Analysis of adult American shad otoliths from shad collected in the Conowingo Dam West Fish Lift, 2009

Abridged report for PFBC website

M.L. Hendricks

Pennsylvania Fish and Boat Commission

Benner Spring Fish Research Station

State College, Pa.

Abstract

A total of 174 adult American shad otoliths were processed from adult shad sacrificed at the Conowingo Dam West Fish Lift in 2009. Based on tetracycline marking and otolith microstructure, 62% of the 173 readable otoliths were identified as wild and 38% were identified as hatchery in origin. Using age composition and otolith marking data, the lift catch was partitioned into its component year classes for both hatchery and wild fish. Results indicated that for the 1986-2002 year classes, stocking of approximately 402 hatchery larvae was required to return one adult to the lifts. For fingerlings, stocking of 196 fingerlings was required to return one adult to the lifts. For wild fish, transport of 1.37 adults to upstream areas was required to return one wild fish to the lifts. Actual survival is even higher since not all surviving adults enter the lifts.

Introduction

Efforts to restore American shad to the Susquehanna River have been conducted by the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC). Primary restoration approaches consisted of: 1) trapping of pre-spawn adults at Conowingo Dam and transfer to areas above dams (1972 to 1999), 2) direct fish passage (1997 to the present), and 3) planting of hatchery-reared fry and fingerlings.

In order to evaluate and improve the program, it was necessary to know the relative contribution of the hatchery program to the overall restoration effort. Toward that end, the Pennsylvania Fish Commission developed a physiological bone mark which could be applied to developing fry prior to release (Lorson and Mudrak, 1987; Hendricks et al., 1991). The mark was produced in otoliths of hatchery-reared fry by immersion in tetracycline antibiotics. Analysis of otoliths of outmigrating juveniles allows discrimination of "wild" vs. hatchery reared fish. The first successful application of tetracycline marking at Van Dyke was conducted in 1984. Marking on a production basis began in 1985 but was only marginally successful (Hendricks, et al., 1986). In 1986, 97.8% tag retention was achieved (Hendricks, et al., 1987) and analysis of outmigrants indicated that 84% of the upstream production (above Conowingo Dam) was of hatchery origin vs. 17% wild (Young, 1987). Similar data has been collected in subsequent years.

Determination of the contribution to the overall adult population below Conowingo Dam of hatchery-reared and wild fish resulting from restoration efforts was more complicated. The adult population of shad below Conowingo Dam includes: 1) wild,

upper bay spawning stocks which are a remnant of the formerly abundant Susquehanna River stock; 2) wild fish of upstream origin which are progeny of adults from out-of-basin or Conowingo trap and transfer efforts, 3) hatchery-reared fish originating from stockings in main stem or tributary areas upstream from Conowingo Dam and 4) hatchery-reared fish originating from stockings below the Conowingo Dam. The latter group were fish which received a "double" tetracycline mark and were planted below Conowingo Dam from 1986 to 1996.

Since mark retention did not approach 100% until 1987, adult hatchery shad from cohorts produced before 1987 did not exhibit 100% marking. For the years in which these fish returned to the river as adults, marking rates could therefore be used only to determine minimum contribution of hatchery-reared fish. For fish which did not exhibit a mark, otolith microstructure (Hendricks et al., 1994) was used to distinguish hatchery fish from wild fish.

Methods

A representative sample of adult shad returning to Conowingo Dam was obtained by sacrificing every 50th shad which entered the West lift. These collections were supplemented with fish sampled from tank-spawning trials at Conowingo Dam. In addition, adult American shad were collected in the upper Chesapeake Bay by Maryland DNR, processed by MDNR staff and are not reported here.

Each sampled fish was sexed, measured and decapitated. Whole heads were frozen and delivered to the Van Dyke Hatchery. Otoliths (sagittae) were extracted,

cleaned, and one otolith was mounted for mark analysis in Permount® on a microscope slide, while the other was stored in mineral oil in 24-well, cell culture clusters.

For mark analysis, otoliths were ground on both sides to produce a thin sagittal section and the specimen examined under UV light for the presence of a tetracycline mark.

Whole otoliths were aged by viewing with a dissecting microscope and a fiber optic light. The best contrast was obtained by directing the light from the side, parallel to the sagittal plane of the otolith. Ageing was done by a single researcher. After initial ageing, length at age was analyzed and apparent outliers were re-examined. We have assembled a collection of several hundred otoliths from known-aged shad based on the presence of a unique tetracycline mark. These were used as reference material.

Historical fish lift catch data was compiled from SRAFRC Annual Progress Reports for the years 1972 through 2009. Age composition data was gathered as follows: for 1996 to 2009, age composition data were collected from the aforementioned otolith analysis. For 1991-1995, age composition data were taken from scale samples collected from the fish used for otolith analysis. These samples were collected by sacrificing every 100th fish collected in the lifts, and as such, represent a truly random sample. For 1989 and 1990, age composition data was determined from the overall fish lift database as reported in SRAFRC Annual Progress Reports by RMC Environmental Services. This database includes holding and transporting mortalities which skew the data slightly toward females and older fish (Hendricks, Backman, and Torsello, 1991).

Recruitment to the lifts by year class was determined for hatchery and wild origin fish by partitioning the lift catch for each year into its component year classes based upon age composition and otolith marking data. Only virgin adults were used to prevent double counting. Total recruitment by year class was determined for hatchery and wild groups by summing the data for each year class over its recruitment history. The number of larvae required to return one adult to the lifts (L/A) was determined for each year class by dividing the number of larvae stocked above dams by the total recruitment of adults which originated as hatchery larvae. Similarly, the number of fingerlings required to return one adult (F/A) was determined for each year class by dividing the number of fingerlings stocked above dams by the total recruitment of adults which originated as hatchery fingerlings. The number of transported adults required to return one adult (TA/A) was determined for each year class by dividing the number of adults transported upstream by the total recruitment of unmarked (wild) adults. Overall L/A, F/A and TA/A were calculated by dividing the sum of the number stocked or transported by the sum of the total recruitment of the group, for the cohorts in question.

