POPULATION ASSESSMENT OF ADULT 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 the population has trended upward. Hickory shad abundance was previously very high and stable within the lower Susquehanna River. More recently a slight decrease has been observed. The Maryland Department of Natural Resources (MDNR) is committed to restoring these species to sustainable, self-producing populations in the Susquehanna River Basin.

METHODS

Data Collection

Adult American shad were angled by MDNR staff from the Conowingo Dam tailrace on the lower Susquehanna River two to four times per week from 27 April through 29 May 2015 (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 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 MDNR 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 4' x 10' 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 brood stock, 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 MDNR hook and line survey in the current and previous years.

A non-random roving creel survey provided catch and effort data from the recreational anglers in the Conowingo Dam tailrace, concurrent with the MDNR American shad hook and line survey. Stream bank anglers were interviewed about American shad catch that day and hours spent fishing. A voluntary logbook survey also provided location, catch and hours spent fishing for American shad in the lower Susquehanna River (including the Conowingo tailrace and Deer Creek) for each participating angler. The same information was collected for hickory shad in various locations throughout the Chesapeake Bay region. Beginning in 2014, anglers could participate in the logbook survey by recording fishing trips through the Volunteer Angler Shad Survey on MDNR's website (http://dnrweb.dnr.state.md.us/fisheries/surveys/login.asp).

MDNR's Restoration and Enhancement Program provided additional hickory shad data (2004-2014) from their brood stock collection. Hickory shad were collected in Deer Creek (a Susquehanna River tributary) for hatchery brood stock and were sub-sampled for age, repeat spawning marks, sex, length and weight. In 2004 and 2005, fish were collected using hook and line fishing. More recently fish have been collected by a combination of electrofishing and hook and line fishing (2006-2015).

Data Analysis

Sex and Age Composition

Male-female ratios were derived for American shad angled at the Conowingo Dam in the Susquehanna River. Hickory shad male-female ratios were derived from data provided by the Restoration and Enhancement Program's brood stock collection on the Susquehanna River.

Alosine scales collected from all rivers were aged following "Massachusetts Division of Marine Fisheries Age and Growth Laboratory: Fish Aging Protocols" (Elzey et al., 2015) as suggested by Atlantic states' ageing experts after ASMFC held the "2013 River Herring Ageing Workshop" (ASMFC 2013). Age determination from scales was attempted for all American shad and river herring samples. A minimum of four scales per sample were cleaned, mounted between two glass slides and read for age and spawning history using a Bell and Howell MT-609 microfiche reader. The scale edge was counted as a year-mark 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. Hickory shad scales from the Susquehanna River were aged by the MDNR Restoration and Enhancement Program. Repeat spawning marks were counted on all alosine scales during ageing, and the percentages of repeat spawners by species and system (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

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 of lifting at the EFL and WFL at Conowingo Dam. Catch-per-angler-hour (CPAH) for American shad angled in the Susquehanna River and hickory shad angled in the region were also calculated from the data collected by the logbook survey (i.e. paper logbook data and online angler reports were combined). The roving creel survey was used to calculate a CPAH for American shad in the Conowingo Dam tailrace.

While CPUE is one of the most commonly used measure of abundance, it can fluctuate year to year 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 other factors may have on a 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 include: surface water temperature (°C), river flow in thousands of cubic feet per second as measured by the USGS Water Resources station 01578310 Susquehanna River at Conowingo, MD (USGS 2015), the number of small generation units operating, the number of large generation units operating, and day of the year. Variance Inflation Factors (VIFs) were used to assess collinearity of the covariates 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, M is the number of fish tagged minus 3% tag loss, and R is the number of tagged fish recaptured at the EFL excluding recaps of previous years' tags. C is corrected to include only fish that were lifted after tagging began in the tailrace. 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. Observations at the WFL were omitted to avoid double counting beginning in 2001, as it became protocol for some fish captured at the WFL to be returned to the tailrace. Calculation of 95% confidence limits (N^*) for the Peteresen 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 estimated bycatch mortality in the previous year (equivalent to catch in a surplus production model). 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}). The estimated bycatch mortality is derived from ocean fisheries landings (L) known to encounter American shad as incidental catch (i.e. the Atlantic herring and mackerel fisheries). A bycatch coefficient (b) is estimated to fit the model to these fisheries' landings. 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 a non-equilibrium approach that follows an observation-error fitting method (i.e., assumes that all errors occur in the relationship between true stock size and the index used to measure it). The model is fit to indices of abundance for

American shad in the Conowingo dam tailrace. Assumptions include accurate adult American shad turbine mortality estimates and proportional bycatch of American shad in the ocean fisheries.

The SPM required starting values for the initial population (B_0) in 1985 (set as 7,876 by the Petersen statistic for this year; calculation described above), a carrying capacity estimate, set as 3,040,551 fish, which was three times the highest Petersen estimate of the time series, an estimate of the intrinsic rate of growth (set as 0.50), and a bycatch coefficient (set at 0.032). These starting values were adjusted by the model during the fitting procedure using Evolver 4.0 for Windows that utilizes a genetic algorithm for optimization. The fitting procedure was constrained to search within r = 0.01 to 1.0, K = 100,000 to 30 million fish, B_0 = 5,682 (the lower confidence limit of the 1985 Petersen statistic) to 1 million fish and b = 0.001 to 1.0.

The model was run multiple times varying the indices of abundance and the landings data from which bycatch mortality was derived. The run with the lowest sum of squares and best parameter estimates was chosen.

