Executive Summary 2021
Maryland Portion Job VI
(**POPULATION ASSESSMENT OF AMERICAN AND HICKORY SHAD IN THE UPPER CHESAPEAKE BAY):**

The Maryland Department of Natural Resources conducts annual surveys targeting adult American shad and hickory shad in the upper Chesapeake Bay (Susquehanna River). American shad are angled from the Conowingo Dam tailrace, measured, sexed, tagged and released. Indices of abundance are derived from these hook and line data and from combined fish lift data. Recreational creel, logbook and online surveys also provide information on American and hickory shad abundance. The Maryland Department of Natural Resources Fish Health and Hatcheries Program provides additional hickory shad data from broodstock collection in the lower Susquehanna River. In 2021, 293 American shad were angled from the Susquehanna River below Conowingo Dam from 22 April through 25 May 2021, and 288 were successfully scale-aged. Males were present in age groups three through seven and females were present in age groups four through seven. The 2016 year-class (age five) was the most abundant for males and the 2015 year-class (age six) was most abundant for females. The trend in arcsine-transformed percentage of repeat spawning American shad continues to increase from historic lows in the 1980s. Estimates of abundance for American Shad in the lower Susquehanna River were relatively consistent with recent years and are well below time series peak values observed in the early 2000s. Hickory shad age structure in the lower Susquehanna River has truncated in recent years, with fewer fish over the age of six. Males were present in age groups three through six and females were present in age groups three through seven. The 2017 year-class (age 4) was the most abundant year class for both males and females. The trend in arcsine-transformed percentage of repeat spawning hickory shad has decreased since monitoring began in 2004.

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

Matthew B. Jargowsky and David Sanderson-Kilchenstein
Maryland Department of Natural Resources, Fishing and Boating Services
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; thereafter, American shad abundance generally decreased until 2007. In recent years, population estimates have been low and variable. Hickory shad abundance has declined from historic levels, but the lower Susquehanna River basin hosts the greatest densities of hickory shad in Maryland (Richardson et al. 2009).

METHODS

Data Collection

Adult American shad were sampled by Maryland Department of Natural Resources staff in the Conowingo Dam tailrace on the lower Susquehanna River two to four times per week from 22 April through 25 May 2021 (Figure 1). Staff angled American shad from shore, while also opportunistically sampling American shad caught by cooperative recreational anglers. Historically, Maryland Department of Natural Resources staff angled American shad from boat using two to three rods simultaneously; each rod was rigged with two shad darts and lead weight was added when necessary to achieve proper depth. This was not done in 2021 due to complications with boat access at the Conowingo Dam tailrace. Captured American shad were sexed (by expression of gonadal products), measured to the nearest mm (fork length [FL] and total length [TL]) and scales were removed below the insertion of the dorsal fin for aging 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 by year) and released. A Maryland Department of Natural Resources hat was awarded for tags returned by recreational anglers.

Normandeau Associates, Inc. was responsible for observing and/or collecting American shad at the Conowingo Dam fish lifts. From 2001 to 2019, the East Fish Lift (EFL) emptied fish into a raceway that directed fish past a viewing window and into the pool above the dam. The West Fish Lift (WFL) captured fish for research purposes using a manual sorting process. Due to the

COVID-19 pandemic, the WFL did not operate in 2020 and the EFL did not start operation until 12 May. The EFL only operated four days before it was shut down due to the passage of 21 northern snakehead *Channa argus* into Conowingo Pond. The EFL did not operate in 2021 to prevent the upstream passage of invasive species (specifically northern snakehead blue catfish *Ictalurus furcatus*, and flathead catfish *Pylodictis olivaris*). The WFL did operate in 2021 and, in addition to collecting fish for research purposes, also collected American shad and river herring for the purposes of upstream transportation.

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

Maryland Department of Natural Resources' Fish Health and Hatcheries Program provided additional hickory shad data (2004–2021) from their brood stock collection. Hickory shad were collected in the Susquehanna River near Lapidum, MD for hatchery brood stock and were sub-sampled for age, repeat spawning marks, sex, length (FL) and weight. Fish were collected primarily by electrofishing, supplemented by hook and line fishing. Scale samples were taken from the first 20 fish per day for age determination.

Ageing Protocol

Aging shad using scales is common practice, as it is the only non-lethal aging structure for these fishes (Cating 1953). Since 1984, Maryland Department of Natural Resources staff have aged American shad using scales, although methods for age determination have changed over time (Cating 1953; Elzey et al. 2015a). Many researchers have called into question the accuracy of scale aging (Elzey et al. 2015b). Hard structures, such as otoliths, often produce higher age agreement among readers compared to scales, though they lack repeat spawning information (Duffy et al. 2012; Elzey et al. 2015b). Only scales were aged in 2021 due to time constraints, sample availability and the desire to remain consistent across years.

American shad scales were aged following established protocols (Elzey et al. 2015a) as recommended by Atlantic States Marine Fisheries Commission (ASMFC) aging experts. A minimum of four scales per sample were cleaned, mounted between two glass slides and read for age and spawning history using a Micron 385 microfiche reader. The scale edge was counted as an annuli due to the assumption that each fish had completed a full year's growth at the time of capture. Ages were not assigned to regenerated scales or to scales that were difficult to read. Repeat spawning marks were counted on all scales during aging. In 2021, age determination was done independently by three readers. In the event of a disagreement in the age or spawning mark estimates, the readers consulted with each other and either reached an agreement or deemed the scale unreadable. If a consensus age or spawning mark could not be determined jointly, the sample was eliminated from further analysis.

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

Data Analysis

Sex and Age Composition

Male-female ratios were derived for American shad and hickory and scales were collected as described above. If the total number of samples per species was greater than 300, approximately 300 random subsamples, proportional to catch by date, were processed for aging and then applied to total catch using an age-length key derived from the subsampled ages. The percentages of repeat spawners by species and system (sexes combined) were arcsine-transformed (in degrees) and then examined for linear trends over time. For all statistics, significance was determined at $\alpha = 0.05$.

Otoliths collected from American shad sampled at the Conowingo Dam were primarily used for hatchery versus wild origin determination. All hatchery produced juvenile American shad stocked in Maryland, Delaware and the Susquehanna River basin have unique fluorescent OTC marks. Otolith examination by the Pennsylvania Fish and Boat Commission (PFBC) indicated the percent of non-hatchery fish present from American shad collected in the WFL.

Relative Abundance

Using catch-per-unit-effort (CPUE) as a measure of relative abundance is a common practice in fisheries science. Catch-per-unit-effort calculated using the arithmetic mean can often be biased by atypical sampling events with excessively high catches. Therefore, for most surveys in this project, CPUE was calculated using the geometric mean (GM CPUE), calculated as the average LN (CPUE + 1) for each fishing/sampling day, transformed back to the original scale. Geometric mean CPUE was calculated using the total number of adult fish lifted per hour of operation at the WFL at Conowingo Dam. Geometric mean catch-per-angler-hour (GM CPAH) for American shad and hickory shad angled in the Susquehanna River Basin were calculated from the data provided by the logbook survey (paper logbook data and online angler reports were combined) and roving creel survey. Start and end dates were defined by the first and last dates a fish was captured for both recreational surveys.