Results and Discussion

A total of 174 shad was sacrificed for otolith analysis from Conowingo Dam in 2009. Of these, 44 were West Lift sacrifices and 130 were from tank-spawn trials. No samples were collected from the East Lift since it was operated in fish passage mode. There was one unreadable otolith (Table 1). A total of 108 (62%) otoliths exhibited wild microstructure and no tetracycline mark. A total of 63 (36%) fish exhibited tetracycline marks including single, triple, quadruple and quintuple marks. No fish were observed

with double marks. Two fish (1%) exhibited hatchery microstructure but the tag could not be read due to autofluorescence. Random samples of adults have been collected since 1989 and the results of the classifications are summarized in Table 2. The contribution of wild (naturally produced) fish to the adult population entering the Conowingo Dam fish lifts during 1989-2009 ranged from 10 to 71% (Table 2, Figure 1). Although the proportion of wild fish in the Conowingo Lift collections was low prior to 1996, the numbers of wild fish showed an increasing trend from 1989 to 2000 and have decreased since 2000 (Figure 2). This is consistent with the coastwide depression of American shad stocks documented in the ASMFC stock assessment (ASMFC 2007).

Fish lift catch, age composition and origin of sacrificed shad are presented in Table 3, while percent virgin by year and age is presented in Table 4. Analysis of otoliths to assess hatchery contribution was not conducted prior to 1989. As a result, the catch for year classes prior to 1986 could not be partitioned into hatchery and wild and are not presented. Year classes after 2003 are not fully recruited and are not included in the analysis. For the period 1986-2003, the number of hatchery larvae required to produce one returning adult (L/A) ranged from 68 to 2,149, with a mean of 402 (Table 5). L/A was high (477-724) for the early cohorts (1986 – 1989). During 1990 to 2002, L/A improved to 68-446, presumably due to improvements in fish culture practices. The highest L/A (2,149) was for the 2003 cohort, a year when high flows hampered stocking efforts.

L/A was surprisingly low in comparison to the reproductive potential of wild fish. If fecundity of wild females is assumed to be 200,000, then 2 of 200,000 eggs must survive to maturity to replace the spawning pair in a stable population. If we assume a

fertilization rate of 60% (comparable to strip-spawning), 60,000 fertilized eggs would be required to produce one wild adult at replacement. This suggests that mortality in the wild is extremely high during incubation and/or for the first week after hatch.

This analysis was repeated for fingerlings stocked above Conowingo Dam (Table 6). For the period 1986-2003, the number of hatchery fingerlings required to produce one returning adult (F/A) ranged from 44 to 305, with an overall value of 196. At first glance, it would appear that stocking fingerlings is advantageous over stocking larvae, however, on average, one must stock 100,000 larvae in a pond to harvest 10,000 to 20,000 fingerlings. Therefore, it would take 700 to 1,400 larvae, stocked in a pond, then harvested and stocked in the river as fingerlings to produce one adult. Considering the cost of pond culture, it is clearly better to stock larvae directly. In future years, F/A is unlikely to change since the last significant fingerling stockings were in 1994 and the last fingerlings recovered were in 1999. The appearance of 220 recruited adults for the 1995 cohort and 43 for the 1996 cohort, when no fingerlings were stocked, is an artifact of erroneous ageing, and highlights the problems with ageing American shad.

A similar analysis was tabulated for wild fish (Table 7). For the period 1986 to 2003, transport of an average of 1.37 adults was required to produce one returning adult, above the level required for replacement. The actual stock/recruitment ratio of wild fish is unknown since some of the wild fish which entered the lifts would have been of Upper Bay origin and not all recruited fish entered the lifts. These factors may act to cancel each other out, but the magnitude of each is not known.

Stress during trucking may account for reduced performance of transported spawners. The high fecundity of the species has the potential to overcome this, since

just a few successful spawners can produce huge numbers of offspring. Another possible explanation is that there may be some threshold number of spawners required to ensure successful spawning. Whatever the cause, stock/recruitment ratios must continue to improve to allow for successful restoration.

Virtual survival rates by cohort and stocking site are reported in Table 8. As expected, some cohorts survived better than others, probably due to environmental conditions. The 1996 cohort exhibited the highest virtual survival rate (146) followed by 1997 (134). The decline in cohort survival since 1997 is troubling, particularly in light of poor hatchery performance in 2003 to 2007. High river flows in 2003 and 2004 negatively impacted survival of hatchery fish. Reduced egg availability was problematic in 2005 and 2006, and severe hatchery mortality problems were encountered in 2007. Cohorts beyond 2002 are not yet fully recruited.

Adult relative survival for individual stocking sites was highly variable between cohorts (Table 8). For example, relative survival for the Juniata River/Juniata or middle Susquehanna sites ranged from 0.00 to 1.00. For the North Branch Susquehanna River the range was from 0.00 to 0.46. For Swatara Cr., relative survival ranged from 0.00 to 0.82. For West Conewago Cr. and Conodoguinet Cr., relative survival ranged from 0.00 to 1.00. Conodoguinet Creek exhibited the highest survival for the 1997 cohort and a very high relative survival for the 1996 and 1999 cohorts (0.83 and 0.88 respectively), but since 1999 it has exhibited very low relative survival. Both adult and juvenile relative survival rates were consistently poor for the West Branch Susquehanna River until 2002 when they were 0.68 and 0.54, respectively. Relative survival of adults for the West Branch was the highest of any site for the 2004 cohort. This may be reflective

of recent water quality improvements associated with mine drainage abatement projects.

