POPULATION ASSESSMENT OF AMERICAN SHAD IN THE UPPER CHESAPEAKE BAY

Harry W. Rickabaugh Jr.
Maryland Department of Natural Resources
Fisheries Service,
301 Marine Academy Drive, Stevensville, MD 21666

INTRODUCTION

The Maryland Department of Natural Resources has conducted annual sampling targeting adult American shad in the upper Chesapeake Bay since 1980 and hickory shad since 1998. The purpose of this sampling is to define stock characterizations including relative abundance indices, age and spawning history and reproductive success.

Since closure of the American shad fisheries to recreational and commercial fishing in 1980, stocks had increased significantly in the lower Susquehanna River until 2001 when American shad abundance decreased to alarming low levels. Hickory shad abundance appears to be very high and stable within the lower Susquehanna River. The Maryland Department of Natural Resources (DNR) is committed to restoring these species to the Susquehanna River Basin to sustainable, self-producing populations.

METHODS AND MATERIALS

I. Adults

a. American Shad

Field Operations

American shad were angled from the Conowingo tailrace (Figure 1) on the Susquehanna River two to five times per week from 15 April through 21 May 2010. Two rods were fished simultaneously, with each rod rigged with two shad darts and lead weight added, when necessary, to achieve proper depth.

All adult American shad sampled were sexed by expression of gonadal products (when possible) and fork length measured (mm). Scale samples were removed below the insertion of the dorsal fin. A minimum of three scales per fish were cleaned, mounted between two glass slides and read for age and spawning history using a microfiche reader. The scale edge was counted as a year-mark since it was assumed that each fish had completed a full year's growth at the time of capture. Fish in good physical condition and females not spent or running ripe were quickly tagged and released. A Maryland DNR Fisheries Service hat was given to fishers as reward for returned tags.

Statistical Analysis

The logistic growth model that described the population and catch estimate time-series was equivalent to a known biomass surplus production model (Macall 2002); except it used numbers as its unit of measure rather than biomass:

$$N_t = N_{t-1} \bullet (r \cdot N_{t-1} \bullet (1-N_{t-1}) / K) - C_{t-1};$$

where N_t was the population in year t;

N_{t-1} was the population in the previous year;

r was the intrinsic rate of population increase;

K was the maximum population size; and

C_{t-1} was losses associated with upstream and downstream fish passage in the previous year (equivalent to catch in a surplus production model).

We employed an observation error model that assumed all residual errors were in the population observations and the logistic equation used to describe the time-series was deterministic and without error (Haddon 2001). This model also assumed a proportional consumption of American shad by striped bass and assumed American shad were landed as proportional bycatch to the Atlantic herring fishery because population estimates without these estimates fell below the catches at Conowingo Dam. Instantaneous annual fishing mortality rates associated with fish passage in year t (F_{tp}) during 1984-2010 were estimated as $\log_e[1- (C_t / N_t)]$ (Ricker 1975). Estimates of abundance were derived from model output.

The Conowingo tailrace estimate utilized American shad captured in the tailrace and tagged and subsequently recaptured by the east fish lift. Fish caught in the east lift were dumped into a trough and directed past a 4'x10' counting window, identified to species, and enumerated by experienced Normandeau technicians. Hourly catch logs by species were subsequently produced and distributed to DNR personnel. American shad possessing a tag were counted and the tag color noted. Annual catch-per-unit-effort (CPUE) for American shad was calculated as the geometric mean of fish caught per lift hour. Annual CPUE of upper Bay American shad captured by hook and line was calculated as the geometric mean of fish caught per boat hour.

Data was also collected from two creel surveys targeting American shad in the lower Susquehanna River. One survey was a roving creel whereby tailrace anglers were visited on site and asked a series of questions regarding effort and success. The second

survey required anglers to record their daily catch, location and hours fished in a logbook that was returned to the Department at the end of the spring fishing season. For both surveys, CPUE was calculated as the number of fish caught per hour fished.

b. Hickory Shad

Relative Abundance

The annual CPUE of Deer Creek hickory shad was calculated as the number of fish caught- per-angler-hour and was obtained from spring logbook data returned from volunteer anglers.

