Executive Summary 2019
Maryland Portion Job VI
(**POPULATION ASSESSMENT OF AMERICAN AND HICKORY SHAD IN THE UPPER CHESAPEAKE BAY):**

The Maryland Department of Natural Resources conducts annual surveys targeting adult American shad and hickory shad in the upper Chesapeake Bay (Susquehanna River). American shad are angled from the Conowingo Dam tailrace, measured, sexed, tagged, and released. Indices of abundance are derived from these hook and line data and from combined fish lift data. Recreational creel, logbook, and online surveys also provide information on American and hickory shad abundance. The Maryland Department of Natural Resources Fish Health and Hatcheries Program provides additional hickory shad data from broodstock collection in the lower Susquehanna River. In 2019, 53 American shad were angled from the Susquehanna River below Conowingo dam from 15 April through 30 May 2019, and 44 were successfully scale-aged. Males were present in age groups four through six and females were present in age groups four through eight. The 2014 year-class (age five) was the most abundant for males and the 2013 year-class (age six) was most abundant for females. The trend in arcsine-transformed percentage of repeat spawning American shad continues to increase from historic lows in the 1980s. Estimates of abundance for American Shad in the lower Susquehanna River were relatively consistent with recent years in 2019 and are well below time series peak values observed in the early 2000's. Hickory shad age structure in the lower Susquehanna River has truncated in recent years, with fewer fish over the age of 6. However, in 2019, an age-eight hickory shad was collected for the first time since 2011. Males were present in age groups three through seven and females were present in age groups three through eight. The 2015 year-class (age 4) was the most abundant year class for both males and females. The trend in arcsine-transformed percentage of repeat spawning hickory shad has decreased since monitoring began in 2004.

POPULATION ASSESSMENT OF AMERICAN AND HICKORY SHAD IN THE UPPER CHESAPEAKE BAY

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INTRODUCTION

The Maryland Department of Natural Resources has conducted annual surveys targeting adult American shad and hickory shad in the upper Chesapeake Bay (Susquehanna River) since 1980 and 1998, respectively. The purpose of these surveys is to define stock characterizations, including sex and age composition, spawning history, relative abundance and mortality.

After closure of the American shad recreational and commercial fisheries in 1980, stocks increased significantly in the lower Susquehanna River until 2001; after this year, American shad abundance generally decreased until 2007. In recent years, population estimates have been low and variable. Hickory shad abundance has declined from historic levels, but the lower Susquehanna River basin hosts the greatest densities of hickory shad in Maryland (Richardson et al. 2009).

METHODS

Data Collection

Adult American shad were angled by Maryland Department of Natural Resources staff from the Conowingo Dam tailrace on the lower Susquehanna River two to four times per week from 15 April through 30 May 2019 (Figure 1). Two or three rods were fished simultaneously; each rod was rigged with two shad darts and lead weight was added when required to achieve proper depth. American shad were sexed (by expression of gonadal products), total length (TL) and fork length (FL) were measured to the nearest millimeter (mm), and scales were removed below the insertion of the dorsal fin for ageing and spawning history analysis. Fish in good physical condition, with the exception of spent or post-spawn fish, were tagged with Floy tags (color-coded to identify the year tagged) and released. A Maryland Department of Natural Resources hat was awarded for returned tags.

Normandeau Associates, Inc. was responsible for observing and/or collecting American shad at the Conowingo Dam fish lifts. American shad collected in the East Fish Lift (EFL) were deposited into a trough, directed past a 1.2 m x 3.0 m counting window, identified to species and counted by experienced technicians. American shad captured from the West Fish Lift (WFL) were counted and either used for experiments (e.g. hatchery broodstock, oxytetracycline [OTC] analysis, sacrificed for otolith extraction) or returned to the tailrace. For both lifts, tags were used to identify American shad captured in the Maryland Department of Natural Resources hook and line survey in the current and previous years.

A non-random roving creel survey provided both American and hickory shad catch and effort data from recreational anglers in the Conowingo Dam tailrace, concurrent with the Maryland Department of Natural Resources American shad hook and line survey. Stream bank anglers were interviewed about shad catch that day and hours spent fishing. A voluntary logbook survey also provided location, catch, and hours fished for American and hickory shad for each participating angler. Beginning in 2014, anglers could participate in the logbook survey by recording fishing trips through the Volunteer Angler Shad Survey on the Maryland Department of Natural Resources' website:

http://dnr.maryland.gov/Fisheries/Pages/survey/index.aspx

Due to the low number of hickory shad typically observed by this project, the Maryland Department of Natural Resources Fish Health and Hatcheries Program provided additional hickory shad data (2004-2019) from their broodstock collection. Hickory shad were collected in in the Susquehanna River near Lapidum, MD for hatchery broodstock and were sub-sampled for age, repeat spawning marks, sex, length (mm FL), and weight (g). In 2004 and 2005, fish were collected using hook and line fishing in both the Susquehanna River and its tributary, Deer Creek. More recently fish have been collected primarily by electrofishing, supplemented by hook and line fishing (2006-2019). Scale samples were taken from the first 20 fish per day for age determination.

Ageing Protocol

American shad scales were aged following established protocols (Elzey et al., 2015) as recommended by Atlantic states' ageing experts (ASMFC 2013). A minimum of four scales per sample were cleaned, mounted between two glass slides and read for age and spawning history using a Micron 385 microfiche reader. The scale edge was counted as an annuli due to the assumption that each fish had completed a full year's growth at the time of capture. Ages were not assigned to regenerated scales or to scales that were difficult to read. Repeat spawning marks were counted on all American shad scales during ageing.

In 2019, American shad age determination was done independently by three readers. If the age and spawning mark estimates did not fully match between at least two readers, the scale was jointly re-read as a group. If a consensus age or spawning mark could not be determined, the sample was eliminated from further analysis.

During the 2018 ageing process, biologists noted that American shad scales with faint or non-distinct annuli produced different age estimates when analyzed on different microfiche readers. Most notably, a Bell and Howell MT-609 microfiche frequently used in past seasons had the tendency to produce younger ages for such scales. Beginning in 2018, efforts were made for all scales to be read on comparable equipment to eliminate any potential bias towards younger ages.

Hickory shad scales from the Susquehanna River were aged by the Maryland Department of Natural Resources Fish Health and Hatcheries Program. Two readers determined the age of each sample independently, and jointly analyzed the sample if necessary to reach a consensus. Hickory shad scales were aged using methods described by Cating (1953).

Data Analysis

Sex and Age Composition

Male-female ratios were derived for American shad collected from the Susquehanna River below Conowingo Dam. Hickory shad male-female ratios were derived from data provided by the

Maryland Department of Natural Resources Fish Health and Hatcheries Program's broodstock collection on the Susquehanna River. The percentages of repeat spawners by species (sexes combined) were arcsine-transformed (in degrees) before looking for linear trends over time. For all statistics, significance was determined at $\alpha = 0.05$.

Relative Abundance

Using catch-per-unit-effort (CPUE) as a measure of relative abundance is a common practice in fisheries science. A geometric mean CPUE (GM CPUE) was calculated as the average LN (CPUE + 1) for each fishing/sampling day, transformed back to the original scale for most of the surveys analyzed by this project. A combined lift GM CPUE was calculated using the total number of adult fish lifted per hour at the EFL and WFL at Conowingo Dam. Catch-per-angler-hour (CPAH) for American and hickory shad angled in the Susquehanna River basin was calculated from the data collected by the logbook survey (paper logbook data and online angler reports were combined) and roving creel survey.

