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. 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 from the Conowingo Dam tailrace on the Susquehanna River two times per week from 4 April through 30 May 2012 (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 (2004-2012) 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 $\alpha = 0.05$.

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 and bycatch mortality in the Atlantic herring fishery 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 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 1:0.72. Of the 191 fish sampled by this gear, 177 were successfully scale-aged (Table 1). Males were present in age groups 3-6 and females were found in age groups 3-8. The 2007 year-class (age 5) and the 2006 year-class (age 6) were the most abundant for males and females, respectively, accounting for 45% of males and 46% of females (Table 1). Thirty-four percent of males and 73% of females were repeat spawners. The arcsine-transformed proportion of these repeat spawners (sexes combined) has significantly increased over the time series (1984-2012; $r^2 = 0.45$, $P < 0.001$; Figure 2).

Relative Abundance

Sampling at the Conowingo Dam occurred for 18 days in 2012. A total of 226 adult American shad were encountered by the gear; 217 of these fish were captured by MDNR staff from a boat and the remaining 9 were captured by shore anglers. MDNR staff tagged 190 (84%) of the sampled fish. To remain consistent with historical calculations, only the 217 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

The EFL operated for 62 days between 2 April and 5 June. The 2012 season was the third longest season of EFL operation and had the highest number of lifts since the EFL became operational in 1991. Of the 22,143 American shad that passed at the EFL, 39% (8,665 fish) passed between 22 April and 11 May. Peak passage was on 24 April; 1,710 American shad were recorded on this date. Twenty-four of the American shad counted at the EFL counting windows were identified as being tagged in 2012; only 2 fish passed that were tagged in 2011 (Table 2).

The Conowingo WFL operated for 37 days. The 1,486 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 5 May. The four tagged American shad recaptured by the WFL in 2012 were fish tagged in 2012 (Table 2).

The Petersen statistic estimated 150,743 American shad in the Conowingo Dam tailrace in 2012, and the SPM estimated a population of 111,500 fish. Despite differences in yearly estimates, the overall population trends derived from each method are similar (Figure 3). Specifically, SPM estimates declined from 2001 to 2007 and increased from 2008 to 2012. 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 vary without trend over the time series (1984-2012; $r^2 = 0.11$, $P = 0.07$). Abundance is particularly variable from 2007-2012 and remains below the high indices observed from 1999 to 2002 (Figure 4). WFL data have not yet been released by Normandeau Associates, Inc., to calculate the combined lift GM CPUE. As of 2011, the 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 5).

The creel survey conducted 58 interviews were conducted over five days during creel survey at the Conowingo Dam Tailrace. The CPAH in 2012 was the third lowest since the start of the survey in 2001 (Table 3), and CPAH has decreased over the time series (2001-2012; $r^2 = 0.46$, $P = 0.02$). Three anglers returned logbooks in 2012. Although American shad CPAH calculated from shad logbook data decreased significantly over the time series (1999-2012; $r^2 = 0.35$, $P = 0.03$), CPAH has steadily increased since 2009 (Table 4).

Mortality

The Conowingo Dam tailrace total instantaneous mortality estimate from catch curve analysis (using repeat spawning instead of age) resulted in $Z = 0.61$.

Hickory Shad

Sex and Age Composition

A total of 1,014 hickory shad were sampled in 2012 by the brood stock collection survey in Deer Creek. The male-female ratio was 2.06:1. Of the total fish captured by this survey, 200 were successfully aged. Males were present in age groups 3-6 and females were found in age groups 3-7. The most abundant year-classes by sex were the 2008 year-class (age 4) for both males (42.6%) and females (33.8%; Table 5). Hickory shad sampled from 2004 to 2012 ranged from 2 to 9 years of age, with ages 3 through 8 present every year except for 2012 (Table 6). In 2012, the oldest fish were age 7. The arcsine-transformed proportion of these repeat spawners (sexes combined) has not changed significantly over the time series (2004-2012; r^2 = 0.028, P = 0.67; Figure 6). However, the total percent of repeat spawners in 2012 (64.0%) is the lowest total percent of repeat spawners of the time series (2004-2012; Table 7).

