluorescent light at 400X magnification at 50-100 watts with a Zeiss Axioskop 20 microscope. The presence and location of an OTC mark epifluorescence is recorded. Epifluorescence is a technique in which transmitted light in the wavelength of 490-515 nm is allowed to strike the specimen. The specimen then absorbs this light energy and reflects light of a longer wavelength back through the microscope objective.

CPUE and Geometric Mean

The juvenile index is described by calculation of a catch per unit effort (CPUE). It is defined as the number of captured juvenile Hickory Shad divided by the number of seine hauls completed. Indices of relative abundance are presented as the total arithmetic mean (AM) catch per haul and geometric mean (GM) catch per haul. The GM has been adopted by the Atlantic States Marine Fisheries Commission (ASMFC) as the preferred index of relative abundance. The GM is a more precise statistical tool for handling these data because it is not as sensitive to a single large sample value. Hickory Shad, like American Shad, are schooling fish and theoretically subject to these types of captures with a large seine net. Since the inception of this project, Hickory Shad CPUE has been used to quantify indices of relative abundance. As a bridge between previous F-57-R progress reports, the 2008 report indicated AM and GM. All indices of relative abundance from 2009 on are now reported as GM only.

Mortality and Abundance Estimates

In addition to providing future broodstock, juvenile stocking is valuable as a pre-migratory stock assessment tool through use of a multiple marking technique. Hatchery stocking is also used to evaluate the efficacy of stocking different life stages and the eventual impact to the returning adult population.

There are assumptions made when using these types of estimates as described by (Ricker 1975):

- The marked fish suffer the same natural mortality as the unmarked fish.
- The marked fish are as vulnerable to capture as are the unmarked fish.
- The marked fish do not lose their mark.
- The marked fish become randomly mixed with the unmarked; or the distribution of fishing effort (in subsequent sampling) is proportional to the number of fish present in different parts of the body of water.
- All marks are recognized and reported on recovery.
- There is only a negligible amount of recruitment to the catchable population during the time of recoveries are being made.

Estimates of juvenile abundance, mortality and survival were derived from the following formulas.

Larval survival to juvenile stocking was calculated by (Ricker 1975):

$$S_1 = \frac{(R_{12})\ M_2}{(M_1)\ R_{22}}$$

$$\text{Variance } S_1 = {S_1}^2\{\left(\frac{1}{R_{12}}\right) + \left(\frac{1}{R_{22}}\right) - \left(\frac{1}{M_1}\right) - \left(\frac{1}{M_2}\right)\}$$

where M_1 is the number of fish marked at the start of the first interval (larval stocking), M_2 is the number of fish marked at the start of the second interval (early juvenile stocking), R_{12} is recaptures of larval marked fish in the second interval (after early juvenile stocking), R_{22} is recaptures of early juvenile interval marked fish in the second interval or (after early juvenile stocking), and S_1 is the survival rate of larvae during interval one (from the time of marking larvae in interval one to time of marking early juveniles in interval two).

Instantaneous mortality is derived from survival estimates and is used in conjunction with stocking data to calculate juvenile abundance:

$$Z = \frac{-\ ln\ ln\ S_1}{interval}$$

Where Z is instantaneous mortality rate and S_1 is survival rate.

Abundance of juvenile shad prior to out migration was also calculated by Chapman's modification to the Peterson estimate (Ricker 1975):

$$N = \frac{\{(C+1)(M+1)\}}{R+1}$$

where N is the population estimate, M is the number of marked fish stocked, C is the number of fish examined for tags (total captures) and R is the number of marked fish that were recaptured (larval or early juveniles).

From Ricker (1975): Calculation of 95% confidence limits based on sampling error using the number of recaptures in conjunction with Poisson distribution approximation.

Chapman's modification (1951):

$$N^* = \frac{\{(C+1)(M+1)\}}{(R+1)}$$

Where R_1 is from Pearson's formula to calculate upper and lower limits:

$$R_1 = R + 1.92 \pm 1.960\sqrt{R + 1.0}$$

Results and Discussion

Patapsco River

No juvenile Hickory Shad were collected by seine from the Patapsco River in 2018. Juvenile Hickory Shad are difficult to recapture with seine gear. Very few Hickory Shad have been captured over the years in any previous restoration work. Juveniles are generally larger in size than American Shad, well developed, and have the ability to avoid sampling gear. Until juvenile Hickory Shad are captured in sufficient numbers, calculation of geometric mean and mortality and abundance estimates are not possible. Currently, adult Hickory Shad assessment is a better indicator of restoration progress (Sub-Project 3).

2019 Sub-Project 2 - Preliminary Results - Work In Progress

No juvenile Hickory Shad were collected by seine from the Patapsco River in 2019.

2018 Sub-Project 3

Objectives

Patuxent River and Choptank River spawning ground surveys commenced in 1999 to collect adult Hickory Shad. Restoration stocking of Hickory Shad began in 1996 on these targeted rivers (Figure 7). In 2008, Patuxent River composition of wild adults indicated a stable population and wild adults exceeded 80% for three consecutive years, so hatchery stocking was suspended. The composition of wild adults in the Choptank River was also stable and exceeded 75% for three consecutive years, so hatchery stocking was suspended in 2015. The Patapsco River was considered for possible restoration in 2013 and added as a target tributary for the F-57 restoration effort in 2018 (Figure 1).

Three quantifiable population variables were identified to evaluate restoration progression and relative abundance of adult Hickory Shad spawning stocks in the targeted tributaries. A fourth objective is to evaluate the population status of Hickory Shad spawning stocks from brood source tributaries.

1) *Estimate catch-per-unit effort (CPUE) in each target river using geometric mean.*
2) *Estimate the contribution of hatchery produced fish to the adult spawning populations.*
3) *Estimate the frequency of virgin and repeat-spawning.*
4) *Monitor the viability of the Susquehanna River as a Hickory Shad brood source through analysis of virgin and repeat-spawning compositions.*

Materials and Methods

Survey Locations

Based on the stable population observed in the Patuxent and Choptank rivers, there is no longer a need to survey the rivers every year. Surveys are conducted every three years to maintain trend data.

Hickory Shad were sampled in the Patapsco River in 2018. Adult sampling was conducted by the Maryland Department of Natural Resources' Maryland Biological Stream Survey (MBSS) using a 4.2 m jon boat with a 2,000 watt generator powering a Smith-Root 1.5

KVA electrofisher in the upper, non-tidal portion of the study area, and by this project using a Smith-Root electrofishing boat SR18-E (Vancouver, WA) in the lower, tidal portion of the study area. The upper section of the river was sampled at three river reaches (Figure 8), and the lower section was sampled at two river reaches (Figure 9).

Sampling was conducted at historical Hickory Shad spawning areas described by anecdotal data and concentrated in river reaches where shad were encountered during previous sampling efforts conducted by the USFWS MDFWCO as part of the Masonville mitigation project (Table 11). The survey was accomplished with three people, one person piloting the boat and two people netting shad from the bow. The survey was sampled in an upstream to downstream direction with constant voltage applied to the entire reach. Total pedal time (s) was recorded to calculate relative abundance (CPUE). Water temperature (°C), dissolved oxygen (ppm), and conductivity (µS/cm) were obtained using a YSI Pro 2030 water quality meter (Yellow Springs, OH).