Catch-per-unit-effort is one of the most commonly used measures of relative abundance, but inter-annual fluctuations may be due to factors other than a change in abundance (e.g. temperature, flow, turbidity, etc.). Index standardization is a method that attempts to remove the influence that other factors may have on CPUE. Standardization is done by fitting statistical models to catch and effort data that incorporate the relationship of the covariates with catch (Maunder and Punt 2004). Due to the non-linear relationship of catch of American shad by hook and line in the Conowingo Dam tailrace, a generalized additive model (GAM) was used to standardize this index of abundance using relevant covariates. A GAM allows for smoothing functions as the link function between catch and covariates. The covariates explored for the model included: surface water temperature (°C), river flow in thousands of cubic feet per second (USGS

Water Resources station 01578310 Susquehanna River at Conowingo, MD; USGS 2019) and day of the year. Variance Inflation Factors (VIFs) were used to assess collinearity to determine which covariates to incorporate in the model (Zuur et al 2009). Several statistical distributions for the response variable were investigated and model selection was determined based on the model with dispersion closest to one, the highest deviance explained and the lowest Akaike Information Criterion (AIC). All models were run in RStudio (R Core Team 2015) utilizing the mgcv package (Wood 2011).

Population Estimates

Chapman's modification of the Petersen statistic was used to estimate abundance of American shad in the Conowingo Dam tailrace (Chapman 1951):

$$N = (C+1)(M+1)/(R+1)$$

where N is the relative population estimate, C is the number of fish examined for tags at the EFL after the annual tagging effort began, M is the number of fish tagged minus 3% tag loss, and R is the number of tagged fish recaptured at the EFL, excluding recapture of previous years' tags. Prior to 2001, C was the number of fish examined for tags at both the EFL and WFL, and R was the number of tagged fish recaptured at both lifts excluding recaps of previous years' tags. Protocol changed in 2001 where some American shad captured at the WFL were returned to the tailrace. Observations at the WFL were omitted to avoid double counting beginning in 2001. Calculation of 95% confidence limits (N^*) for the Petersen statistic were based on sampling error associated with recaptures in conjunction with Poisson distribution approximation (Ricker 1975):

$$N^* = (C+1)(M+1)/(R^t+1)$$

where

$$R^t = (R+1.92) \pm (1.96\sqrt{(R+1)})$$

Overestimation of abundance by the Petersen statistic (due to low recapture rates) necessitated the additional use of a biomass surplus production model (SPM; MacCall 2002, Weinrich et al. 2008):

$$N_t = N_{t-1} + [r\, N_{t-1}(1-(N_{t-1}/ K))] - C_{t-1}$$

where N_t is the population (numbers) in year t, N_{t-1} is the population (numbers) in the previous year, r is the intrinsic rate of population increase, K is the maximum population size, and C_{t-1} is losses associated with upstream and downstream fish passage and ocean bycatch in the previous year (equivalent to catch in SPM). Fish passage mortalities are calculated as 100% of adult American shad emigrating back through Holtwood Dam (N_{Holt}) and 25% for adult American shad emigrating back through the Conowingo Dam (N_{Cono}). Annual ocean bycatch estimates (L) are provided by the Northeast Fishery Science Center and are extrapolated from data generated by the Northeast Fisheries Observer Program. A bycatch coefficient (b) represents the estimated proportion of total American shad bycatch that is specific to the Susquehanna stock. Therefore losses in the previous year are calculated as:

$$C_{t-1} = N_{Holt} + 0.25 * (N_{Cono} - N_{Holt}) + b * L$$

Model parameters were estimated using the evolutionary procedure in the Solver application of Microsoft Excel. The model was fit to indices of relative abundance for American shad in Conowingo dam tailrace. Assumptions included: 1) accurate estimates of adult American shad turbine mortality, 2) the indices of relative abundance chosen for the fitting procedure were proportional to true abundance, 3) any losses from the stock were associated with mortality (no straying occurs), and 4) environmental influences were constant.

The SPM requires starting values for the initial population (B_0) in 1985, a carrying capacity estimate (K), an estimate of the intrinsic rate of growth (r) and a bycatch coefficient (b). For model development in 2019 the starting values were as follows: B_0 was set as 7,876, which was the Petersen statistic for 1985, K was set as 10,089,920 fish, which was ten times the highest Petersen estimate of the time series, r was set as 0.5, and b was set at 0.005. These starting values were adjusted by the model during the fitting procedure, which was constrained to search within r = 0.01 to 1.0, K = 1 million to 30 million fish, B_0 = 5,000 to 100,000 fish and b = 0.0 to 0.05. Additionally, the model was constrained to produce population estimates greater than the total number of American shad lifted or removed by the Conowingo Dam fish lifts. The model was run multiple times varying the indices of abundance. The run with the lowest sum of squares, lowest AICc, and reasonable parameter estimates was chosen.

Mortality

Chapman-Robson methodology (1960) was used to estimate total instantaneous mortalities (Z) of adult American shad and hickory shad from all systems surveyed where age data were available. Age composition data was used in the analysis, where the first age-at-full recruitment was the age with the highest frequency and estimates were only made when data was available from three or more age-classes (including first fully-recruited age). Therefore Z was calculated as:

$$Z = -1 * ln (T / (N + T - 1))$$

where T is calculated as:

$$T = 0 * n_0 + 1 * n_1 + 2 * n_2 + \ldots A * n_A$$

where n_0 is the number of fish at the first fully recruited age, n_1 is the number of fish one year older than first fully recruited age, and this is carried out for all age groups greater than the first fully recruited age. The Chapman-Robson estimate is less biased than traditional catch curve methods (Dunn et al. 2002) and was recommended for use by peer reviewers of the most recent river herring benchmark stock assessment (ASMFC 2012).

Juvenile Abundance

The Maryland Department of Natural Resources Estuarine Juvenile Finfish Seine Survey (EJFS) provided juvenile indices (geometric mean catch per haul) for American shad in the upper Chesapeake Bay and baywide, among other river systems in Maryland. Hickory shad juvenile indices are not developed by this survey due to small sample sizes.

RESULTS

American Shad

Sex and Age Composition

The male-female ratio of adult American shad captured by hook and line from the Conowingo Dam tailrace in 2019 was 1:0.69. Of the 53 fish sampled by this gear, 44 were successfully scale-aged (Table 1). Males were present in age groups four through six and females were found in age groups four through eight. The 2014 year-class (age five) was the most abundant for males (46.2%) and the 2013 year-class (age six) was most abundant for females (38.9%; Table 1). Forty-two percent of males and 72% of females were repeat spawners (Figure 2). The arcsine-transformed proportion of these repeat spawners (sexes combined) significantly increased over the time series (1984-2019; $r^2 = 0.67$, $P < 0.001$; Figure 3). Analysis by PFBC of 283 American shad otoliths collected from the WFL at Conowingo Dam showed that 68% were wild fish and 32% were hatchery-produced fish in 2019; these percentages were similar to those from 2018 where 61% were wild fish and 39% were hatchery-produced fish.

Relative Abundance

Hook and line sampling at the Conowingo Dam occurred for 12 days in 2019. A record low total of 53 adult American shad were encountered by the gear; all of these fish were captured by Maryland Department of Natural Resources staff from a boat. No shore sampling occurred in 2019. Peak catch by hook and line (14 fish) occurred on 28 May 2019 at a surface water temperature of 20°C. This was later than peak catch in many other years and considerably later than peak catch at the Conowingo EFL. Maryland Department of Natural Resources staff tagged 43 (90%) of the sampled fish. No American shad tag recaptures were reported by recreational or commercial fishermen in 2019.

The Conowingo EFL operated for 46 days between 1 April and 31 May 2019. Of the 4,787 American shad that passed at the EFL, 73% (3,472 fish) passed between 1 May and 12 May 2019. Peak passage was on 3 May; 1,314 American shad were recorded on this date. Only one floy tagged American shad was counted at the EFL and was identified as being tagged in 2019 (Table 3).

The Conowingo WFL operated for 20 days between 1 May and 31 May 2019. The 390 captured American shad were retained for hatchery operations, sacrificed for otolith collection or returned alive to the tailrace. Peak capture from the WFL was on 1 May, when 132 American shad were collected. No tagged American shad were recaptured by the WFL in 2019 (Table 3).

The various model configurations explored for developing a GAM for the hook and line index and model performance are summarized in Table 4. Due to observed collinearity of day of the year with surface water temperature, day of the year was removed from the model. Since GAMs are highly sensitive to collinearity, a more stringent VIF cutoff may be necessary. For example, Booth et al. (1994) suggest a cutoff of 1.5. This more stringent cutoff would lead to the removal of the flow variable, leaving only surface water temperature. For this reason, models that included temperature and flow, and models that just included temperature were explored.