Population Estimates

Chapman's modification of the Petersen method 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 after the annual tagging effort began, M is the number of fish tagged minus 3% tag loss and R is the number of tagged fish recaptured, excluding recapture of previous years' tags. Prior to 2001, data from both the EFL and WFL were used in the population estimate. Beginning in 2001, observations at the WFL were omitted to avoid double counting, as it became protocol for some fish captured at the WFL to be returned to the tailrace. However, in 2021, due to the EFL not operating, only data from the WFL were used. Calculation of 95% confidence limits (N^*) for the Petersen method 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

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

Mortality

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

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

where N is the total number of fully recruited fish and T was calculated as:

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

where n_0 is the number of fish at the first fully recruited age, n_1 is the number of fish one year older than first fully recruited age and this is carried out for all age groups greater than the first fully recruited age (A). The Chapman-Robson estimate is less biased than traditional catch curve methods (Dunn et al. 2002).

Juvenile Abundance

The Maryland Department of Natural Resources Estuarine Juvenile Finfish Seine Survey (EJFS) provided juvenile indices (geometric mean catch-per-seine-haul) for American shad from fixed stations in the upper Chesapeake Bay dating back through 1959. The survey uses a 30.5 m (100 ft) x 1.24 m (4.1 ft) bagless beach seine of untreated 6.4 mm (0.25 in) bar mesh, which is set by hand. One end is held from shore and the other is fully stretched perpendicular from the beach, or until depths reach 1.6 m (5.2 ft), and is swept with the current. When depths do not exceed 1.6 m, the area swept is the equivalent to a 729 m^2 (2392 ft^2) quadrant. Hickory shad data are not reported by the EJFS due to historically infrequent encounters.

RESULTS

American Shad

Sex and Age Composition

The male-female ratio of adult American shad captured by hook and line from the Conowingo Dam tailrace in 2021 was 1:1.23. Of the 293 fish sampled by this gear, 288 were successfully scale-aged (Table 1). Males were present in age groups three through seven and females were found in age groups four through seven. The 2016 year-class (age five) was the most abundant for males (40.7%) and the 2015 year-class (age six) was most abundant for females (39.9%; Table 2). Forty-six percent of males and 53.6% of females were repeat spawners (Figure 2). The arcsine-transformed proportion of repeat spawners (sexes combined) significantly increased over the time series (1984–2021; $R^2 = 0.68$, $P < 0.001$; Figure 3). Analysis by PFBC of 189 American shad otoliths collected from the WFL at Conowingo Dam showed that 64% were wild fish and 36% were hatchery-produced fish in 2021, which are similar to percentages estimated in 2019.

Relative Abundance

Hook and line sampling from shore at the Conowingo Dam tailrace was conducted over 13 days in 2021. A total of 293 adult American shad were sampled by Maryland Department of Natural Resources staff. Peak sampling (92 fish) occurred on 6 May 2021 at a surface water temperature of 15°C. Maryland Department of Natural Resources staff tagged 276 (94%) of the sampled fish. Since all sampling was done from shore in 2021, an estimate of American shad relative abundance could not be calculated from the hook and line data. One tagged American shad was recaptured by a recreational angler in 2021.

The Conowingo WFL operated for 59 days between 1 April and 5 June 2021 and lifted a total of 6,825 American shad. Most American shad 79.3% (5,410 fish) were lifted between either 27 April and 3 May (2,499 fish) or 19 May and 28 May (2,911 fish) 2021. Peak passage was on 22 May, when 735 American shad were counted. During the period of lift operations in 2021, Conowingo Dam was in spill conditions on 12 May and 13 May, though the WFL was still able to operate during this time. Twenty-two tagged American shad were counted at the WFL and were identified as being tagged in 2021 (8% of the total number of shad tagged). Since the start of the tagging study in 1986, the percentage of tags recaptured at the fish lifts has significantly declined over time ($R^2 = 0.50$, $P < 0.001$; Figure 4). Of the 6,825 American shad lifted at the WFL, 6,413 were successfully transported upstream of the Safe Harbor Dam, 220 were released back downstream due to being in poor condition or spent, 136 were sacrificed for life history information, 42 were holding mortalities, 10 were lift mortalities and 4 were transport mortalities.

The Conowingo Dam fish lifts provided another opportunity to measure American shad relative abundance. Like all measures of relative abundance, there are caveats to accepting these indices as indicative of true abundance. Lift efficiency and river flows affected run counts at Conowingo Dam, while the number and frequency of lifts affected GM CPUE. Both indices measured in this region of the Susquehanna River showed a broad general trend that abundance was low in the 1990s, increased to a peak in the early 2000s and then declined to low levels of abundance (Figure 5).

Ninety interviews were conducted over eleven days during the creel survey at the Conowingo Dam tailrace. While GM CPAH increased in 2021 relative to 2019 (Figure 6), GM CPAH has decreased over the time series (2001–2021; $R^2 = 0.26$, $P = 0.018$). Two anglers returned paper logbooks in 2021. Forty-one anglers participated online by recording their trips through the Maryland Department of Natural Resources' Volunteer Angler Shad Survey (34 of these anglers fished in the Susquehanna River). American shad GM CPAH calculated from shad logbook data combined with data from Maryland Department of Natural Resources' Volunteer Angler Shad Survey decreased in 2021 relative to 2020 (Figure 6). Online angler data was included in the CPAH calculation beginning in 2014. The logbook GM CPAH estimate of adult American shad relative abundance peaked in 2001 but has exhibited no significant trend over the time series (2001–2021; Figure 6).

Population Estimates

The Petersen method estimated 75,671 American shad in the Conowingo Dam tailrace in 2021, with an upper confidence limit of 112,140 fish and a lower confidence limit of 50,712 fish (Figure 7). The Petersen estimates followed a similar pattern to that of the lift GM CPUE estimates, with low numbers of American shad in the 1990s, increasing to a peak in the early 2000s and then declining to low numbers thereafter (Figure 7). American shad abundance has likely been relatively stable at low levels in recent years, though the estimate for 2021 is the lowest estimate since 1994.

Mortality

The Conowingo Dam tailrace total instantaneous mortality (Z) estimate for American shad, sexes combined, in 2021 was 0.93; there was no significant trend in mortality estimates from the Conowingo Dam over the time series (1984–2021; Figure 8).

Juvenile Abundance

Juvenile American shad abundance indices provided by the EJFS (1959–2021) demonstrated no significant trend in the upper Chesapeake Bay (Figure 9). While the Susquehanna

River is likely the dominant producer of juvenile American shad in the Upper Chesapeake Bay, it should be noted that other small rivers in Maryland (North East, Elk, and Sassafras Rivers) provide a minor amount of spawning habitat that may contribute to this population as well. Juvenile indices were not corrected for hatchery contribution.

Hickory Shad

Sex and Age Composition

In the Susquehanna River, 63 hickory shad were sampled by the broodstock collection survey in 2021. The male-female ratio was 1:1.03. All were successfully aged (Table 3). Males were present in age groups three through six and females were present in age groups three through seven (Table 4). The 2017 year-class (age 4) was the most abundant year-class for both males (61.3%) and females (46.9%; Table 4). The arcsine-transformed proportion of repeat spawners (sexes combined) decreased significantly over the time series (2004–2021; R^2 = 0.49, P = 0.001; Figure 10).

