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Toward Validation of a Juvenile Index of Abundance for American Shad in the York River, Virginia

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Abstract.—A time series of relative abundance of juvenile American shad *Alosa sapidissima* in the York River, Virginia, was obtained for the years 1979–2000 (except for the years 1988–1990) from sampling with a push net. Until now, no evaluation of the validity of the survey has been made. We asked five questions about survey results: (1) On theoretical grounds, is there a preferred computational form for an annual index of abundance? (2) Do observed trends in relative abundance depend critically on the computational form of the index? (3) Can the index be correlated with results from an independent survey? (4) Does the survey cover the entire freshwater nursery zone of the juveniles? (5) Does the index depend critically on abundance of juveniles in a particular tributary? Annual indices of abundance were calculated four ways as: (1) an arithmetic mean of all catches taken over time and space, (2) a geometric mean of all catches taken over time and space, (3) the maximum value of the mean catch per cruise calculated as the geometric mean over stations, and (4) the area under the curve of mean catch per cruise versus time. The choice of index form depends on the choice of assumptions, for example, whether residence time on the survey grounds remains constant from year to year, or whether a constant fraction of the population is present each year when the peak abundance is reached. The best formulation could not be resolved on theoretical grounds. All push-net-based indices were highly correlated ($R >$ 0.83), however, so form of the index does not appear critical. The push-net index was highly correlated with an independent seine index. The predictability of the seine index from the push-net data suggests the two surveys provide valid indications of the trends in abundance. The proportion of the population in the sampling region may vary from year to year. The York River index is more heavily influenced by the abundance of shad in the Mattaponi River than in the Pamunkey River (both York River tributaries in Virginia).

Introduction

Acknowledging the need for protection and restoration of American shad *Alosa sapidissima* in its native range, the Atlantic States Marine Fisheries Commission (ASMFC) recently set specific monitoring requirements for the participating states (ASMFC 1999). The management plan requires that certain states report an annual juvenile abundance index (JAI) that is intended to provide a measure of annual recruitment success, prediction of potential fishery yields, and triggers for either relaxing or restricting fisheries (Rago et al. 1995). Other fishery management plans (e.g., those for striped bass *Morone saxatilis* and blue crab *Callinectes sapidus*) also use juvenile abundance indices (Rago et al. 1995; Kahn et al. 1998) for these purposes. An index of juvenile abundance for American shad in the Connecticut River, New England, has been positively correlated with recruitment of adult females 4–6 years later (Crecco et al. 1983); however, in no other stock have models been developed to relate juvenile abundance to subsequent adult abundance of American shad.

In 1979, the Virginia Institute of Marine Science (VIMS) initiated a monitoring program for juvenile American shad that generates an annual index of juvenile abundance in the York River, Virginia. After 19 years of monitoring (no sampling occurred in 1988–1990), the question still remains as to what the York River index measures: juvenile abundance on the spawning grounds, future recruitment, spawning stock biomass, hatching success and larval survival, or some un-interpretable

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quantity. Many methods of JAI calculation exist, and it is not well understood which index best represents year-class strength.

The York River JAI cannot be compared at present to subsequent estimates of recruitment to the adult stock because the time series of age-specific adult abundance estimates is short. However, we can query the time series to see if the index performs as expected. We describe the field methods used and the methods of computing indices of juvenile abundance. We then ask the following questions: (1) On theoretical grounds, is there a preferred computational form for the index of abundance? (2) Do the observed trends in relative abundance depend critically on the computational form of the index? (3) Can the index of abundance obtained from push-net data be correlated with results from an independent seine survey? (4) Does the survey cover the entire freshwater nursery zone of juveniles in the river and, if not, is there any reason to believe the proportion of the population available to the survey varies from year to year? Because the York River JAI is a combination of two separate tributary surveys, we also asked, (5) Does the index depends critically on any one tributary?

Study Area

The Pamunkey and Mattaponi rivers are adjacent tributaries that converge in West Point, Virginia, to form the York River which flows to the Chesapeake Bay (Figure 1). The Pamunkey River has a larger watershed (3,768 km^2) and higher average discharge rates (47.5 m^3/s) than does the Mattaponi River (2,274 km^2; 27.2 m^3/s, respectively) (Bilkovic et al. 2002). American shad spawning grounds span from river kilometer (rkm) 98 to rkm 150 on the Pamunkey River and from rkm 81 to rkm 124 on the Mattaponi River (Bilkovic et al. 2002).