Overall, models that included both temperature and flow explained more deviance, but only slightly more than models with just temperature, which indicated temperature had a greater effect on catch than flow (Table 4). Of the models that included both temperature and flow, results indicated that both models 2 and 3 were acceptable. Model 2 was slightly over-dispersed, while model 3 was slightly under-dispersed. Slight under-dispersal is generally preferable to being over-dispersed (Laura Lee, North Carolina Department of Environment and Natural Resources, pers. comm.), so model 3 was chosen as the best fit model.

The best fit model utilized temperature and flow as explanatory variables linked to catch using cubic spline regression, year as a factor level, with the natural logarithm of effort as an offset, and a negative binomial response distribution. This model showed no obvious signs of pattern in the residuals (Figure 4). The standardized annual hook and line CPUE exhibits substantial year to year variability and peaked in 1998 (Figure 5). Relative abundance has generally declined since that time and reached its lowest level in 2019.

The Conowingo Dam fish lifts provide another opportunity to measure American shad relative abundance. Both counts of fish lifted at the Conowingo Dam and the combined lift GM CPUE mirrored the hook and line index for years when both the East and West Fish lifts were operating (Figure 6). Like all measures of relative abundance, there are caveats to accepting these indices as indicative of true abundance. Lift efficiency and river flows affected run counts at Conowingo Dam, while the number and frequency of lifts affected GM CPUE. All three indices measured in this region of the Susquehanna River showed a broad general trend that abundance was low in the 1990s, increased to a peak in the early 2000s, and then declined to low levels of abundance (Figures 5, 6).

Thirty-two anglers targeting shad were interviewed over six days during the creel survey at the Conowingo Dam Tailrace. Catch per angler hour of American shad increased in 2019 relative to 2018 (Table 5), but has no significant trend over the time series (2001-2019; $r^2 = 0.15$, $P = 0.11$).

Two anglers returned paper logbooks in 2019. Additionally, six anglers participated online by recording their trips through Maryland Department of Natural Resources' Volunteer Angler Shad Survey. American shad CPAH calculated from shad logbook data combined with data from Maryland Department of Natural Resources' Volunteer Angler Shad Survey increased marginally in 2019 relative to 2018 (Table 6). Online angler data was included in the CPAH calculation beginning in 2014. The logbook CPAH estimate of adult American shad relative abundance peaked in 2001, but has exhibited no significant trend over the time series (2001-2019; $r^2 = 0.14$, $P = 0.11$; Table 6).

Population Estimates

The Petersen statistic estimated 102,813 American shad in the Conowingo Dam tailrace in 2019 with an upper confidence limit of 179,095 fish and a lower confidence limit of 30,728 fish (Figure 7). The SPM with the lowest sum of squares that best represented American shad in the Conowingo Dam tailrace utilized the CPUE from the hook and line survey. This run estimated a population of 57,606 American shad in the Conowingo Dam tailrace in 2019 and produced realistic estimates of the model parameters r, K and B_0 ($r = 0.247$, $K = 23{,}426{,}254$, $B_0 = 71{,}109$; Figure 7).

Despite differences between the Petersen estimate and SPM, the overall population trends derived from each population model were fairly similar (Figure 7). Specifically, the SPM showed an increasing population size from the beginning of the time series to a peak in 2000, followed by a rapid decline through 2007. Petersen estimates followed a similar pattern if the high levels of uncertainty in 2004 and 2008 (due to low recapture rates) are considered. The SPM exhibited retrospective bias in the terminal years of the time series, falsely suggesting a slight increase in population size since 2013. American shad abundance has likely been relatively stable at low levels in recent years, though some decline may still be occurring.

Mortality

The Conowingo Dam tailrace total instantaneous mortality estimate (Z) for American shad, sexes combined, in 2019 was 0.87; there was no significant trend in mortality estimates from the Conowingo Dam over the time series (1984-2019; $r^2 = 0.00$, $P = 0.80$; Figure 8). Sex-specific mortality estimates were not calculated in many years, including 2019, due to either limited sample size or failure to exhibit two ages past the age of full recruitment, a requirement of the Chapman-Robson age-based method.

Juvenile Abundance

The 2019 juvenile abundance index of American shad provided by the EJFS exhibited a minor decline in the Upper Chesapeake Bay (Figure 9). While the Susquehanna River is likely the dominant producer of juvenile American shad in the Upper Chesapeake Bay, it should be noted that other small rivers in Maryland (North East, Elk, and Sassafras Rivers) that provide a minor amount of spawning habitat may contribute to this population as well.

Hickory Shad

Sex and Age Composition

In the Susquehanna River, 191 hickory shad were sampled by the broodstock collection survey in 2019. The male-female ratio was 1:1.29. Of the total fish captured by this survey, 98 were successfully aged. Males were present in age groups three through seven and females were present in age groups three through eight (Table 7). The 2015 year-class (age 4) was the most abundant year class for both males (42.5%) and females (46.6%, Table 7). In 2019, an age eight hickory shad was observed for the first time since 2011 (Table 8). The arcsine-transformed proportion of repeat spawners (sexes combined) decreased significantly over the time series (2004-2019; $r^2 = 0.41$, $P = 0.008$; Figure 10).

Relative Abundance

Hickory shad relative abundance in the lower Susquehanna River basin, expressed as CPAH, derived from logbook data was 3.84 in 2019; this was a decrease from the 2018 value (6.16, Table 9). Hickory shad logbook CPAH varied without trend over the time series (2001-2019; $r^2 = 0.02$, $P = 0.60$). Hickory shad CPAH from the creel survey was 2.14 in 2019, which was an increase from the 2018 value (1.99, Table 10). Creel survey CPAH varied without trend over the time series (2001-2019; $r^2 = 0.10$, $P = 0.21$).

Mortality

Total instantaneous hickory shad mortality, sexes combined, in the Susquehanna River was estimated as Z = 0.85, which was a decrease from 2018 (Z = 1.12). Mortality has increased over the time series (2004-2019; $r^2 = 0.34$, $P = 0.02$; Figure 11). Sex-specific mortality estimates were not calculated due to limited sample sizes in most years of the survey.

DISCUSSION

American Shad

American shad are historically one of the most important exploited fish species in North America, but the stock has drastically declined due to the loss of habitat, overfishing, ocean bycatch, stream blockages, pollution, and exposure to invasive predators. American shad restoration in upper Chesapeake Bay began in the 1970s with the building of fish lifts and the stocking of juvenile American shad. Maryland closed the commercial and recreational American shad fisheries in 1980, and the ocean intercept fishery closed in 2005. While the American shad adult stock has shown some improvement in select river systems, the 2020 ASMFC stock assessment indicated that most stocks have not recovered and populations remain near historic lows (ASMFC 2020).

The population size of American shad in the lower Susquehanna basin was relatively stable over the past ten years, although at a much lower level than the peak observed in 2000, and compared to historical abundance. This follows a period (2001-2007) when calculated indices of relative abundance generally decreased (including the hook and line CPUE, lift CPUE, logbook CPAH and creel CPAH).

The Petersen estimate and SPM results were both useful techniques for providing estimates of American shad abundance at Conowingo Dam. Both models indicate that the population is depleted and likely near historic lows. The apparent increase in population in recent years (2013-2019) according to the SPM is due to retrospective bias. In reality, the abundance of American shad in the Susquehanna River is stable or in slight decline. The SPM likely underestimates American shad abundance, while the Petersen statistic likely overestimates the population, especially in years of low recapture rates of tagged fish. Trends, rather than the actual numbers, produced by the models should be emphasized when assessing the American shad population at the Conowingo Dam tailrace. Recovery of this population is limited by the available spawning habitat below Conowingo Dam and stocking success. Relicensing of Conowingo Dam is anticipated in 2021. Stipulations of the settlement agreement between Exelon Generation Co LLC and the Maryland Department of the Environment should improve fish passage and contribute to rebuilding anadromous fish stocks in the Susquehanna River.