Mortality Estimates

Two methods were utilized to estimate total instantaneous mortality of hickory shad based on scale repeat spawning marks**.** For the first method, hickory shad total instantaneous mortalities (Z) were estimated by the $\log_e$-transformed spawning group frequency, plotted against the corresponding number of times spawned (assuming consecutive spawning; ASMFC 1988);

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

where S_{fx} = number of fish with 1,2,...f spawning marks in year x;

a = y-intercept;

W_{fx}= frequency of spawning marks (1,2,...f) in year x.

The second method averaged the differences between the natural logs of the spawning group frequency to provide an overall Z between age groups. The Z calculated for these fish represents mortality associated with repeat spawning.

RESULTS

I. Adults

a. American shad

Sex and Age Composition

The 2010 male-female ratio of adult American shad captured by hook and line from the Conowingo tailrace was 1.14:1. Of the 486 fish sampled by this gear, 437 were successfully scale-aged (Table 1). Those American shad not aged directly because of regenerated scales, were not assigned ages.

Males were present in age groups 3-7 while females were found in age groups 4-8 (Table 1). The 2005 year-class of males (age V) was the most abundant age group sampled, accounting for 44.9% of the total catch. For females, the 2006 (age IV) was the most abundant age group, accounting for 44.3%, of the total catch.

Repeat Spawning

The percentages of Conowingo tailrace repeat spawning American shad in 2010 was 31.8% for males and 27.4% for females (Table 1). The arcsine-transformed proportions of these upper Bay repeat spawners (sexes combined) has significantly increased for the time series ($r^2 = 0.55$ $p < 0.001$; Figure 2).

Relative Abundance

During east lift operations from 5April to 6 June 2010, clerks counted 37,757 American shad passing the viewing window. Peak passage was on 20 April when 2,272 American shad were recorded. Breakdown of the 115 marked fish observed is listed below.

East Lift		
Tag Color	Year Tagged	Number Recaptured
Pink	2010	106
Orange	2009	9
West Lift		
Tag Color	Year Tagged	Number Recaptured
Pink	2010	21
Orange	2009	1
Green	2008	1

In 2010, the west lift at Conowingo Dam operated from 21 April to 25 May. The 5,605 American shad caught in the west lift were returned to the tailrace, used for experimentation or retained for hatchery operations. Peak capture from the west lift was on 6 May when 1,128 American shad were recorded. Twenty-three tagged American shad were recaptured in 2010 from the west lift

The Conowingo tailrace American shad relative population estimate in 2010 was 93,949 (Figure 3).

Estimates of hook and line geometric mean (GM) CPUEs indicated no significant trend for the 1984-2010 time series, but did increase from 1984 to 2002, dropped sharply in 2003 and has been variable with a slightly declining trend through 2010 (Table 2, Figure 4). The Conowingo Dam fish lift GM significantly increased over the 1980-2010 time series ($r^2 = 0.40$, $p<0.001$; Figure 5). However, the GM decreased steadily from the time series high in 2002 through 2008 before increasing slightly in 2009 and 2010.

The angler-based roving creel in the Conowingo Dam's tailrace interviewed thirty-six anglers in 2010 on only four days because of time constraints. Catch-per-angler-hour (CPAH) from these anglers was 1.78, an increase from 2009 when the CPAH was 1.41 (Table 3). CPAH from 2001-2010 has varied with no significant trend. American shad

logbook data indicated a decrease in CPAH compared to 2009 (Table 4) but there was no significant trend for the time series (1999-2010, r^2=0.39, *P*=0.03).

b. Hickory shad

Relative Abundance

Hickory shad CPAH ranged from 3.5 to 8.4 for the time series with the lowest value (3.5) estimated in 2010 (Table 5). There was also no significant tend for the time series (1998-2010, r^2=0.12, *P*=0.25).

Mortality Estimates

Richardson (et al 2004) noted that ninety percent of hickory shad in Deer Creek have spawned by age four and this stock generally consisted of few virgin fish. The oldest fish in their sample was nine years old and using Hoenig's (1983) estimation of natural mortality ($\ln (M_x) = 1.46 - 1.01\{\ln (t_{max})\}$), M was 0.47.