Mortality

Catch curve analysis was used to estimate total instantaneous mortality (Z) of adult American and hickory shad in the Susquehanna River. The number of repeat spawning marks was used in this estimation instead of age because ageing techniques for American shad scales are tenuous (McBride et al. 2005). Therefore, the Z calculated for these fish represents mortality associated with repeat spawning. Assuming that consecutive spawning occurred, the ln-transformed spawning group frequency was plotted against the corresponding number of times spawned:

$$\ln(S_{fx} + 1) = a + Z * W_{fx}$$

where S_{fx} is number of fish with 1,2,...f spawning marks in year x, a is the y-intercept, and W_{fx} is frequency of spawning marks (1,2,...f) in year x. Using Z, annual mortality (A) for American Shad was obtained from a table of exponential functions and derivatives (Ricker 1975). This calculation of Z may bias mortality high if skip spawning is occurring (ASMFC 2012).

RESULTS

American shad

Sex and Age Composition

The male-female ratio of adult American shad captured by hook and line from the Conowingo tailrace was 1:0.78. Of the 308 fish sampled by this gear, 279 were successfully scale-aged (Table 1). Males were present in age groups 3-6 and females were found in age groups 3-8. The 2010 (age 5) year-class was the most abundant for males and females, accounting for 40% of males and 52% of females (Table 1). Thirty-eight percent of males and 65% of females were repeat spawners. The percentages of repeat spawners for both males and females decreased in 2015, after a steady increase from 2008-2014 (Figure 2). The arcsine-transformed proportion of these repeat spawners (sexes combined) has significantly increased over the time series (1984-2015; $r^2 = 0.49$, $P < 0.001$; Figure 3).

Relative Abundance

Sampling at the Conowingo Dam occurred for 12 days in 2015. A total of 308 adult American shad were encountered by the gear; all of these fish were captured by MDNR staff from a boat; no shore sampling occurred in 2015. Peak catch by hook and line (107 fish) occurred on 8 May 2015 at a surface water temperature of 18°C. MDNR staff tagged 298 (97%) of the sampled fish. No tagged American shad recaptures were reported from either commercial fishermen or recreational anglers in 2015. However, one American shad tagged in 2014 was recaptured by MDNR anglers while fishing in the tailrace.

The EFL operated for 46 days between 3 April and 31 May 2015. Of the 8,341 American shad that passed at the EFL, 85% (7,127 fish) passed between 1 May and 15 May 2015. Peak passage was on 13 May; 1,154 American shad were recorded on this date. Seven of the American shad counted at the EFL counting windows were identified as being tagged in 2015 and two were identified as being tagged in 2014 (Table 2).

The Conowingo WFL operated for 19 days between 29 April and 27 May 2015. The 875 captured American shad were retained for hatchery operations, sacrificed for characterization data collection, or returned alive to the tailrace. Peak capture from the WFL was on 13 May, same as the EFL, when 298 American shad were collected. Eight tagged American shad were recaptured by the WFL in 2015, 1 was tagged in 2014 and 7 were tagged in 2015 (Table 2). The 2014 tagged fish was sacrificed for biological sampling and was found to be a 512 mm TL, six year old female, stocked by PFBC in the West Branch Susquehanna River in 2009 (pers. comm. Joshua Tryninewski, PFBC).

The various model configurations explored for developing a GAM for the hook and line index and how each model performed are summarized in Table 3. Due to observed collinearity of day of the year with surface water temperature, day of the year was removed from the model. The number of small generation units operating and the number of large generation units operating had large VIF values (>3) and were also 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 indicates temperature has a greater effect on catch than flow (Table 3). The model results also indicate that both models 2 and 3 are acceptable. Model 2 is slightly over-dispersed, while model 3 is slightly under-dispersed. It was suggested that being slightly under-dispersed would be better than being over-dispersed (Laura Lee, North Carolina Department of Environment and Natural Resources, pers. comm.), therefore model 3 was chosen as the best fit model. A bootstrap procedure could be used to test the predictive ability of models 2 and 3, and evaluate model performance by fitting a linear regression to the observed versus predicted values. A bootstrap evaluation will be further developed as time allows.

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 log 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 annual hook and line CPUE generated using the best fit GAM shows abundance is variable from 2007-2015, with an increase in recent years, but remains below the high indices observed from 1999-2002 (Figure 5).

The Conowingo Dam lifts provide another opportunity to measure American shad abundance in this region for comparison to the hook and line index. Both the run count of fish lifted at Conowingo Dam and the combined lift GM CPUE, for years when both the East and West Fish lift were operating, mirror the hook and line index (Figure 6). Like all relative measures of abundance there are caveats to accepting these indices as indicative of true abundance. Run counts at Conowingo Dam are affected by the lift efficiency and river flows, while the GM CPUE is affected by the number and frequency of lifts. All three indices measured in this region of the Susquehanna River show a broad general trend that abundance was low in the 1990s, increased to a peak in the early 2000s and has since declined to low levels of abundance (Figures 5 and 6). However, the increase observed in the hook and line index in recent years is not apparent in the other two indices.

Sixty-four interviews were conducted over five days during the creel survey at the Conowingo Dam Tailrace. The CPAH increased in 2015 (Table 4), but has decreased over the time series (2001-2015; $r^2 = 0.36$, $P = 0.02$). The coefficient of determination from this analysis indicates the data only has a marginal fit to the predicted linear model, there is a lot of variability in the data, or perhaps a different model should be explored.

Three anglers returned logbooks in 2015. Additionally, eight anglers participated online by recording their trips through MDNR's Volunteer Angler Shad Survey. American shad CPAH calculated from shad logbook data combined with data from MDNR's Volunteer Angler Shad Survey was similar to the 2014 CPAH estimate (2.05; Table 5). Online angler data was included in the CPAH calculation for the second time in 2015. The logbook CPAH estimate of adult American shad relative abundance has decreased significantly over the time series (2000-2014; $r^2 = 0.51$, $P = 0.003$; Table 5).