Stocking site/cohort specific relative survival of juvenile shad was correlated to that for adult shad (Figure 3) but the relationship was not significant ($p=0.81$). This result is counter-intuitive since it is logical to assume that groups which exhibited better survival as juveniles would also exhibit better survival as adults. Either survival to the juvenile stage has no strong relationship to survival to adulthood, one of the recapture samples are not representative of the population, or errors in aging resulted in incorrect partitioning of the lift catch which had the effect of randomizing the data. It is difficult to believe that stocking site carries with it some survival advantage (or disadvantage) which is expressed between the Fall outmigration, when juveniles are recaptured, and the Spring spawning migration, when returning adults are recaptured several years later. It is equally unlikely that the Conowingo Fish Lifts select for or against adult shad based on the site where they were stocked. It seems more likely that collections of juveniles at Holtwood, Peach Bottom and Conowingo somehow select for or against fish based on stocking site, however the mechanism by which that occurs is not known. Perhaps distance between the stocking site and juvenile recapture site, coupled with river flow and migration rate are somehow interacting to produce a recapture sample that is not representative of the population. Errors in otolith aging certainly occur and can be as much as 60 to 80% (McBride et al. 2005). Aging errors, coupled with small sample size in some of the recapture groups (Table 8) could explain the lack of correlation between juvenile and adult survival.

It is interesting that a similar phenomenon was detected when analyzing recaptures of shad marked according to egg source river. For the 1989 to 1994 cohorts, relative survival of juveniles from Hudson River source larvae was always 1.00, while relative survival of Delaware River source larvae ranged from 0.06 to 0.83 with a mean of 0.29 (Hendricks, 2001). Clearly, Hudson River source juveniles were recaptured at a much higher rate than Delaware River source juveniles. When recapture rates of adults at the Conowingo Fish Lifts were analyzed, the trend was reversed. Relative survival of Delaware source adults ranged from 0.83 to 1.00 with a mean of 0.96, compared to a range of 0.29 to 1.00 and a mean of 0.75 for Hudson River adults. This analysis was also dependent upon correct aging. It is possible that aging errors were the cause of both of these anomalous observations. For this reason, marking protocols for 2004 and beyond included an alternating marking scheme to provide known age specimens (see Job III).

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Figure 1. Estimated composition of adult Amercian shad caught at Conowingo Dam, based on otolith microstructure and tetracycline marking.

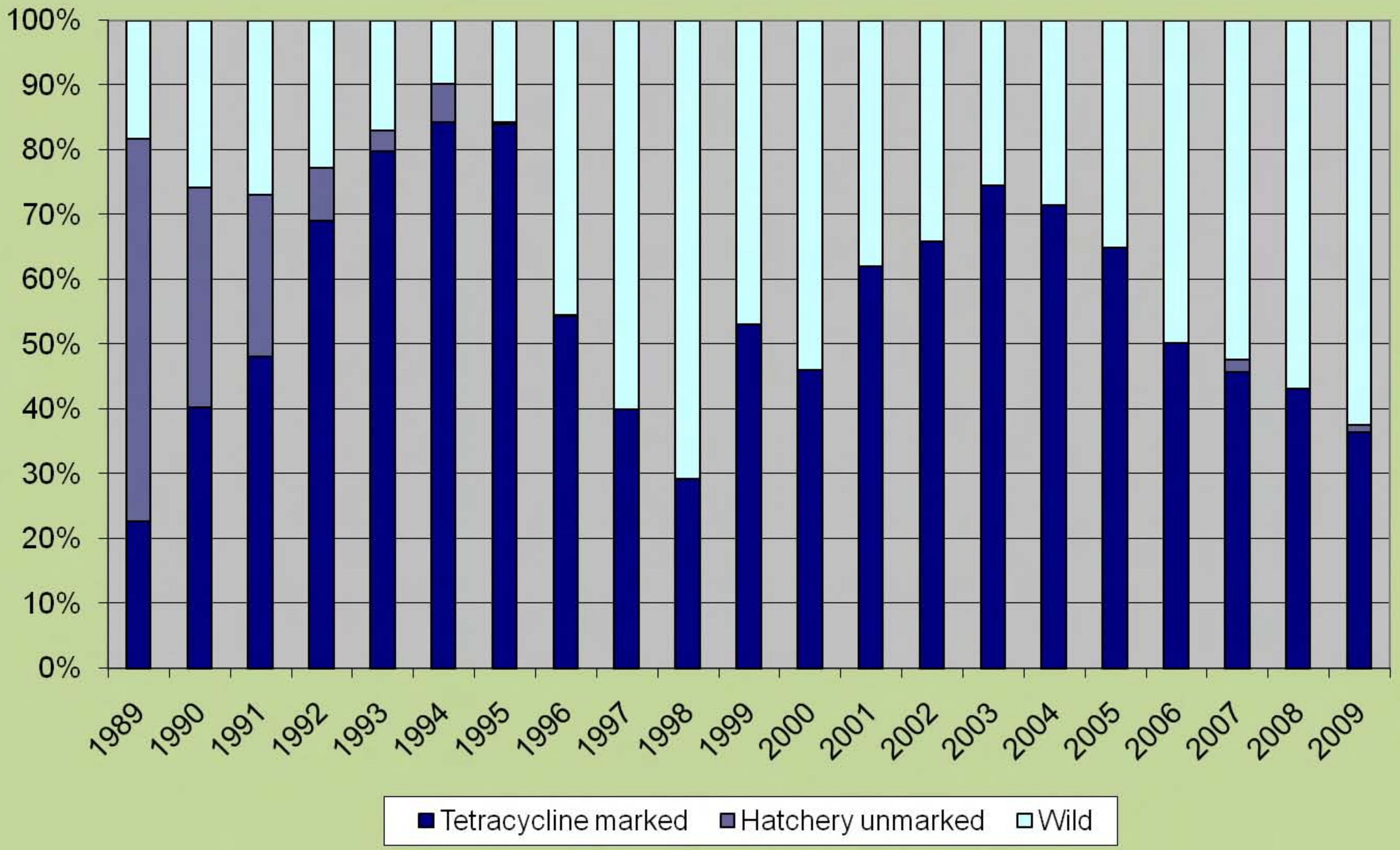

Figure 2. Catch of American shad at the Conowingo Dam Fish Lifts.

