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

Genine K. Lipkey
Maryland Department of Natural Resources, Fisheries Service
301 Marine Academy Drive, Stevensville, MD 21666

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. Hickory shad abundance appears to be high and stable within the lower Susquehanna River. 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 30 April through 3 June 2014 (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. All American shad were sexed (by expression of gonadal products), total length (mm TL) and fork length (mm FL) were measured, and scales were removed below the insertion of the dorsal fin for ageing and spawning history analysis. Fish in good physical condition were tagged with Floy tags (color-coded to identify the year tagged) and released. A MDNR hat was given to fishers as a reward 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 tagged in the current year and in previous years.

Recreational data from a non-random roving creel survey were collected from anglers in the Conowingo Dam tailrace during the spring. In this survey, stream bank anglers were interviewed about American and hickory shad catch and hours spent fishing. A voluntary mail and online logbook survey also provided location, catches and hours spent fishing for American and hickory shad in the Susquehanna River for each participating angler.

MDNR's Susquehanna 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; fish have been collected using electrofishing gear from 2006 to the present.

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.

Age determination from scales was attempted for American shad scales collected from the Conowingo Dam. American shad scales were aged using Cating's method (Cating 1953). 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 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

Catch-per-unit-effort (CPUE) in the Conowingo Dam tailrace was calculated as the number of adult fish captured per boat hour. Data for both the EFL and the WFL were used to calculate a combined lift CPUE, which was the total number of adult fish lifted per hour of lifting. The geometric mean (GM) of adult American shad CPUE for both the tailrace area and the lifts was then calculated as the average LN (CPUE + 1) for each fishing/lifting day, transformed back to the original scale. Catch-per-angler-hour (CPAH) for American shad and hickory shad in the Susquehanna River were also calculated from both the roving creel survey and shad logbooks.

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) for 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 was obtained from a table of exponential functions and derivatives (Ricker 1975).

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 1:1.15. Of the 437 fish sampled by this gear, 428 were successfully scale-aged (Table 1). Males were present in age groups 3-7 and females were found in age groups 4-9. The 2009 (age 5) and 2008 (age 6) year-classes were the most abundant for males and females, respectively, accounting for 49% of males and 45% of females (Table 1). Sixty-five percent of males and 84% of females were repeat spawners. The percentages of repeat spawners for both males and females have steadily increased since 2008, and the arcsine-transformed proportion of these repeat spawners (sexes combined) has significantly increased over the time series (1984-2014; $r^2 = 0.50$, $P < 0.001$; Figure 2).

Relative Abundance

Sampling at the Conowingo Dam occurred for 14 days in 2014. A total of 487 adult American shad were encountered by the gear; 421 of these fish were captured by MDNR staff from a boat and the remaining 66 were captured by shore anglers. MDNR staff tagged 427 (97%) of the sampled fish. To remain consistent with historical calculations, only the 421 fish captured from the boat were used to calculate the hook and line CPUE. No tagged American shad recaptures were reported from either commercial fishermen or recreational anglers in 2014, however one American shad tagged in 2013 was recaptured by MDNR anglers while fishing in the tailrace.

The EFL operated for 54 days between 4 April and 7 June 2014. Of the 10,425 American shad that passed at the EFL, 86% (8,936 fish) passed between 26 April and 13 May 2014. Peak passage was on 13 May; 3,043 American shad were recorded on this date. Twenty of the American shad counted at the EFL counting windows were identified as being tagged in 2014 and four were identified as being tagged in 2013 (Table 2).

The Conowingo WFL operated for 27 days between 22 April and 30 May 2014. The 513 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 29 April when 290 American shad were collected. No tagged American shad were recaptured by the WFL in 2014 (Table 2).

Estimates of hook and line GM CPUE vary without trend over the time series (1984-2014; r^2 = 0.07, P = 0.16). Abundance is particularly variable from 2007-2014, but remains below the high indices observed from 1999 to 2002 (Figure 3). The Conowingo Dam combined lift GM CPUE significantly increased over the time series (1980-2014; r^2 = 0.199, P = 0.007), but has declined since 2011 to very low levels (Figure 4).