Relative Abundance

Shad logbook data indicated that hickory shad CPAH did not vary significantly over the time series (1998-2012; r^2 = 0.13, P = 0.19); however, hickory shad CPAH decreased in 2012 (Table 8).

Mortality

Total instantaneous mortality in the Susquehanna River (Deer Creek) was estimated as Z = 0.68.

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).

The population size of American shad appears to be increasing in the lower Susquehanna, particularly since 2007 (SPM estimate). This follows a period (2002 to 2007) when calculated indices of abundance generally decreased (including the hook and line CPUE, logbook CPAH and creel CPAH). Despite this increase in population size, the 2012 hook and line CPUE was the lowest it has been since 1986 and there is no significant trend in CPUE over time. 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. The Potomac River CPUE is increasing (1996-2012); however, the CPUE in the Nanticoke River shows no significant trend (1988-2011), which suggests uneven area-wide recovery.

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, 50% of aged American shad at the Conowingo Dam were repeat spawners in 2012. This increase in repeat spawners may be related to the end of truck and transport methods in 1997. During truck and transport, American shad were transported above dams where turbine mortality was nearly ensured for all fish returning downstream. However, the population size did decrease after truck and transport ended in 1997, confirming that multiple factors contribute to the recovery of American shad in the lower Susquehanna River (i.e., spawning habitat, juvenile success, percent of repeat spawners).

The total instantaneous mortality rate for American shad captured in the Conowingo Dam tailrace in 2012 is below the benchmark Z_{30} assigned to rivers in neighboring states (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 (1998-2012), 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.

Hickory shad age structure has remained relatively 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 2004-2012 time series, with the percent of repeat spawners ranging between 64-89%.

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. 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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TABLES

Table 1. Number of adult American shad and repeat spawners by sex and age sampled from the Conowingo Dam tailrace in 2012.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	4	0	1	0	5	0
4	31	5	1	0	32	5
5	46	15	14	5	60	20
6	22	15	34	25	56	40
7	0	0	23	23	23	23
8	0	0	1	1	1	1
Totals	103	35	74	54	177	89
Percent Repeats	34.0%		73.0%		50.3%	

Table 2. Number of recaptured American shad in 2012 at the Conowingo Dam East and West Fish Lifts by tag color and year.

East Lift		
Tag Color	Year Tagged	Number Recaptured
Orange	2012	24
Green	2011	2
West Lift		
Tag Color	Year Tagged	Number Recaptured
Orange	2012	4

Table 3. American shad recreational creel survey data from the Susquehanna River below Conowingo Dam, 2001-2012. Due to sampling limitations, no data were available for 2011.

Year	Number of Interviews	Hours Fished for American Shad	American Shad Catch	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	120	1.41
2010	36	64	114	1.78
2011				
2012	58	189	146	0.77

Table 4. Catch (numbers), effort (hours fished) and catch per angler hour from spring logbooks for American shad, 1999-2012.

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
2012	171.5	486	2.83

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 2012.

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	40	0	13	0	53	0
4	55	42	24	18	79	60
5	28	28	21	21	49	49
6	6	6	9	9	15	15
7	0	0	4	4	4	4
8	0	0	2	2	0	0
Totals	129	76	87	66	200	128
Percent Repeats	58.9%		73.2%		64.0%	

Table 6. Percent of hickory shad by age and number sampled from the brood stock collection survey in Deer Creek by year, 2004-2012.

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	
2012	200		49.3	76.4	51.3	17.3	5.6		

Table 7. Percent repeat spawning hickory shad (sexes combined) by year from the brood stock collection survey in Deer Creek, 2004-2012.

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

Table 8. Catch (numbers), effort (hours fished) and catch per angler hour from spring logbooks for hickory shad, 1998-2012.

