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

Karen M. Capossela

Maryland Departments 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

METHODS

Data Collection

Adult American shad were angled from the Conowingo Dam tailrace on the Susquehanna River two to five times per week from 10 May through 18 May 2011 (Figure 1). Two 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 (TL) and fork length (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 (including unspent or ripe females) 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) at the Conowingo Dam were deposited into a trough, directed past a 4' x 10' counting window, identified to species and counted by experienced technicians. American shad recaptured from the West Fish Lift (WFL) at the Conowingo Dam were counted and either used for experiments (e.g., hatchery brood stock, oxytetracycline analysis, sacrificed for otolith extraction) or returned to the tailrace. For both lifts, tags were used to identify returning American shad.

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 logbook survey also provided location, catch 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 (2004-2011) from their brood stock collection in the Susquehanna River. Hickory shad were collected in Deer Creek (a Susquehanna River tributary) for hatchery brood stock and were subsampled 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 $\alpha = 0.05$.

Mean length-at-age was calculated by sex for American shad captured by hook and line at the Conowingo Dam. Linear regressions were used to examine trends in American shad mean lengths by age and sex over time (1980-2011) for ages with consistent representation.

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.

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 and WFL, M is the number of fish tagged and R is the number of tagged fish recaptured.

Overestimation of abundance by the Petersen statistic (due to low recapture rates) necessitated the additional use of a biomass surplus production model (SPM; Macall 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 in the previous year (equivalent to catch in a surplus production model). The dynamics of this population are governed by the logistic growth curve. 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). Assumptions include an annually proportional consumption of American shad by striped bass, proportional bycatch of American shad in the Atlantic herring fishery, and correct adult American shad turbine mortality estimates. The SPM required an initial population estimate in 1985, which was set as the 1985 Petersen statistic (calculation described above).

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 1:2.28. Of the 197 fish sampled by this gear, 172 were successfully scale-aged (Table 1). Males were present in age groups 4-6 and females were found in age groups 4-7. The 2006 year-class (age 5) was the most abundant for both sexes, accounting for 50% of males and 52.5% of females (Table 1). Twenty-eight percent of males and 24.6% of females were repeat spawners. The arcsine-transformed proportion of these repeat spawners (sexes combined) has significantly increased over the time series (1984-2011; $r^2 = 0.46$, $P < 0.001$; Figure 2).

Male American shad generally return to the Susquehanna River at an earlier age than females (1980-2011; Table 2). Mean length-at-age for females is greater than the corresponding mean length-at-age for males (Table 2); mean length has significantly decreased for male American shad at ages 4-6 and for female American shad at ages 4-7 since 1980 (Table 3; Figures 3, 4). The majority of the declines in mean length occurred in the beginning of the time series, with more recent values becoming fairly stable.

Relative Abundance

Sampling at the Conowingo Dam was restricted in 2011 due to heavy rains and high river flows. Only 197 adult American shad were sampled from the Conowingo tailrace over 7 sampling days; 125 of these fish were captured by MDNR staff from a boat and the remaining 72 were captured by shore anglers. MDNR staff tagged 196 (99.5%) of the sampled fish. To remain consistent with historical calculations, only the 125 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.

Operation of the EFL was delayed for most of April 2011 due to river water temperatures being less than 50.0°F and the onset of high river flows in excess of 100,000 cubic feet per second (cfs). The EFL operated for only 15 days between 25 April and 19 May. Exelon ceased EFL operations on 19 May due to the lack of successful American shad passage upstream at the Holtwood Dam facility. Of the 20,571 American shad that passed at the EFL, 87% (17,900 fish) passed between 11 May and 16 May. Peak passage was on 14 May when 5,013 American shad were recorded. Twenty of the American shad counted at the EFL counting windows were identified as being tagged in 2011; only 4 fish passed that were tagged in 2010 (Table 4).

In 2011, the Conowingo WFL operated for 15 days between 13 May and 5 June. The 3,074 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 16 May when 1,185 American shad were collected. Four of the six tagged American shad recaptured by the WFL in 2011 were fish tagged in 2011; the other two recaptured fish were tagged in 2010 (Table 4).