Eighty-one interviews were conducted over seven days during the creel survey at the Conowingo Dam Tailrace. The CPAH increased in 2014 (Table 3), but has decreased over the time series (2001-2014; r^2 = 0.44, P = 0.01). Nine anglers returned logbooks in 2014; all but one logbook contained information from fishing trips in the lower Susquehanna River. 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 the fourth lowest in the time series and has decreased significantly over the time series (2000-2014; $r^2 = 0.51$, $P = 0.003$; Table 4). It should be noted that for years 2000 through 2002, which report the highest CPAH values (Table 4), two separate logbooks were used for American and hickory shad, and not all anglers returned both logbooks. Beginning in 2003, to allow anglers to record data on both shad species if encountered, a combined logbook was distributed. 2014 was the first year online angler data was used in the CPAH calculation.

Population Estimates

The Petersen statistic estimated 163,609 American shad in the Conowingo Dam tailrace in 2014 with an upper confidence limit of 246,502 fish and a lower confidence limit of 107,699 fish. 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 118,883 American shad in the Conowingo Dam tailrace in 2014 and produced realistic estimates of the model parameters r, K and B_0 ($r = 0.45$, $K = 5{,}023{,}091$, $B_0 = 58{,}755$).

Despite differences in yearly estimates, the overall population trends derived from each population model are similar (Figure 5). 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 showed no specific trend (2008-2014; Figure 5). Petersen estimates follow a similar pattern if the high levels of uncertainty in 2004 and 2008 (due to low recapture rates) are considered (Figure 5).

Mortality

The Conowingo Dam tailrace total instantaneous mortality estimate from catch curve analysis (using repeat spawning instead of age) resulted in Z = 0.71 (A = 50.8%).

Hickory Shad

Sex and Age Composition

A total of 602 hickory shad were sampled in 2014 by the brood stock collection survey in Deer Creek. The male-female ratio was 1:0.7. Of the total fish captured by this survey, 100 were successfully aged. Males and females were present in age groups 3-6 (Table 5). The most abundant year-class by sex was the 2009 year-class (age 4) for females (49%) and the 2008 year-class (age 5) for males (43%; Table 6). Since 2012 no hickory shad of ages greater than 7 have been observed (Table 6). The arcsine-transformed proportion of repeat spawners (sexes combined) has not changed significantly over the time series (2004-2014; r^2 = 0.22, P = 0.15; Figure 18), but has decreased since 2009. The total percent of repeat spawners in 2014 (59.0%) was the lowest of the time series (2004-2014; Table 7).

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); however, hickory shad CPAH decreased in 2014 (Table 8).

Mortality

Total instantaneous mortality in the Susquehanna River (Deer Creek) was estimated as Z = 0.36.

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).

The population size of American shad in the lower Susquehanna appears to be relatively stable over the past seven years (2007-2014; 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).

The calculated indices of abundance in the lower Susquehanna River all increased in 2014, with the exception of the combined lift CPUE. Gizzard shad are increasing in abundance in the Susquehanna drainage and may reduce the number of lifted American shad by using the lifts themselves, thus affecting lift CPUE, which has been decreasing since 2011.

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 in recent years (2007-2014), albeit at low levels. The SPM likely underestimates American shad abundance, while the Petersen statistic likely overestimates the population, especially in years of low recapture of tagged fish. Regardless, the SPM population estimates were within the Petersen confidence intervals for the last three years. 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.

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), and Cating's method of using transverse grooves is no longer recommended. Comparisons of American shad scales from different populations show different groove frequencies to the freshwater zone and first three annuli (Duffy et al. 2011). Ageing other hard structures such as otoliths produces higher age agreement between readers compared to scales (Elzey at al. 2015, 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, 75% of aged American shad at the Conowingo Dam were repeat spawners in 2014, and, on average, 54% 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 80%. 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 (1989-2014; Lipkey and Jarzynski 2015), and James Rivers (2000-2002; Olney et al., 2003).

Historically, calculated Z for American shad in the lower Susquehanna River has been well above the target Z_{30} (1984 – 2005; ASMFC 2007). The 2014 mortality estimate continues this pattern, with a calculated Z for American shad in the Conowingo Dam tailrace (Z=0.71) being above the Z_{30} established for rivers in neighboring states (range=0.54−0.64), with the exception of Albemarle Sound, NC (Z_{30}=0.76; ASMFC 2007).