The Patapsco River sampled by this project was divided into two sections. The first section "upstream" includes the area from the wastewater treatment plant located just west of Maryland Rt. 648 to approximately 1.44 km downstream to I-895. The second section "downstream" begins 0.37 km north of I-895 and continues downstream 1.47 km to the bridge at West Patapsco Avenue.

Maryland Biological Stream Survey sampled three portions of the non-tidal freshwater region of the Patapsco River (Figure 8). Site 591 is from 200 m above Deep Run to 200 m below Stony Run, 0.63 km long. Site 592 runs from Route 1, 0.59 km downstream to the Elkridge Furnace Inn. Site 593 is in the Bloede Dam tailrace.

It is likely that shad utilize tidal freshwater areas downstream of our collection sites, but increasing river width, depth and increased conductivity reduces capture efficiency with electrofishing gear. Additionally, anecdotal evidence indicates that substantial spawning habitat and fish movement also exists upstream of currently sampled stream reaches, but sampling upstream habitat is limited by electrofishing boat access. In 2013-2017 surveys by the USFWS MDFWCO and MBSS, sufficient numbers of Hickory Shad were captured in the current sample reaches to perform analysis.

A sub-sample of 20 Hickory Shad was collected per day for age, composition and spawning attempt analysis. All other observed shad were counted to calculate CPUE. Fish collected were measured for total length (TL; mm), fork length (FL; mm) and sex was determined. Scale samples were taken for age estimation and spawning mark interpretations. Otoliths were extracted to determine hatchery origin adult composition. Shad scales were cleaned, mounted between glass slides, and age was estimated and spawning attempts were counted using a microfiche reader. Two biologists interpreted the scales independently. In cases where readers disagreed on an age estimate, a consensus age was used as the final age. Scales were aged using methods described by Cating (1953).

Catch Per Unit Effort Analysis

In an effort to standardize data collection, bracketing CPUE data began in 2011. With this methodology, sampling will begin each year before Hickory Shad return and continue until zero Hickory Shad are captured at the end of the spawning run. This will ensure that biologists sampled the area throughout the entire duration of the spawning run and will reduce sampling bias.

The GM has been adopted by this project as the preferred index of relative abundance to evaluate stock status and restoration progress. The GM is calculated from the $\log_e(x+1)$ transformation, where x is the number of Hickory Shad encountered per shock time (min). Beginning and ending zeros are omitted from the analysis. One is added to all catches in order to transform zero catches, because the log of zero does not exist (Ricker 1975). The one is then removed to accurately represent the GM data. Since the $\log_e$-transformation stabilizes the variance of catches (Richards 1992), the GM estimate is more precise than the arithmetic mean (AM), and is not as sensitive to a single large sample value. The GM is almost always lower than the AM (Ricker 1975). The GM was calculated independently for each of the five sample sites.

Origin Composition (Hatchery vs. Wild)

The percentage of hatchery versus wild origin Hickory Shad adults sampled on the spawning grounds provides insight into the impact to the adult population of stocking larval and juvenile shad. The presence of adult hatchery origin fish on the spawning grounds early in restoration may stimulate annual natural production. As restoration efforts continue, a transition from a high proportion of hatchery origin fish to a high proportion of wild fish year after year indicates natural reproduction events leading to successful recruitment to the spawning population. Observation of changes from mostly hatchery contribution to a population dominated by wild origin adults is a good indication of whether or not hatchery contributions are having a substantial effect upon the adult spawning stock population.

Virgin and Repeat-Spawning Compositions

A third estimator uses analysis of virgin and repeat-spawning compositions. The number of spawning migrations by an individual fish can be determined through examination of Hickory Shad scales. The composition of virgin and repeat-spawn frequency observed on the spawning grounds provides additional insight into population stability and recruitment. Low levels of virgin-spawners may indicate problems associated with juvenile recruitment to the adult stock, or poor spawning success. Conversely, a high level of virgin-spawners usually indicates successful recruitment of individual year classes to the adult spawning stock. A substantial contribution of virgin-spawners and several repeat-spawning classes utilizing the spawning grounds year after year is indicative of a stable spawning stock.

Results and Discussion

Patapsco River Adult Hickory Shad Spawning Stock

Sixty-one Hickory Shad were observed on the Patapsco River in 2018, but only 36 were collected. Hickory Shad were collected for length, sex, otolith and scale analysis. Twenty-one Hickory Shad were collected by MBSS in the upstream reaches of the Patapsco River from 21 February to 24 May when water temperature ranged from 3.4°C to 22.2°C. In the lower reaches, this project collected 15 Hickory Shad from 12 April to 31 May when water temperature ranged from 9.1°C to 22.0°C (Figure 10).

Patapsco River Hickory Shad CPUE

The mean relative abundance (GM) for Hickory Shad on the Patapsco River was calculated for each of the samples sites independently (Table 12). Site 592, which was sampled by the MBSS, had the highest GM at 0.49 fish/min. The uppermost MBSS site (593) and the downstream site sampled by this project both indicated a GM of 0.00 fish/min.

Patapsco River Hickory Shad Origin Composition (Hatchery vs. Wild)

In 2018, 36 Hickory Shad were captured in the electrofishing survey on the Patapsco River. Origin was determined on 34 of the samples by examining OTC marks. The samples comprised one larval hatchery origin (3%), 16 early juvenile hatchery origin (47%) and 17 wild origin (50%) Hickory Shad (Table 13). The two samples where origin could not be determined was due to the sample being lost or destroyed during processing.

Patapsco River Hickory Shad Virgin and Repeat-Spawning Compositions

Thirty-six Hickory Shad scale samples were collected in 2018. All of the 36 scale samples collected were successfully analyzed and used to determine the annual spawning attempt composition. The 2018 sample population consisted of 31% virgin spawners, 19% second-time spawners, and 50% third-time spawners (Table 14).

Patapsco River Hickory Shad Spawning Stock Discussion

Survey results for 2018 indicate that the Patapsco River supports a wild Hickory Shad population and hatchery inputs are supplementing the stock. Hatchery and wild origin adult Hickory Shad were present in both the virgin and second-time spawning groups. Hatchery origin fish with more than two spawning attempts would not be encountered based on when stocking was initiated. Ideally, wild populations would indicate additional spawning groups returning, however, sample sizes were small, and these spawning groups may have been missed. The presence of wild virgin spawners indicates this population is sustaining itself at a very low level.

Hatchery stocking of early juveniles appears to be successful. Of the adult Hickory Shad successfully examined for OTC marks, 16 of 17 (94%) were of early juvenile origin. This suggests that larvae stocked into the Patapsco River did not successfully recruit to the 2018 sample population. Spring rains in this urban system cause the gauge height and river flow to rise and fall rapidly during the period when larvae are being stocked. It is likely they are being flushed from the system during heavy flows. Project biologists may search for alternative stocking locations that provide protection from high spring flows.