Relative Abundance

Hickory shad GM CPAH in 2021 for both the creel survey and the logbook survey marginally increased from the previous year (Figure 11). Hickory shad relative abundance from both the creel and logbook surveys show no significant trend over time.

Mortality

Total instantaneous mortality (Z) for hickory shad, sexes combined, in the Susquehanna River was estimated to be 1.03, which increased from 2019 (Z = 0.85). Mortality has gradually increased over the time series (2004–2021; R^2 = 0.25, P = 0.026; Figure 12).

DISCUSSION

American Shad

American shad were historically one of the most important fish species in North America, but the stock drastically declined throughout the twentieth century due to the loss of habitat, overfishing, ocean bycatch, stream blockages, pollution and exposure to invasive predators. 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 both the commercial and recreational American shad fisheries in 1980, and the ocean intercept fishery closed in 2005. While the American shad adult stock has shown some improvement in select river systems, a 2020 ASMFC stock assessment indicated that most stocks have not recovered and populations remain near historic lows (ASMFC 2020).

The population size of American shad in the lower Susquehanna basin has been relatively stable since 2010, although at a much lower level than the peak observed in the early 2000s and compared to historical abundance. However, since the population of American shad is not closed during sampling (i.e., mortality, immigration and emigration are occurring), the Petersen method likely overestimates the population size. The recapture rates of tagged American shad have also drastically declined over the past twenty years, so any comparisons of population size estimates among years should be made with caution. Therefore, the trend in population size, rather than the actual estimates themselves, should be emphasized when assessing the American shad population at the Conowingo Dam tailrace.

Estimates of relative abundance for the lower Susquehanna River also show peaks in abundance around 2001, followed by declines thereafter. The recreational creel and logbook survey GM CPAH has been relatively stable since 2004; however, Conowingo lift totals and GM CPUE have only partially stabilized in recent years. American shad lift totals briefly increased in

2016 and 2017 but less than 8,000 shad have been lifted per year since then, which are the lowest totals since 1988. Estimates of relative abundance for juvenile American shad in the upper Chesapeake Bay indicate that after many years of minimal juvenile production from the early 1980s through the mid-1990s, there have been several years of successful spawns.

The percent of repeat spawning American shad below the Conowingo Dam increased over time. The percent of repeat spawners was usually less than 10% in the Conowingo Dam tailrace throughout the 1980s (Weinrich et al. 1982). In contrast, 50% of aged American shad at the Conowingo Dam were repeat spawners in 2021, and on average, 47% of aged fish were repeat spawners over the past five years. Similar estimates of repeat spawning were observed in recent years for American shad collected from Virginia rivers (Hilton et al. 2022) and from the Potomac River (Bourdon and Jarzynski. 2019), which is unimpeded by dam construction within the natural migration range of anadromous fishes.

Significant resources have been invested in the restoration of American shad in the Susquehanna River basin. While initial restoration efforts were successful, population declines over the past 20 years and the arrival of new invasive predators have cast uncertainty over the long-term viability of the species in the river. Population declines may be driven in part by the limited suitable spawning habitat below Conowingo Dam, poor upstream passage efficiency, low stocking success, poor water quality and offshore bycatch. Declines in recapture rates of tagged American shad at the Conowingo Dam fish lifts also indicate that a lower percentage of American shad in the Conowingo Dam tailrace are using the fish lifts than in the past. While the reason for this is unknown, it could be due to increasing gizzard shad, *Dorosoma cepedianum*, populations overcrowding the fish lifts, precluding other anadromous fish species from entering them (SRAFRC 2010). While increasing gizzard shad abundance at the dam may be independent of

American shad recapture rates, there is a strong negative correlation between the two since 1997 (1997–2021; $R^2 = 0.49$, $P < 0.001$; Figure 13).

The relicensing agreement for the Conowingo Dam included more than $200 million to improve both upstream and downstream fish passage, water quality and environmental monitoring. Trap and transport will also again be used to transport American shad upstream. From 1985 to 1996, most American shad that were lifted at the Conowingo Dam were placed in a holding tank and transported upstream of the York Haven Dam. The York Haven Dam is the last of the four downstream dams on the Susquehanna River, so any shad transported above it had access to 60 miles of unimpeded river for spawning habitat. Beginning in 1997, upon completion of fish lifts at the three most downstream dams, the EFL began releasing fish directly upstream into Conowingo Pond, and only a portion of shad (6%) were trapped and transported. Following the completion of York Haven Dam's fish ladder in 2000, trap and transport was suspended in favor of volitional passage. Unfortunately, while all four dams passed record numbers of American shad in 2001, those numbers drastically declined in subsequent years.

The trap and transport program was reinstated in 2021 when increases in invasive predator populations at Conowingo Dam caused volitional passage to be suspended. Volitional passage will remain suspended through at least 2025, meaning trap and transport will be the only mode of upstream transportation for the next several years. In 2021, American shad were only transported upstream of the Safe Harbor Dam (i.e., south of the York Haven Dam); however, fish will also be transported upstream of the York Haven Dam starting in 2022. If the trap and transport of American shad was one of the primary reasons for the population increase seen in the 1990s, and if the suspension of it was partially responsible for the subsequent decline, American shad populations at the Conowingo Dam could increase again as early as 2024 when part of the 2021 year-class returns.

Hickory Shad

Hickory shad stocks in Maryland and along the U.S. Atlantic Coast have drastically declined due to habitat loss, overfishing, stream blockages and pollution. A statewide moratorium on the harvest of hickory shad in Maryland waters was implemented in 1981 and is still in effect today. Adult hickory shad are difficult to capture due to their aversion to fishery independent (fish lifts) and dependent (pound and fyke net) gears, which makes assessing their populations difficult. Very few hickory shad have ever been observed using the fish lifts at the Conowingo Dam, with no more than 20 hickory shad being counted at the EFL viewing window during a given year. Despite these low numbers of hickory shad, Deer Creek (a tributary of the Susquehanna River, downstream of Conowingo Dam) has some of the greatest densities of hickory shad in Maryland (Richardson et al. 2009).

Prior to 2012, hickory shad age distribution was relatively consistent, with a wide range of ages, up to age-nine, and a high percentage of older fish. Age distribution has truncated since that time, and only a single age-seven fish was present in 2021. Richardson et. al (2004) found 90% of hickory shad from the upper Chesapeake Bay had spawned by age four, and this stock generally consisted of few virgin fish. Since then, the percentage of repeat spawning fish decreased significantly over the time series. Fewer older fish combined with a smaller proportion of repeat spawners may indicate poor year-classes and/or an increase in mortality at older ages.

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

Adult hickory shad may spawn up to six weeks before American shad (late March to late April versus late April to early June), and juvenile hickory shad reach a larger size earlier in the summer. Juveniles also exhibit negative phototaxis, migrating to deeper, darker water away from the shallow beaches sampled by haul seines. 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).

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Table 1. Percent catch-at-age for American shad, sexes combined, angled from the Conowingo Dam tailrace, 1982–2021.