If Z is calculated using the freshwater spawning marks as in American shad, then mortality estimates for hickory shad estimated from the spawning group frequency plotted against the corresponding number of times spawned resulted in a Z of 0.74. The average difference between the natural logs of the spawning group frequency produced a Z of 0.57. In general, the resultant Z was attributed to natural mortality since both recreational and commercial fishing for hickory shad were banned.

DISCUSSION

1. American shad

a. Adults

Prior to 1997, American shad captured from both fish lifts were individually handled so that all fish, both marked and unmarked, could be totaled. Beginning in 1997, the east fish lift became fully automated. Consequently, two trained observers stationed at the east lift-viewing window recorded both total counts and number of tagged American shad. This change in operating procedure at the east lift increased the chances of missing both tagged and untagged American shad and misidentifying tag colors. These errors could, therefore, affect the accuracy of the Petersen population estimates.

All American shad commercial fisheries in the Atlantic Ocean were closed on 31 December 2004. Since this fishery resulted in landings of mixed stocks in excess of 1.2 million lbs (ASMFC 1998), and a moratorium exists for American shad in the Chesapeake Bay, increases in relative abundances were expected. However, the three indicators of relative abundance (tailrace relative population estimates, hook and line geometric mean CPUEs, and Conowingo Dam lift geometric mean CPUEs) declined from 2003 to 2008 and have shown only modest increases through 2010.

Several factors contributing to this decline in abundance could be related to poor recruitment, Striped bass predation (Crecco et al 2006) and American shad harvested in the ocean as "bait". Because of the difficulty in identifying and differentiating the four alosines, many subadults may be caught as bycatch, appearing as bait in various markets particularly in New England and southern Canada (K Hattala pers. comm, NY Dept. Env. Cons.).

b. Juveniles

Baywide juvenile American shad production in 2010 remained at a very low levels for the third year (Figure 6). Juvenile American shad indices in the upper Chesapeake Bay

(Figure 7) have been primarily driven by wild production below Conowingo Dam as indicated by the continued absence of hatchery-marked fish collected by the Juvenile Striped Bass Recruitment Survey. The low upper Chesapeake Bay juvenile index values in recent years may demonstrate the decreasing trend in adult abundance and/or a change in environmental conditions.

2. Hickory shad

a. Adults

Hickory shad are difficult to capture because of their aversion to fishery independent (fish lifts and traps) and fishery dependent (commercial pound and fyke nets) gears. Consequently, angler effort and success was collected from logbooks provided to anglers targeting hickory shad. Biological data and scale samples were obtained from hickory shad collected during electrofishing from Lapidum to the mouth of Deer Creek by DNR aquaculture personnel.

Deer Creek, a tributary to the Susquehanna River in Harford County has the greatest densities of hickory shad in Maryland (Richardson et al 2004). Natural mortality is approximately equal to the estimate of total mortality, demonstrating minimum mortality by hook and line and ocean bycatch.

b. Juveniles

Haul seine sampling during the mid summer and fall likely missed hickory shad because of their large size, avoidance to the gear and their preference for deep water. Since adults may spawn from mid March through late April, up to six weeks before American shad, juvenile hickory shad reach a larger size earlier. Consequently, in order to accurately represent their juvenile abundance, sampling would need to be initiated by early June.

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Table 1. Numbers of adult American shad and repeat spawners by sex and age sampled from the Conowingo tailrace in 2010.

Conowingo Dam Tailrace

AGE	Male		Female		Total	
	N	Repeats	N	Repeats	N	Repeats
3	14	0	0	--	14	0
4	97	3	89	0	186	3
5	106	57	82	26	188	83
6	17	17	27	26	44	43
7	2	2	2	2	4	4
8	0	--	1	1	1	1
Totals	236	75	201	55	437	134
Percent Repeats	31.8		27.4		30.7	

Table 2. Conowingo Dam tailrace hook and line data, 1982-2010.