Population Estimates

The Petersen statistic estimated 302,909 American shad in the Conowingo Dam tailrace in 2015 with an upper confidence limit of 552,595 fish and a lower confidence limit of 156,386 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, and used the Atlantic herring and mackerel combined landings to estimate bycatch losses. This run estimated a population of 139,973 American shad in the Conowingo Dam in 2015 and produced realistic estimates of the model parameters *r*, *K* and B_0 (r = 0.56, K = 1,005,502, B_0 = 54,176; Figure 8).

Despite differences in yearly estimates, the overall population trends derived from each population model are similar (Figures 7 and 8). Specifically, the SPM showed an increasing population size from the beginning of the time series to a peak in 2001, followed by a decline through 2007. Since 2007 the population size has shown a slight increase in recent years (2012-2015; Figure 8). Petersen estimates follow a similar pattern if the high levels of uncertainty in 2004 and 2008 (due to low recapture rates) are considered (Figure 7), although they show a greater increase towards the end of the time series compared to the SPM estimates.

Mortality

The Conowingo Dam tailrace total instantaneous mortality estimate from catch curve analysis (using repeat spawning instead of age) resulted in Z = 1.03 (A = 64.3%) in 2015, which is much higher than both the 2013 (Z = 0.67) and the 2014 (Z = 0.71) estimates.

Hickory Shad

Sex and Age Composition

In Deer Creek, 590 hickory shad were sampled by the broodstock collection survey. The male-female ratio was 1:0.84. Of the total fish captured by this survey, 113 were successfully aged. Males and females were present in age groups 2-6 (Table 6). The most abundant year-class was the 2011 year-class (age 4) for males (41%) and females (47%, Table 7). Since 2012 no hickory shad of ages greater than 7 have been observed (Table 7). The arcsine-transformed proportion of repeat spawners (sexes combined) has not changed significantly over the time series (2004-2015; r^2 = 0.32, P = 0.06), but has decreased since 2009. The total percent of repeat spawners in 2015 (59.0%) remains the same as last year, at the lowest percentage of the time series (2004-2015; Table 8).

Relative Abundance

Shad logbook and Volunteer Angler Shad Survey data indicated that hickory shad CPAH did not vary significantly over the time series (1998-2014; r^2 = 0.13, P = 0.16). Hickory shad CPAH was the lowest year on record since 1998 when this survey began (Table 9). However, there were considerably fewer fishing trips for hickory shad in 2015, and the fewest hours spent fishing for hickory shad on record. With the extended cold temperatures and the wet start to spring, fishing opportunities during the Hickory shad run may have been limited in 2015.

Mortality

Total instantaneous hickory shad mortality in the Susquehanna River (Deer Creek) was estimated as Z = 0.68. This estimate is similar to the 2013 Z estimate (Z = 0.78), but much higher than the 2014 estimate (Z = 0.36). The large fluctuations in the estimated values of natural mortality by catch curve warranted exploration of another method for comparison, such as Hoenig's (1983) equation ($\ln(M_x) = 1.46 - 1.01\{\ln(t_{max})\}$). Based on a t_{max} of 9, Hoenig's (1983) equation estimates natural mortality at M = 0.47, which is similar to the 2014 estimate.

River Herring

While hook and line fishing for American shad in the Conowingo tailrace it is not uncommon to capture river herring. In 2015, any river herring encountered were measured to the nearest mm FL and TL, sexed, and scales were taken to support a research project for George Mason University (GMU). Samples were collected by MDNR and were aged by GMU. Seven blueback herring were captured, four females and three males, ranging in size from 219-248 mm FL, and ages 3-5, with one sample marked as regenerated.

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 and pollution. American shad restoration in the 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. The American shad adult stock has shown some improvement since the inception of restoration efforts, although the 2007 ASMFC stock assessment indicated that stocks were still declining in most river systems along the east coast (ASMFC 2007).

Peak capture of American shad in the Conowingo tailrace by hook and line occurred almost a week before peak passage was observed at the East and West Fish Lifts in 2015. Surface water temperature for peak capture by hook and line was within the optimal migration temperature for American shad (17-19°C, Legget and Walburg 1972) at 18°C, whereas peak passage at the lifts occurred at 21°C; above the optimal migration temperature and just above the optimal temperature for spawning (14-20°C, Stier and Crance 1985). This suggests migration of American shad past Conowingo Dam on the Susquehanna was occurring outside optimal temperatures in 2015, which is ultimately not conducive to successful spawning. 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.

The population size of American shad in the lower Susquehanna appears to be relatively stable over the past eight years (2007-2015; SPM estimate), although at a much lower level than the peak observed from 2000-2001 and compared to historical abundance. This follows a period (2001-2007) when calculated indices of abundance generally decreased (including the hook and line CPUE, lift CPUE, logbook CPAH and creel CPAH). However, the calculated indices of abundance in the lower Susquehanna River all continued to increase in 2015, with the exception of the run count at Conowingo dam, which showed a decline in 2015. Gizzard shad are increasing in abundance in the Susquehanna drainage and may reduce the number of lifted American shad by using the lifts themselves.

The Petersen estimate and the SPM are both useful techniques for providing estimates of American shad abundance at the Conowingo Dam. Both models show the population to be relatively stable (2007-2015), with gradual increases in the last 2–3 years. The SPM likely underestimates American shad abundance, while the Petersen statistic likely overestimates the population, especially in years of low recapture of tagged fish. Trends, rather than the actual numbers, produced by the models should be emphasized when assessing the population at the Conowingo Dam in the Susquehanna River. The trends in these population estimates indicate that the population has stabilized at some low level, likely limited by the available spawning habitat below Conowingo and stocking success. The PFBC data currently estimates stocking contributes approximately 40% of the adult American shad population in the Conowingo tailrace.