Year	N	Mean Age	Age							
			2	3	4	5	6	7	8	9
1982	73	3.88	0	25	63	12	0	0	0	0
1983	9	4.89	0	0	11	89	0	0	0	0
1984	124	4.31	0	24	36	26	11	2	0	0
1985	174	4.40	0	13	48	28	10	1	0	0
1986	425	4.00	0	24	53	22	1	0	0	0
1987	386	4.17	0	17	49	33	1	0	0	0
1988	252	4.00	1	25	49	21	3	0	0	0
1989	269	4.29	0	17	43	32	7	0	0	0
1990	305	4.56	0	5	45	39	9	1	0	0
1991	347	5.08	0	2	19	49	27	2	0	0
1992	371	5.12	0	5	16	48	22	8	0	0
1993	233	4.87	0	3	36	36	21	4	0	0
1994	435	4.77	0	3	33	50	12	2	0	0
1995*	620	4.88	0	2	25	52	19	1	0	0
1996*	446	4.75	0	6	34	36	22	2	0	0
1997*	606	4.92	0	10	42	33	12	2	0	0
1998	308	4.68	0	3	44	38	11	2	0	0
1999*	821	4.50	0	9	44	39	7	0	0	0
2000*	737	4.59	0	1	52	41	5	1	0	0
2001*	969	4.83	0	4	27	48	20	2	0	0
2002*	800	5.21	0	2	20	37	29	12	1	0
2003	781	4.96	0	2	29	38	22	8	0	1
2004	386	5.05	0	2	21	52	22	3	0	0
2005	385	5.22	0	2	26	31	32	9	1	0
2006	338	4.65	0	5	46	35	7	4	2	0
2007	449	4.82	0	4	36	38	20	1	1	0
2008	161	4.60	0	4	48	36	11	1	0	1
2009	622	4.45	0	3	59	30	8	1	0	0
2010	437	4.64	0	3	43	43	10	1	0	0
2011	172	5.13	0	0	19	52	27	2	0	0
2012	177	5.36	0	3	18	34	32	13	1	0
2013	297	6.03	0	0	5	30	33	24	6	2
2014	428	5.37	0	1	13	43	35	8	0	0
2015	279	4.77	0	8	29	45	15	3	0	0
2016	366	5.09	0	1	15	59	23	2	0	0
2017	264	4.67	0	5	33	52	10	0	0	0

* indicates years where not all fish were aged and an age-length key was subsequently used to assign ages.

Table 1. (Continued)

Year	N	Mean Age	Age							
			2	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2018	160	5.16	0	3	14	52	28	3	1	0
2019	44	5.27	0	0	25	34	32	7	2	0
2020	-	-	-	-	-	-	-	-	-	-
2021	288	5.27	0	1	21	38	30	10	0	0

Table 2. Number of adult American shad and repeat spawners by sex and age sampled from the Conowingo Dam tailrace (hook and line) in 2021.

Age	Male		Female		Total	
	N	**Repeats**	**N**	**Repeats**	**N**	**Repeats**
3	3	0	0	0	3	0
4	43	9	18	3	61	12
5	55	23	54	25	109	48
6	24	20	61	39	85	59
7	10	10	20	15	30	25
Totals	135	62	153	82	288	144
Percent Repeats	45.9%		53.6%		50.0%	

Table 3. Percent catch-at-age for hickory shad, sexes combined, sampled by the brood stock collection survey in the Susquehanna River and Deer Creek (a lower Susquehanna tributary), 2004–2021.

Year	N	Mean Age	Age							
			2	3	4	5	6	7	8	9
2004	80	5.3	0	8	24	28	19	19	4	0
2005	80	5.4	0	6	18	29	34	11	1	1
2006	178	4.9	1	9	32	30	20	7	2	0
2007	139	5.2	0	7	24	34	21	12	2	1
2008	149	4.9	0	9	30	34	20	5	2	0
2009	118	5.1	0	8	17	45	20	10	1	0
2010	240	4.6	0	13	38	31	11	7	0	0
2011	216	4.3	0	30	30	27	9	3	1	0
2012	200	4.2	0	27	40	25	8	2	0	0
2013	193	4.2	0	21	46	24	8	1	0	0
2014	100	4.5	0	11	37	40	12	0	0	0
2015	113	4.0	1	30	43	20	5	0	0	0
2016	120	4.4	0	21	31	36	12	1	0	0
2017	59	4.5	0	17	31	37	14	2	0	0
2018	40	4.3	0	15	53	25	8	0	0	0
2019	98	4.5	0	14	45	25	11	4	1	0
2020	-	-	-	-	-	-	-	-	-	-
2021	63	4.4	0	6	54	30	8	2	0	0

Table 4. Number of adult hickory shad and repeat spawners by sex and age sampled from the brood stock collection survey in the Susquehanna River in 2021.

Age	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	3	0	1	0	4	0
4	19	3	15	1	34	4
5	8	5	11	2	19	7
6	1	1	4	2	5	3
7	0	0	1	1	1	1
8	0	0	0	0	0	0
Totals	31	9	32	6	63	15
Percent Repeats	29. 0%		18. 8%		23. 8%	

Figure 1. Conowingo Dam tailrace (Susquehanna River) hook and line sampling location for American shad in 2021.