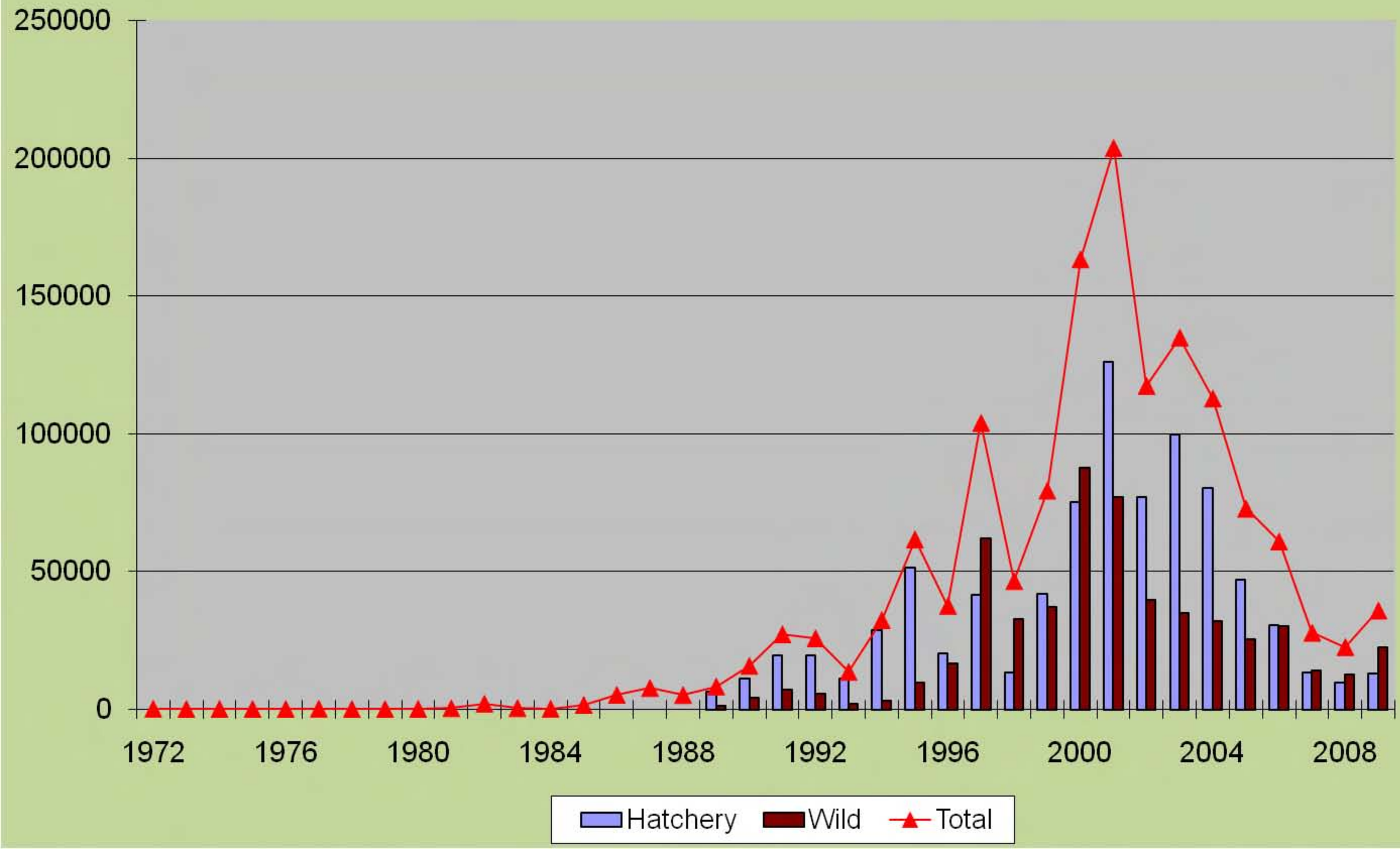

Figure 3. Stocking site/cohort specific relative survival of juvenile shad vs. adult shad, Susquehanna River, 1995-2005.