The Petersen statistic estimated 186,330 American shad in the Conowingo Dam tailrace in 2011, and the SPM estimated a population of 103,500 fish. Despite differences in yearly estimates, the overall population trends derived from each method are similar (Figure 5). Specifically, SPM estimates declined from 2001 to 2007 and increased from 2008 to 2011. Petersen estimates follow a similar pattern if the high levels of uncertainty in 2004 and 2008 (due to low recapture rates) are considered.

Estimates of hook and line GM CPUE have significantly increased over the time series (1984-2011; $r^2 = 0.21$, $P = 0.01$), although abundance is variable from 2005-2011 and remains below the high indices observed from 1999 to 2002 (Figure 6). The Conowingo Dam combined lift GM CPUE significantly increased over the time series (1980-2011; $r^2 = 0.38$, $P < 0.001$); however, the GM CPUE decreased steadily from 2002 to 2008 before increasing slightly from 2009 through 2011 (Figure 7).

Due to the limited number of sampling days in 2011, we did not obtain enough data from the angler-based roving creel survey at the Conowingo Dam tailrace to calculate CPAH. Data from previous years are included in Table 5. Although American shad CPAH calculated from shad logbook data decreased significantly over the time series (1999-2011; $r^2 = 0.38$, $P = 0.03$), CPAH has remained relatively level since 2008 (Table 6).

Mortality

The Conowingo Dam tailrace total instantaneous mortality estimate from catch curve analysis (using repeat spawning instead of age) resulted in Z = 1.40 (A = 73.5%).

Hickory Shad

Sex and Age Composition

A total of 1,648 hickory shad were sampled in 2011 by the brood stock collection survey in Deer Creek. The male-female ratio was 1.41:1. Of the total fish captured by this survey, 216 were successfully aged. Males were present in age groups 3-7 and females were found in age groups 3-8. The most abundant year-classes by sex were the 2008 year-class (age 3) for males (34.9%) and the 2007 year-class (age 4) for females (33.3%; Table 7). Hickory shad sampled from 2004 to 2011 ranged from 2 to 9 years of age, with ages 3 through 8 present every year (Table 8). The arcsine-transformed proportion of these repeat spawners (sexes combined) has not changed significantly over the time series (2004-2011; $r^2 = 0.028$, $P = 0.69$; Figure 8). However, the percent of repeat spawning males in 2011 (63.6%, Table 7) was lower than the percent of repeat spawning males in 2010 (74.4%), and the total percent of repeat spawners in 2011 (68.5%) was the second lowest total percent from 2004 to 2011 (Table 9).

Relative Abundance

Shad logbook data indicated that hickory shad CPAH did not vary significantly over the time series (1998-2011; $r^2 = 0.11$, $P = 0.25$); however, hickory shad CPAH increased in 2011 and is the highest it has been since 2007 (Table 10).

Mortality

Total instantaneous mortality in the Susquehanna River (Deer Creek) was estimated as Z = 0.67 (A = 48.8%).

DISCUSSION

American Shad

American shad are historically one of the most important exploited fish species in North America. However, the stock has drastically declined due to the loss of habitat, overfishing, ocean bycatch, stream blockages and pollution. Restoration of American shad 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).

American shad abundance has increased at the Conowingo Dam in the Susquehanna River since the 1980s: hook and line CPUE (1984-2011) and combined lift CPUE (1980-2011) have increased over their respective time series. As a cautionary note, hook and line estimates of abundance are not highly sensitive to changes in abundance because this gear can become saturated. In addition, 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. However, the Petersen statistic and SPM estimates of American shad abundance at the Conowingo Dam tailrace (1986-2011) support the observed increasing trends in CPUE. Factors contributing to this increase may include increased adult recruitment from stronger year-classes and reduced fish lift efficiencies (which may decrease the catchability of adult American shad at Conowingo Dam and reduce turbine mortality). Despite the overall increasing trends, a period of decreasing abundance is evident in all estimates between 2002 and 2007, including logbook CPAH.