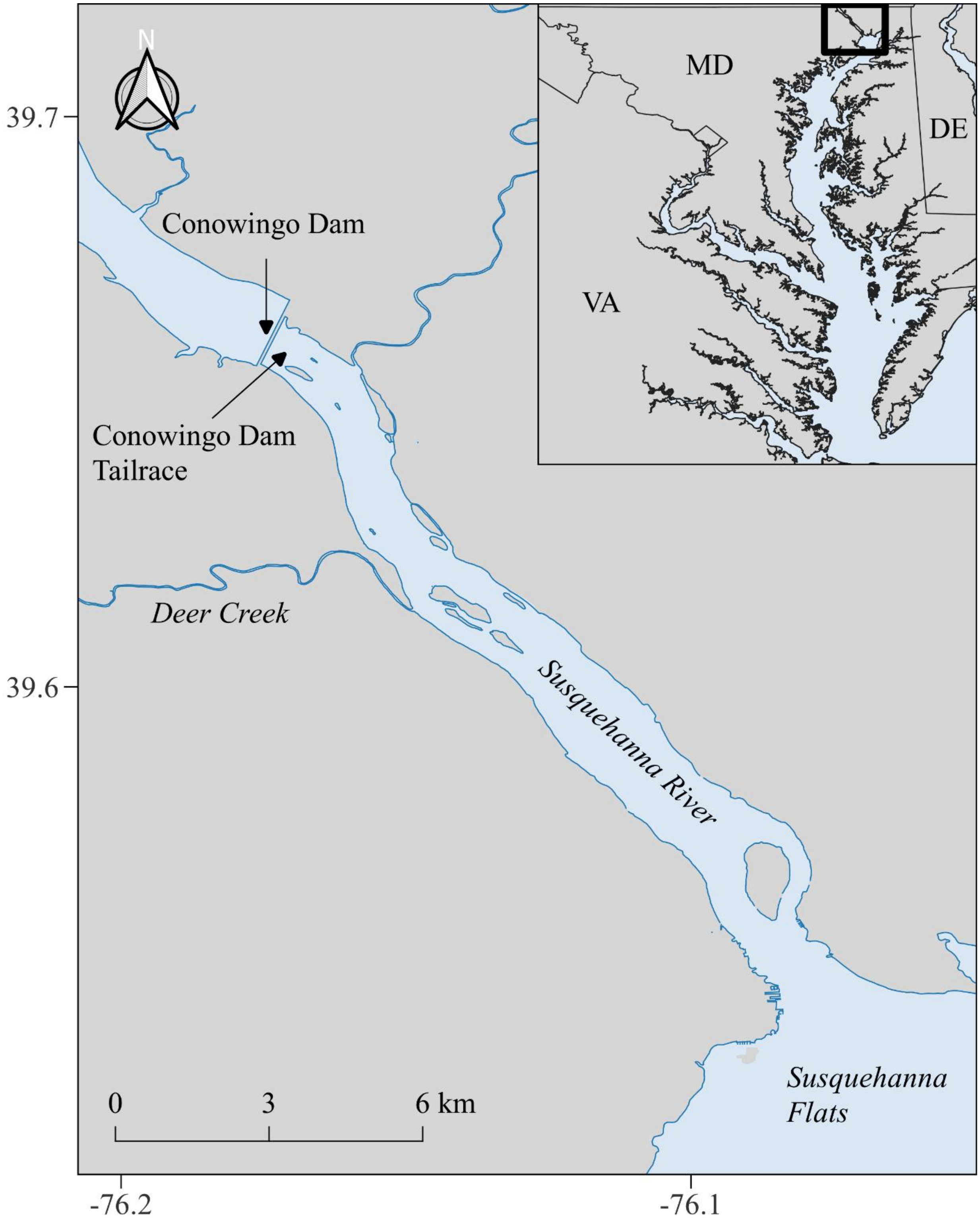

Figure 2. Percentage of American shad repeat spawners by sex collected in the Conowingo Dam tailrace, 1982–2021.

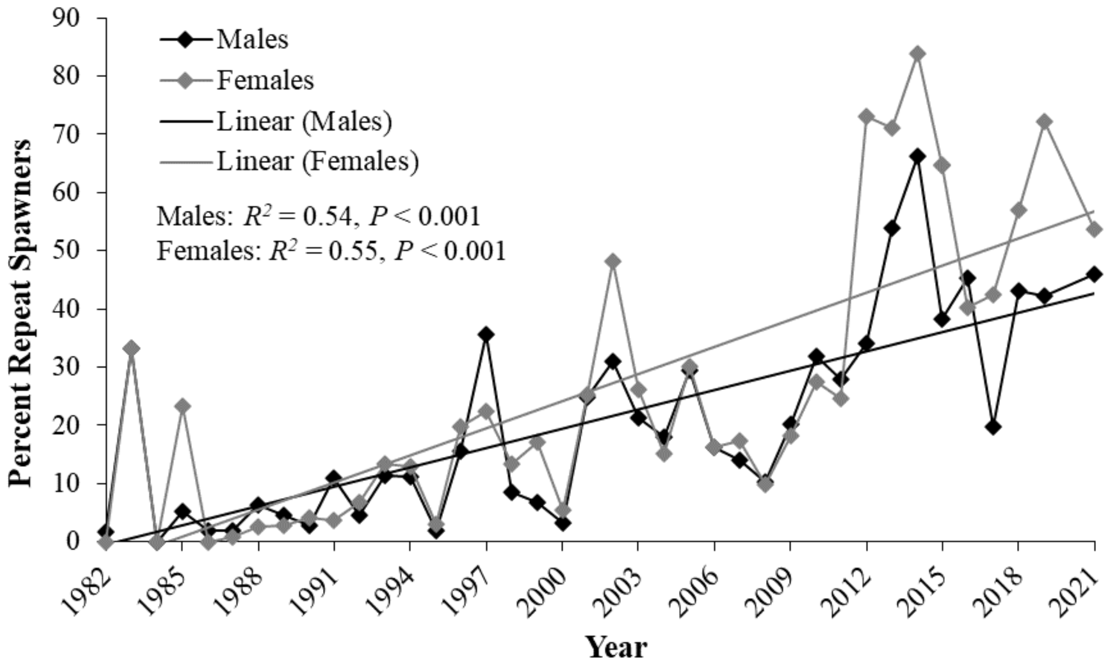

Figure 3. Arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace, 1984–2021.

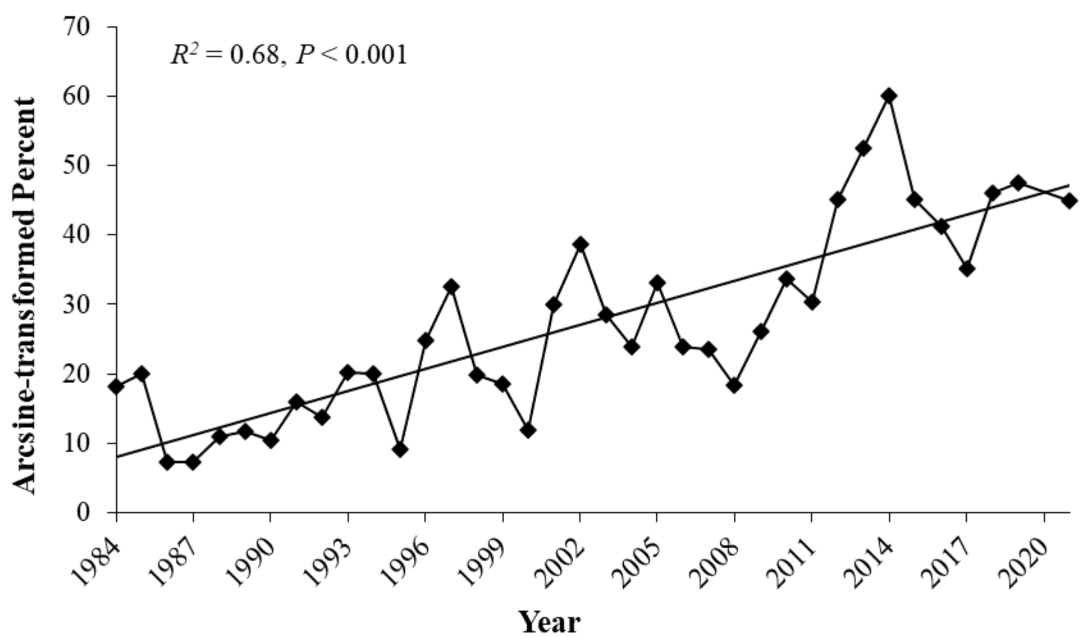

Figure 4. Percentage of tagged American shad recaptured at the Conowingo Dam fish lifts, 1986–2021.