Field Methods

Push-Net Sampling

Juvenile American shad were collected weekly by push net (Kriete and Loesch 1980) on the Pamunkey and Mattaponi rivers from June through August of 1979–1987 and 1991–2000. Sampling was modified in 1991 to current methods. Since 1991, annual surveys include more stations, more cruises, and a shorter time between cruises than was characteristic of the period 1979–1987. Thus, the JAIs

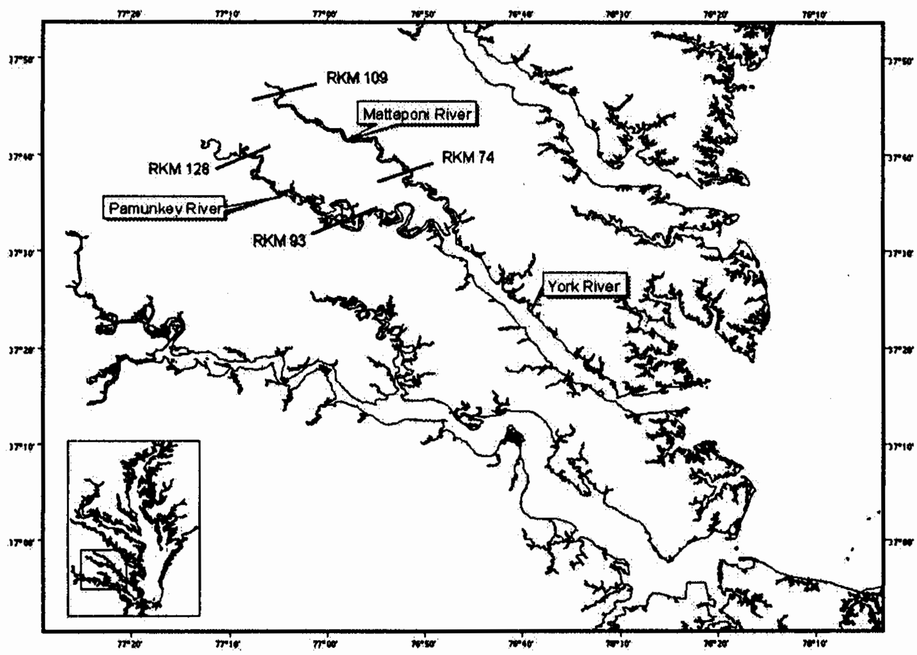

Figure 1.—The York River estuary and its setting within the Chesapeake Bay. Push-net sampling for juvenile American shad is conducted in the Mattaponi and Pumunkey rivers. River kilometer (RKM) lines indicate the start and end of the minimum sampling zone in each river.

from each time period (1979–1987 and 1991–2000) are considered separately in our analysis.

Sampling cruises for juveniles in the Virginia JAI surveys begin on the Pamunkey River at rkm 128 and on the Mattaponi River at rkm 109. The sampling area is divided into 9.3-km river blocks. Each river block is further divided into five 1.9-km stations. Three sampling stations are randomly chosen for every river block. Surveys proceed downriver for a minimum of 12 stations covering four sampling blocks (approximately 37 km) and end when collections no longer yield juvenile *Alosa*, normally just below the incursion of salt water at West Point, Virginia.

The number of juvenile American shad collected at each station is standardized for volume of flow through the net (Loesch and Kriete 1983) according to the following equation:

$$C_i = \frac{n_i w}{r_i a f},$$

where C_i = the number of fish caught in the ith tow standardized for flow, n_i = number of fish caught in the ith tow, w = standard volume of water filtered by the net when traveling a specific constant speed for a given amount of time (655 m^3 at 1,200 revolutions per min for 5 min for this study), r_i = revolutions of the flowmeter on the ith tow, a = area of the net (2.25 m^2 for this study), and f = standard unit of conversion on the flowmeter (0.0267 m/revolution).