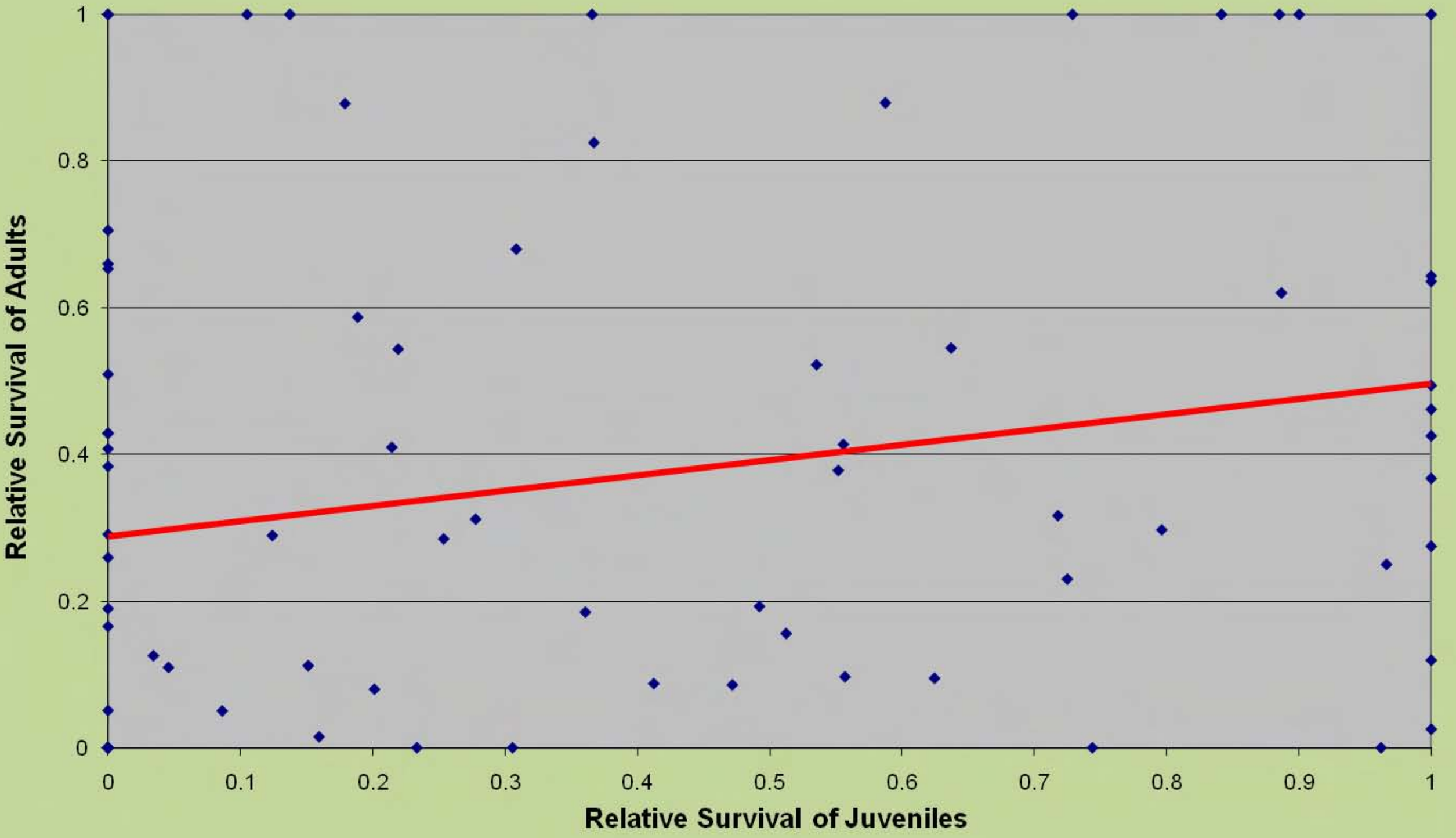

Table 1. Microstructure classification and tetracycline marking of adult American shad collected in the Susquehanna River, 2009. One of every 50 fish collected from the Conowingo West Fish Lift was sacrificed for analysis.

		Conowingo Dam	
Conowingo Dam		N	%
Wild Microstructure, No TC Mark		108	62%
Hatchery Microstructure			
No TC Mark*		2	1%
Single TC Mark	Day 3	2	1%
Double TC Mark	Days 3,6 or 3,7	0	0%
Triple TC Mark	Days 3,6,9	31	18%
	Days 3,6,12	1	1%
	Days 3,9,12	12	1%
	Days 3,12,15	1	1%
	Days 3,15,18	1	0%
Quadruple TC Mark	Days 3,6,12,15	2	1%
	Days 3,9,12,15	1	1%
Quintuple TC Mark	Days 3,6,9,12,15	11	6%
	Days 3,6,9,12,18	1	1%
	Total Hatchery	65	38%
	Total readable otoliths	173	
	Unreadable Otoliths**	1	
	Total	174	

*Includes poor grinds, marks which are present but cannot be specifically assigned, and otoliths with autofluoresence obscuring mark.
**Includes missing, broken and poorly ground otoliths.

Table 2. Origin of adult American shad collected at Conowingo Dam Fish Lifts, based on otolith analysis.

		Hatchery									
	Sample:	Larvae									
	One			below					Naturally		Total
	in	Susquehanna		Conowingo Dam		Fingerling		Unmarked**	reproduced		sample
Year	??	N	%	N	%*	N	%*	N	N	%	size
1989	50	36	82*	-		-		94	29	18	159
1990	100	49	73*	1	1	-		42	32	26	124
1991	100	111	67*	8	5	3	2	63	68	27	253
1992	100	154	73*	8	4	2	1	19	54	23	237
1993	100	76	64*	21	18	2	2	4	21	17	124
1994	100	217	81*	22	8	3	1	17	28	10	287
1995	100	255	77*	19	6	4	1	1	52	16	331
1996	100	180	48*	22	6	4	1	1	172	45	379
1997	50	84	34	12	5	4	2	0	150	60	250
1998	50	29	22	7	5	2	2	0	92	71	130
1999	50	90	48	9	5	1	1	0	88	47	188
2000	50	78	40	11	6	0	0	0	104	54	193
2001	50	120	58	9	4	0	0	0	79	38	208
2002	50	118	65	2	1	0	0	0	62	34	182
2003	50	146	74	0	0	0	0	0	50	26	196
2004	50	113	72	0	0	0	0	0	45	28	158
2005	50	176	64	2	1	0	0	0	96	35	274
2006	50	89	50	0	0	0	0	0	88	50	177
2007	50	71	47	1	1	0	0	3	81	52	156
2008	50	76	43	0	0	0	0	0	100	57	176
2009	50	63	38	0	0	0	0	2	108	62	173
Totals		2,331	59	154	4	25	1	246	1,599	37	4,355

*Unmarked hatchery fish distributed among groups based on annual percentage.
**Distinguished from naturally-reproduced fish by otolith microstructure.

Table 3. Age composition and origin of Susquehanna River American shad collected at the Conowingo Dam Fish Lifts.