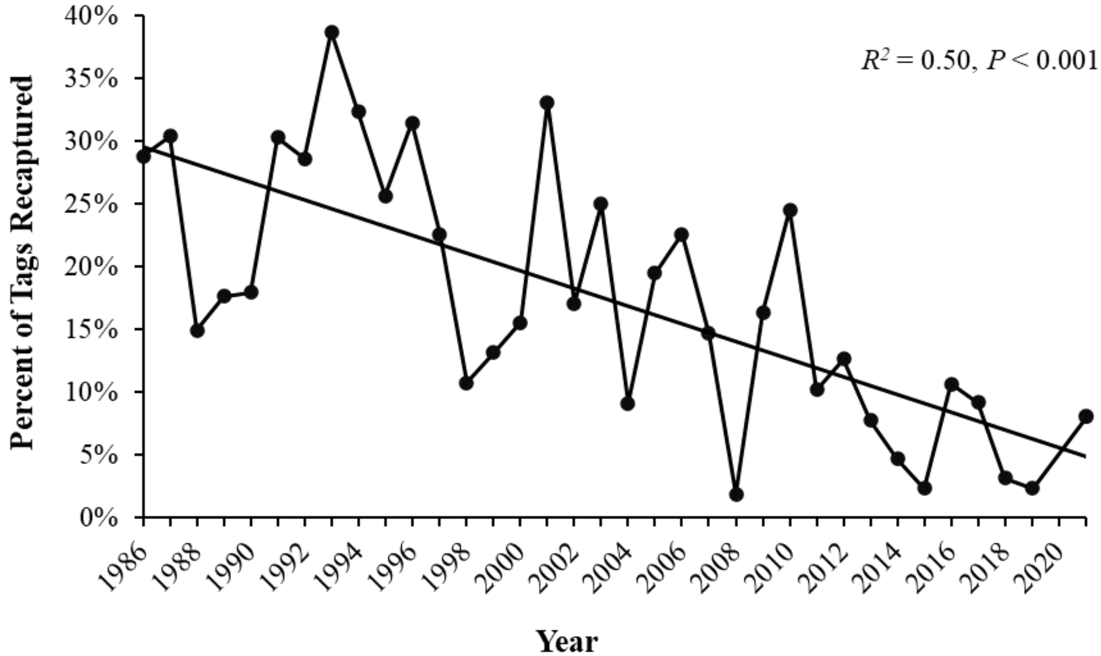

Figure 5. American shad GM CPUE (catch-per-lift-hour), 1985–2021, and the total number of American shad lifted at the East and West Fish Lifts, 1972–2021, at the Conowingo Dam. From 1972–1990, and in 2021, only the West Fish Lift operated.

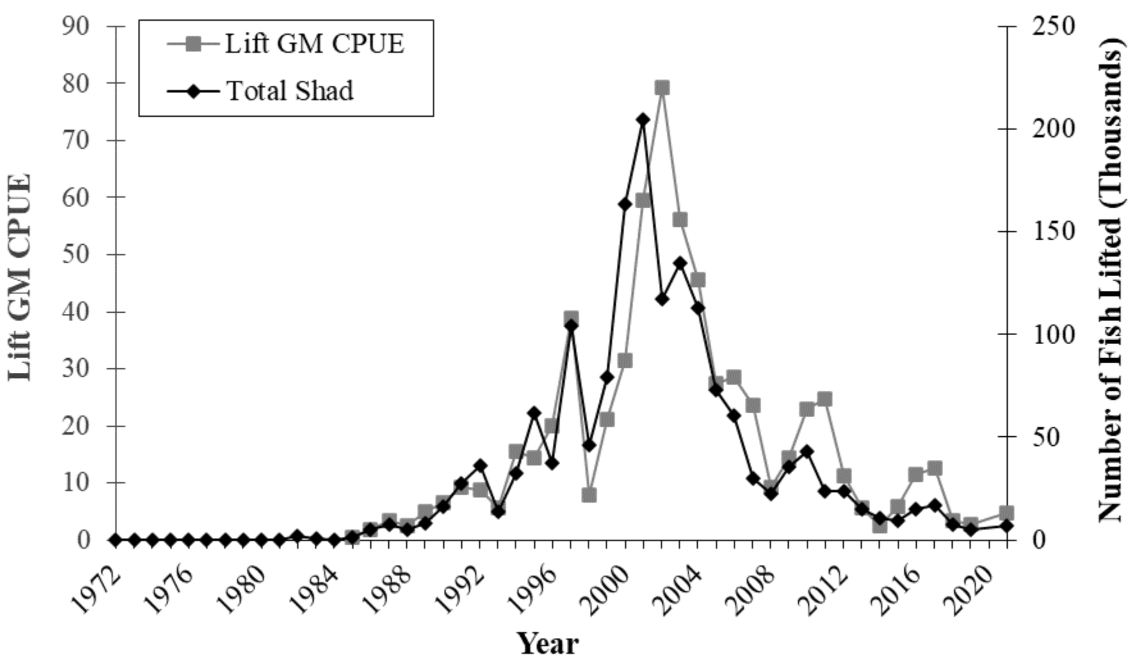

Figure 6. Geometric mean CPAH (catch-per-angler-hour) of American shad by recreational anglers in the Susquehanna River below Conowingo Dam, measured through creel and logbook surveys, 2001–2021.

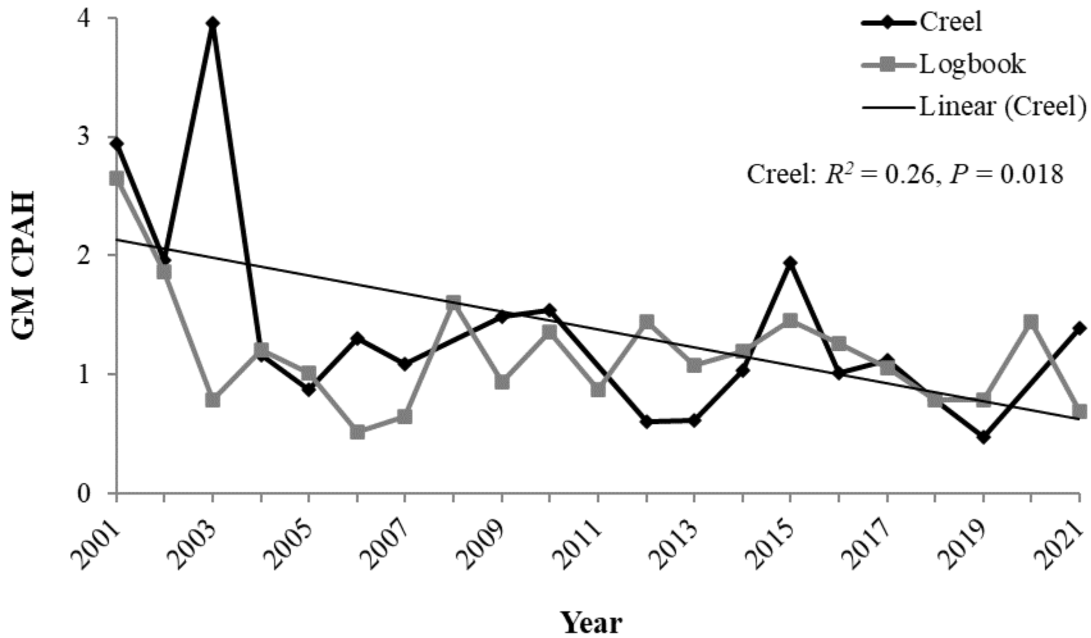

Figure 7. Conowingo Dam tailrace adult American shad abundance estimates from the Petersen method with 95% confidence limits, 1986–2021.