Ageing American shad using scales is common practice, as it the only non-lethal ageing structure for this fish. However, ageing accuracy has been called into question by many (ASMFC 2007). Ageing other hard structures such as otoliths produces higher age agreement between readers compared to scales (Duffy et al. 2012). 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 has increased over time, particularly since the truck and transport to locations above Safe Harbor Dam ceased in 1997 when the EFL was automated. The percent of repeat spawners was generally less than 10% in the early 1980s in the Conowingo Dam tailrace (Weinrich et al. 1982). In contrast, 50% of aged American shad at the Conowingo Dam were repeat spawners in 2015, and, on average, 60% of aged fish were repeat spawners over the past four years. Turbine mortality for dams above the Conowingo Dam is considered to be 100%, and the end of truck and transport in 1997 may have resulted in more fish surviving to return in following years, which also indicates that fewer adults are reaching optimal spawning habitat above Safe Harbor Dam. However, the same trend occurs in the Potomac River, a free flowing river, unimpeded by dam construction: the average percent of repeat spawners was 17% in the 1950s (Walburg and Sykes 1957), and is currently 67%. Increased repeat spawning in both river systems may indicate increased survival of adult fish. This could be due to decreased harvest 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 show increasing trends in repeat spawners include the Merrimack (1999-2005; ASMFC 2007), Nanticoke (Lipkey and Jarzynski 2014), and James Rivers (2000-2002; Olney et al., 2003).

Historically, calculated Z for American shad in the lower Susquehanna River has been above the target Z_{30} (1984 – 2005; ASMFC 2007). The 2015 mortality estimate continues this pattern, with a calculated Z for American shad in the Conowingo Dam tailrace (Z=1.03) being well above the Z_{30} established for rivers in neighboring states (range=0.54−0.76, ASMFC 2007).

As previously mentioned these calculated mortality estimates may be high if skip spawning is occurring (ASMFC 2012).

Hickory Shad

Hickory shad stocks have drastically declined due to the loss of habitat, 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 are historically observed using the EFL in the Susquehanna River. A notable exception was in 2011 when 20 hickory shad were counted at the EFL counting window. Despite the traditionally low number of hickory shad observed passing the Conowingo Dam, Deer Creek (a tributary to the Susquehanna River) has the greatest densities of hickory shad in Maryland (Richardson et al. 2009). Catch rates exceed four fish per hour for all years except 2009, 2010 and 2015 according to shad logbook data collected from anglers (1998-2015). There were considerably fewer fishing trips for hickory shad in 2015, and the fewest hours spent fishing for hickory shad on record. With the extended cold temperatures and the wet start to spring, fishing opportunities during the Hickory shad run may have been limited in 2015.

Previously, hickory shad age structure has remained relatively consistent, with a wide range of ages and a high percentage of older fish, although the past four years (2012-2015) have seen no hickory shad over the age of 7. In 2015, 95% of fish were age 5 or younger and no hickory shad were observed over the age of 6. This suggests the age structure of hickory shad has become truncated in recent years. Ninety percent of hickory shad from the upper Chesapeake Bay spawn by age four, and this stock generally consists of few virgin fish (Richardson et. al

2004). Repeat spawning in 2014 and 2015 were the lowest of the time series, which coincides with fewer hickory shad reaching those older ages. Fewer older fish combined with a smaller proportion of repeat spawners may indicate poor year classes and/or an increase in natural 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.).

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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 2015.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	19	0	2	1	21	1
4	59	12	22	8	81	20
5	60	35	66	44	126	79
6	14	11	29	22	43	33
7	0	0	7	6	7	6
8	0	0	1	1	1	1
9	0	0	0	0	0	0
Totals	152	58	127	82	279	140
Percent Repeats	38.2%		64.6%		50.2%	

Table 2. Number of recaptured American shad in 2015 at the Conowingo Dam East and West Fish Lifts by tag color and year.

East Lift			West Lift		
Tag Color	Year Tagged	Number Recaptured	Tag Color	Year Tagged	Number Recaptured
Yellow	2014	2	Yellow	2014	1
Blue	2015	7	Blue	2015	7

Table 3. The six generalized additive model (GAM) configurations and performance statistics explored for standardizing the hook and line catch per unit effort index.

Model Number	Cofactor(s)	Response Variable Distribution	N	Effective Degrees of Freedom	Deviance Explained	Dispersion	AIC
1	Temp + Flow	Poisson	429	45.34	44.8%	10.04	6341.43
2	Temp + Flow	Tweedie	429	35.88	46.6%	2.72	3640.97
3	Temp + Flow	Negative Binomial	429	35.51	42.6%	0.84	3683.65
4	Temp	Poisson	429	36.78	42.2%	10.22	6523.36
5	Temp	Tweedie	429	33.53	45.3%	2.73	3645.69
6	Temp	Negative Binomial	429	33.60	41.3%	0.84	3687.81

Table 4. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from the recreational creel survey in the Susquehanna River below Conowingo Dam, 2001-2015. 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	90	202.9	991	4.88
2002	52	85.3	291	3.41
2003	65	148.2	818	5.52
2004	97	193.3	233	1.21
2005	29	128.8	63	0.49
2006	78	227.3	305	1.34
2007	30	107.5	128	1.19
2008	16	32.5	24	0.74
2009	40	85.0	120	1.41
2010	36	64.0	114	1.78
2012	58	189.0	146	0.77
2013	63	161.8	107	0.66
2014	81	227.0	312	1.37
2015	64	158.9	263	1.65

Table 5. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from spring logbooks for American shad, 2000-2015. Multiple logbooks were used from 2000 until 2003, when a single logbook was utilized to collect data on both shad species. Beginning in 2014, data from Maryland's Volunteer Angler Shad Survey was combined with logbook data.