Seine Survey

The VIMS seine survey produces a JAI of striped bass, but other species including juvenile American shad are collected. Seines are hauled by hand in daylight hours during the summer (July–September) at stations in the York (rkm 52), Pamunkey (spanning rkm 67–102), and Mattaponi (spanning rkm 61–97) rivers; the gear is a 1.2-m x 30.5-m seine with a 6.4-mm mesh (Austin et al. 1995). Seine survey JAIs for American shad were calculated as seasonal geometric mean catch rates over all hauls.

Forms of the Juvenile Index

Four forms of the juvenile abundance index were computed from the push-net data for each season of sampling. (1) The arithmetic mean (AM) is an average of mean catch computed for each cruise in a given year (i.e., an average of averages). (2) The geometric mean (GM) is the back-transformed average of the logarithmic transformation of all catches at all stations. (3) The maximum geometric mean (MGM) is the largest of the cruise-specific geometric mean catch rates. (4) The areal index (RM) is an integrated seasonal index (also termed the area-under-the-curve index) that is calculated according to the trapezoidal rule as follows:

$$\text{JAI}_{\text{areal}} = \frac{1}{2}\sum_{i=1}^{n-1} D_i (R_i + R_{i+1}),$$

where D_i = the number of days between cruise i and cruise $i + 1$, n = the number of cruises, and R_i = the geometric mean cruise catch rate for cruise i. Because the sampling sometimes started after the first appearance of juveniles and ended before all juveniles had left the area, the catch is assumed to be zero $0.5D_1$ days before the first cruise and $0.5D_{n-1}$ days after the last cruise.

Arithmetic, maximum geometric, and areal indices for the York River were calculated by summing the JAIs of each tributary in each year from 1979 to 2000. Geometric mean indexes for the York River were calculated by averaging the logarithmic transformations of all catches at all stations in both rivers in a given season. Relative standard errors (rse) were calculated for each form of the index as the standard deviation of the index time series divided by the mean of the series.

The area-under-the-curve method was used to investigate the question of spatial coverage of the surveys. Areal estimates of abundance were calculated separately for all river-blocks on the Mattaponi and Pamunkey rivers from 1991 to 2000. Block-specific index values for each river were compared within and between years to note any spatial trends in juvenile abundance.

Results and Conclusions

(1) Is there a Preferred Computational Form?

Maximum catch rate is an appropriate form when it is known that at some single point in time all of the population is in the survey area or, equivalently, that a fixed proportion of the population is present. For example, juveniles may gradually grow large enough to be captured by the survey gear and then stay in the survey area until some environmental event triggers the start of an exodus. If the temporal pattern of susceptibility to the gear and exodus varies from year to year, then maximum catch rate may be the best index to use. However, this approach is problematic if the temporal trend in abundance has multiple peaks in some years. This would suggest that the fraction of the population occurring when catch rates reach a peak varies from year to year.

The areal index assumes that the residence time in the sampling area remains constant from year to year. If, however, in some years an early environmental signal triggers an early departure from the sampling area, then the area-under-the-curve method will measure residence time as much as it measures abundance.

If the window of time during which the juvenile population is surveyed remains the same from year to year, then the use of the average catch rate is equivalent to the area-under-the-curve method because the average and total catches are simply related by a constant factor. However, if the sampling window varies from year to year then the use of averages is problematic. For example, suppose that year 2 is exactly the same as year 1 except that the juvenile American shad become vulnerable to the sampling gear 3 weeks later than in year 1, and suppose that sampling begins on the same date each year and continues until catches decline to zero. Then, for year 2, the area-under-the-curve method will add 3 weeks of zeroes to the total (i.e., not change the total at all). The average catch rate method, however, will average in 3 weeks of zeroes and thus lower the index inappropriately.

Because methods of index calculation require different assumptions, we conclude that the appropriate form of the index (in terms of bias) cannot be resolved on purely theoretical grounds.