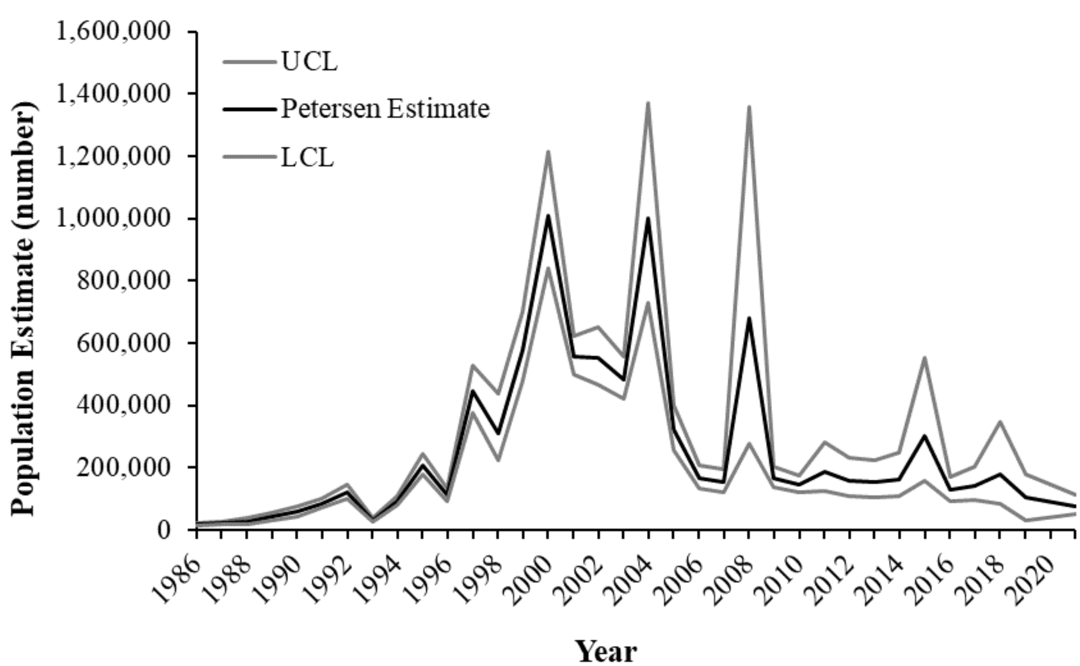

Figure 8. Age-based Chapman-Robson total instantaneous mortality (*Z*) estimates for American shad, sexes combined, captured in the Conowingo Dam tailrace (1984–2021). The $Z_{40\%SBPR}$ reference point was determined in the 2020 ASMFC benchmark stock assessment for American shad and is specific to the southern iteroparous region.

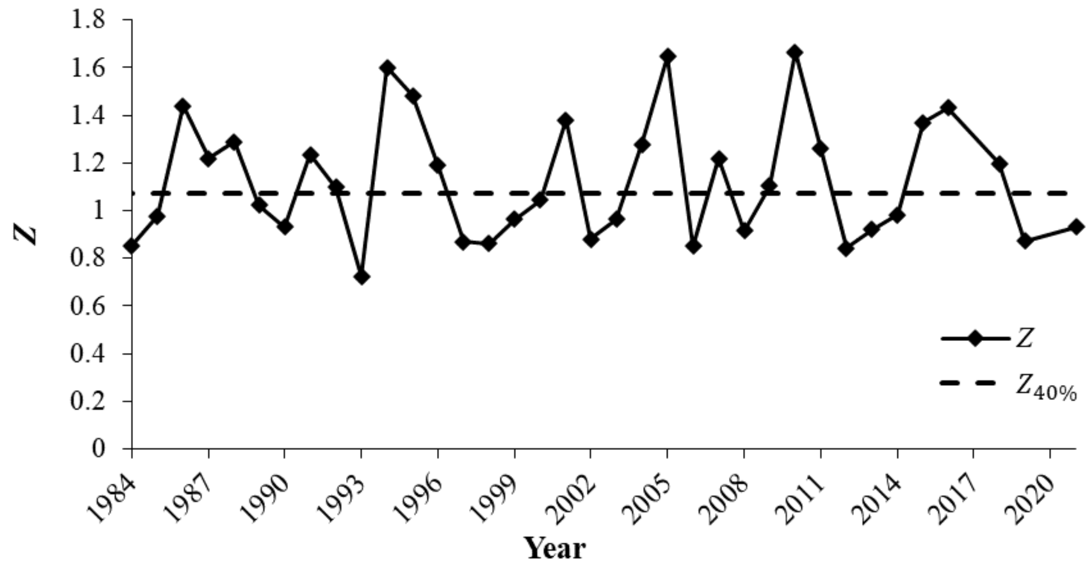

Figure 9. Upper Chesapeake Bay juvenile American shad GM CPUE (catch-per-seine-haul), 1959–2021.

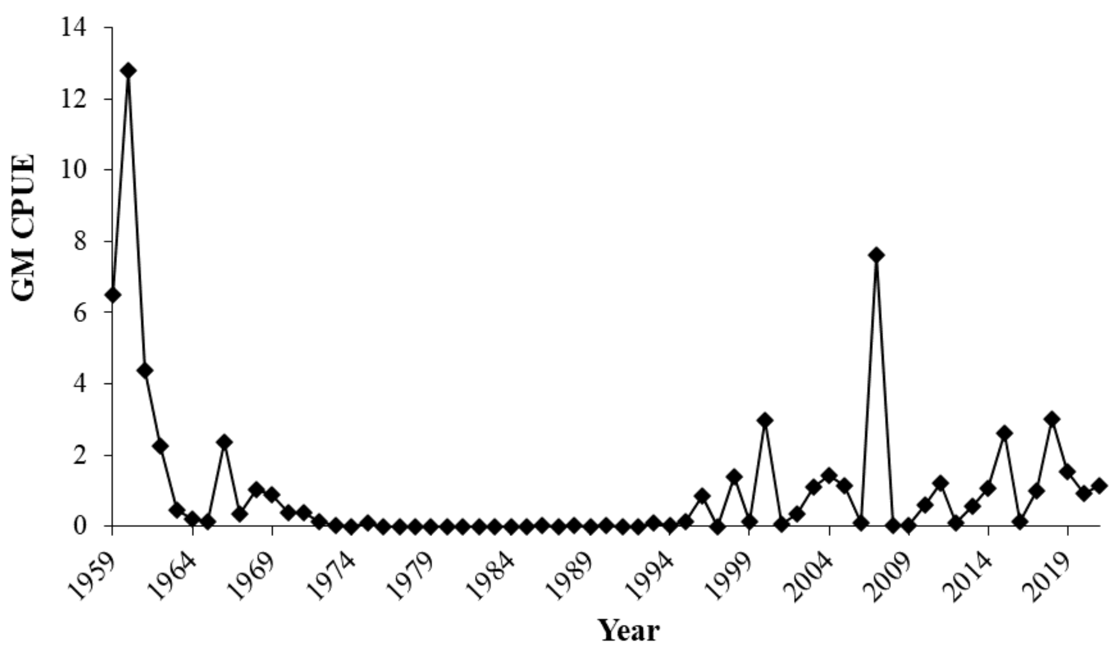

Figure 10. Arcsine-transformed percentages of repeat spawning hickory shad (sexes combined) collected from the Susquehanna River and Deer Creek (a lower Susquehanna River tributary), 2004–2021.