Calculated indices of abundance for the lower Susquehanna River exhibited varying trends in 2019. While the hook and line CPUE declined to the lowest level on record for the survey, both the recreational creel and logbook survey CPUE increased relative to 2018. The Conowingo lift CPUE (east and west fish lifts combined) decreased relative to 2018, and approached the time series minimum observed in 2014; the total number of American shad captured by the lifts was the lowest on record. All indices remain well below peak CPUE observed in the late 1990's and early 2000's. Susquehanna River American shad continue to be significantly impacted.

Peak capture of American shad in the Conowingo Dam tailrace by hook and line occurred over three weeks later than peak passage at both the East and West Fish Lifts. However, peak capture by hook and line was only 14 fish in 2019, which is substantially lower than in other years. Due to high river flows, the dam consistently operated at full generation and was frequently under spill conditions, both of which may impede or eliminate hook and line fishing opportunities. Peak hook and line capture in 2019 coincided with a brief period of decreased river flow, which likely attributed to increased angling success. Surface water temperature during peak capture by hook and line (20°C) was slightly above the optimum migration temperature (17-19°C; Leggett and Whitney 1972) but still within commonly observed migration temperature values. Peak passage at the East Fish Lift (15.6°C) was below the optimum migration temperature range (Leggett and Whitney 1972). Additionally, water temperatures at peak capture both by hook and line and at the East Fish Lift were within the optimal temperature range for spawning (14-20°C; Stier and Crance 1985). Efficient and timely passage of American shad at Conowingo Dam is important to ensure migration and spawning occurs at the appropriate temperatures and in the appropriate habitats.

Ageing American shad using scales is common practice, as it is the only non-lethal ageing structure for this fish. However, many researchers have called into question the accuracy of scale ageing (ASMFC 2020). Ageing other hard structures, such as otoliths, produces higher age agreement between readers compared to scales (Duffy et al. 2012), but ageing from otoliths sacrifices repeat spawning information. We will remain consistent with historical ageing methods until alternative ageing structures or techniques can be implemented in our lab.

The percent of repeat spawning American shad below the Conowingo Dam increased over time. The percent of repeat spawners was usually less than 10% in the Conowingo Dam tailrace throughout the 1980s (Weinrich et al. 1982). In contrast, 55% of aged American shad at the Conowingo Dam were repeat spawners in 2019, and, on average, 47% of aged fish were repeat spawners over the past five years. Similar estimates of repeat spawning were observed in recent years for American shad collected from Virginia rivers (Hilton et al., 2019), and from the Potomac

River which is unimpeded by dam construction within the natural migration range of anadromous fishes. The average percent of repeat spawners from the Potomac River was 17% in the 1950s (Walburg and Sykes 1957), but was 65% in 2019 (Bourdon and Jarzynski, 2019). Increased repeat spawning in these river systems may indicate increased survival of adult fish. This could be due to decreased bycatch in Atlantic Ocean fisheries, increased abundance leading to more fish reaching older ages, reductions in natural mortality, and/or reader bias. Additional river systems along the Atlantic coast that had increasing trends in repeat spawners included the Merrimack River (1999-2005; ASMFC 2007), the Nanticoke River (1988-2019; Bourdon and Jarzynski, 2019) and the James Rivers (2000-2002; Olney et al., 2003).

Juvenile American shad indices decreased marginally baywide and in the upper Chesapeake Bay in 2019. However, indices for both of these systems remain above average and are considerably higher than indices observed during the period of minimal juvenile production from late 1970's through the mid 1990's.

Hickory Shad

Hickory shad stocks have drastically declined due to habitat loss, overfishing, stream blockages and pollution. A statewide moratorium on the harvest of hickory shad in Maryland waters was implemented in 1981 and is still in effect today.

Adult hickory shad are difficult to capture due to their aversion to fishery independent (fish lifts) and dependent (pound and fyke net) gears. Very few hickory shad were historically observed using the EFL in the Susquehanna River. A notable exception was in 2011 when 20 hickory shad were counted at the EFL viewing window. Despite the traditionally low number of hickory shad observed passing the Conowingo Dam, Deer Creek (a tributary to the Susquehanna River downstream of Conowingo Dam) has the greatest densities of hickory shad in Maryland

(Richardson et al. 2009). Nearly half (46%) of all hickory shad reported in statewide logbook and volunteer angler surveys were captured in Deer Creek or at the confluence of Deer Creek with the Susquehanna River.

Prior to 2012, hickory shad age structure was relatively consistent, with a wide range of ages and a high percentage of older fish. Age structure has truncated since that time, although a single age-eight fish was present in 2019, the first time a fish over the age of seven has been observed since 2011. Richardson et. al (2004) found ninety percent of hickory shad from upper Chesapeake Bay had spawned by age four, and this stock generally consisted of few virgin fish. However, the percentage of repeat spawning fish captured has decreased significantly over the time series and reached its lowest value in 2019. Fewer older fish combined with a smaller proportion of repeat spawners may indicate poor year classes and/or an increase in mortality at older ages.

Estimates of Z are primarily attributed to M because only a catch and release fishery exists for hickory shad in Maryland. Hickory shad ocean bycatch is minimized compared to the other alosines because both mature adults and immature sub-adults migrate and overwinter closer to the coast (ASMFC 2009). This is confirmed by the fact that few hickory shad are observed portside as bycatch in the ocean small-mesh fisheries (Matthew Cieri, Maine Dep. Marine Res., pers. comm.).

Adult hickory shad may spawn up to six weeks before American shad (late March to late April versus late April to early June), and juvenile hickory shad reach a larger size earlier in the summer. Because of their larger size, ability to avoid gear, and preference for deeper water, sampling for juvenile hickory shad from mid-summer through fall is generally unsuccessful (Richardson et al. 2009). These juveniles also exhibit the same negative phototaxis as the adults, migrating to deeper, darker water away from the shallow beaches sampled by haul seines.

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Table 1. Number of adult American shad and repeat spawners by sex and age sampled from the Conowingo Dam tailrace in 2019.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
4	7	0	4	0	11	0
5	12	6	3	2	15	8
6	7	5	7	7	14	12
7	0	0	3	3	3	3
8	0	0	1	1	1	1
Totals	26	11	18	13	44	24
Percent Repeats	42.3%		72.2%		54.5%	

Table 2. Proportion at age of American shad, sexes combined, angled from the Conowingo Dam tailrace, 1982-2019. * indicates years where not all fish were aged and an age-length key was subsequently used to assign ages.

Year	N	Age							
		2	3	4	5	6	7	8	9
1982	73	0.00	0.25	0.63	0.12	0.00	0.00	0.00	0.00
1983	9	0.00	0.00	0.11	0.89	0.00	0.00	0.00	0.00
1984	124	0.00	0.24	0.36	0.26	0.11	0.02	0.00	0.00
1985	174	0.00	0.13	0.48	0.28	0.10	0.01	0.00	0.00
1986	425	0.00	0.24	0.53	0.22	0.01	0.00	0.00	0.00
1987	386	0.00	0.17	0.49	0.33	0.01	0.00	0.00	0.00
1988	252	0.01	0.25	0.49	0.21	0.03	0.00	0.00	0.00
1989	269	0.00	0.17	0.43	0.32	0.07	0.00	0.00	0.00
1990	305	0.00	0.05	0.45	0.39	0.09	0.01	0.00	0.00
1991	347	0.00	0.02	0.19	0.49	0.27	0.02	0.00	0.00
1992	371	0.00	0.05	0.16	0.48	0.22	0.08	0.00	0.00
1993	233	0.00	0.03	0.36	0.36	0.21	0.04	0.00	0.00
1994	435	0.00	0.03	0.33	0.50	0.12	0.02	0.00	0.00
1995*	620	0.00	0.02	0.25	0.52	0.19	0.01	0.00	0.00
1996*	446	0.00	0.06	0.34	0.36	0.22	0.02	0.00	0.00
1997*	606	0.00	0.10	0.42	0.33	0.12	0.02	0.00	0.00
1998	308	0.00	0.03	0.44	0.38	0.11	0.02	0.00	0.00
1999*	821	0.00	0.09	0.44	0.39	0.07	0.00	0.00	0.00
2000*	737	0.00	0.01	0.52	0.41	0.05	0.01	0.00	0.00
2001*	969	0.00	0.04	0.27	0.48	0.20	0.02	0.00	0.00
2002*	800	0.00	0.02	0.20	0.37	0.29	0.12	0.01	0.00
2003	781	0.00	0.02	0.29	0.38	0.22	0.08	0.00	0.01
2004	386	0.00	0.02	0.21	0.52	0.22	0.03	0.00	0.00
2005	385	0.00	0.02	0.26	0.31	0.32	0.09	0.01	0.00