Both the Petersen estimate and the SPM are useful techniques for providing estimates of American shad abundance at the Conowingo Dam. The SPM likely underestimates American

shad abundance. For example, the Conowingo Dam lift efficiency (defined as annual number of American shad lifted at Conowingo Dam divided by population estimate) was as high as 98.7 % in 2004, and it is unlikely that the dam passed nearly 100% of the fish in the Conowingo Dam tailrace. Conversely, the Petersen statistic likely overestimates the population, especially in years of low recapture of tagged fish. However, the trends (rather than the actual numbers) produced by the estimate/model should be emphasized when assessing the population at the Conowingo Dam in the Susquehanna River.

Scales are the only validated ageing structures for determining the age of American shad (Judy 1960, McBride et al. 2005). However, 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). Until alternative ageing structures are investigated, we will remain consistent with historical ageing methods; however, we discarded scales that were difficult to interpret and continue to use repeat spawning marks to calculate mortality rates.

The percent of repeat spawning American shad has increased over time. 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, 26% of aged American shad at the Conowingo Dam were repeat spawners in 2011, and, on average, 20% of aged fish were repeat spawners over the past five years. If stock abundance is correlated to the number of repeat spawners, the increase in repeat spawners in the Conowingo Dam tailrace may be related to the abundance increases observed over the time series.

Total instantaneous mortality rate for American shad captured in the Conowingo Dam tailrace in 2011 is within the range of reported Z estimates from other studies (ASMFC 2007). The mortality estimate may be a maximum rate because repeat spawning marks are assessed during the spawning season after fish have returned to freshwater but before developing a new spawning mark.

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. In the Susquehanna River, very few hickory shad are historically observed using the EFL. A notable exception was 2011: 20 hickory shad were counted at the EFL counting window, which is more than three times the previous high in 2002. 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). According to shad logbook data collected from Deer Creek anglers (1998-2011), catch rates exceed four fish per hour for all years except 2009 and 2010. 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 Maryland DNR staff during that spring season. Overall, catch rates have been quite variable, but CPAH in 2011 was the fourth highest CPAH of the 14 year time series.

Hickory shad age structure has remained consistent, with a wide range of ages and a high percentage of older fish. Ninety percent of hickory shad from the Susquehanna spawned by age four, and this stock generally consists of few virgin fish (Richardson et. al 2004). Repeat spawning has remained relatively consistent over the 2004-2011 time series, with the percent of repeat spawners ranging between 67-89%.

Because only a catch and release fishery exists for hickory shad in Maryland, estimates of Z are attributable solely to natural mortality. The high percent of repeat spawners is also indicative of very low bycatch mortality. Since both mature adults and immature sub-adults migrate and overwinter closer to the coast, hickory shad ocean bycatch is minimized compared to the other alosines (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.).

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.

Judy, M.H. 1960. Validity of age determination from scales of marked American shad. U.S. Fish and Wildlife Service Fishery Bulletin 185:161-170.

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.

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.

TABLES AND FIGURES

Table 1. Number of adult American shad and repeat spawners by sex and age sampled from the Conowingo Dam tailrace in 2011.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	0	0	0	0	0	0
4	18	0	14	0	32	0
5	25	7	64	10	89	17
6	7	7	40	16	47	23
7	0	0	4	4	4	4
8	0	0	0	0	0	0
Totals	50	14	122	30	172	44
Percent Repeats	28.0%		24.6%		25.6%	

Table 2. Mean length-at-age by sex for American shad sampled at the Conowingo Dam, 1980-2011.