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
2012	184.0	857	4.66

FIGURES

Figure 1. Conowingo Dam (Susquehanna River) hook and line sampling location for American shad in 2012.

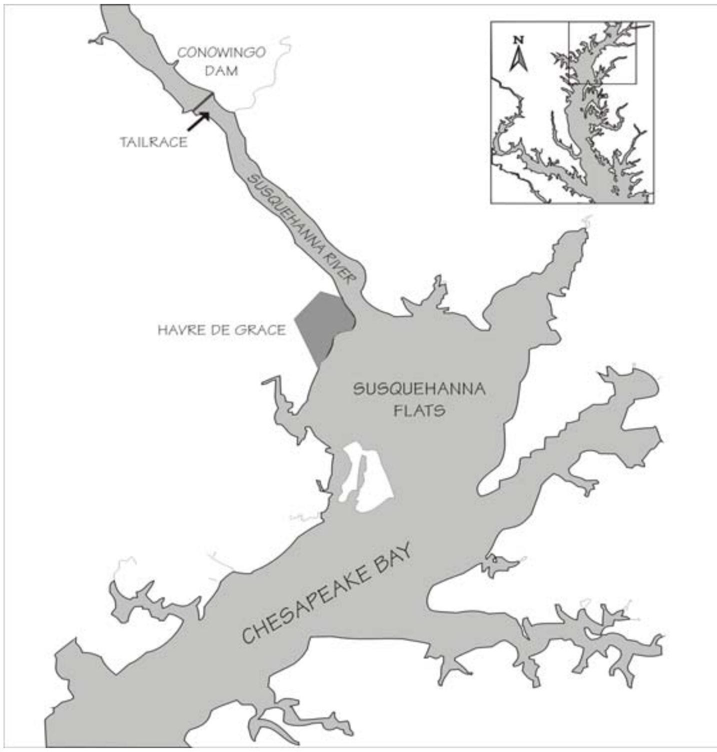

Figure 2. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984-2012.

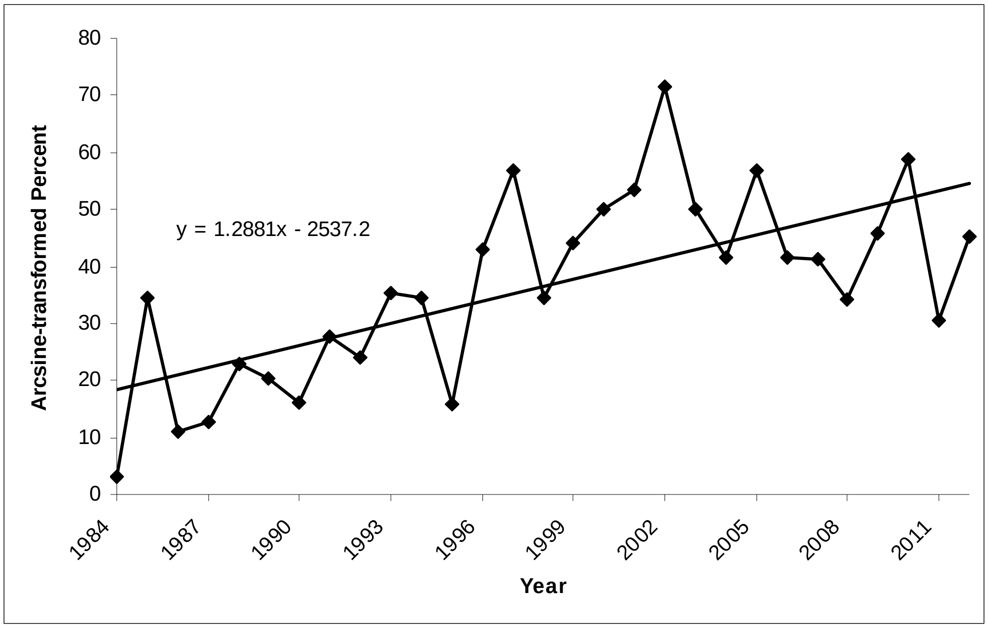

Figure 3. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen statistic and the surplus production model (SPM), 1986-2012.