The absence of Hickory Shad at both the upper and lowermost sample narrows the location where Hickory Shad spawning may be occurring on the Patapsco River (Figure 8). The GM at Site 592 (middle MBSS site) was four times as high as Site 591 (lower MBSS site) and the upstream site by this project (Figure 9). It is likely that fish caught in these areas are transient, and spawning is occurring near Site 592 (Table 12). In addition, beginning zeros were not obtained for Hickory Shad in the 2018 sample period. Due to the high capture rate during the first sampling week, it is likely that a large portion of the Hickory Shad run was missed, which caused the 2018 GM to be underestimated. A more robust analysis of GM will occur when the dataset is larger.

2019 Sub-Project 3 – Preliminary Results – Work in Progress

Electrofishing surveys were conducted on the Patapsco River for 12 weeks from 21 March to 10 June 2019. Thirty adult Hickory Shad were captured and retained for scale age and otolith analysis. A complete analysis of CPUE, origin composition and repeat spawning analysis will be available in the 2020 F-57-R progress report.

Susquehanna River (Brood Source) Hickory Shad Spawning Stock

The Susquehanna River Hickory Shad population has been the sole brood source for restoration efforts (Figure 2). This population declined along with other Chesapeake Bay Hickory Shad stocks during the 1970s, but experienced resurgence during the 1990s as a dominant year class appeared in 1993. This year class provided a sufficient source of broodstock adults when they began to return as spawning adults in 1996 (Minkkinen et.al. 2000). Strong and stable Hickory Shad spawning runs have occurred since 1996, and have been sufficient to support broodstock collection and a large catch-and-release recreational fishery.

Analysis of spawning attempt data indicate a spawning population that naturally recruits several spawning year classes to the spawning grounds annually (Table 15). In 2018, 40 Hickory Shad scale samples were collected for spawning composition analysis. All samples were analyzed successfully. A consistent pattern has occurred for several years, as 4+ substantial spawning year classes recruit every year.

Reduced stocking goals results in fewer sampling days (two days in 2018) needed to collect broodstock. As a result, fewer samples are being collected than in the past, which potentially results in less robust age and repeat spawn analysis. In future years, additional samples should be collected daily to increase sample size and minimize the potential for missed year classes.

2018 Overall Restoration Progress:

Patapsco River

The Patapsco River is in the early stages of the restoration effort. It is encouraging to see wild origin adults (50%) returning to the spawning population in 2018. Hatchery stocked early juveniles comprised (47%) of the adult population, suggesting the new pond harvesting and stocking techniques are benefitting early juvenile survival. Most of the wild fish are from a remnant population that existed prior to the initiation of stocking, since their estimated ages average 4 years old. Repeat spawning analyses in 2018 indicate that 31% of returning adults are virgin spawners, with 19% returning for the second time and 50% returning a third time. The composition of the adult population will be monitored in the future until the wild component of the adult population changes from mostly hatchery to mostly wild origin population. At that point we may be able to say that the Hickory Shad population in the Patapsco River is restored to a point that further stocking is not needed. Any further conclusions made about the spawning stock of Hickory Shad on the Patapsco River would be premature. More inferences can be made when a larger more robust dataset exists.

Patuxent River

In 2012, the Patuxent River was determined to demonstrate a static pattern of relative abundance, which could indicate a population at carrying capacity. The last year of hatchery stocking was 2007. Despite the healthy spawning populations that occurred prior to 2009, it appears that the repeat spawning population has been in a steady decline based on sample size. Fewer fish are returning to spawn more than twice, which is an indicator of poor spawning population health. However the Patuxent River is susceptible to runoff and Secchi disk disc attenuation coefficient readings near zero during the adult migration. Small sample size (n=26) could be a contributing factor to the reduced number of repeat spawning attempts detected. If sample size and repeat spawning attempts continue to decline through the next sample period (2020), project biologists will determine if the Patuxent River Hickory Shad population will require future hatchery inputs.

Choptank River

Beginning in 2010, all of the project restoration effort was focused on the Choptank River. This was to permit maximum stocking impact and more detailed analysis of assessment activities. The lack of Hickory Shad juvenile recaptures hinders a complete assessment of the restoration effort, but trend data using adult electrofishing surveys demonstrated a stable population of adult Hickory Shad. Several year-classes of repeat spawners were observed from a robust sample size (n=137) in 2017. While not statistically significant, the GM was considerably higher than in 2014, which was the last year the survey was conducted on the Choptank River. This is a positive indicator of a stable population. Choptank River adults will be sampled in 2020.

Future comparison of the relative abundance estimate (CPUE) trends will be invaluable to evaluate the success of the restoration progress on both the Patuxent and Choptank rivers. the Maryland Department of Natural Resources staff will continue to survey these rivers on a three-year rotational basis. Success of this program relies on future generations continuing to naturally spawn in these rivers when hatchery inputs no longer supplement natural populations.

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Table 1. *Maryland Department of Natural Resources 2018 Hickory Shad broodstock collection data.*

Date	Females	Males
4/25/2018	37	55
4/26/2018	71	92

Table 2. *Maryland Department of Natural Resources 2018 Hickory Shad stocking goals for the Patapsco River.*

Stocking phase	Stocking goal	Amount Stocked
Larvae	500,000	915,000
Early Juvenile	75,000	85,000

Table 3. *Maryland Department of Natural Resources 2018 tank spawn Hickory Shad egg production.*

Total eggs produced	7,178,510
Overall fertilization	41.79%
Fertilized eggs produced	3,000,605
Total larvae stocked	915,000
Total juveniles stocked	85,000

Table 4. *Historical stocking summary for larval and juvenile Hickory Shad in the Patapsco River since the inception of Hickory Shad restoration efforts (including fish passage work 1997-2004).*

Patapsco River Hickory Shad

Year	Larvae	Early Juveniles
1997	1,695,000	0
1998	250,000	0
1999	825,700	0
2000	500,000	0
2001	0	0
2002	0	0
2003	0	0
2004	542,000	0
2005	0	0
2006	0	0
2007	0	0
2008	0	0
2009	0	0
2010	0	0
2011	0	0
2012	0	0
2013	561,000	77,000
2014	538,500	73,000
2015	1,045,000	82,500
2016	580,000	35,000
2017	750,000	82,000
2018	915,000	85,000
Total	**8,202,200**	**434,500**

Table 5. *Maryland Department of Natural Resources 2018 Hickory Shad stocking events in the Patapsco River.*

Date	Life stage	Mark	Number
5/3/2018	Larvae	Day 1	465,000
5/3/2018	Larvae	Day 1	100,000
5/5/2018	Larvae	Day 1	250,000
5/6/2018	Larvae	Day 1	100,000
5/30/2018	Early Juvenile	Day 1, 3	65,000
6/7/2018	Early Juvenile	Day 1, 3	20,000

Table 6. *Maryland Department of Natural Resources annual Hickory Shad stocking production in all tributaries, 1996-2018. The juvenile category includes fish stocked as early juveniles (late June) and late juveniles (July/August)*

Year	Larvae Stocked	Juvenile Stocked
1996	871,000	20,622
1997	10,689,000	35,982
1998	11,466,000	31,979
1999	16,825,000	4,601
2000	13,869,000	66,944
2001	4,999,679	93,645
2002	2,675,000	119,606
2003	2,310,000	118,551
2004	9,757,000	130,332
2005	4,410,000	403,000
2006	4,095,000	382,000
2007	1,700,000	211,500
2008	6,238,581	364,500
2009	2,737,636	242,000
2010	4,260,000	117,000
2011	4,399,000	143,750
2012	2,503,203	380,100
2013	560,000	471,000
2014	520,000	240,500
2015	1,045,000	82,500
2016	795,000	35,000
2017	750,000	87,000
2018	915,000	85,000
Total	**108,390,099**	**3,867,112**