Males

Year	Age									
	2	3	4	5	6	7	8	9	10	11
1980		381	427	462	495					
1981	292	363	417	470						
1982		384	411	460	458					
1983				413						
1984		332	381	434	470					
1985		360	387	426	450					
1986		324	395	430	440					
1987	238	341	379	431	433					
1988	288	332	395	440	490					
1989		347	371	435	473					
1990	250	345	389	419	473	495				
1991	250	343	378	412	445	480	530			
1992	275	319	375	406	430	451				
1993		325	371	414	434	455				
1994		351	381	409	449	505	540			
1995		336	375	412	452	483				
1996		340	379	427	456					
1997		341	378	420	458	472				
1998	280	346	387	411	442	455				
1999	287	338	371	405	427			460		
2000		344	381	417	452	450				
2001		350	394	419	456	476				

2002		346	379	419	454	455				
2003		361	389	415	450	447		480		
2004		350	392	424	440					
2005		355	383	416	447	467	485			
2006		348	388	416	461	468				
2007		358	387	418	448	465	503			
2008		355	383	414	434					
2009		351	380	400	429					
2010		361	392	413	436	445				
2011			384	417	445					

Table 2 continued. Mean length-at-age by sex for American shad sampled at the Conowingo Dam, 1980-2011.

Females

Year	Age									
	2	3	4	5	6	7	8	9	10	11
1980			447	479	528	524				
1981			464	487	512					
1982			436	471	527					
1983			472	459	470					
1984			403	468	492	551				
1985		349	424	457	496	511				
1986		387	431	470	518					
1987		387	413	466	505					

1988		384	428	466	524					
1989		340	421	474	521	526				
1990		360	414	444	493	538				
1991			410	436	471	516	550			
1992			407	434	457	496	540			
1993			399	427	454	476	493			
1994			411	433	470	484				
1995			408	437	471	502	485			
1996		355	416	447	484	499				
1997		362	402	451	481	506	516			
1998			419	439	466	485	525	562		
1999		420	406	440	463	473		540	505	
2000			415	446	478	497	498		540	
2001		359	421	449	479	502	523			
2002			423	455	482	504	509			
2003			420	442	473	500		510		
2004			429	454	473	515	518	520		
2005			427	452	474	498	546			
2006		354	419	446	467	483	494	519		
2007			422	447	471	502	514	526		
2008			419	442	469	484		506		
2009			415	442	467	483	503			
2010			422	444	464	502	515			
2011			417	442	462	485				

Table 3. Regression statistics for American shad mean length by age and sex over time (1980-2011). Only ages with consistent representation over time were considered. Bolded values indicate significant changes in mean length-at-age over time.

	Males				Females			
Age	N	Slope	r^2	*P*	N	Slope	r^2	*P*
3	30	-0.003	< 0.001	0.9925				
4	31	-0.523	0.1431	**0.0359**	32	-0.625	0.1361	**0.0377**
5	32	-1.121	0.4188	**< 0.001**	32	-0.945	0.3688	**< 0.001**
6	30	-0.884	0.2255	**0.0080**	32	-1.607	0.4762	**< 0.001**
7					26	-1.290	0.3403	**0.002**

Table 4. Number of recaptured American shad in 2011 at the Conowingo Dam East and West Fish Lifts by tag color and year.

East Fish Lift		
Tag Color	Year Tagged	Number Recaptured
Green	2011	20
Pink	2010	4
West Fish Lift		
Tag Color	Year Tagged	Number Recaptured
Green	2011	4
Pink	2010	2

Table 5. Recreational creel survey data from the Susquehanna River below Conowingo Dam, 2001-2010. Due to sampling limitations, no data were available for 2011.

Year	Number of Interviews	Total Fishing hours	Total Catch of American Shad	Mean Number of American shad caught per 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

Table 6. Catch (numbers), effort (hours fished) and catch per angler hour from spring logbooks for American shad, 1999-2011.

Year	Total Reported Angler Hours	Total Number of American Shad	Catch Per Angler Hour
1999	160.5	463	2.88
2000	404	3,137	7.76
2001	272.5	1,647	6.04
2002	331.5	1,799	5.43
2003	530	1,222	2.31
2004	291	1035	3.56
2005	258.5	533	2.06
2006	639	747	1.17
2007	242	873	3.61
2008	559.5	1,269	2.27
2009	378	967	2.56
2010	429.5	857	2.00
2011	174	413	2.37

Table 7. Numbers of adult hickory shad and repeat spawners by sex and age sampled from the brood stock collection survey in Deer Creek in 2011.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	45	0	20	0	65	0
4	36	35	29	28	65	63
5	36	35	23	23	59	58
6	10	10	9	9	19	19
7	2	2	4	4	6	6
8	0	0	2	2	2	2
Totals	129	82	87	66	216	148
Percent Repeats	63.6%		75.9%		68.5%	

Table 8. Percent of hickory shad by age and number sampled from the brood stock collection survey in Deer Creek by year, 2004-2011.