Year	Number of Participants	Total Reported Angler Hours	American Shad Catch (numbers)	Catch Per Angler Hour
2000	10	404.0	3,137	7.76
2001	8	272.5	1,647	6.04
2002	8	331.5	1,799	5.43
2003	9	530.0	1,222	2.31
2004	15	291.0	1035	3.56
2005	12	258.5	533	2.06
2006	16	639.0	747	1.17
2007	10	242.0	873	3.61
2008	14	559.5	1,269	2.27
2009	15	378.0	967	2.56
2010	16	429.5	857	2.00
2011	9	174.0	413	2.37
2012	5	180.5	491	2.77
2013	6	217.3	313	1.44
2014	16	228.0	467	2.05
2015	11	154.0	348	2.18

Table 6. Numbers of adult hickory shad and repeat spawners by sex and age sampled from the brood stock collection survey in Deer Creek in 2015.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
2	1	0	0	0	1	0
3	19	0	15	0	34	0
4	23	20	26	19	49	39
5	10	9	13	13	23	22
6	3	3	3	3	6	6
Totals	56	32	57	35	113	67
Percent Repeats	57.1%		61.4%		59.3%	

Table 7. Percent of hickory shad by age and number sampled from the brood stock collection survey in Deer Creek by year, 2004-2015.

Year	N	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
2004	80		7.5	23.8	27.5	18.8	18.8	3.8	
2005	80		6.3	17.5	28.8	33.8	11.3	1.3	1.3
2006	178	0.6	9.0	31.5	29.8	20.2	7.3	1.7	
2007	139		6.5	23.7	33.8	20.9	12.2	2.2	0.7
2008	149		9.4	29.5	33.6	20.1	5.4	2.0	
2009	118		7.6	16.9	44.9	19.5	10.2	0.8	
2010	240		12.5	37.9	31.3	11.3	6.7	0.4	
2011	216		30.1	30.1	27.3	8.8	2.8	0.9	
2012	200		26.5	39.5	24.5	7.5	2.0		
2013	193		21.2	45.6	23.8	8.3	1.0		
2014	100		11.0	37.0	40.0	12.0			
2015	113	0.9	30.1	43.4	20.4	5.3			

Table 8. Percent repeat spawning hickory shad (sexes combined) by year from the brood stock collection survey in Deer Creek, 2004-2015.

Year	N	Percent Repeats
2004	80	68.8
2005	80	82.5
2006	178	67.4
2007	139	79.1
2008	149	83.9
2009	118	89.0
2010	240	75.4
2011	216	68.5
2012	200	64.0
2013	193	74.1
2014	100	59.0
2015	113	59.3

Table 9. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from spring logbooks for hickory shad, 1998-2015. Multiple logbooks were used from 1998 until 2003, when a single logbook was utilized to collect data on both shad species. Beginning in 2014, data from Maryland's Volunteer Angler Shad Survey was combined with logbook data.

Year	Number of Returned Logbooks	Total Reported Angler Hours	Total Number of Hickory Shad	Catch Per Angler Hour
1998	19	600	4,980	8.30
1999	15	817	5,115	6.26
2000	14	655	3,171	14.8
2001	13	533	2,515	4.72
2002	11	476	2,433	5.11
2003	14	635	3,143	4.95
2004	18	750	3,225	4.30
2005	19	474	2,094	4.42
2006	20	766	4,902	6.40
2007	17	401	3,357	8.37
2008	22	942	5,465	5.80
2009	15	561	2,022	3.60
2010	16	552	1,956	3.54
2011	9	224	1,802	8.03
2012	6	198	867	4.38
2013	6	259	1,679	6.49
2014	19	275	1,204	4.38
2015	15	197	371	1.88

Figure 1. Conowingo Dam (Susquehanna River) hook and line sampling location for American shad in 2015.

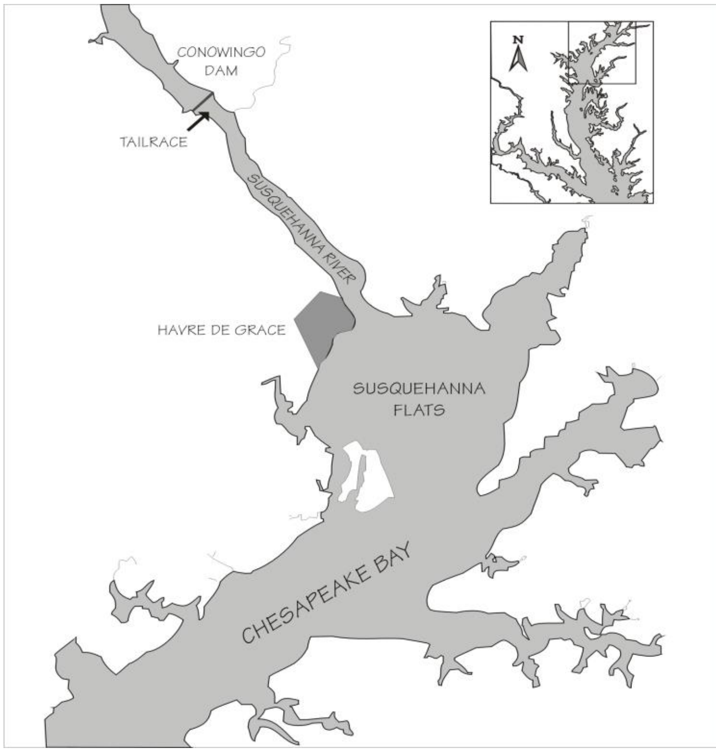

Figure 2. Percent of American shad repeat spawners by sex collected in the Conowingo Dam tailrace (1982-2015).