In general, it is difficult to obtain a valid measure of variance because of the inherent nature of the sampling. For example, if only 1 d is sampled per week, we have no replication within weeks. We did, however, have a way to judge relative variability of the indices. The variation in an index over a 21-year period is due to three things: actual variation in abundance, sampling variability, and nonsampling error (the error resulting from assumption violations). Since all types of indicies are calculated from the same data, actual variation in abundance and sampling variability are the same for all methods of calculating the index. Hence, differences in the indices reflect the nonsampling error. Now, if the nonsampling error is independent of the abundance, then a less variable index with a lower rse must be better than a more variable one. However, the assumption that error is independent of abundance cannot be assessed from available data.

(2) Do Survey Results Depend Critically on the Form of the Index?

Catch data for each tributary of the York River are depicted in Figures 2 and 3. Forms of the index of juvenile abundance are shown in Table 1. Multiple peaks in catch rates occurred in 8 years (1983, 1991, 1992, 1995, 1996, and 1998–2000) on the Pamunkey River and 8 years (1983, 1992–1993, 1995–1996, and 1998–2000) on the Mattaponi River. We conclude that the use of the maximum catch rate in these years may be problematic as described previously. Note that in a number of years (1979, 1980, 1981, and 1991 on the Mattaponi River, and 1979, 1980, 1981, 1982, 1985, and 1994 on the Pamunkey River), the highest count was obtained in the first survey, suggesting that a late start to the sampling may have resulted in missing the early part of residence on the juvenile nursery grounds. In this case, use of the maximum geometric mean as an index may be appropriate, but it would be better if the study design specified that sampling begin earlier so that other index forms might be used.

All forms of the index indicate 1996 and 2000 were years of record high juvenile abundance and 1992 was the year of lowest abundance (Table 2). However, no other year has the same rank for all forms of the JAI. In five cases (1980, 1984, 1986–1987, and 1997), the rank is the same for three forms of the indices. Other rankings of years possess less agreement among indices.

Forms of the JAI are more highly correlated under the current sampling protocol (1991–2000) than during the previous survey protocol (1979–1987) (Table 3). Under the current survey methodology, all comparisons were highly significant. Generally, regressions of the MGM against other measures of relative abundance have lower R^2 values.

Due to multiple peaks in seasonal catch rates and the observation that the maximum geometric mean has a weaker relationship with the other measures, we conclude that the MGM is not a preferred index. The forms of the index are highly correlated; thus, among the AM, GM, and RM, we conclude that there is no superior form of calculation.

(3) Is the Push-Net Index Correlated with Results from an Independent Survey?

Mattaponi, Pamunkey, and York river indices for the seine survey are shown in Table 4. Geometric mean JAIs based on push-net data were compared to those based on seine survey catches. All regressions were highly significant with high R^2 values (Table 5). Although not an explicit validation of ei-