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	2.78	0.93	

Table 9. Percent repeat spawning hickory shad (sexes combined) by year from the brood stock collection survey in Deer Creek, 2004-2011.

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

Table 10. Catch (numbers), effort (hours fished) and catch per angler hour from spring logbooks for hickory shad, 1998-2011.

Year	Total Reported Angler Hours	Total Number of Hickory Shad	Catch Per Angler Hour
1998	600.0	4,980	8.30
1999	817.0	5,115	6.26
2000	655.0	3,171	14.8
2001	533.0	2,515	4.72
2002	476.0	2,433	5.11
2003	635.0	3,143	4.95
2004	750.0	3,225	4.30
2005	474.0	2,094	4.42
2006	766.0	4,902	6.40
2007	401.0	3,357	8.37
2008	942.0	5,465	5.80
2009	561.0	2,022	3.60
2010	552.0	1,956	3.54
2011	224.3	1,802	8.03

Figure 1. Conowingo Dam (Susquehanna River) hook and line sampling location for American shad in 2011.

Figure 2. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984-2011.

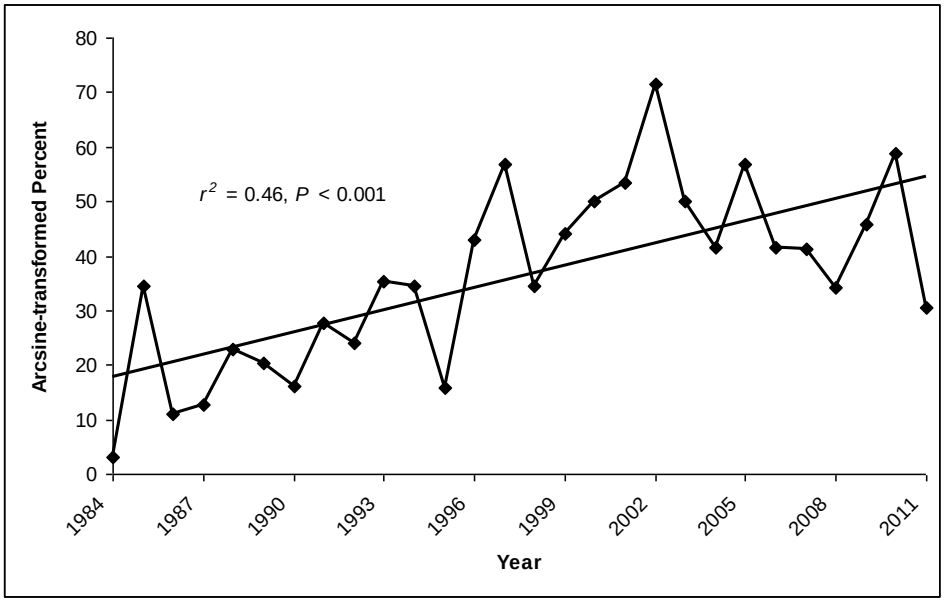

Figure 3. Mean length by age over time for male American shad, 1980-2011. Trend lines are included for ages where mean length varies significantly over time.