Year	Total Catch	Hours fished	CPUE	GM CPUE
1982	88	N/A	N/A	N/A
1983	11	N/A	N/A	N/A
1984	126	52	2.42	1.07
1985	182	85	2.14	1.05
1986	437	147.5	2.96	1.85
1987	399	108.8	3.67	6.71
1988	256	43	5.95	6.54
1989	276	42.3	6.52	7.09
1990	309	61.8	5.00	3.6
1991	437	77	5.68	5.29
1992	383	62.75	6.10	5.05
1993	264	47.5	5.56	4.8
1994	498	88.5	5.63	5.22
1995	625	84.5	7.40	7.1
1996	446	44.25	10.08	9.39
1997	607	57.75	10.51	10.2
1998	337	23.75	14.19	9.86
1999	823	52	15.83	15.94
2000	730	35.75	20.42	13.98
2001	972	65.75	14.78	15.12
2002	812	60	13.53	15.94
2003	774	69.3	11.17	9.4
2004	474	38.75	12.23	9.48
2005	412	57.92	7.11	9.2
2006	360	33.75	10.28	7.61
2007	468	52.91	8.85	8.13
2008	164	39.85	4.12	3.14
2009	668	58.50	11.42	9.38
2010	485	62.00	7.82	5.11

Table 3. Recreational creel survey data from the Susquehanna River below Conowingo Dam, 2001-2010.

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 4. Summary of the spring American shad logbook data, 1999-2010.

Year	Number of Returned Logbooks	Total Reported Angler Hours	Total Number of American Shad Caught	Mean Number of American Shad Caught Per Hour
1999	7	160.5	463	2.88
2000	10	404.0	3,137	7.76
2001	8	272.5	1,647	6.04
2002	8	331.5	1,799	5.43
2003	9	530.0	1,222	2.31
2004	15	291.0	1,035	3.56
2005	12	258.5	533	2.06
2006	16	639.0	747	1.17
2007	10	242.0	873	3.61
2008	14	559.5	1,269	2.27
2009	10	378.0	967	2.56
2010	14	429.5	857	2.00

Table 5. Summary of the spring hickory shad log book data from Deer Creek, 1998-2010.

Year	Number of Returned Logbooks	Total Reported Angler Hours	Total Number of Hickory Shad Caught	Mean Number of Hickory Shad Caught per Hour
1998	19	600	4,980	8.30
1999	15	817	5,115	6.26
2000	14	655	3,171	4.84
2001	13	533	2,515	4.72
2002	11	476	2,433	5.11
2003	14	635	3,143	4.95
2004	18	750	3,225	4.30
2005	19	474	2,094	4.42
2006	20	766	4,902	6.40
2007	17	401	3,357	8.37
2008	22	942	5,465	5.80
2009	15	561	2,022	3.60
2010	16	552	1956	3.54

Figure 1. Location of the hook and line sampling in Conowingo Dam tailrace in 2010.