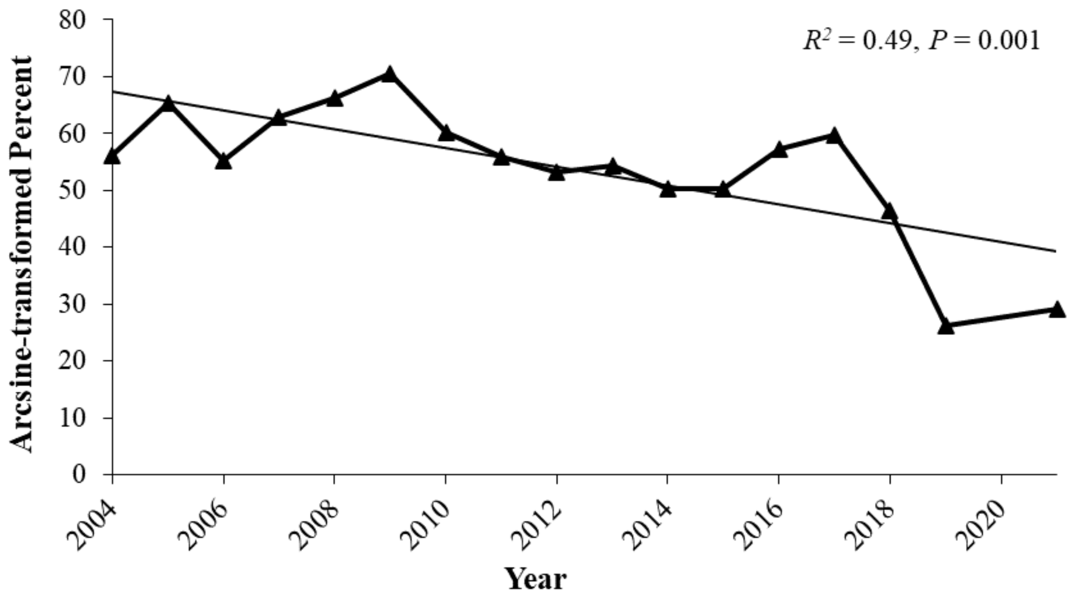

Figure 11. Geometric mean CPAH (catch-per-angler-hour) of hickory shad by recreational anglers in the Susquehanna River below Conowingo Dam, measured through creel and logbook surveys, 2001–2021.

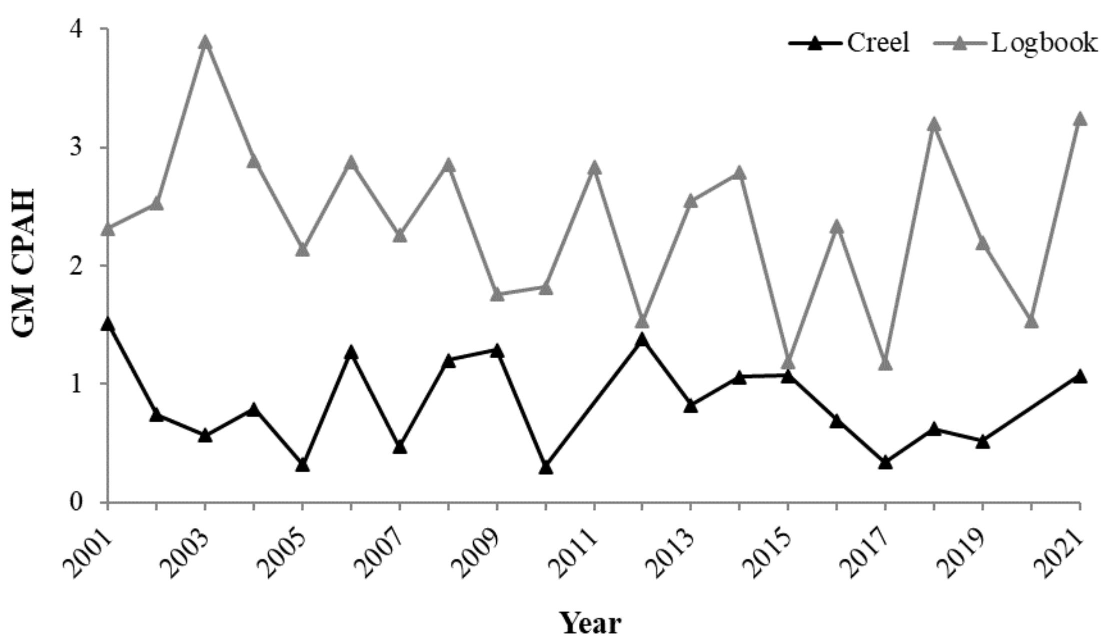

Figure 12. Age-based Chapman-Robson total instantaneous mortality (Z) estimates for hickory shad, sexes combined, captured in the Susquehanna River (2004–2021).

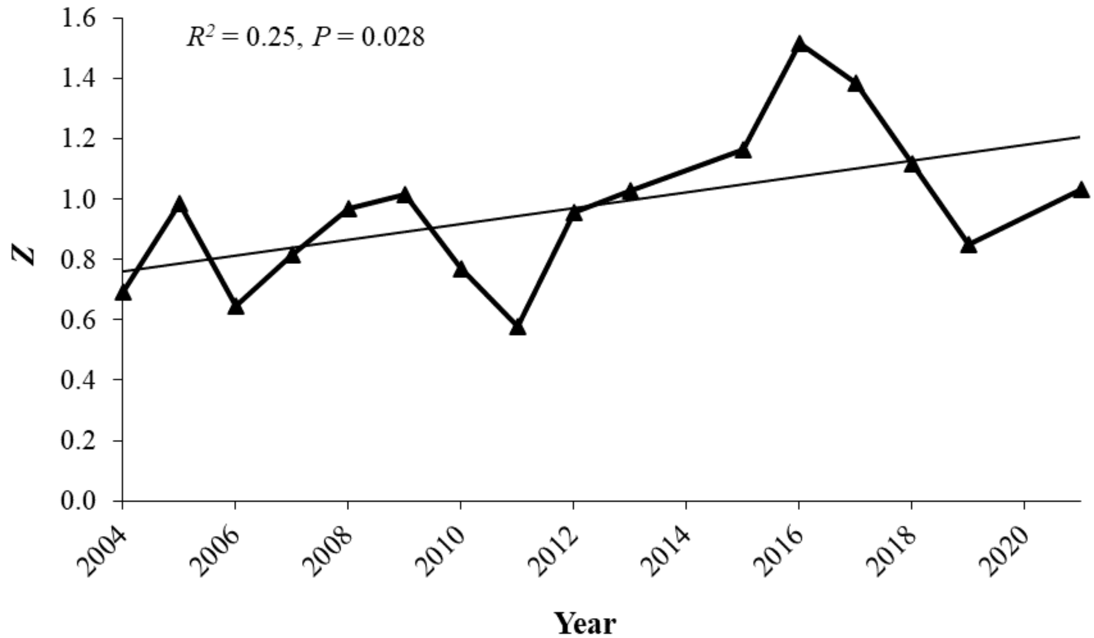

Figure 13. Percentage of tagged American shad recaptured at the Conowingo Dam fish lifts, 1997–2021, and gizzard shad CPUE at the East Fish Lift, 1997–2020, and West Fish Lift, 2021.