Table 7. *Historical stocking summary for larval and juvenile Hickory Shad in the Choptank River since the inception of the restoration effort (1996-2014).*

Choptank River Hickory Shad

Year	Larvae	Early Juveniles	Late Juveniles
1996	125,000	0	7,963
1997	5,571,000	0	0
1998	4,991,000	0	0
1999	8,719,000	0	0
2000	5,634,000	0	38,508
2001	1,158,800	0	19,907
2002	1,050,000	25,000	0
2003	700,000	34,500	0
2004	4,090,000	42,350	0
2005	2,430,000	177,000	0
2006	1,770,000	220,000	0
2007	1,080,000	149,500	0
2008	3,028,000	225,000	0
2009	1,953,000	120,000	0
2010	4,260,000	117,000	0
2011	4,399,000	143,750	0
2012	2,503,000	380,100	0
2013	560,000	471,000	0
2014	520,000	240,500	0
Total	**54,541,800**	**2,345,700**	**66,378**

Table 8. *Stocking summary for larval and juvenile Hickory Shad in Marshyhope Creek, a previous target tributary, since the inception of the restoration effort (2001-2009).*

Marshyhope Creek Hickory Shad

Year	Larvae	Early Juveniles	Late Juveniles
2001	1,230,000	0	0
2002	300,000	26,000	17,247
2003	500,000	17,000	18,551
2004	500,000	14,000	5,482
2005	370,000	66,000	0
2006	750,000	70,000	0
2007	100,000	25,500	0
2008	2,209,000	140,000	0
2009	785,000	122,000	0
Total	**6,744,000**	**480,500**	**41,280**

Table 9. *Historical stocking summary for larval and juvenile Hickory Shad in the Nanticoke River since the inception of the restoration effort (2001-2006).*

Nanticoke River Hickory Shad

Year	Larvae	Early Juveniles	Late Juveniles
2001	1,230,000	0	0
2002	975,000	0	11,058
2003	625,000	11,500	0
2004	1,000,000	0	0
2005	450,000	40,000	0
2006	225,000	22,000	0
Total	**4,505,000**	**73,500**	**11,058**

Table 10. *Historical stocking summary for larval and juvenile Hickory Shad in the Chester River since the inception of the restoration effort (2003-2008).*

Chester River Hickory Shad

Year	Larvae
2003	90,000
2004	200,000
2005	0
2006	0
2007	0
2008	602,000
Total	**892,000**

Table 11. *Maryland Department of Natural Resources and Maryland Biological Stream Survey 2018 adult Hickory Shad electrofishing survey starting and ending coordinates for the Patapsco River. *Site 593 has no ending coordinates because it only occurs in the Bloede Dam tailrace.*

River	Starting latitude/longitude	Ending latitude/longitude
Patapsco River "upstream"	39.224738° N -076.640593° W	39.225127° N -076.628076° W
Patapsco River "downstream"	39.229178° N -076.625855° W	39.239058° N -076.616996° W
Patapsco River Site 591	39.212930° N -076.699898° W	39.216105° N -076.696884° W
Patapsco River Site 592	39.216443° N -076.705498° W	39.213893° N -076.702091° W
Patapsco River Site 593	39.246999° N -076.760885° W	*

Table 12. *Geometric Mean (GM) calculated at all sites samples by the Maryland Department of Natural Resources and Maryland Biological Stream Survey on the Patapsco River in 2018.*

	Site				
Year	***Upstream***	***Downstream***	***591***	***592***	***593***
2018	0.12	0.00	0.11	0.38	0.00

Table 13. *2018 Maryland Department of Natural Resources and Maryland Biological Stream Survey Hickory Shad adults caught on the Patapsco River.*

Date	Sample #	Sex	Age	Spawn Marks	Origin
4/26/2018	2018-0001	Male	4	1	Wild
4/26/2018	2018-0002	Male	5	2	Early Juvenile
4/26/2018	2018-0003	Male	3	0	Early Juvenile
4/26/2018	2018-0004	Male	4	1	Early Juvenile
4/26/2018	2018-0005	Male	3	0	Wild
4/26/2018	2018-0006	Female	3	0	Early Juvenile
4/26/2018	2018-0007	Male	5	2	Early Juvenile
4/26/2018	2018-0008	Male	3	0	Early Juvenile
4/26/2018	2018-0009	Male	3	0	Wild
4/26/2018	2018-0010	Female	5	0	No Sample
5/3/2018	2018-0011	Male	5	2	Early Juvenile
5/3/2018	2018-0012	Male	3	0	Wild
5/3/2018	2018-0013	Female	4	0	Wild
5/3/2018	2018-0014	Male	3	0	Wild
5/3/2018	2018-0015	Female	5	2	Early Juvenile
5/3/2018	2018-0016	Female	5	2	Wild
5/3/2018	2018-0017	Male	4	1	Wild
5/3/2018	2018-0018	Female	6	2	Wild
5/3/2018	2018-0019	Female	5	2	Early Juvenile
5/15/2018	2018-0020	Female	5	1	Wild
5/15/2018	2018-0021	Male	4	1	Wild
4/12/2018	2018-0102	Female	5	2	Larvae
4/12/2018	2018-0103	Male	5	2	Early Juvenile
4/12/2018	2018-0104	Male	5	2	Wild
4/12/2018	2018-0105	Female	5	2	Early Juvenile
4/12/2018	2018-0106	Female	5	2	Early Juvenile
4/12/2018	2018-0107	Male	4	1	Early Juvenile
4/12/2018	2018-0108	Male	5	2	Early Juvenile
4/12/2018	2018-0109	Female	6	2	Wild
4/12/2018	2018-0110	Male	6	2	No Sample
4/12/2018	2018-0111	Female	5	2	Early Juvenile
4/12/2018	2018-0112	Male	5	1	Wild
4/12/2018	2018-0113	Male	5	0	Wild
4/17/2018	2018-0116	Female	5	2	Early Juvenile
5/3/2018	2018-0164	Female	6	2	Wild
5/9/2018	2018-0171	Male	3	0	Wild

Table 14. *2018 Maryland Department of Natural Resources electrofishing survey Patapsco River Hickory Shad spawning attempt composition for 2018.*

		Spawning Attempts					
Sample Year	**Sample Size (n)**	**1 Virgin Spawners**	**2**	**3**	**4**	**5**	**6**
2018	36	11 (31%)	7 (19%)	18 (50%)	0 (0%)	0 (0%)	0 (0%)

Table 15. *2018 Maryland Department of Natural Resources brood fish collections. Susquehanna River Hickory Shad spawning attempt composition for sample years 2004-17.*