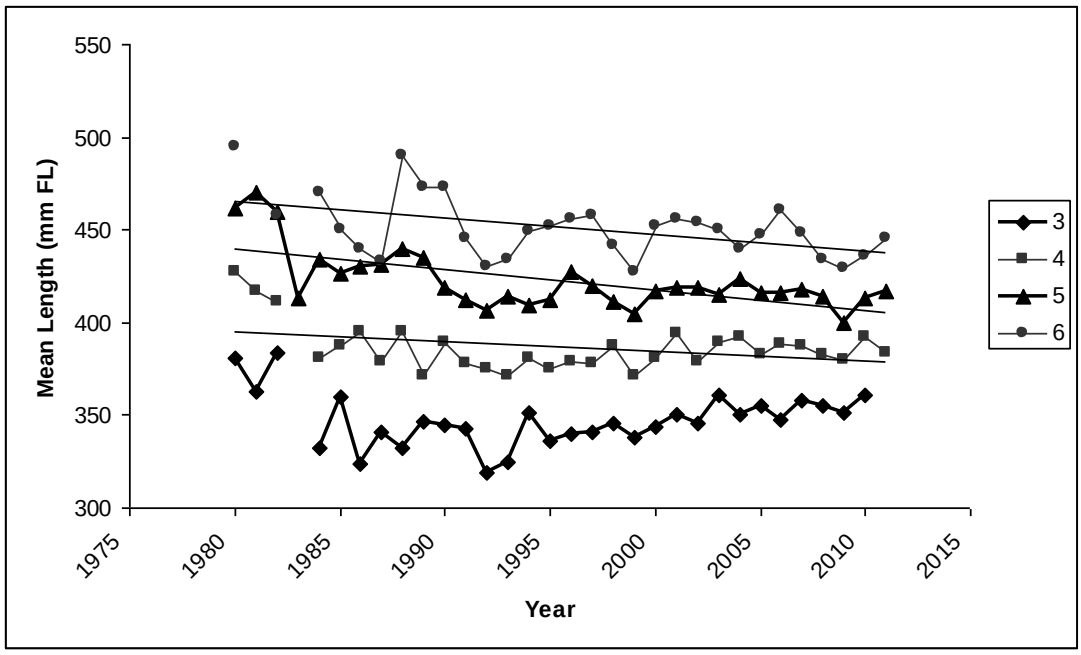

Figure 4. Mean length by age over time for female American shad, 1980-2011. Trend lines are included for ages where mean length varies significantly over time.

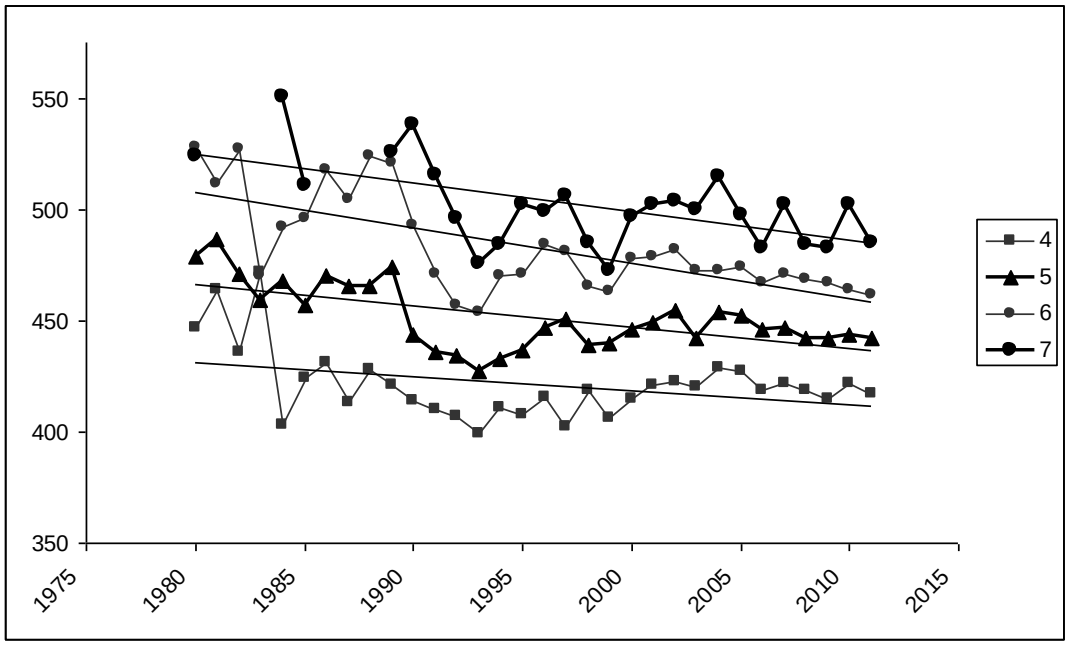

Figure 5. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen statistic and the surplus production model (SPM), 1986-2011.