Year	Total Fish lift catch	% Age composition 11	10	9	8	7	6	5	4	3	2	% Composition by Hatchery Release Site: Above Dams larvae %		Above Dams fingerlings %		Below Dams %		Wild %	
1988	5,146			0.0	0.0	4.0	31.7	38.1	21.2	4.7	0.4	71%	*			6%	*	23%	*
1989	8,218			0.0	0.0	4.3	18.1	41.5	30.2	5.6	0.2	82%						18%	
1990	15,719			0.0	0.1	5.5	32.7	45.2	15.0	1.5	0.0	73%				1%		26%	
1991	27,227			0.0	0.0	10.7	36.7	38.4	12.4	1.7	0.0	67%		2%		5%		27%	
1992	25,721			0.0	0.6	12.3	35.7	36.8	11.7	2.9	0.0	73%		1%		4%		23%	
1993	13,546			0.0	0.0	3.2	21.6	52.8	21.6	0.8	0.0	64%		2%		18%		17%	
1994	32,330			0.0	0.0	3.3	22.6	54.7	19.3	0.0	0.0	81%		1%		8%		10%	
1995	61,650			0.0	0.0	3.2	12.4	51.9	28.5	4.0	0.0	77%		1%		6%		16%	
1996	37,513			0.0	0.0	0.8	16.1	41.5	33.6	7.6	0.3	48%		1%		6%		45%	
1997	103,945			0.0	0.0	0.0	10.5	18.1	44.8	26.2	0.4	34%		2%		5%		60%	
1998	46,481			0.0	0.0	0.8	10.9	48.1	37.2	3.1	0.0	22%		2%		5%		71%	
1999	79,370			0.0	0.5	1.1	8.1	33.5	46.5	10.3	0.0	48%		1%		5%		47%	
2000	163,331			0.0	0.0	1.0	9.9	27.6	51.0	10.4	0.0	40%		0%		6%		54%	
2001	203,776			0.0	0.0	2.0	21.4	50.5	24.0	2.0	0.0	56%		0%		4%		38%	
2002	117,348			0.5	1.6	6.0	27.7	40.2	15.2	8.7	0.0	65%		0%		1%		34%	
2003	134,937			0.0	1.0	7.2	31.4	25.8	32.0	2.6	0.0	74%		0%		0%		26%	
2004	112,786			0.0	1.9	14.9	15.5	48.4	11.2	8.1	0.0	72%		0%		0%		28%	
2005	72,822	0.4	0.0	0.4	1.8	6.6	34.4	22.3	30.8	3.3	0.0	64%		0%		1%		35%	
2006	60,869			0.6	0.6	4.5	11.9	52.8	26.1	2.8	0.6	50%		0%		0%		50%	
2007	25,464				1.3	2.0	43.4	29.6	23.0	0.7		48%		0%		0%		52%	
2008	22,541				0.6	5.1	28.7	30.9	25.3	9.6		43%		0%		0%		57%	
2009	35,806					2.3	9.9	32.0	55.8			37%						63%	

*No estimate of hatchery contribution available, used mean of 1989-1996.

Used scale ages for 1988-1996, otolith ages for 1997-2009.

Table 4 . Percent virgin American shad collected in the Conowingo Dam fish lifts, Susquehanna River.

	% Virgin*									
Year	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1988			100%	100%	91%	99%	96%	97%	100%	100%
1989			100%	100%	83%	92%	91%	97%	100%	100%
1990			100%	100%	87%	91%	93%	99%	100%	100%
1991			100%	50%	78%	88%	85%	93%	100%	100%
1992			100%	75%	78%	81%	87%	98%	100%	100%
1993			100%	100%	100%	82%	88%	100%	100%	100%
1994			100%	100%	100%	94%	94%	93%	100%	100%
1995			100%	100%	100%	86%	95%	100%	100%	100%
1996			100%	100%	88%	87%	89%	97%	100%	100%
1997			100%	100%	88%	87%	89%	97%	100%	100%
1998			100%	100%	88%	87%	89%	97%	100%	100%
1999			100%	100%	88%	87%	89%	97%	100%	100%
2000			100%	100%	50%	68%	69%	97%	100%	100%
2001			100%	100%	100%	100%	99%	100%	100%	100%
2002			0%	33%	45%	50%	44%	74%	100%	100%
2003			100%	50%	73%	93%	87%	95%	100%	100%
2004			100%	33%	63%	84%	83%	100%	100%	100%
2005				20%	26%	46%	66%	68%	100%	
2006			0%	0%	63%	76%	75%	96%	100%	100%
2007				100%	67%	53%	64%	77%	100%	
2008				0%	22%	51%	64%	84%	100%	
2009					100%	73%	81%	94%		

* 1996-1999- used the average of 1994,1995, 2000 and 2001

Table 5. Recruitment of virgin hatchery larvae, stocked above dams, to the Conowingo Fish Lifts, Susquehanna River.

	Cohort																
Year	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
1988	13																
1989	373	16															
1990	1,690	166	0														
1991	5,909	2,098	307	0													
1992	5,419	5,966	2,139	545	0												
1993	277	1,530	4,014	1,867	69	0											
1994	0	859	5,534	13,395	4,682	0	0										
1995		0	1,517	5,069	23,425	13,570	1,916	0									
1996			0	133	2,505	6,619	5,854	1,365	51								
1997				0	0	3,196	5,668	15,275	9,191	141							
1998					0	70	978	4,439	3,755	322	0						
1999						205	359	2,678	11,344	17,191	3,902	0					
2000							0	175	4,062	11,122	29,067	13,621	0				
2001								0	582	8,146	47,757	50,621	6,982	0			
2002								0	279	2,090	10,869	12,777	9,909	6,271	0		
2003									515	257	1,887	18,271	26,933	31,258	11,320	0	
2004										0	495	7,114	9,561	29,204	14,846	6,433	0
2005											0	136	761	7,000	7,473	9,811	1,871
2006												0	0	425	2,461	11,902	8,945
2007													0	0	157	1,707	3,289
2008														0	0	49	1,143
2009															0	0	153
Total recruits to lifts:	13,680	10,635	13,510	21,008	30,681	23,661	14,776	23,932	29,777	39,270	93,977	102,539	54,146	74,156	36,258	29,902	15,248
Larval releases (millions):	9.90	5.18	6.45	13.46	5.62	7.22	3.04	6.54	6.42	10.00	7.47	8.02	11.70	13.50	9.46	5.51	2.59
Number of larvae to return 1 adult:	724	487	477	641	183	305	206	273	216	255	79	78	216	182	261	184	170
Survival	0.0014	0.0021	0.0021	0.0016	0.0055	0.0033	0.0049	0.0037	0.0046	0.0039	0.0126	0.0128	0.0046	0.0055	0.0038	0.0054	0.0059

Mean number of larvae to return 1 adult (1986-2003): 378

Table 6. Recruitment of hatchery fingerlings, stocked above dams, to the Conowingo Fish Lifts, 1986- 1999.