		Spawning Attempts						
Sample year	**Sample Size (n)**	**1 Virgin Spawners**	**2**	**3**	**4**	**5**	**6**	**7**
2004	80	25 (31%)	11 (14%)	17 (21%)	20 (25%)	6 (8%)	1 (1%)	
2005	80	14 (18%)	10 (13%)	22 (28%)	25 (31%)	7 (9%)	2 (3%)	
2006	178	58 (33%)	29 (16%)	48 (27%)	29 (16%)	11 (6%)	3 (2%)	
2007	139	29 (21%)	26 (19%)	40 (29%)	23 (17%)	17 (12%)	3 (2%)	1 (1%)
2008	149	24 (16%)	37 (25%)	50 (34%)	29 (19%)	7 (5%)	2 (1%)	
2009	118	13 (11%)	19 (16%)	54 (46%)	20 (17%)	11 (9%)	1 (1%)	
2010	240	59 (25%)	72 (30%)	73 (30%)	25 (10%)	10 (4%)		1 (0.4%)
2011	216	67 (31%)	65 (30%)	57 (26%)	19 (9%)	6 (3%)	2 (1%)	
2012	200	72 (36%)	64 (32%)	45 (23%)	15 (8%)	4 (2%)		
2013	193	73 (38%)	62 (32%)	41 (21%)	15 (8%)	2 (1%)		
2014	100	41 (41%)	19 (19%)	30 (30%)	10 (10%)			
2015	113	46 (41%)	41 (36%)	21 (19%)	5 (4%)			
2016	120	35 (29%)	38 (32%)	36 (30%)	10 (8%)	1 (1%)		
2017	60	15	19	20	5			

		(25%)	(32%)	(33%)	(8%)			
2018	40	19 (48%)	13 (33%)	5 (13%)	3 (8%)			

Figure 1. *Maryland Department of Natural Resources 2018 target tributary for shad restoration project.*

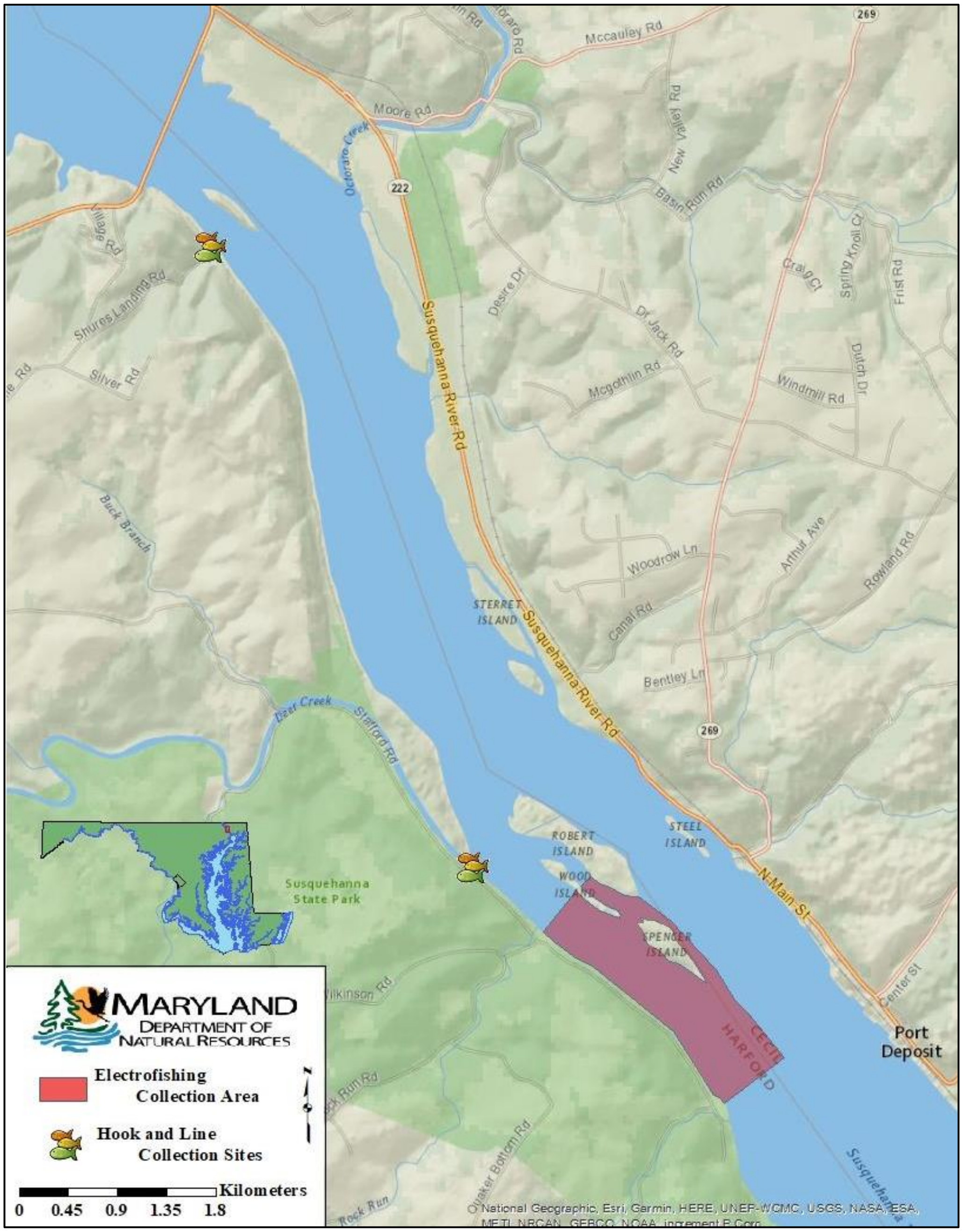

Figure 2. *Maryland Department of Natural Resources 2018 Hickory Shad broodstock collection site on the Susquehanna River.*

Figure 3. *Maryland Department of Natural Resources participating fish culture facilities in the restoration project. GenOn Energy Chalk Point is a power company that cultures fish for the restoration effort. The University of Maryland Center for Environmental Science Aquaculture and Restoration Ecology Laboratory (UMCES-AREL)*