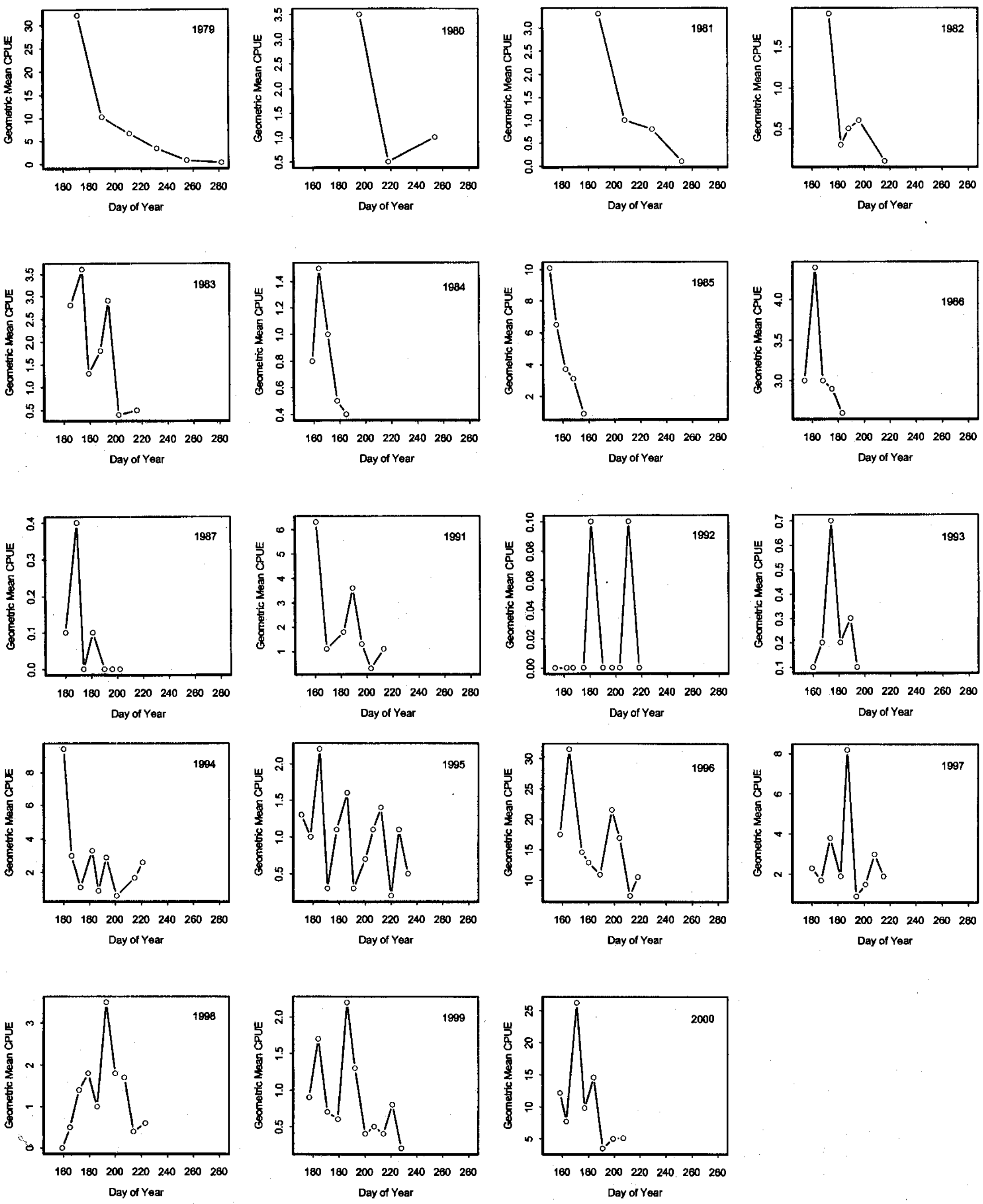

Figure 2.—Geometric mean cruise-specific catch rates of juvenile American shad in the Pamunkey River. CPUE = catch per unit effort.

ther survey, the results confirm that the relative abundance of juvenile American shad is measured similarly in both surveys. The predictability of the seine index from the push-net data suggests the two surveys provide valid indications of the trends in abundance.

(4) Does the Survey Cover the Entire Freshwater Nursery Zone of the Juveniles?

Areal estimates of abundance by station are depicted in Figure 4. The largest number of river blocks inhabited by juveniles occurred in 1996, a year of