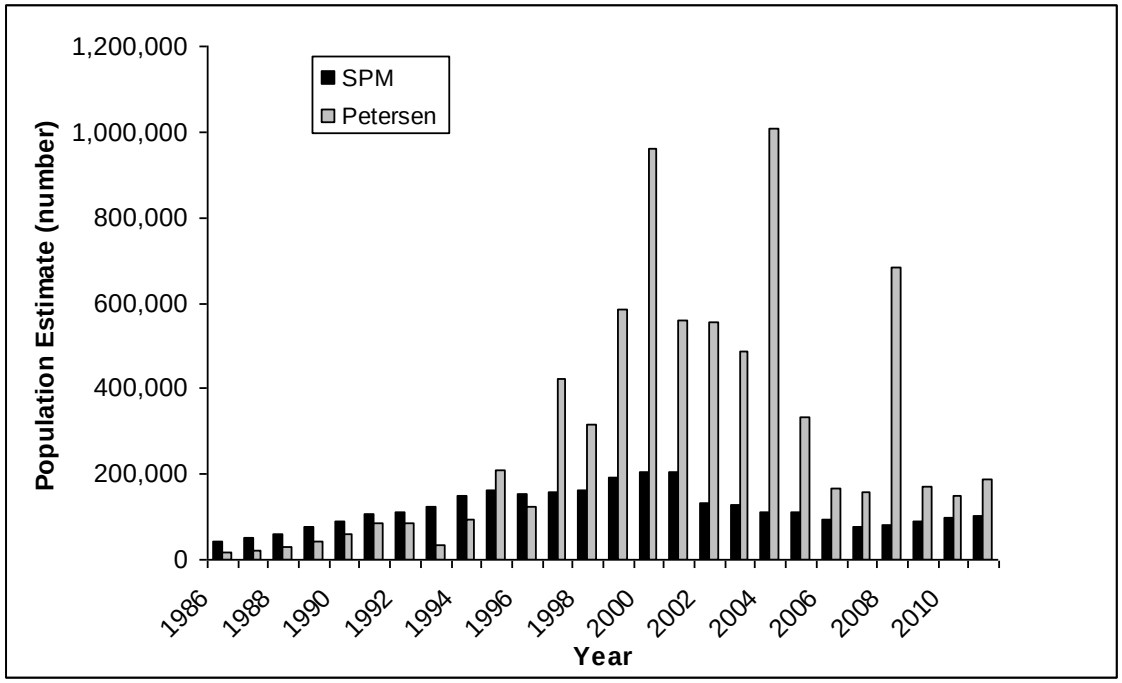

Figure 6. American shad geometric mean CPUE (fish per boat hour) from the Conowingo Dam tailrace hook and line sampling, 1984-2011.