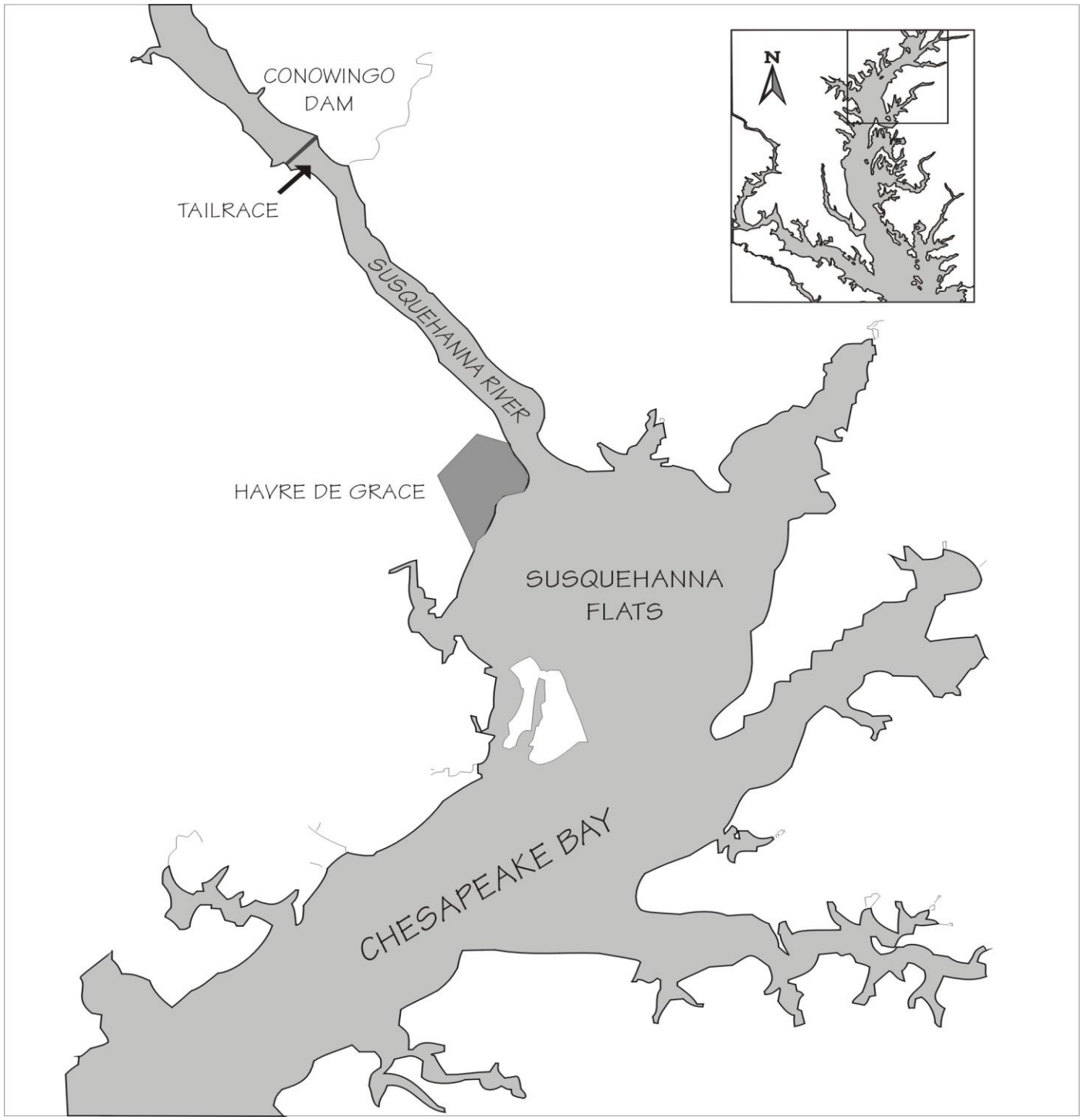

Figure 2. Trends in arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Conowingo Dam tailrace (1984-2010).