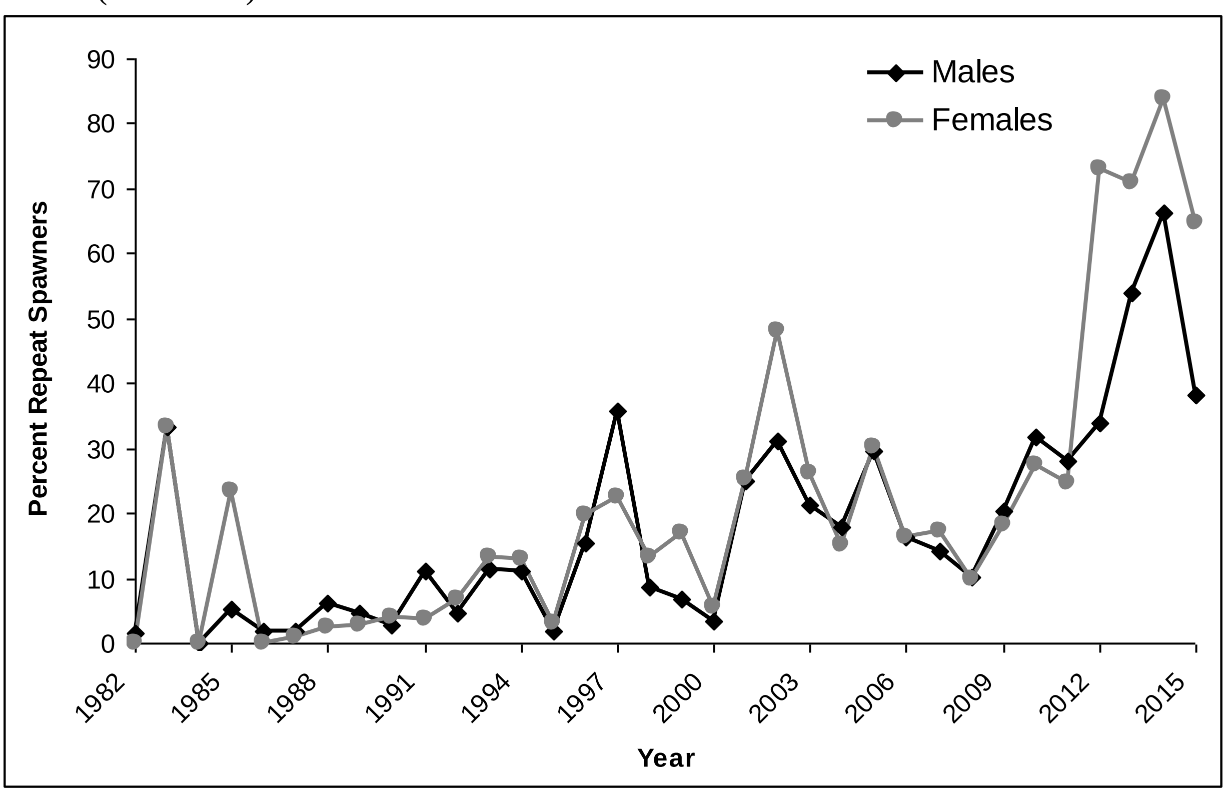

Figure 3. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984-2015.

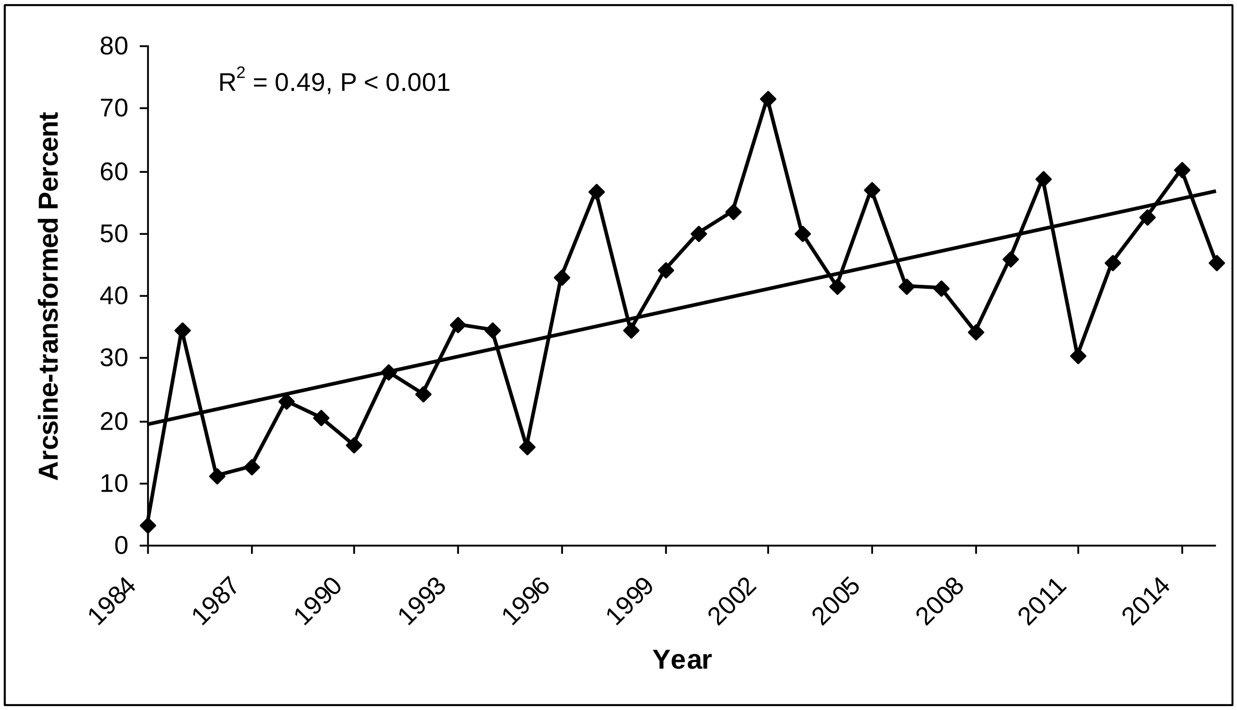

Figure 4. Pearson residuals from the best fit generalized additive model (GAM) used to standardize the Susquehanna River hook and line catch per unit effort (CPUE) index.