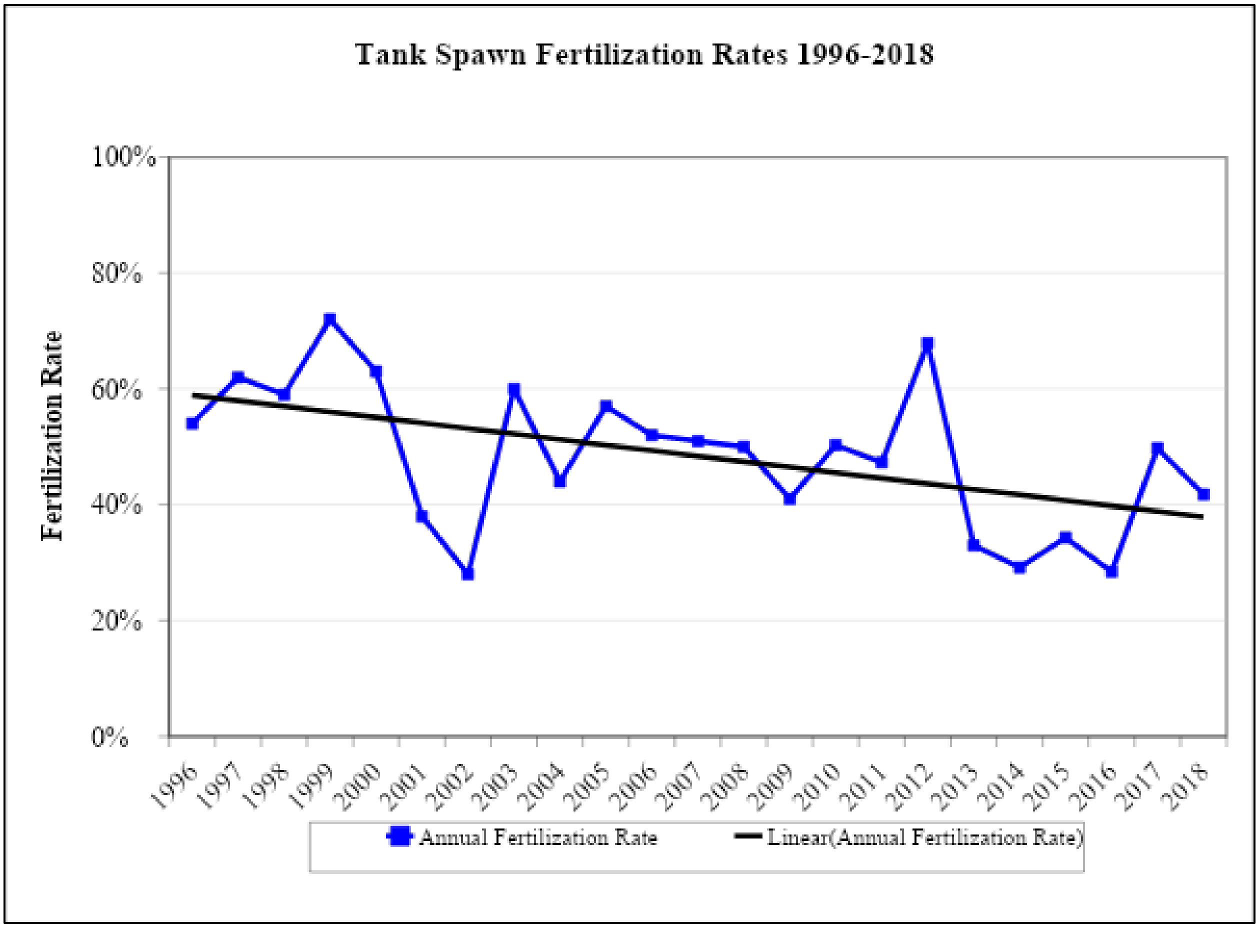

Figure 4. *Maryland Department of Natural Resources tank spawn fertilization rates for Hickory Shad, 1996-2018.*

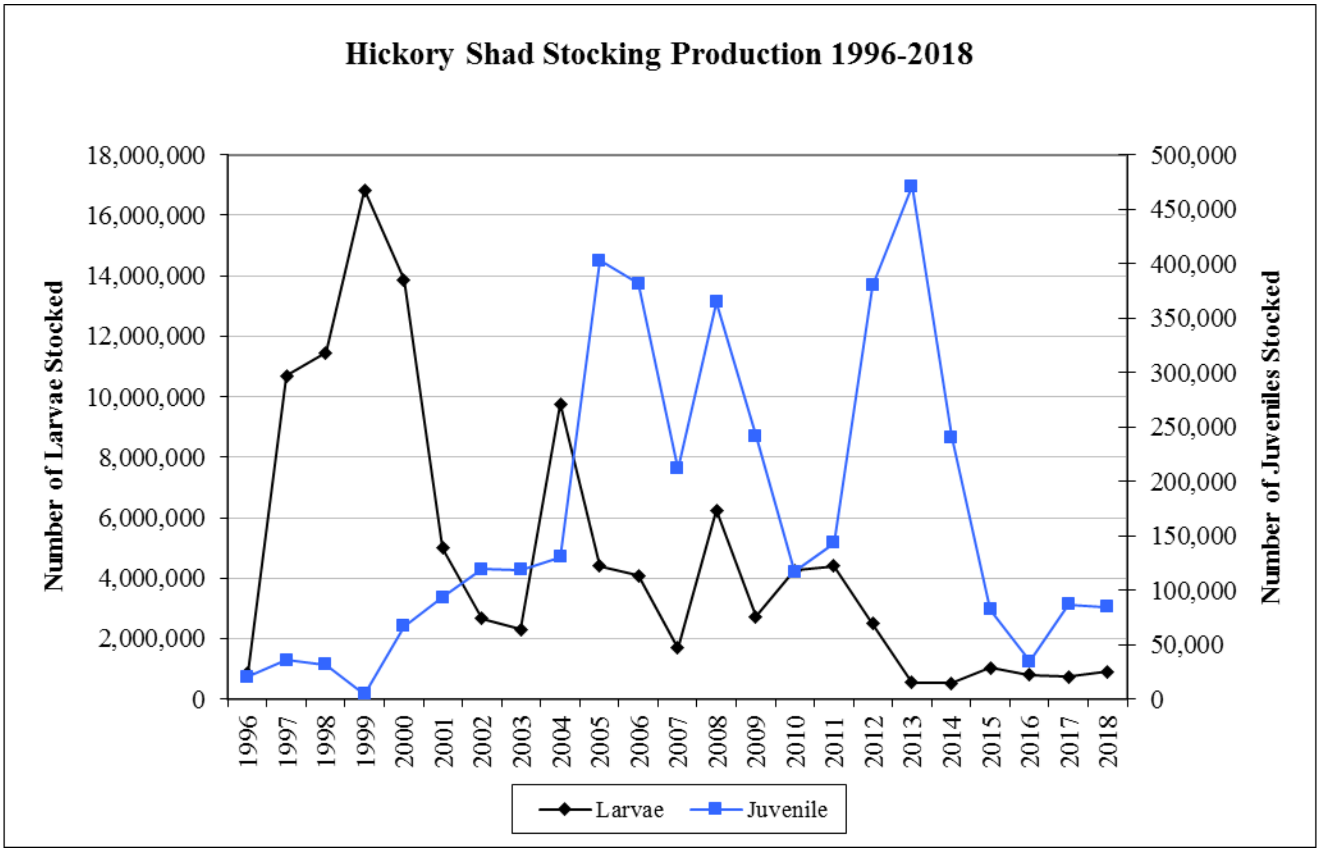

Figure 5. *Maryland Department of Natural Resources annual Hickory Shad stocking production in all tributaries, 1996-2018. The juvenile category includes fish stocked as early juveniles (late June) and late juveniles (July/August). Fish were stocked into the Choptank River, Patuxent River, Nanticoke River, Patapsco River, and Chester River.*