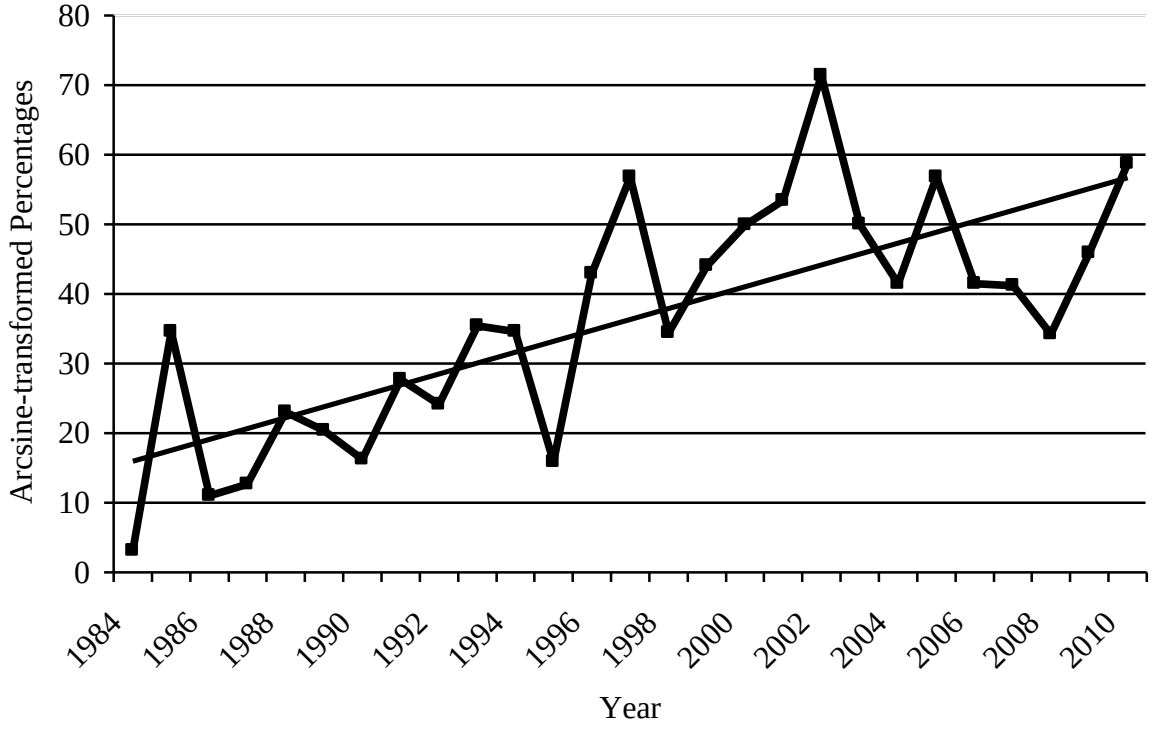

Figure 3. Conowingo Dam tailrace relative estimates of American shad 1984-2010.

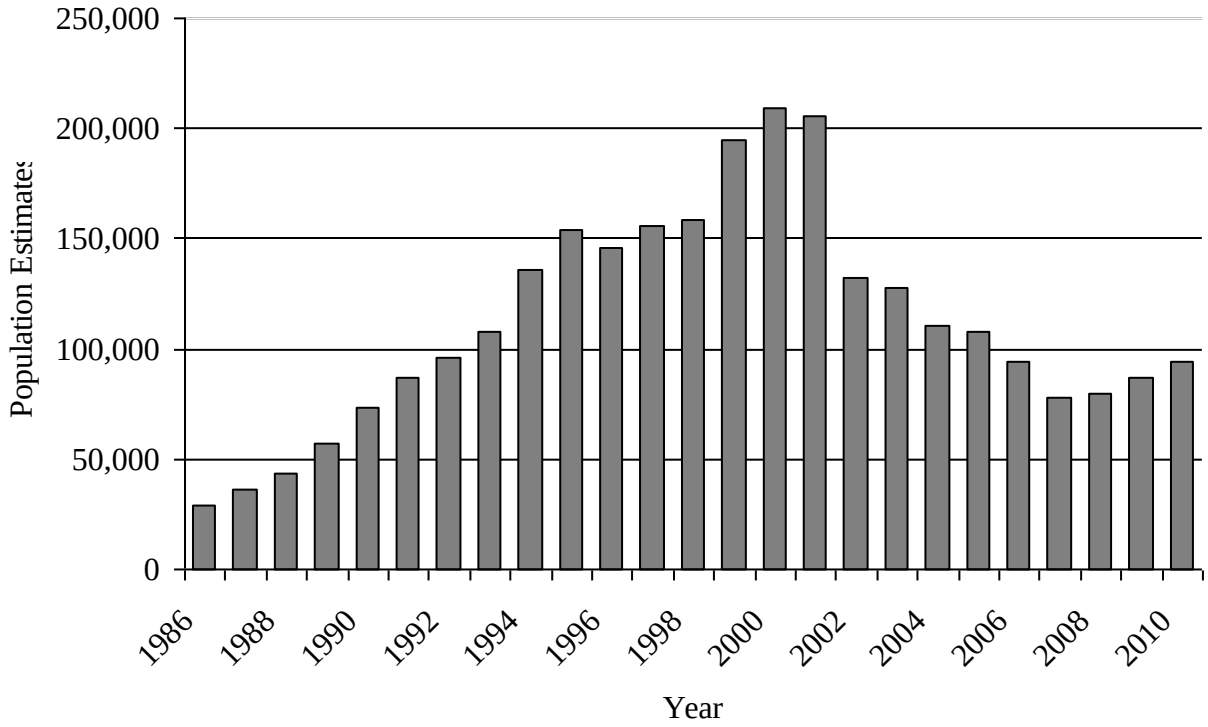

Figure 4. Geometric mean CPUEs from Conowingo Dam tailrace hook and line sampling, 1984-2010.