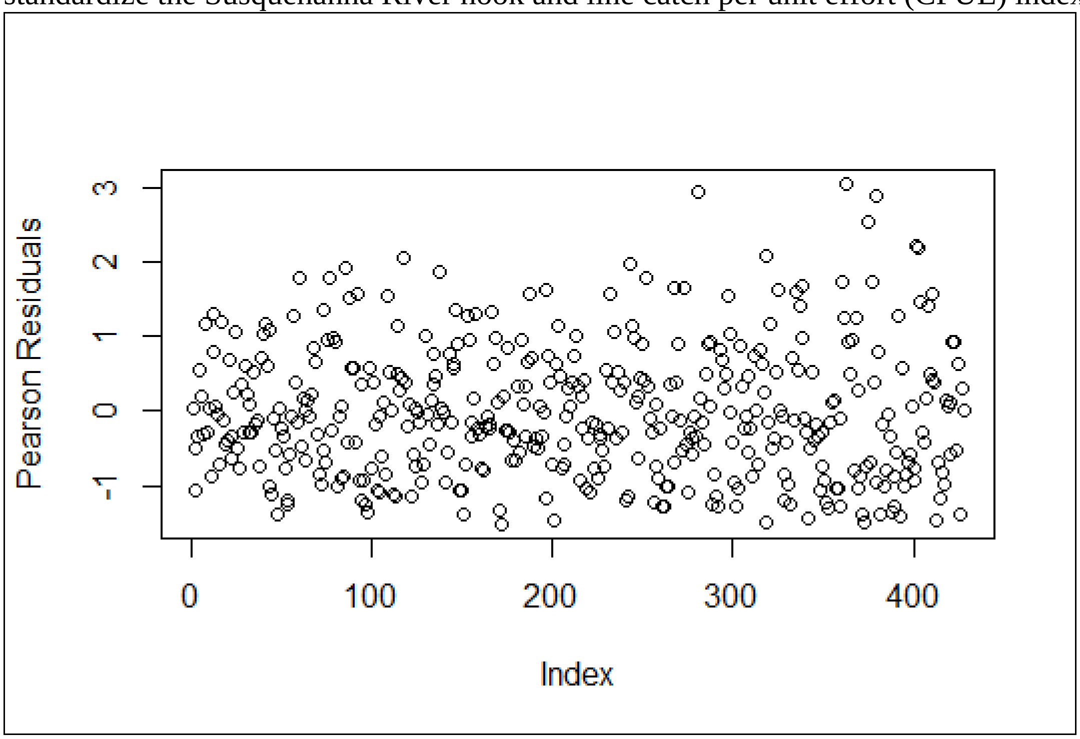

Figure 5. American shad standardized CPUE with 95% confidence intervals estimated by a generalized additive model for the Conowingo Dam tailrace hook and line sampling, 1987-2015.

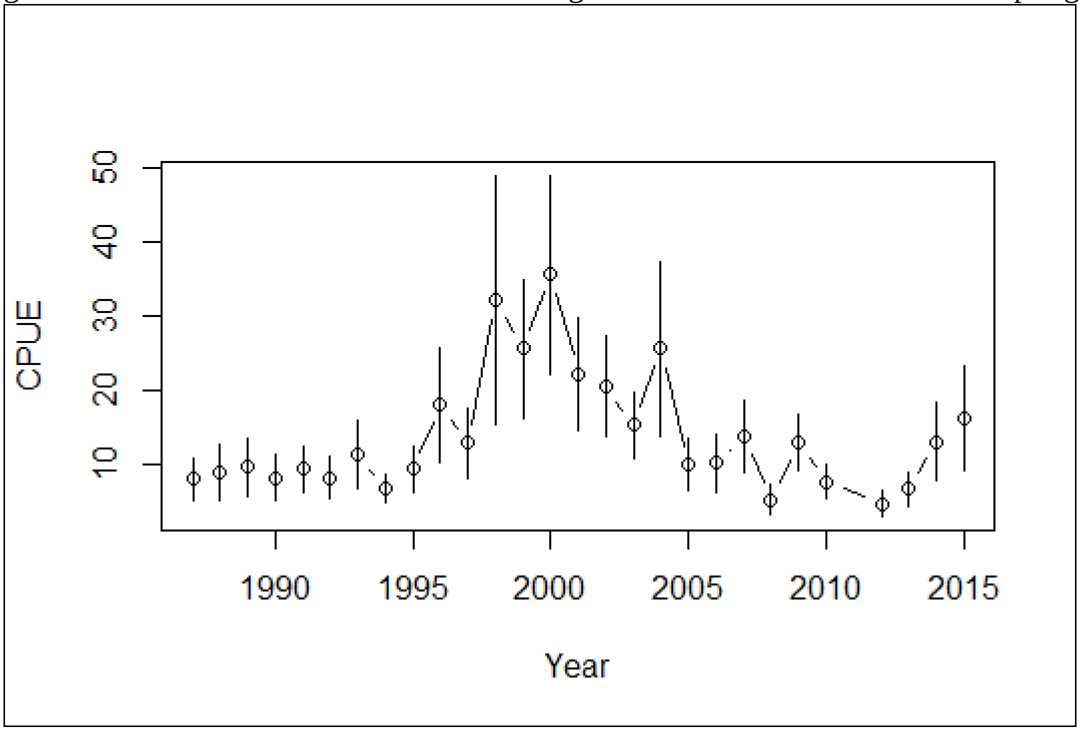

Figure 6. American shad geometric mean CPUE (fish per lift hour) and the total number of American shad lifted at the East and West Fish Lifts at the Conowingo Dam, 1991-2015.