2006	338	0.00	0.05	0.46	0.35	0.07	0.04	0.02	0.00
2007	449	0.00	0.04	0.36	0.38	0.20	0.01	0.01	0.00
2008	161	0.00	0.04	0.48	0.36	0.11	0.01	0.00	0.01
2009	622	0.00	0.03	0.59	0.30	0.08	0.01	0.00	0.00
2010	437	0.00	0.03	0.43	0.43	0.10	0.01	0.00	0.00
2011	172	0.00	0.00	0.19	0.52	0.27	0.02	0.00	0.00
2012	177	0.00	0.03	0.18	0.34	0.32	0.13	0.01	0.00
2013	297	0.00	0.00	0.05	0.30	0.33	0.24	0.06	0.02
2014	428	0.00	0.01	0.13	0.43	0.35	0.08	0.00	0.00
2015	279	0.00	0.08	0.29	0.45	0.15	0.03	0.00	0.00
2016	366	0.00	0.01	0.15	0.59	0.23	0.02	0.00	0.00
2017	264	0.00	0.05	0.33	0.52	0.10	0.00	0.00	0.00
2018	160	0.00	0.03	0.14	0.52	0.28	0.03	0.01	0.00
2019	44	0.00	0.00	0.25	0.34	0.32	0.07	0.02	0.00

Table 3. Number of recaptured American shad in 2019 at the Conowingo Dam East and West Fish Lifts.

East Lift			West Lift		
Tag Color	Year Tagged	Number Recaptured	Tag Color	Year Tagged	Number Recaptured
Green	2019	1	Green	2019	0

Table 4. The six generalized additive model (GAM) configurations and performance statistics explored for standardizing the hook and line catch per unit effort index, 1987-2019.

Model Number	Cofactor(s)	Response Variable Distribution	N	Effective Degrees of Freedom	Deviance Explained	Dispersion	AIC
1	Temp + Flow	Poisson	481	47.63	45.50%	10.19	7095.13
2	Temp + Flow	Tweedie	481	38.74	40.80%	3.08	4026.96
3	Temp + Flow	Negative Binomial	481	38.80	39.60%	0.92	4058.02
4	Temp	Poisson	481	40.01	42.60%	10.47	7325.11
5	Temp	Tweedie	481	36.16	38.00%	3.09	4041.08
6	Temp	Negative Binomial	481	36.19	36.90%	0.91	4075.52

Table 5. Catch, effort, and catch-per-angler-hour (CPAH) of American shad from the recreational creel survey in the Susquehanna River below Conowingo Dam, 2001-2019. Due to sampling limitations, no data were available for 2011.

Year	Number of Interviews	Hours Fished for American Shad	American Shad Catch (numbers)	American Shad CPAH
2001	87	199.4	991	4.97
2002	52	85.3	291	3.41
2003	64	146.7	818	5.58
2004	95	189.3	233	1.23
2005	26	51.8	62	1.20
2006	70	210.8	305	1.45
2007	30	107.5	128	1.19
2008	16	32.5	24	0.74
2009	39	85.0	120	1.41
2010	31	50.5	112	2.22
2012	45	188.8	145	0.77
2013	52	168.8	105	0.62
2014	79	227.5	321	1.41
2015	57	153.4	272	1.77
2016	125	309.0	606	1.96
2017	73	190.5	483	2.54
2018	61	120.9	152	1.26
2019	32	62.1	163	2.62

Table 6. Catch, effort and catch-per-angler-hour (CPAH) from spring logbooks for American shad, 2001-2019. Since 2014, data from Maryland's online Volunteer Angler Shad Survey has been combined with traditional logbook data.

Year	Number of Participants	Total Reported Angler Hours	American Shad Catch (numbers)	Catch Per Angler Hour
2001	12	574.0	1,735	3.02
2002	12	516.0	1,801	3.49
2003	13	614.0	1,221	1.99
2004	17	430.5	1,033	2.40
2005	18	403.5	531	1.32
2006	19	736.5	768	1.04
2007	17	547.5	868	1.59
2008	22	750.3	1,268	1.69
2009	15	536.8	964	1.80
2010	16	488.3	865	1.77
2011	9	166.3	46	0.28
2012	5	168.5	344	2.04
2013	6	226.3	263	1.16
2014	15	232.0	467	2.01
2015	10	169.5	346	2.04
2016	9	254.0	487	1.92
2017	10	157.0	227	1.45
2018	7	249.5	242	0.97
2019	8	101.0	218	2.16

Table 7. Number of adult hickory shad and repeat spawners by sex and age sampled from the brood stock collection survey in Deer Creek (Susquehanna River tributary) in 2019.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	10	0	4	0	14	0
4	17	1	27	0	44	1
5	8	4	16	2	24	6
6	4	3	7	4	11	7
7	1	1	3	3	4	4
8	0	0	1	1	1	1
Totals	40	9	58	10	98	19
Percent Repeats	22.5%		17.2%		19.4%	

Table 8. Proportion at age of hickory shad, sexes combined, sampled from the broodstock collection survey in the Susquehanna River and Deer Creek (a lower Susquehanna tributary), 2004-2019.

Year	N	Age							
		2	3	4	5	6	7	8	9
2004	80	0.00	0.08	0.24	0.28	0.19	0.19	0.04	0.00
2005	80	0.00	0.06	0.18	0.29	0.34	0.11	0.01	0.01
2006	178	0.01	0.09	0.32	0.30	0.20	0.07	0.02	0.00
2007	139	0.00	0.07	0.24	0.34	0.21	0.12	0.02	0.01
2008	149	0.00	0.09	0.30	0.34	0.20	0.05	0.02	0.00
2009	118	0.00	0.08	0.17	0.45	0.20	0.10	0.01	0.00
2010	240	0.00	0.13	0.38	0.31	0.11	0.07	0.00	0.00
2011	216	0.00	0.30	0.30	0.27	0.09	0.03	0.01	0.00
2012	200	0.00	0.27	0.40	0.25	0.08	0.02	0.00	0.00
2013	193	0.00	0.21	0.46	0.24	0.08	0.01	0.00	0.00
2014	100	0.00	0.11	0.37	0.40	0.12	0.00	0.00	0.00
2015	113	0.01	0.30	0.43	0.20	0.05	0.00	0.00	0.00
2016	120	0.00	0.21	0.31	0.36	0.12	0.01	0.00	0.00
2017	59	0.00	0.17	0.31	0.37	0.14	0.02	0.00	0.00
2018	40	0.00	0.15	0.53	0.25	0.08	0.00	0.00	0.00
2019	98	0.00	0.14	0.45	0.25	0.11	0.04	0.01	0.00

Table 9. Catch, effort and catch-per-angler-hour (CPAH) from logbooks for hickory shad, 2001-2019. Since 2014, data from Maryland's online Volunteer Angler Shad Survey has been combined with traditional logbook data.

Year	Number of Participants	Total Reported Angler Hours	Hickory Shad Catch (numbers)	Catch Per Angler Hour
2001	12	574.0	2,665	4.64
2002	12	571.0	2,438	4.27
2003	13	631.0	3,120	4.94
2004	17	748.5	3,233	4.32
2005	18	555.5	2,098	3.78
2006	19	811.0	4,928	6.08
2007	17	590.0	3,396	5.76
2008	22	981.8	5,411	5.51
2009	15	573.8	1,936	3.37
2010	16	615.0	1,943	3.16
2011	9	235.3	1,794	7.62
2012	5	194.5	836	4.30
2013	6	246.3	1,656	6.72
2014	15	237.0	1,036	4.37
2015	10	194.5	401	2.06
2016	9	319.0	1,270	3.98
2017	10	188.0	570	3.03
2018	7	237.5	1,462	6.16
2019	8	129.0	495	3.84

Table 10. Catch, effort, and catch-per-angler-hour (CPAH) of hickory shad from the recreational creel survey in the Susquehanna River below Conowingo Dam, 2001-2019. Due to sampling limitations, no data were available for 2011.