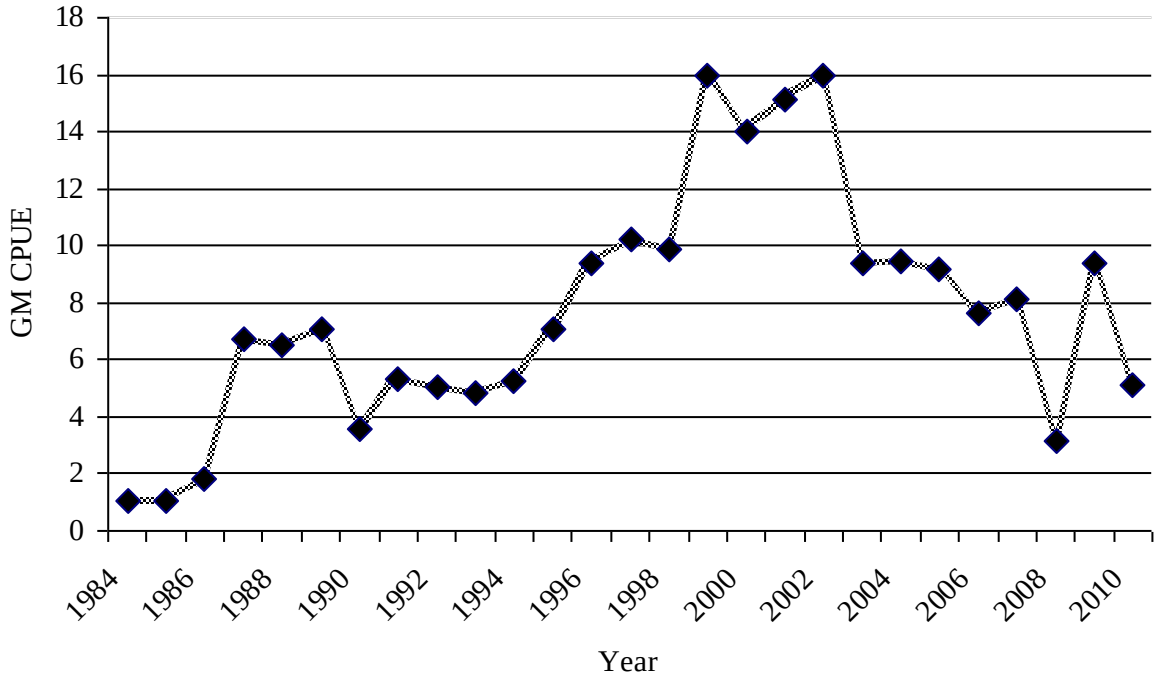

Figure 5. Geometric mean CPUE of American shad from the lifts at Conowingo Dam, 1980-2010.