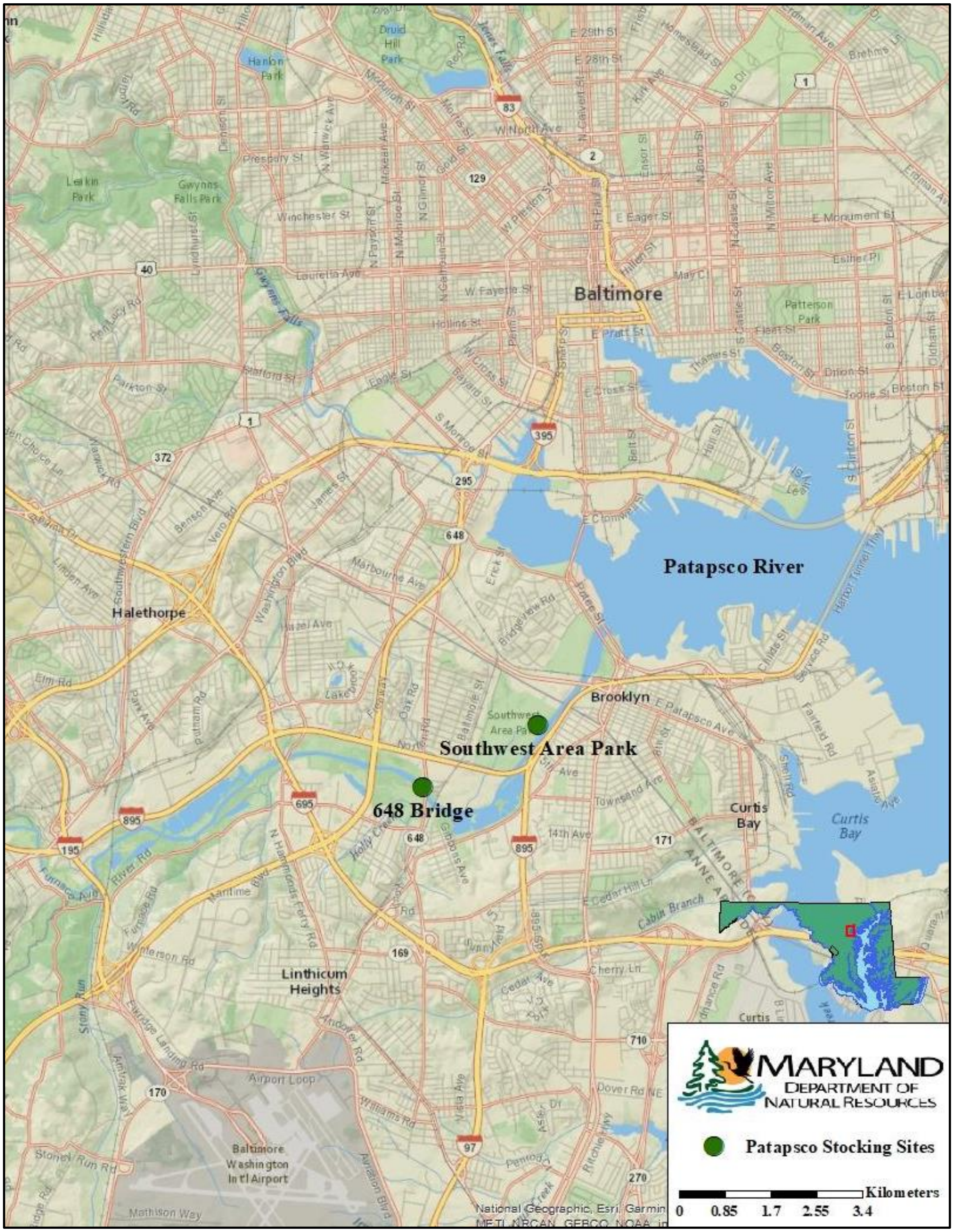

Figure 6. *Maryland Department of Natural Resources Patapsco River stocking sites in 2018.*

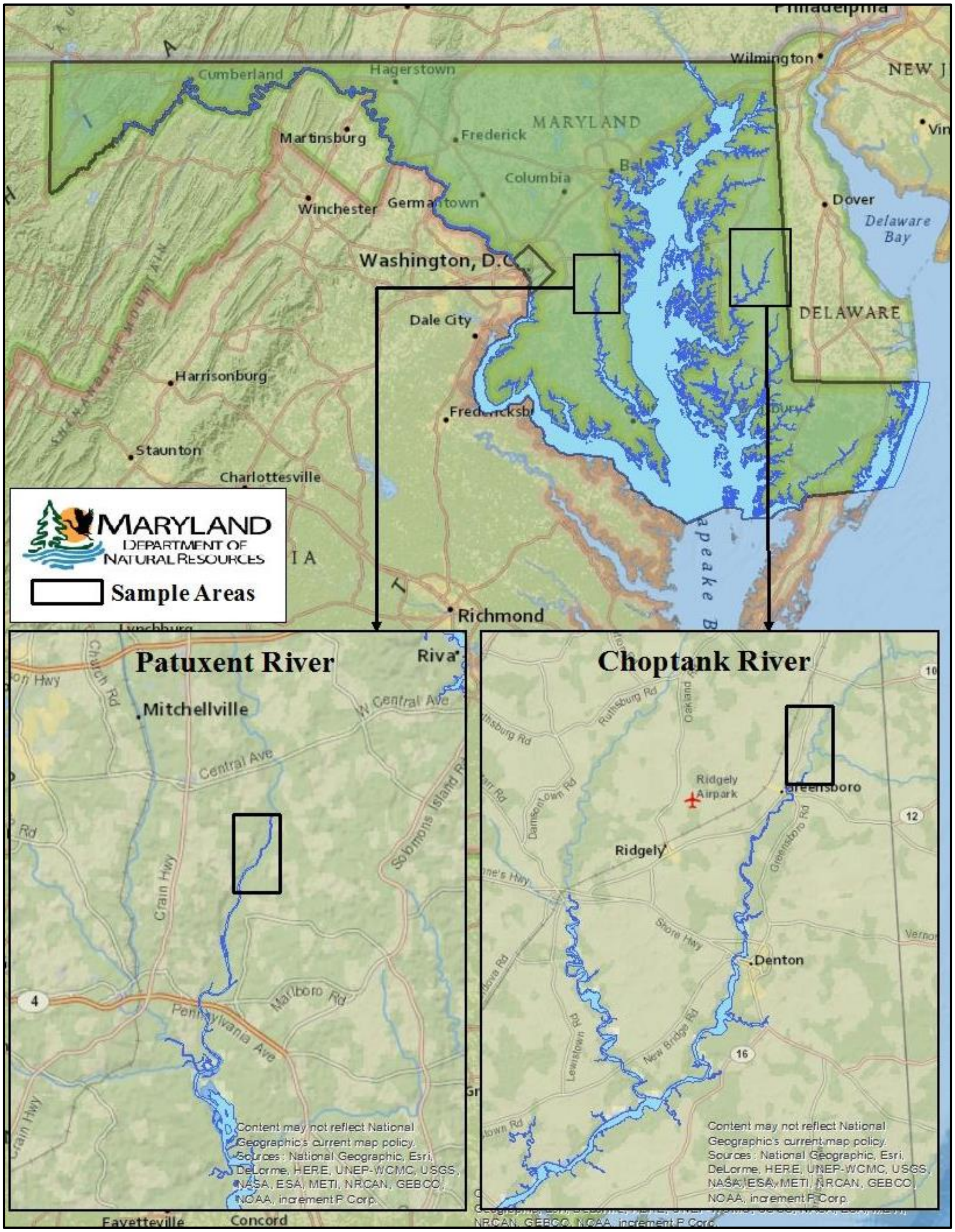

Figure 7. *Maryland Department of Natural Resources adult Hickory Shad electrofishing survey starting and ending locations sampled on the Patuxent River and Choptank River.*