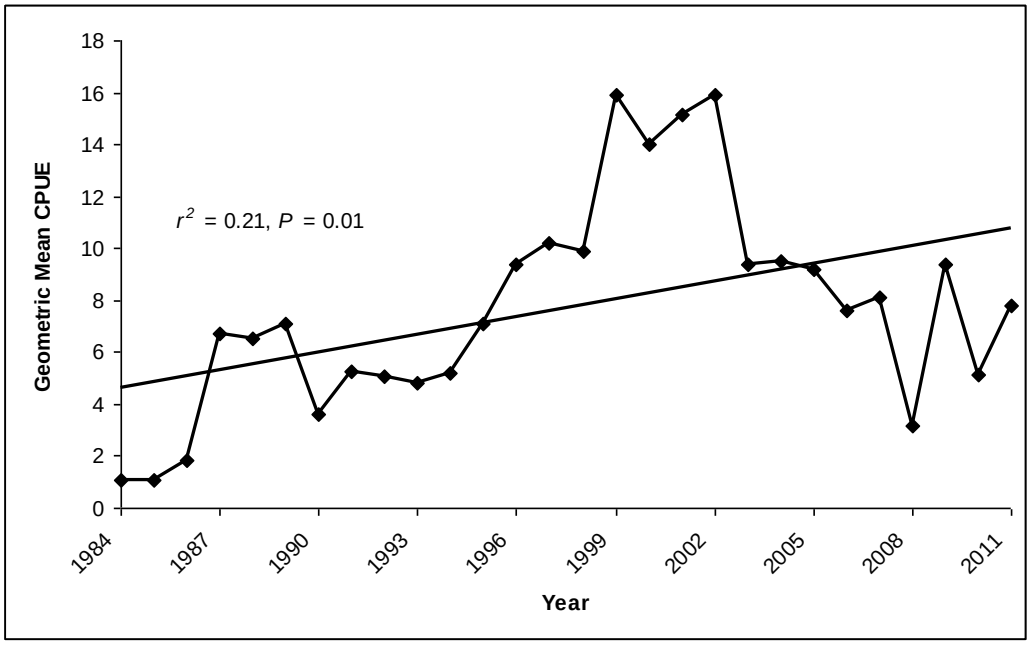

Figure 7. American shad geometric mean CPUE (fish per lift hour) from the East and West Fish Lifts at the Conowingo Dam, 1980-2011.

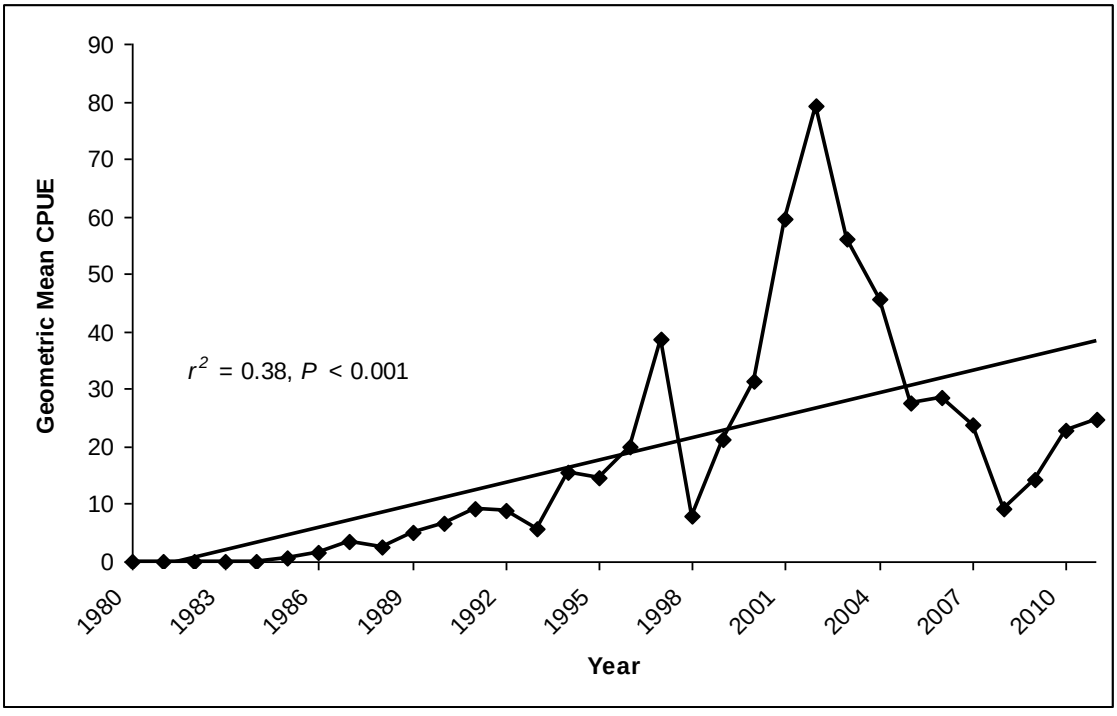

Figure 8. Arcsine-transformed percentages of repeat spawning hickory shad (sexes combined) collected from Deer Creek (Susquehanna River), 2004-2011.