Juvenile American shad indices increased baywide, in the upper Chesapeake Bay and the Nanticoke River in 2014. The juvenile index in the Potomac River slightly decreased in 2014, but continues to be greater than all other systems. This suggests weather conditions were more favorable for successful recruitment in 2014. Fish lifted above the Conowingo Dam may reduce the number of potential spawners due to turbine mortality, and inefficient lift facilities above the Conowingo Dam may also prevent spawners from reaching optimal spawning habitat above the York Haven Dam, thus affecting juvenile production. Predation by apex predators, particularly striped bass and the invasive flathead and blue catfish, may also affect juvenile survival.

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. Only two hickory shad were observed in the EFL in 2014. 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 and 2010 according to shad logbook data collected from Deer Creek anglers (1998-2014). Hickory shad are sensitive to light and generally strike artificial lures more frequently when flows are somewhat elevated and the water is slightly turbid. Consequently, the low CPAH for hickory shad in 2009 may be directly related to the low flow and clear water conditions encountered by Deer Creek anglers and observed by MDNR staff during that spring season.

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 three years (2012-2014) have seen no hickory shad over the age of 7. In 2014, 88% 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 was 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. The high percent of repeat spawners is also indicative of very low bycatch mortality. 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.).

Hickory shad adults 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 sensitivity to light as the adults, migrating to deeper, darker water away from the shallow beaches sampled by haul seines.

LITERATURE CITED

ASMFC. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Washington, D. C. 465 pp.

ASMFC. 2007. American shad stock assessment report for peer review. Volume III. Washington, D. C. 546 pp.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. Univ. Calif. Publ. Stat. 1:131-160.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish and Wildlife Service Fishery Bulletin 85:187-199.

Duffy, W.J., R.S. McBride, S.X. Cadrin and K. Oliveira. 2011. Is Cating's methods of transverse groove counts to annuli applicable for all stocks of American shad? Transactions of the American Fisheries Society 140:1023-1034.

Elzey, S.P., K.A. Rogers and K.J Trull. 2015. Comparison of 4 aging structures in the American shad (*Also sapidissima*). Fishery Bulletin 113:47-54.

Lipkey, G.K., and A. Jarzynski. 2015. Project 2, Job 1. Stock assessment of adult and juvenile anadromous species in the Chesapeake Bay and select tributaries. Maryland Department of Natural Resources, Federal Aid Annual Report F-61-R-4, Annapolis, Maryland.

Macall, A.D. 2002. Use of known-biomass production models to determine productivity of west coast groundfish stocks. North American Journal of Fisheries Management 22:272-279.

McBride, R.S., M.L. Hendricks and J.E. Olney. 2005. Testing the validity of Cating's (1953) method for age verification of American shad using scales. Fisheries 30:10-18.

Olney, J. E., D.A. Hopler Jr, T.P. Gunter Jr, K.L. Maki, and J.M. Hoenig. 2003. Signs of recovery of American shad in the James River, Virginia. *American Fisheries Society Symposium*. Eds. K. E. Limburg, and J. R. Waldman. 35: 323-329.

Richardson, B. R., C. P. Stence, M.W. Baldwin and C.P. Mason. 2009. Restoration of American shad and hickory shad in Maryland's Chesapeake. 2008 Final Progress Report. Maryland Department of Natural Resources, Report F-57-R. Annapolis, Maryland.

Richardson, B.M., R.P. Morin, M.W. Baldwin and C.P. Stence. 2004. Restoration of American shad and hickory shad in Maryland's Chesapeake Bay. 2003 Final Progress Report. Maryland Department of Natural Resources. Annapolis, Maryland.

Ricker, W. E. 1975. *Computation and interpretation of biological statistics of fish populations*. Fisheries Research Board of Canada Bulletin 191.

Weinrich, D.W., A. Jarzynski and R. Sadzinski. 2008. Project 2, Job 1. Stock assessment of adult and juvenile anadromous species in the Chesapeake Bay and select tributaries. Maryland Department of Natural Resources, Federal Aid Annual Report F-61-R-4, Annapolis, Maryland.