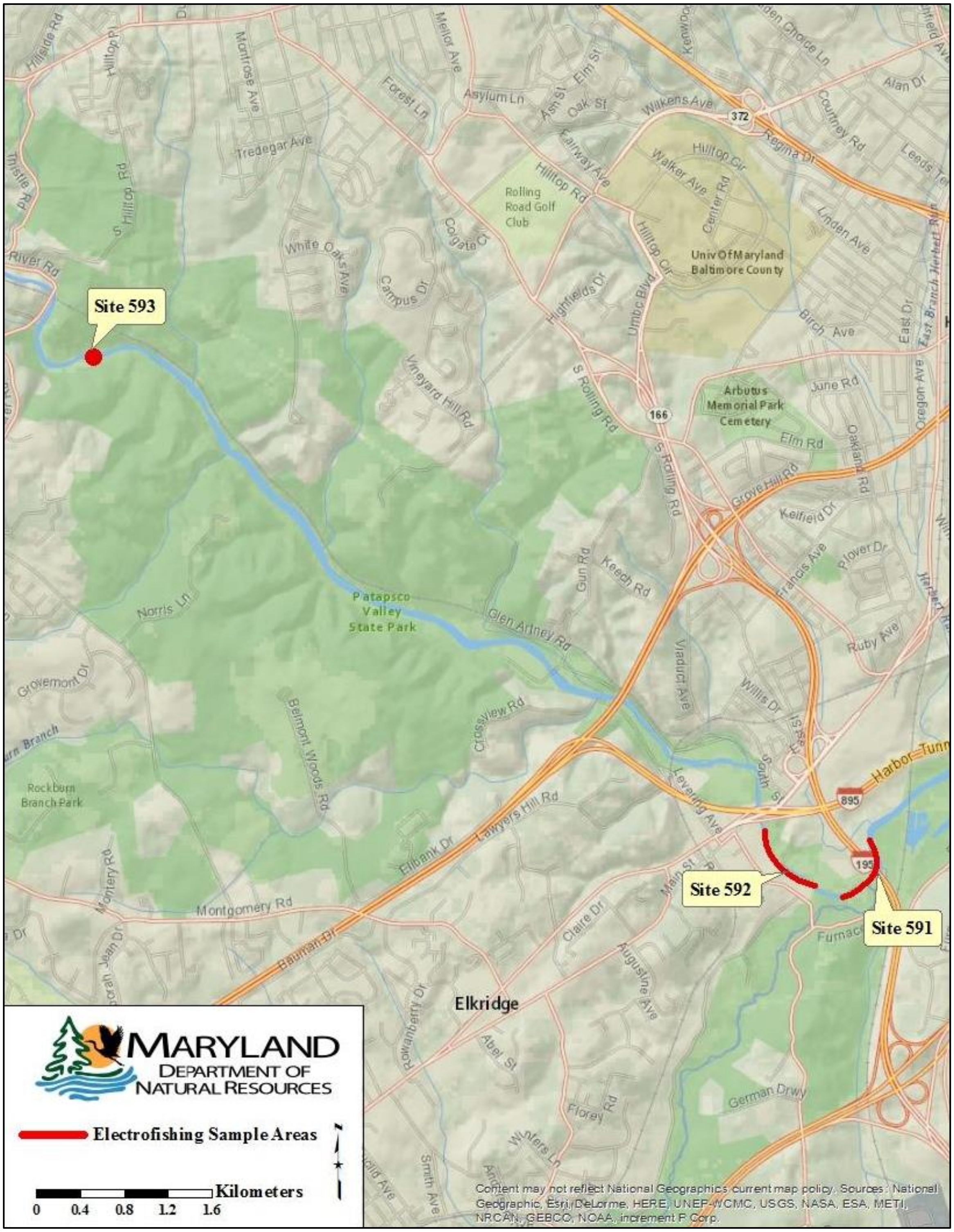

Figure 8. *Maryland Biological Stream Survey 2018 electrofishing survey sites on the upper non-tidal freshwater portion of the Patapsco River.*

Figure 9. *Maryland Department of Natural Resources 2018 electrofishing survey sites on the lower tidal freshwater portion of the Patapsco River.*

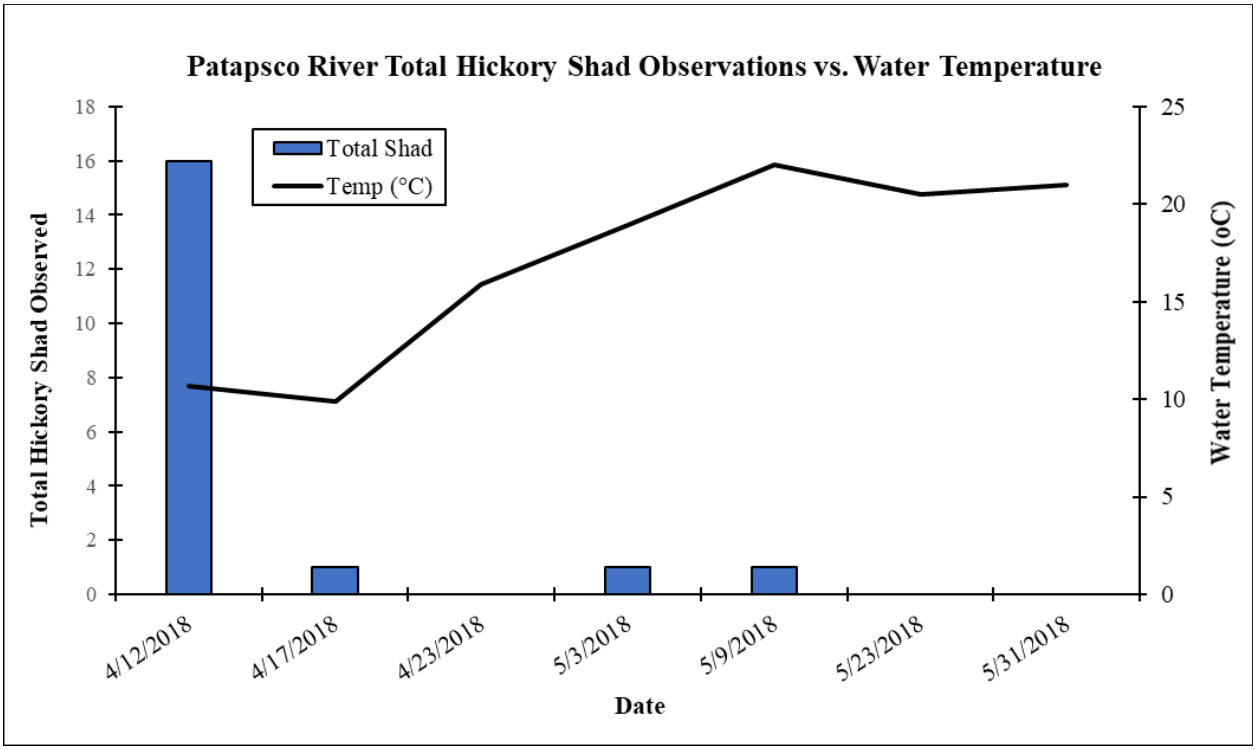

Figure 10. *2018 Maryland Department of Natural Resources electrofishing collections and observations of adult Hickory Shad in the Patapsco River*.