Year	Number of Interviews	Hours Fished for Hickory Shad	Hickory Shad Catch	Hickory Shad CPAH
2001	87	199.4	449	2.25
2002	52	85.3	139	1.63
2003	64	146.7	97	0.66
2004	95	189.3	131	0.69
2005	26	51.8	24	0.46
2006	70	210.8	202	0.96
2007	30	107.5	53	0.49
2008	16	32.5	39	1.20
2009	39	85.0	158	1.86
2010	31	50.5	25	0.50
2012	45	188.8	242	1.28
2013	52	168.8	151	0.89
2014	79	227.5	345	1.52
2015	57	153.4	286	1.86
2016	125	309.0	517	1.67
2017	73	190.5	154	0.81
2018	61	120.9	240	1.99
2019	32	62.1	133	2.14

Figure 1. Conowingo Dam (Susquehanna River) hook and line sampling location for American shad in 2019.

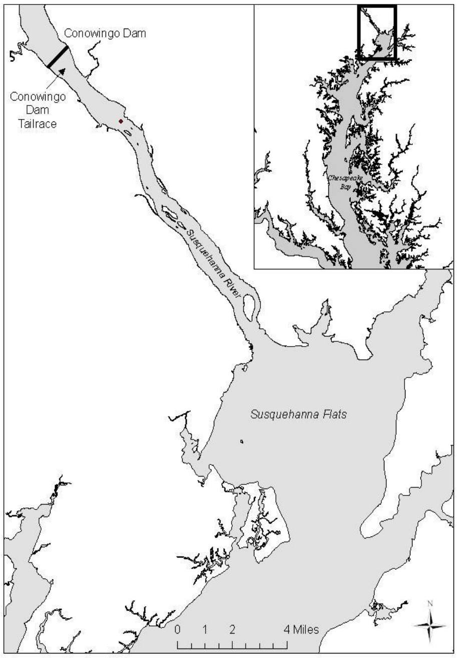

Figure 2. Percent of American shad repeat spawners by sex collected in the Conowingo Dam tailrace (1982-2019).

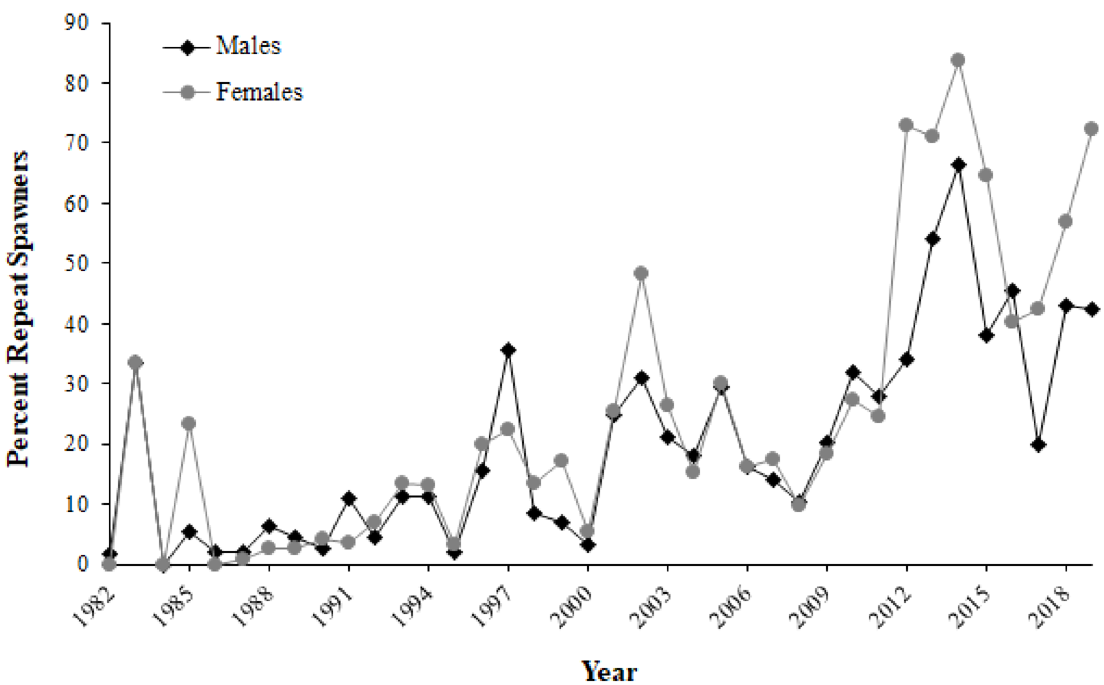

Figure 3. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984-2019.

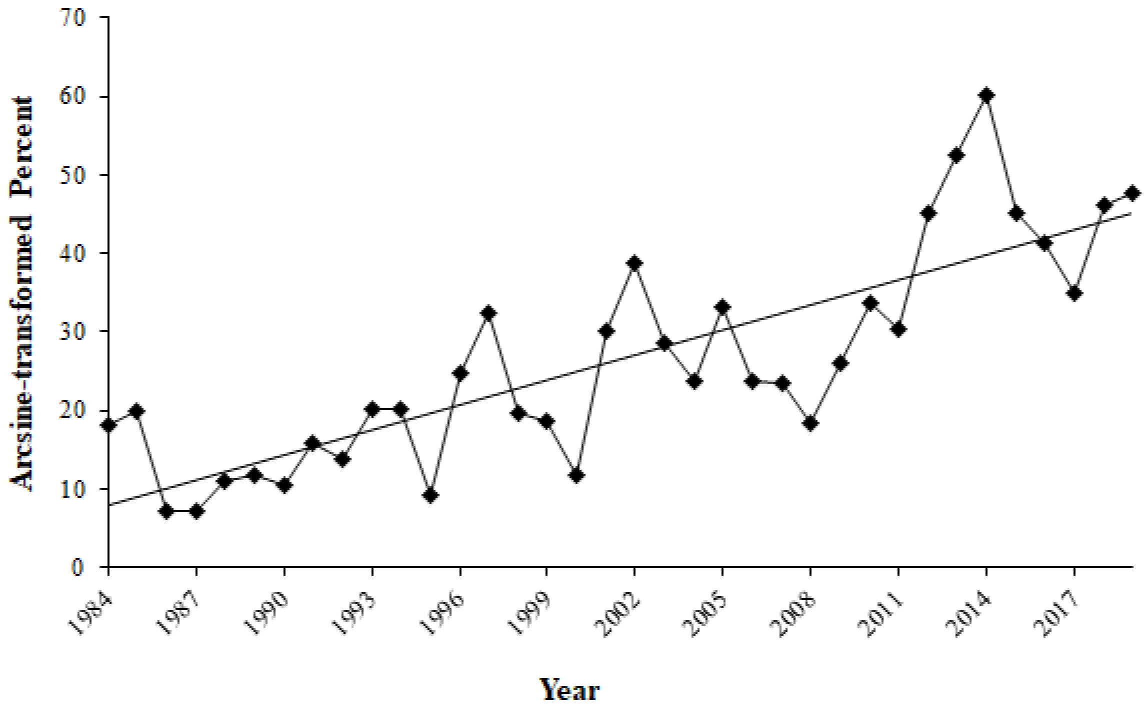

Figure 4. Pearson residuals from the best fit generalized additive model (GAM) in 2019 used to standardize the Susquehanna River hook and line catch per unit effort (CPUE) index.