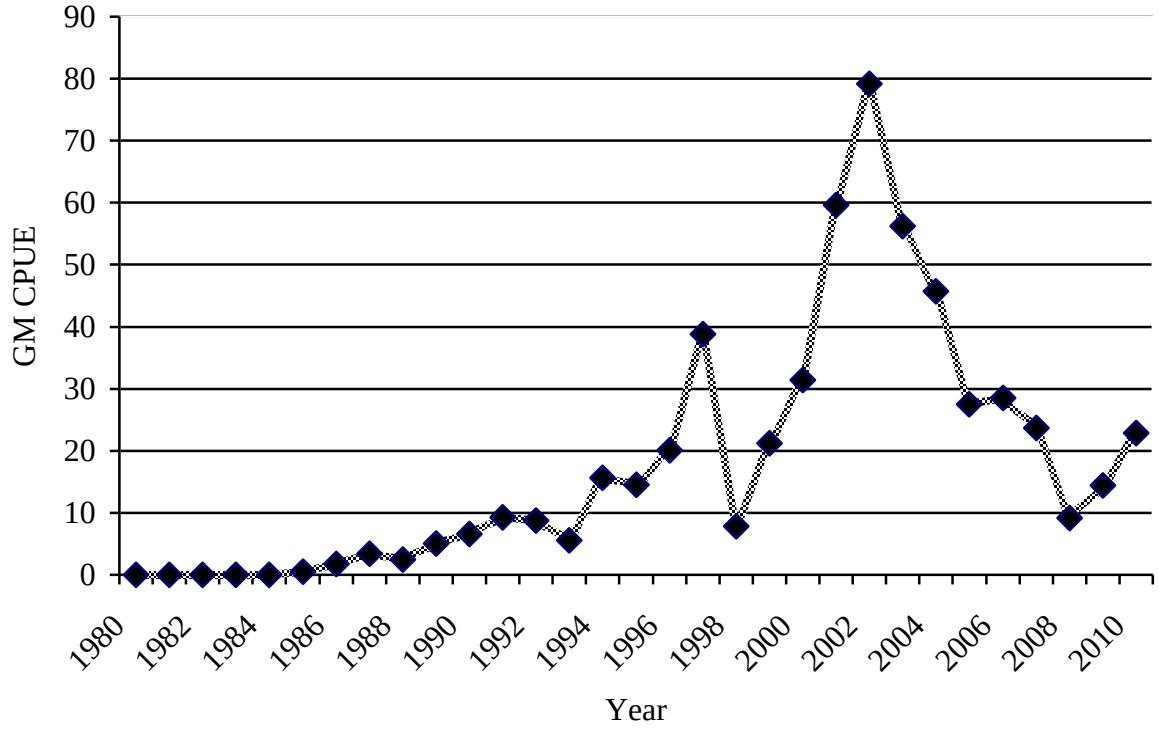

Figure 6. Baywide juvenile American shad geometric mean CPUEs, 1959-2010.

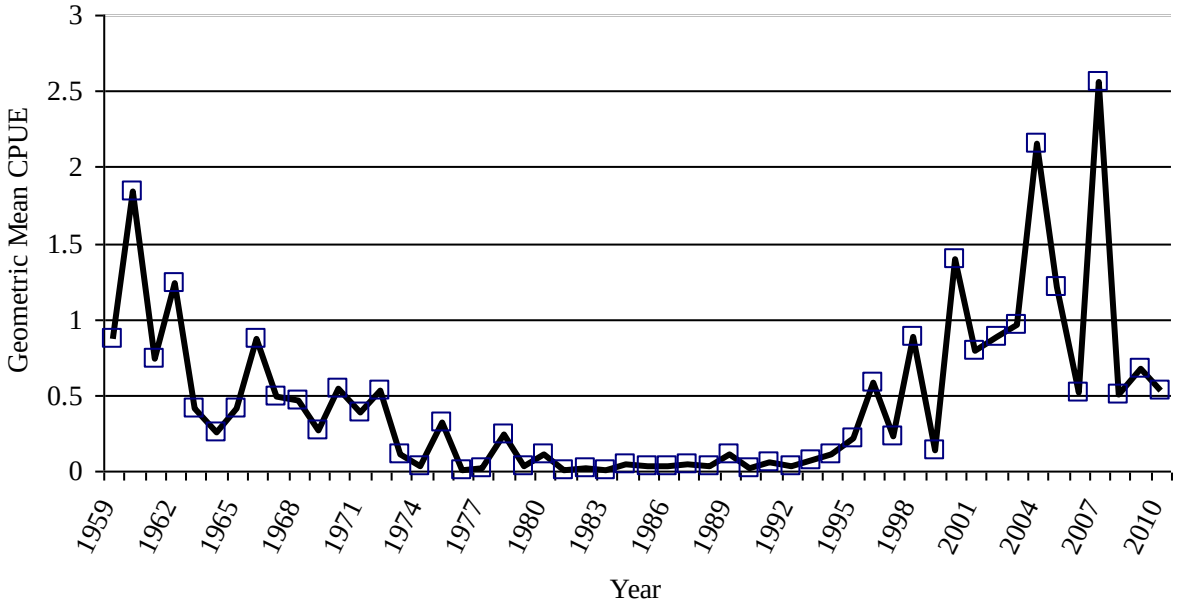

Figure 7. Upper Chesapeake Bay juvenile American shad geometric mean CPUEs, 1959-2010.