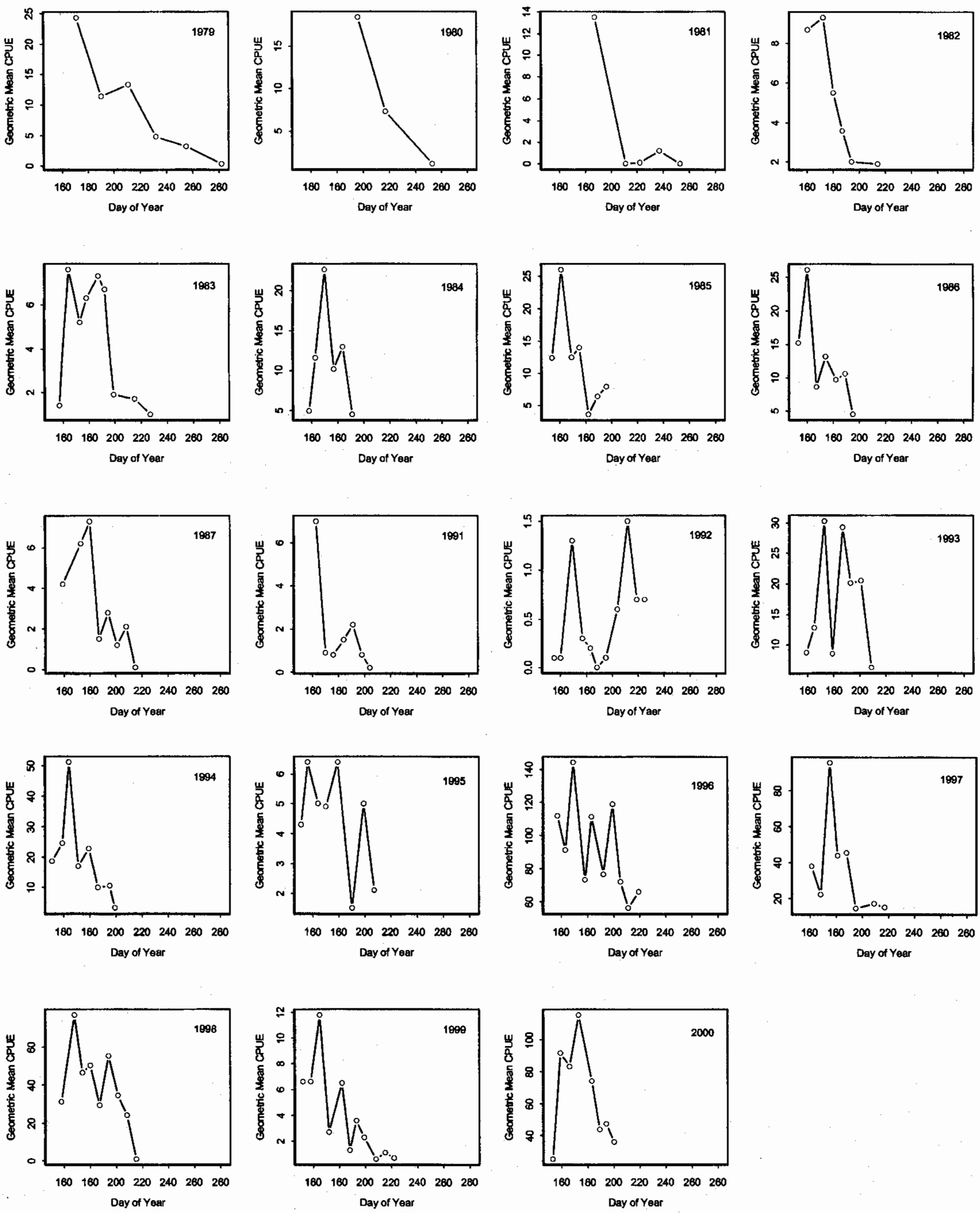

Figure 3.—Geometric mean cruise-specific catch rates of juvenile American shad in the Mattaponi River. CPUE = catch per unit effort.

record high index values. The smallest number of river blocks inhabited by American shad occurred in years of low index values (1992–1993).

In some years (1998 and 2000 on the Pamunkey River; 1993 and 2000 on the Mattaponi River), catches in the upriver stations appear to contribute more to the overall annual catch. However, in other years, downriver stations are more productive than upriver stations (1994 and 1996–1998 on the Mattaponi River). Large catches at the far-

Table 1.—Forms of an index of abundance of juvenile American shad in the York River (1979–2000). AM = arithmetic mean; GM = geometric mean; MGM = maximum geometric mean; and RM = areal mean. York River = total Mattaponi + Pamunkey; rse = relative standard error; and ns = no sampling.