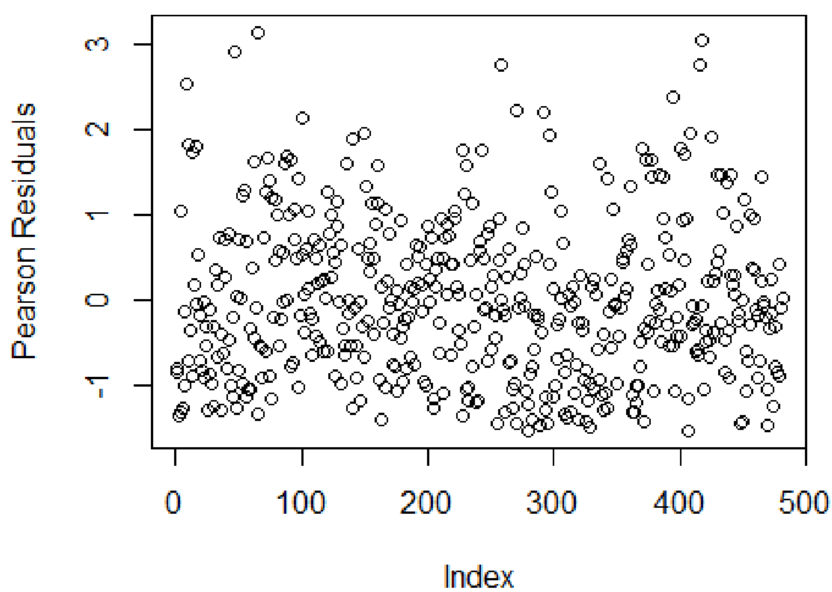

Figure 5. American shad standardized CPUE with 95% confidence intervals estimated by a generalized additive model for the Conowingo Dam tailrace hook and line sampling, 1987-2019. Estimates were not made in 2011 due to the small sample size of catch data with complete observations of environmental covariates.

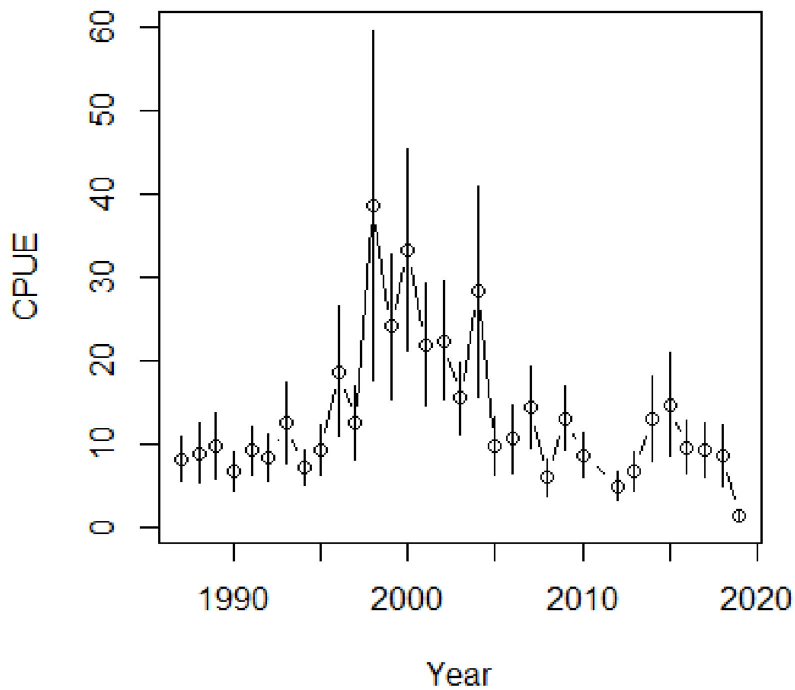

Figure 6. American shad geometric mean CPUE (fish per lift hour) and the total number of American shad lifted at the East and West Fish Lifts at the Conowingo Dam, 1991-2019.

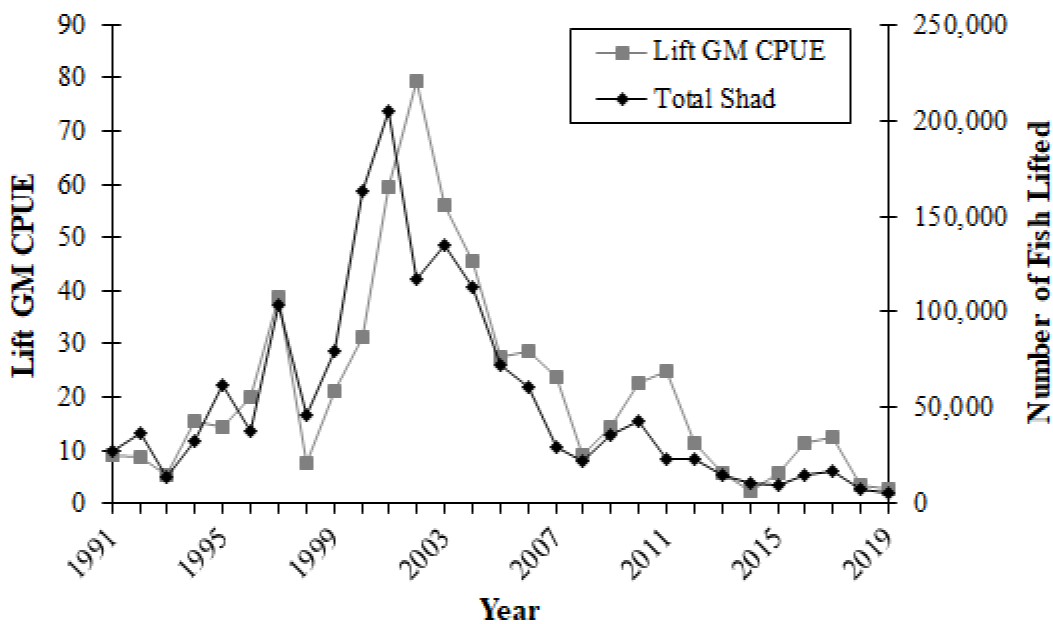

Figure 7. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen statistic (with 95% confidence limits) and the surplus production model (SPM), 1985-2019. Note the different scales.

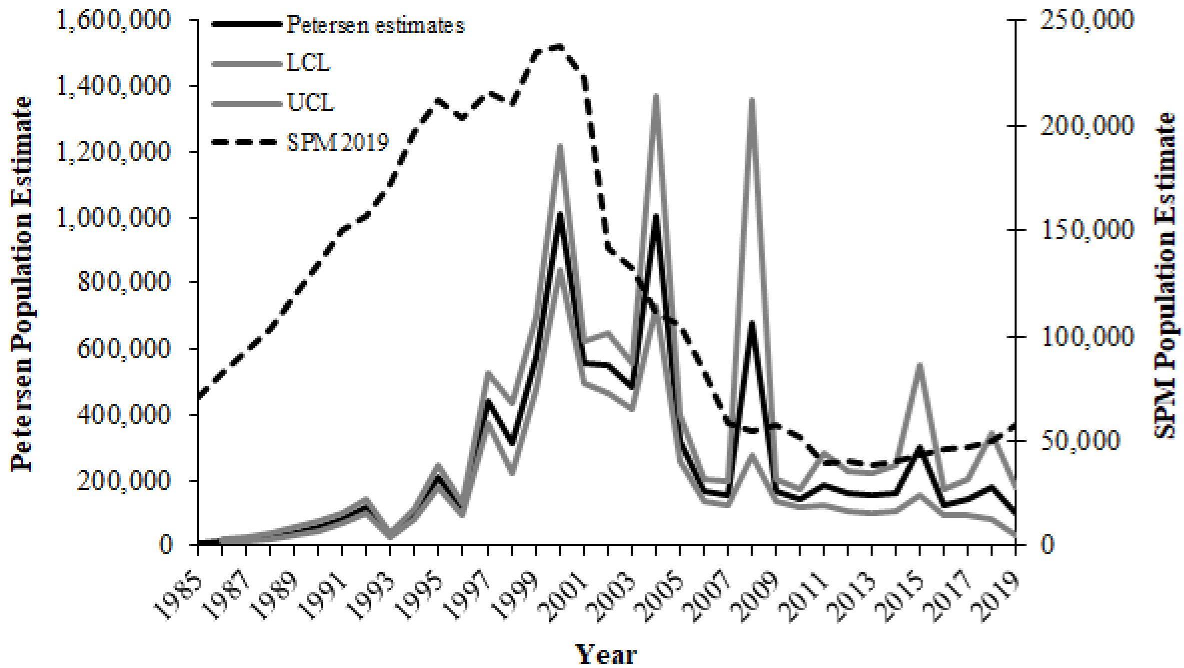

Figure 8. Age-based Chapman-Robson total instantaneous mortality (Z) estimates for American shad, sexes combined, captured in the Conowingo dam tailrace (1984-2019). The Z40% SBPR reference point was determined by the 2020 ASMFC American shad benchmark stock assessment and is specific to the southern iteroparous population.