Weinrich, D.W., M.E. Dore and W.R. Carter III. 1982. Job II. Adult population characterization. Maryland Department of Natural Resources, 1981 Federal Aid Annual Report F-37-R, Annapolis, Maryland.

Table 1. Number of adult American shad and repeat spawners by sex and age sampled from the Conowingo Dam tailrace in 2014.

AGE	Male		Female		Total	
	N	Repeats	N		N	Repeats
3	3	0	0	3	3	0
4	50	11	5	4	50	11
5	97	76	89	5	97	76
6	45	39	104	6	45	39
7	4	4	30	7	4	4
8	0	0	0	8	0	0
9	0	0	1	9	0	0
Totals	199	130	229	Totals	199	130
Percent Repeats	65.3%		83.8%		75.2%	

Table 2. Number of recaptured American shad in 2014 at the Conowingo Dam East and West Fish Lifts by tag color and year.

East Lift		
Tag Color	Year Tagged	Number Recaptured
Pink	2013	4
Yellow	2014	20
West Lift		
Tag Color	Year Tagged	Number Recaptured
NA	NA	0

Table 3. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from the recreational creel survey in the Susquehanna River below Conowingo Dam, 2001-2014. Due to sampling limitations, no data were available for 2011.

Year	Number of Interviews	Hours Fished for American Shad	American Shad Catch	Catch Per Angler Hour
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
2011				
2012	58	189.0	146	0.77
2013	63	161.8	107	0.66
2014	81	273.8	312	1.14

Table 4. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from spring logbooks for American shad, 2000-2014. 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	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

Table 5. Numbers of adult hickory shad and repeat spawners by sex and age sampled from the brood stock collection survey in Deer Creek in 2014.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	9	0	2	0	11	0
4	20	6	17	6	37	12
5	28	25	12	10	40	35
6	8	8	4	4	12	12
Totals	65	39	35	20	100	59
Percent Repeats	60.0%		57.1%		59.0%	

Table 6. Percent of hickory shad by age and number sampled from the brood stock collection survey in Deer Creek by year, 2004-2014.

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	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	
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	0.93	
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			

Table 7. Percent repeat spawning hickory shad (sexes combined) by year from the brood stock collection survey in Deer Creek, 2004-2014.

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

Table 8. Catch (numbers), effort (hours fished) and catch-per-angler-hour (CPAH) from spring logbooks for hickory shad, 1998-2014. 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 Logbooks/Anglers	Total Reported Angler Hours	Hickory Shad Catch	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

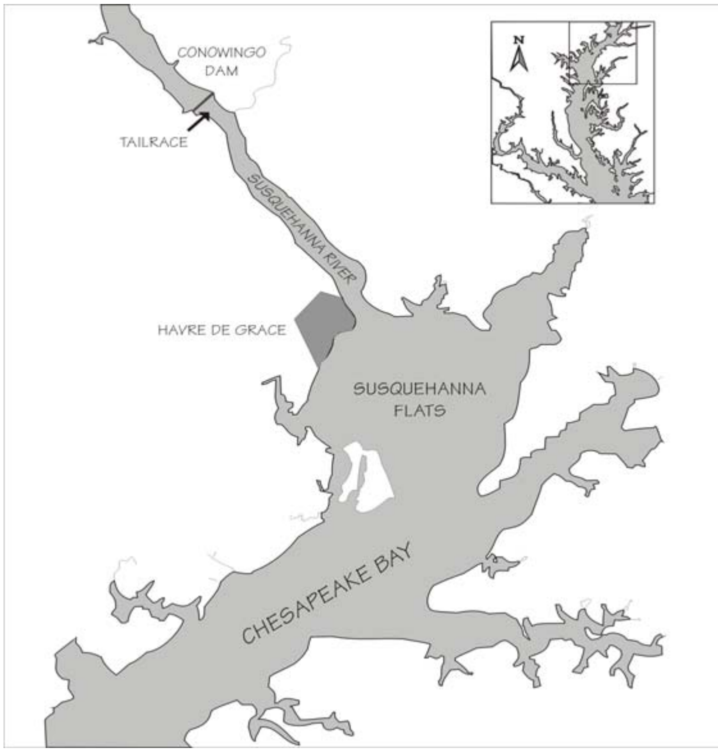

Figure 1. Conowingo Dam (Susquehanna River) hook and line sampling location for American shad in 2014.