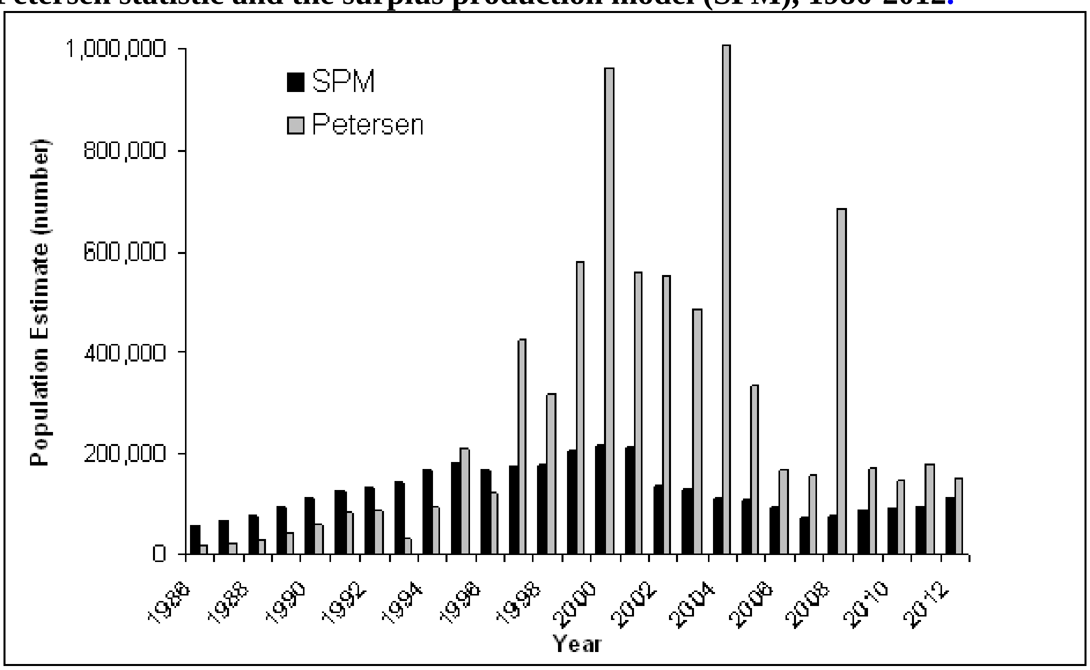

Figure 4. American shad geometric mean CPUE (fish per boat hour) from the Conowingo Dam tailrace hook and line sampling, 1984-2012.