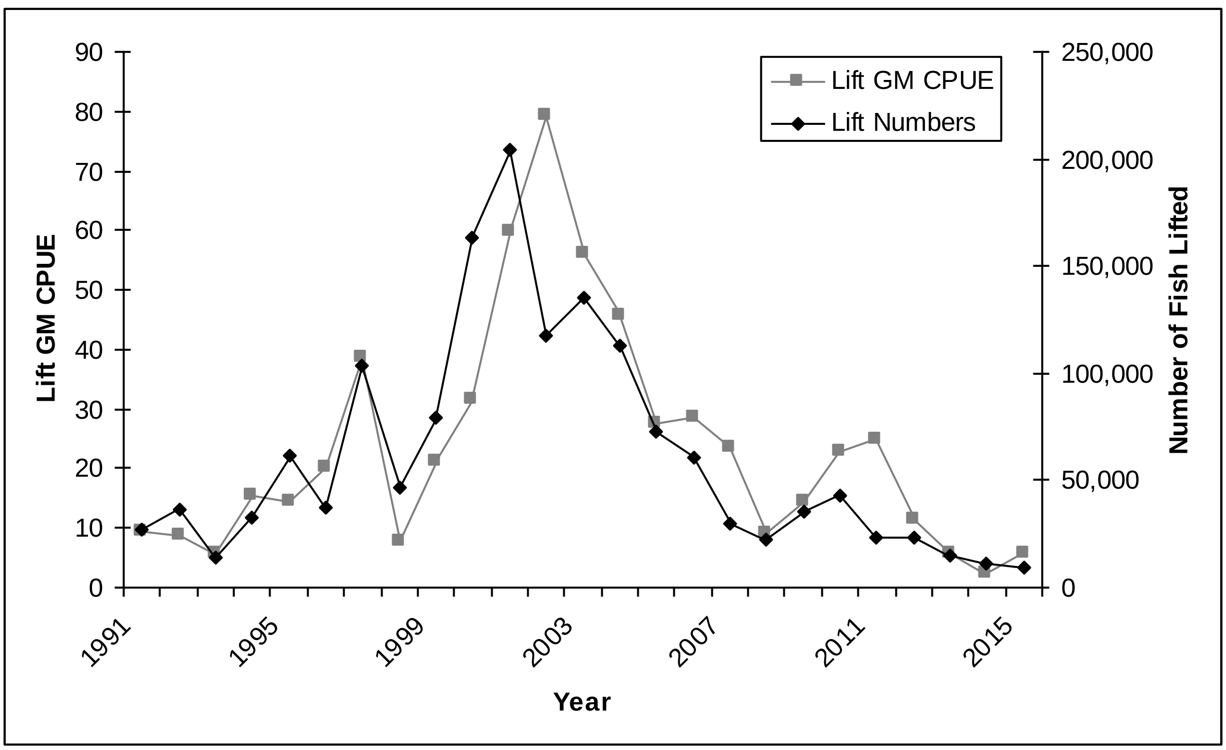

Figure 7. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen statistic with 95% confidence limits, 1986-2015.

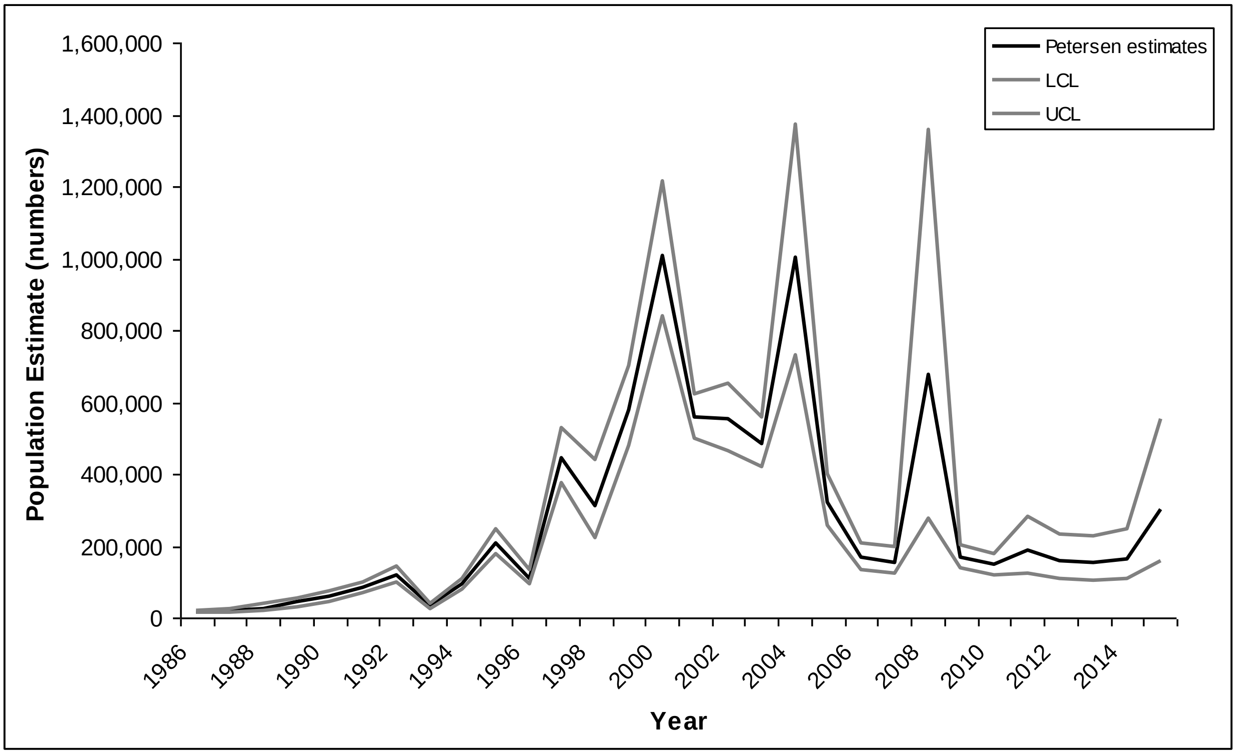

Figure 8. Conowingo Dam tailrace adult American shad abundance estimates from the surplus production model (SPM), 1986-2015.