	Cohort													
Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1988	0 *													
1989	0	0												
1990	0	0	0											
1991	160	57	8	0										
1992	70	77	28	7	0									
1993	7	40	106	49	2	0								
1994	0	12	77	185	65	0	0							
1995		0	24	80	368	213	30	0						
1996			0	3	56	147	130	30	1					
1997				0	0	152	269	724	724	7				
1998					0	5	67	306	259	22	0			
1999						2	4	30	126	191	43	0		
2000							0	0	0	0	0	0	0	
2001								0	0	0	0	0	0	0
2002									0	0	0	0	0	0
2003										0	0	0	0	0
2004											0	0	0	0
2005												0	0	0
2006												0	0	0
2007													0	0
2008														0
2009														
Total recruits to lifts:	238	186	242	324	490	519	501	1,091	1,111	220	43	0	0	0
Fingerlings stocked/10,000:	7.25	8.15	6.40	6.04	9.00	5.44	2.18	7.94	13.95	0.00	0.00	2.50	0.00	0.00
Number of fingerlings to return 1 adult:	305	437	264	186	184	105	44	73	126	0	0			

Mean number of fingerlings to return 1 adult (1986-1994): 192

Table 7. Recruitment of naturally reproduced American shad to the Conowingo Fish Lifts, 1986- 2002.

	Cohort																
Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1988	55																
1989	83	4															
1990	601	59	0														
1991	2,388	848	124	0													
1992	1,703	1,875	672	171	0												
1993	73	406	1,065	496	18	0											
1994	0	104	667	1,615	565	0	0										
1995	0	0	308	1,030	4,761	2,758	389	0									
1996		0	0	126	2,383	6,298	5,570	1,298	48								
1997			0	0	0	5,684	10,081	27,168	16,346	251							
1998				0	0	223	3,103	14,084	11,913	1,020	0						
1999					0	201	351	2,619	11,092	16,809	3,816	0					
2000						0	0	233	5,417	14,830	38,756	18,161	0				
2001							0	0	393	5,500	32,246	34,180	4,714	0			
2002								0	146	1,098	5,711	6,713	5,206	3,295	0		
2003									181	90	664	6,426	9,473	10,994	3,982	0	
2004										0	197	2,833	3,807	11,630	5,912	2,562	0
2005											0	74	415	3,818	4,076	5,351	1,021
2006												0	0	420	2,434	11,769	8,845
2007													0	0	167	1,819	3,505
2008														0	0	64	1,504
2009															0	0	261
Total recruits to lifts:	4,904	3,295	2,837	3,439	7,727	15,164	19,495	45,402	45,535	39,599	81,389	68,388	23,616	30,157	16,571	21,566	14,875
Adults transported/1000:	4.08	6.55	4.64	6.09	14.79	22.90	13.72	10.53	27.88	55.77	33.83	31.36	10.65	39.66	21.9	89.8	11.7
lts transported to return 1 adult:	0.83	1.99	1.63	1.77	1.91	1.51	0.70	0.23	0.61	1.41	0.42	0.46	0.45	1.32	1.32	4.16	0.79

Mean number of adults transported to return 1 adult (1986-2003): 1.34

Table 8. Virtual survival rates of marked American shad, by stocking site, recaptured as adults at the Conowingo Dam West Fish Lift.
Virtual Survival rate = Recruitment to the Conowingo Fish Lifts X 10,000, divided by the number stocked.

Cohort	Number Stocked (M)	Stocking location	Egg source	Number Recaptured (R)	Recruitment to Conowingo Fish Lifts	Virtual Survival Rate	Cohort Virtual Survival Rate	Adult Relative Virtual Survival Rate	Juvenile Relative Survival Rate
1995	9,070,999	Juniata or middle Susq.	Hud./Del.	93	66,229	73		0.40	0.65
1995	220,000	Conodoguinet Cr.	Hudson	1	860	39		0.22	0.77
1995	230,000	Conodoguinet (mouth)	Hudson	7	4,175	182		1.00	0.90
1995	198,000	Conestoga R.	Hudson	1	429	22		0.12	1.00
1995	190,000	Conestoga (mouth)	Hudson	1	638	34		0.18	0.36
1995	93,000	Muddy Cr.	Hudson	1	860	92		0.51	0.00
1995	520,000	below Conowingo (mid-channel)	Hud./Del.	6	3,847	74		0.41	0.00
1995	411,000	below Conowingo (nearshore)	Hud./Del.	6	2,862	70	73	0.38	0.00
1996	5,730,000	Juniata or middle Susq.	Hud./Del.	117	96,643	169		0.68	0.31
1996	561,000	West Br. Susq. R.	Hud./Del.	5	4,337	77		0.31	0.28
1996	683,000	North Br. Susq. R.	Hudson	10	7,819	114		0.46	1.00
1996	172,000	Conodoguinet Cr.	Delaware	4	3,521	205		0.83	0.37
1996	277,000	Conestoga R.	Delaware	0	0	0		0.00	0.00
1996	43,000	Standing Stone Cr.	Delaware	2	1,067	248		1.00	0.00
1996	1,087,000	below Conowingo	Hud./Del./Susq.	13	11,563	106	146	0.43	0.00
1997	3,037,000	Juniata or middle Susq.	Hud./Del.	86	63,010	207		0.62	0.89
1997	2,270,000	Juniata	Hud./Del.	30	20,872	92		0.27	1.00
1997	486,000	Jun. R. (Huntingdon)	Hudson	6	3,740	77		0.23	0.72
1997	622,000	West Br. Susq. R.	Hudson	2	1,821	29		0.09	0.41
1997	1,199,000	North Br. Susq. R.	Hud./Del.	14	10,026	84		0.25	0.97
1997	174,000	Conodoguinet Cr.	Delaware	8	5,821	335		1.00	0.14
1997	231,000	Conestoga R.	Hudson	3	2,237	97	134	0.29	0.12
1998	8,925,000	Jun. & Susq. R.	Hud./Del.	69	41,486	46		0.32	0.72
1998	321,000	W. Conewago Cr.	Hudson	7	4,714	147		1.00	0.89
1998	565,000	Juniata R.	Susq.	3	1,599	28		0.19	0.49
1998	305,000	Conodoguinet Cr.	Hudson	2	1,276	42		0.28	0.25
1998	1,126,000	North Br. Susq. R.	Hudson	9	6,075	54		0.37	1.00
1998	229,000	Conestoga R.	Hudson	1	638	28		0.19	0.00
1998	230,000	Swatara Cr.	Hudson	0	0	0		0.00	0.96
1998	56,000	West Br. Susq. R.	Susq.	0	0	0	47	0.00	0.00
1999	10,229,000	Juniata R.	Hud./Del.	182	96,189	94		1.00	0.73
1999	373,000	Conodoguinet Cr.	Hudson	5	3,085	83		0.88	0.59
1999	984,000	W. Br. Susq. R.	Hudson	0	0	0		0.00	0.00
1999	236,000	Conestoga R.	Hudson	2	1,428	60		0.64	1.00
1999	219,000	W. Conewago Cr.	Hudson	1	164	8		0.08	0.20
1999	249,000	Swatara Cr.	Hudson	1	696	28		0.30	0.80
1999	1,211,000	N. Br. Susq. R.	Hudson	8	4,665	39	79	0.41	0.21