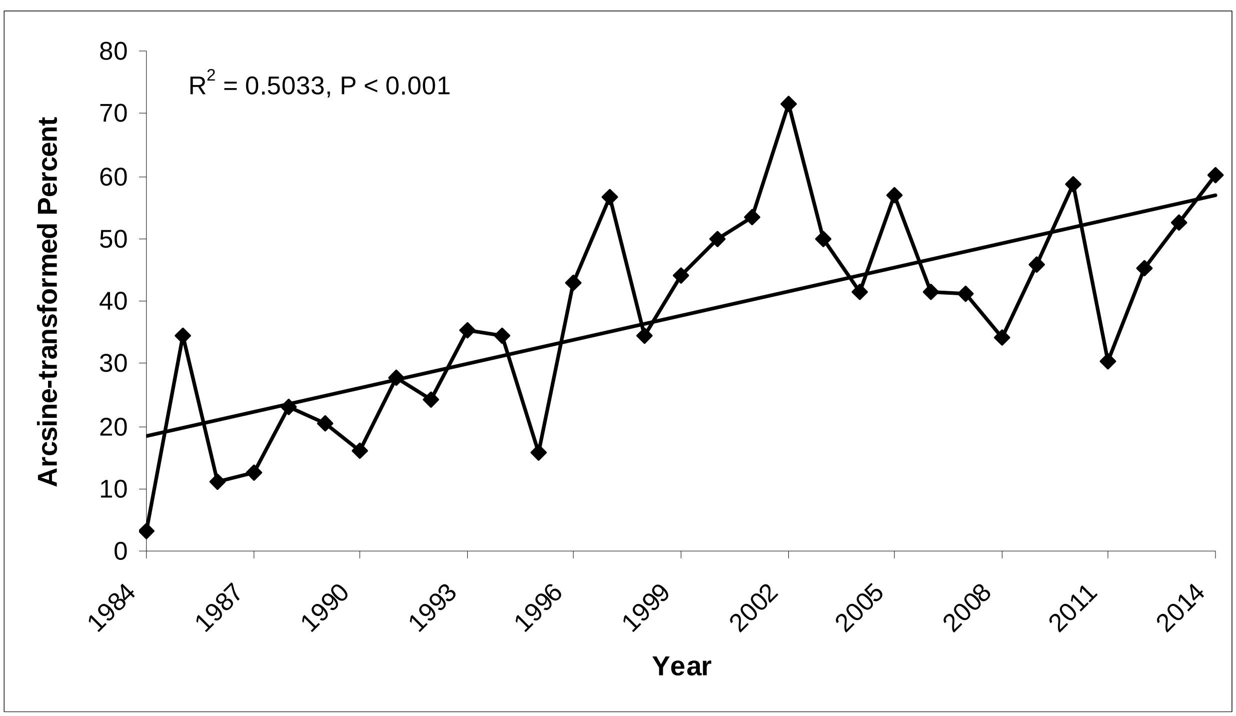

Figure 2. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984-2014.