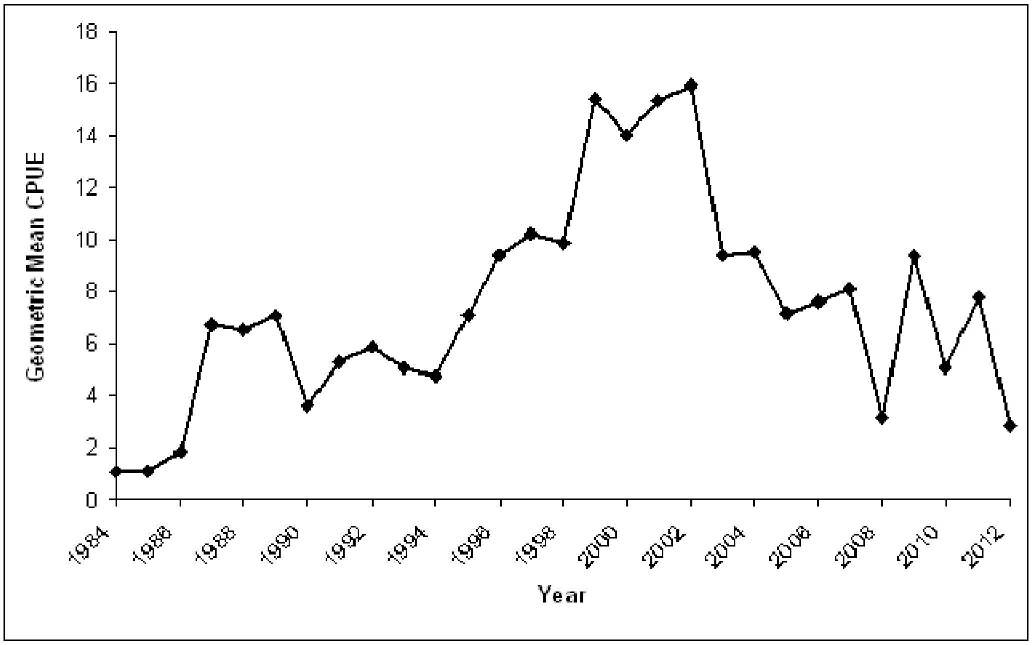

Figure 5. American shad geometric mean CPUE (fish per lift hour) from the East and West Fish Lifts at the Conowingo Dam, 1980-2011. Data for 2012 have not yet been released.

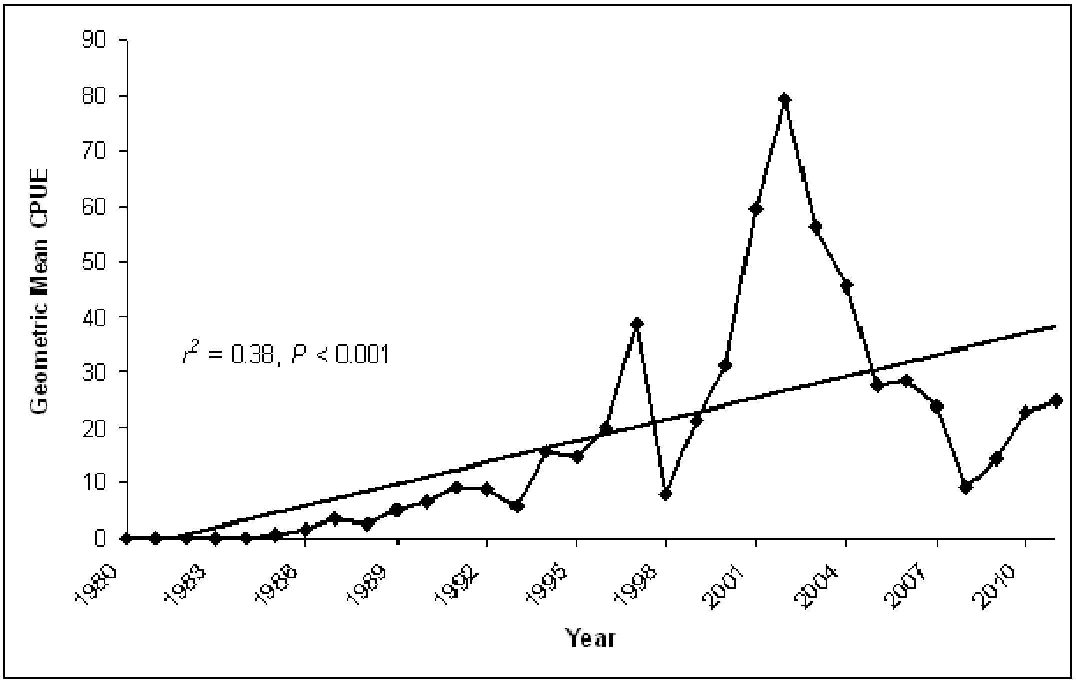

Figure 6. Arcsine-transformed percentages of repeat spawning hickory shad (sexes combined) collected from Deer Creek (Susquehanna River), 2004-2011.