Table 8. (continued)

Cohort	Number Stocked (M)	Stocking location	Egg source	Number Recaptured (R)	Recruitment to Conowingo Fish Lifts	Virtual Survival Rate	Cohort Virtual Survival Rate	Adult Relative Virtual Survival Rate	Juvenile Relative Survival Rate
2000	7,369,000	Juniata & Susq. R.	Hudson	57	20,522	28		0.43	1.00
2000	111,000	Conodoguinet Cr.	Hudson	0	0	0		0.00	0.74
2000	109,000	W. Conewago Cr.	Hudson	1	714	65		1.00	0.84
2000	961,000	W. Br. Susq. R.	Hud/Susq.	0	0	0		0.00	0.23
2000	231,000	Conestoga R.	Hudson	5	1,329	58		0.88	0.18
2000	33,000	Swatara Cr.	Hudson	0	0	0		0.00	0.00
2000	975,000	N. Br. Susq. R.	Hudson	6	2,641	27	26	0.41	0.56
2001	1,940,860	Juniata & Susq. R.	Hudson	51	14,420	74		0.49	1.00
2001	1,859,345	Juniata & Susq. R.	Susq.	60	15,245	82		0.55	0.64
2001	22,450	W. Br. Susq. R.	Susq.	0	0	0		0.00	0.00
2001	306,860	W. Br. Susq. R.	Susq.	2	505	16		0.11	0.05
2001	140,821	Conodoguinet Cr.	Susq.	1	266	19		0.13	0.03
2001	169,545	W. Conewago Cr.	Susq.	1	128	8		0.05	0.09
2001	210,831	Conestoga R.	Susq.	11	3,171	150		1.00	0.11
2001	182,490	Swatara Cr.	Susq.	1	266	15		0.10	0.56
2001	676,982	N. Br. Susq. R.	Hudson	4	1,586	23	65	0.16	0.51
2002	1,906,173	Juniata R.	Hud/Susq.	26	5,447	29		0.11	0.15
2002	216,560	Juniata R.	Susq.	25	5,528	255		1.00	0.37
2002	101,350	W. Br. Susq. R.	Hud/Susq.	5	1,351	133		0.52	0.54
2002	2,000	Conodoguinet Cr.	Susq.	0	0	0		0.00	0.00
2002	18,924	Conestoga R.	Susq.	1	341	180		0.71	0.00
2002	15,000	Swatara Cr.	Susq.	1	164	110		0.43	0.00
2002	21,000	N. Br. Susq. R.(PA)	Hudson	0	0	0		0.00	0.00
2002	158,790	N. Br. Susq. R.(NY)	Susq.	3	384	24		0.09	0.62
2002	2,000	Chemung R. (NY)	Hudson	0	0	0		0.00	0.00
2002	198,351	Chemung R. (NY)	Hudson	1	128	6	51	0.03	1.00
2003	5,712,662	Juniata/Susq. R.	Hudson	17	3,191	6		0.30	0.29
2003	1,947,223	Juniata/Susq. R.	Susquehanna	22	3,636	19		1.00	0.73
2003	591,558	W. Br. Susq. R.	Hudson	1	542	9		0.49	0.36
2003	167,774	Conodoguinet Cr.	Hudson	0	0	0		0.00	0.32
2003	158,146	Conestoga R.	Hudson	0	0	0		0.00	0.00
2003	293,183	W. Conewago Cr.	Hudson	0	207	7		0.38	0.55
2003	107,867	Swatara Cr.	Hudson	1	128	12		0.64	1.00
2003	800,129	N. Br. Susq. R.(PA)	Hudson	1	128	2		0.09	0.47
2003	491,988	N. Br. Susq. R.(NY)	Hudson	2	499	10		0.54	0.22
2003	414,721	Chemung R. (NY)	Hudson	1	128	3	8	0.17	0.00
2004	2,043,369	Juniata/Susq. R.	Hudson	8	3,094	15		0.29	0.00
2004	840,575	Juniata/Susq. R.	Susquehanna	11	2,858	34		0.65	0.00
2004	282,143	W. Br. Susq. R.	Hudson	5	1,468	52		1.00	0.00
2004	200	Conodoguinet Cr.	Hudson	0	0	0		0.00	0.00
2004	60,273	Conestoga R.	Hudson	0	207	34		0.66	0.00
2004	142,155	W. Conewago Cr.	Hudson	0	0	0		0.00	0.00
2004	53,261	Swatara Cr.	Hudson	0	0	0		0.00	0.00
2004	479,805	N. Br. Susq. R.(PA)	Hudson	0	0	0		0.00	0.00
2004	484,933	N. Br. Susq. R.(NY)	Hudson	1	128	3		0.05	0.00
2004	343,253	Chemung R. (NY)	Hudson	2	463	13	17	0.26	0.00