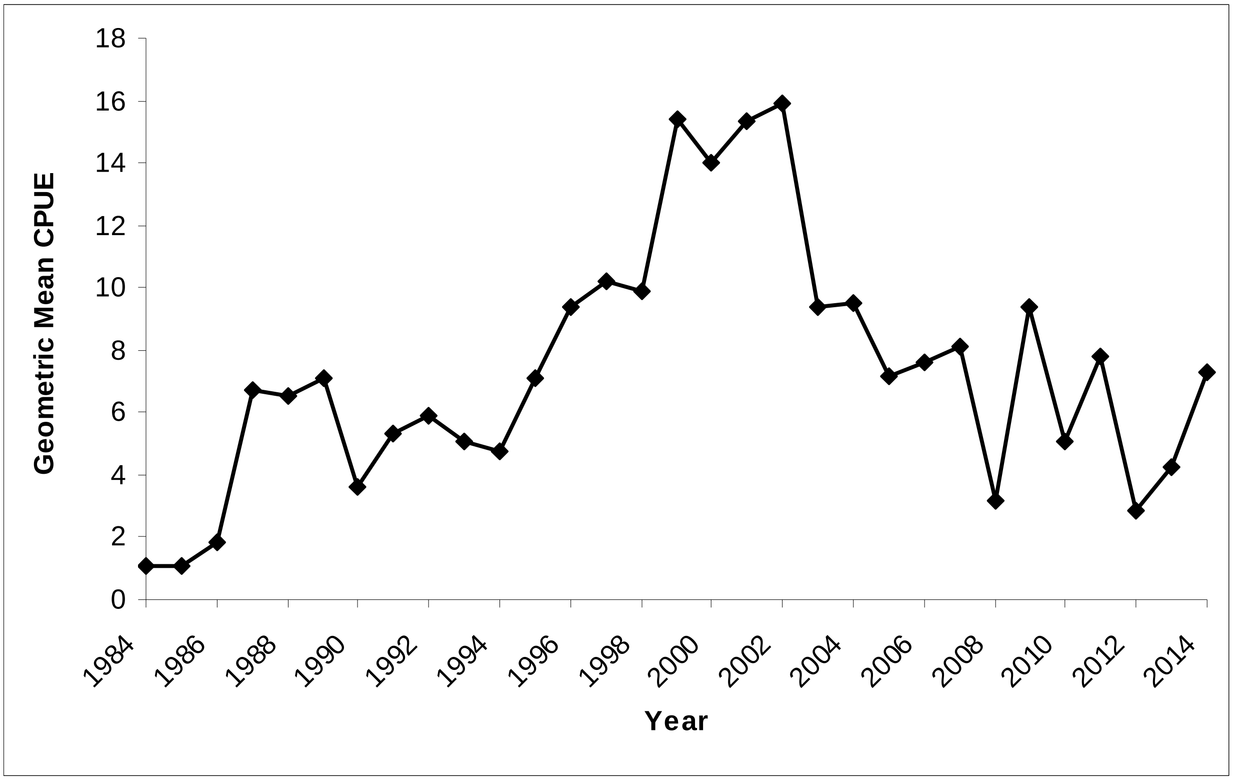

Figure 3. American shad geometric mean CPUE (fish per boat hour) from the Conowingo Dam tailrace hook and line sampling, 1984-2014.