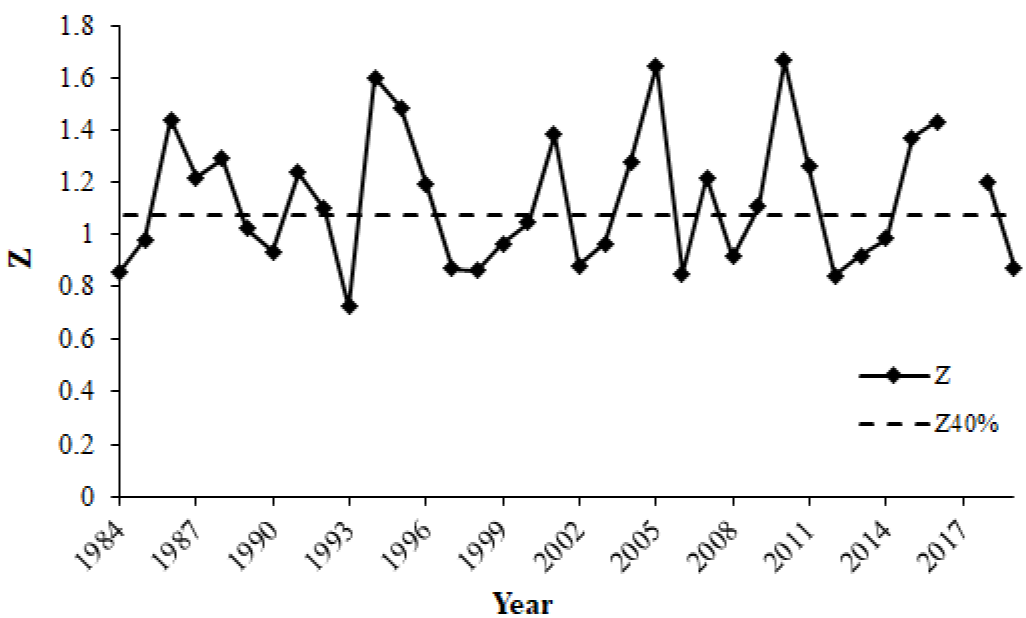

Figure 9. Upper Chesapeake Bay juvenile American shad geometric mean CPUE (catch per haul), 1959-2019.

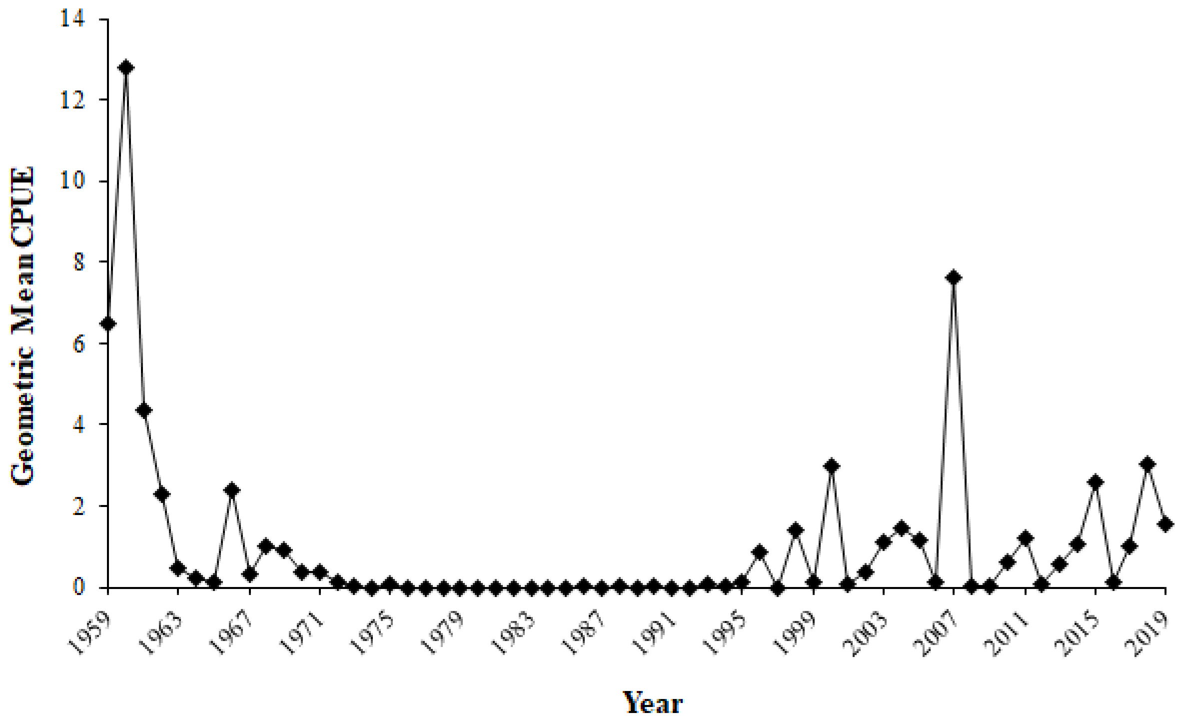

Figure 10. Arcsine-transformed percentages of repeat spawning hickory shad (sexes combined) collected from the Susquehanna River and Deer Creek (a lower Susquehanna River tributary), 2004-2019.

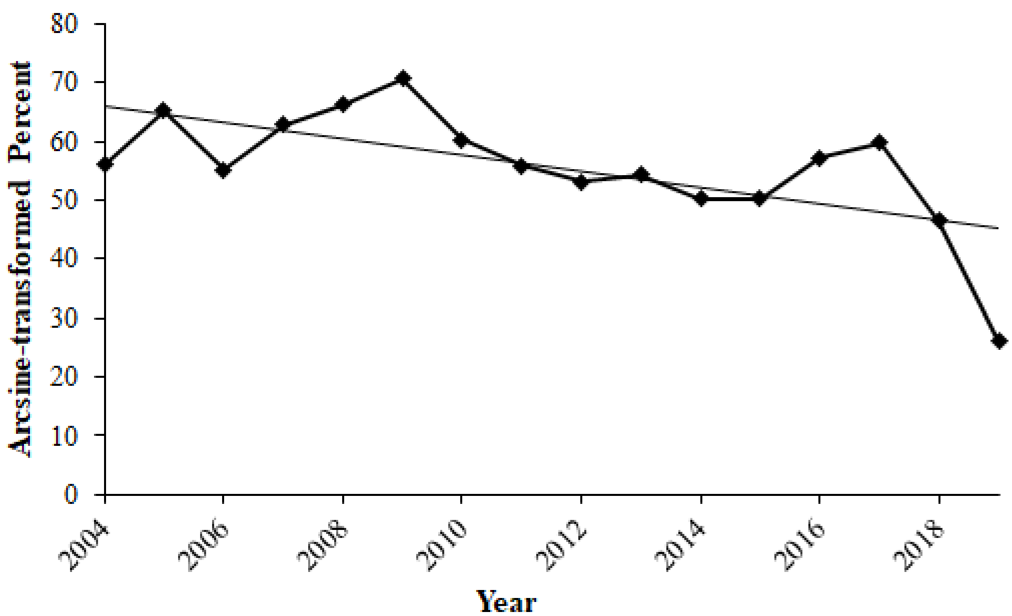

Figure 11. Age-based Chapman-Robson total instantaneous mortality (Z) estimates for hickory shad, sexes combined, captured in the Susquehanna River (2004-2019).