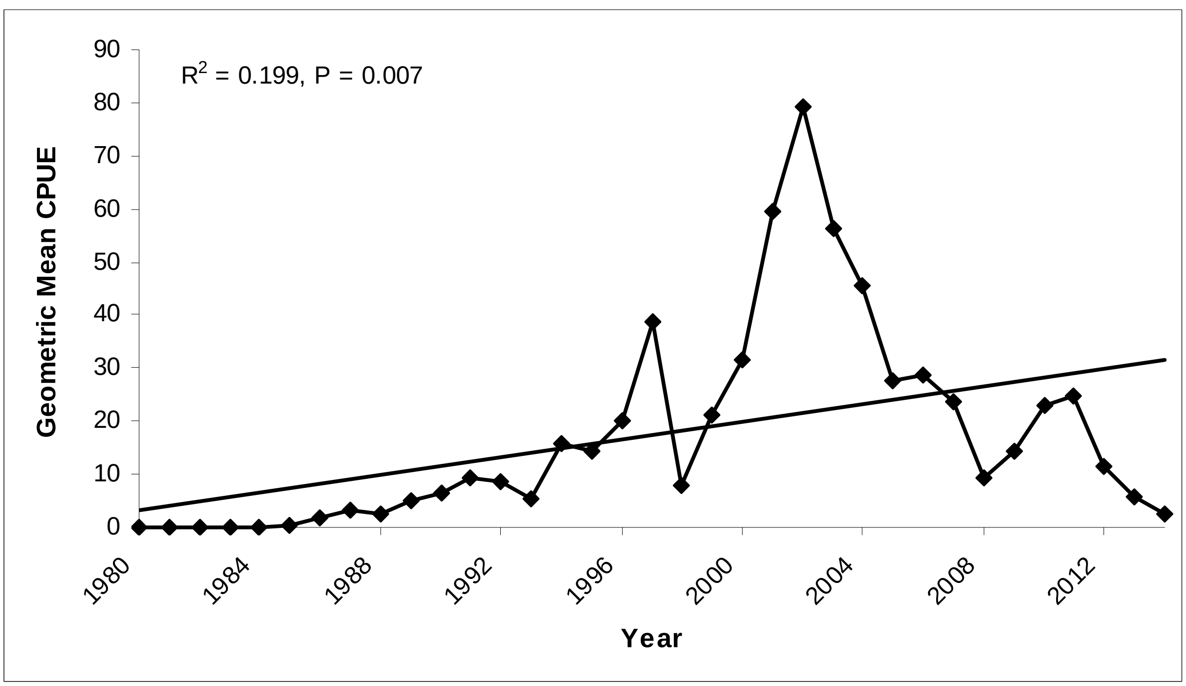

Figure 4. American shad geometric mean CPUE (fish per lift hour) from the East and West Fish Lifts at the Conowingo Dam, 1980-2014.

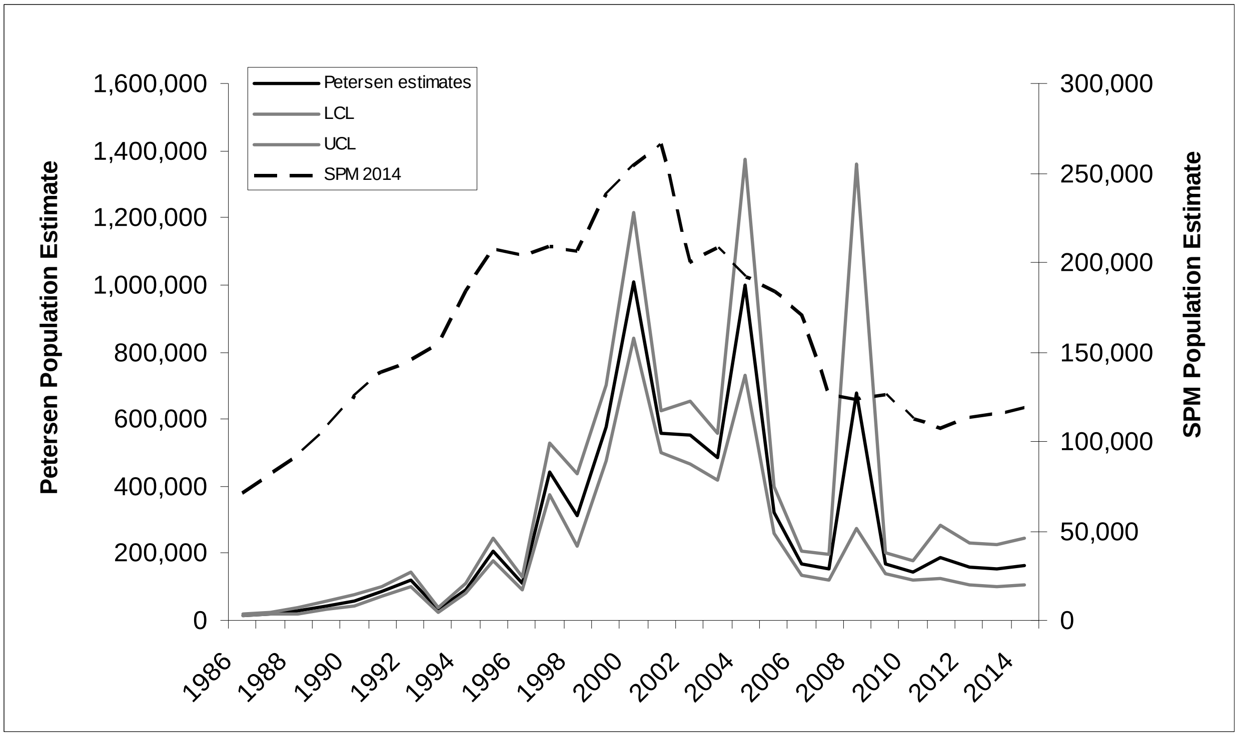

Figure 5. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen statistic and the surplus production model (SPM), 1986-2014.