	Mattaponi River				Pamunkey River				York River			
Year	AM	GM	MGM	RM	AM	GM	MGM	RM	AM	GM	MGM	RM
1979	14.2	7.1	24.3	1,163.5	16.5	5.1	32.0	940.5	30.7	5.9	56.3	2,104.1
1980	16.2	6.6	18.4	635.8	3.2	1.2	3.5	126.5	19.3	3.6	21.9	762.3
1981	4.0	1.2	13.5	343.2	2.3	1.1	3.3	107.1	6.2	1.2	16.8	450.3
1982	9.9	4.4	9.3	327.9	1.0	0.6	1.9	32.5	10.9	1.9	11.2	360.4
1983	7.5	3.6	7.6	300.1	3.4	1.7	3.6	105.1	10.9	2.6	11.2	405.2
1984	20.1	9.5	22.6	446.2	1.3	0.7	1.5	26.6	21.4	4.1	24.1	472.8
1985	17.6	10.7	26.0	585.8	8.6	3.3	10.1	143.2	26.3	6.5	36.1	729.0
1986	19.8	11.2	26.1	616.5	5.6	3.2	4.4	116.7	25.3	6.8	30.5	733.2
1987	5.5	2.6	7.3	229.0	0.1	0.1	0.4	4.8	5.6	0.8	7.6	233.7
1988	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
1989	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
1990	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
1991	2.7	1.4	7.0	92.9	3.8	1.8	6.3	128.9	6.5	1.6	13.3	221.7
1992	0.8	0.4	1.5	40.7	0.0	0.0	0.1	1.9	0.8	0.2	1.6	42.6
1993	27.0	15.2	30.3	973.4	0.3	0.2	0.7	11.0	27.3	6.3	31.0	984.4
1994	29.4	14.7	51.2	1,074.0	5.1	2.2	9.4	172.3	34.6	5.6	60.6	1,246.3
1995	8.7	4.2	6.4	274.4	1.7	0.9	2.2	87.2	10.4	1.8	8.6	361.6
1996	125.3	88.9	144.1	6,325.7	26.1	14.8	31.5	1,082.5	151.4	34.8	175.6	7,408.2
1997	47.6	29.8	95.4	2,102.6	5.0	2.4	8.2	169.1	52.5	7.5	103.5	2,271.7
1998	48.7	28.6	76.9	2,540.0	2.8	1.1	3.5	89.5	51.5	5.3	80.4	2,629.5
1999	9.2	3.0	11.8	301.9	1.8	0.8	2.2	67.9	11.0	1.6	14.0	369.8
2000	80.9	57.9	115.6	3,617.7	19.9	8.8	26.2	567.1	100.8	23.0	141.8	4,184.7
rse	1.2	1.4	1.1	1.3	1.3	1.4	1.3	1.5	1.2	1.3	1.1	1.3

Table 2.—Years of monitoring juvenile abundance on the York River (1979–2000) ranked from lowest to highest years of abundance for each form of the juvenile abundance index. Like years are in bold italics and the number of agreements noted. Abbreviations are: AM = arithmetic mean; GM = geometric mean; MGM = maximum geometric mean; RM = areal mean; and # agree = number of agreements among indices.

AM	GM	MGM	RM	# agree
1992	***1992***	***1992***	***1992***	4
1987	***1987***	***1987***	1991	3
1981	***1981***	1995	1987	2
1991	1999	1983	1982	0
1995	1991	1982	***1995***	2
1982	1995	1991	1999	0
1983	1982	1999	***1983***	2
1999	1983	***1981***	***1981***	2
1980	***1980***	***1980***	1984	3
1984	***1984***	***1984***	1985	3
1986	1998	***1986***	***1986***	3
1985	1994	1993	1980	0
1993	1979	1985	***1993***	2
1979	1993	***1979***	1994	2
1994	1985	***1994***	1979	2
1998	1986	***1998***	1997	2
1997	***1997***	***1997***	1998	3
2000	***2000***	***2000***	***2000***	4
1996	***1996***	***1996***	***1996***	4

thest upriver stations might suggest that sampling farther upriver would result in larger annual index values. However, sampling farther upstream is precluded by a 1.5-m depth requirement of the sampling gear. Because the nursery zone is considered the freshwater area of each river, the absolute downriver end of sampling fluctuates based on summer low river flows and salt wedge movement. We conclude that measuring abundance of juveniles based on static upriver stations in a fluctuating habitat will artificially deflate the index in some years.

(5) Does the Index Depend Critically on Any One Tributary Survey?

Ratios of Mattaponi to Pamunkey river JAIs indicate that the relative abundance of American shad is almost always greater on the Mattaponi River (Table 6). The greatest difference in relative abundance was observed in 1993 when the abundance of juveniles on the Mattaponi River was 40–90 times larger than that of the Pamunkey River. Similarly, differences were also large in 1984 (12–17 times), 1987 (19–50 times), 1992 (11–23 times), 1997 (9–12 times), and 1998 (17–28 times). Despite the physical similarities of the two tributaries and

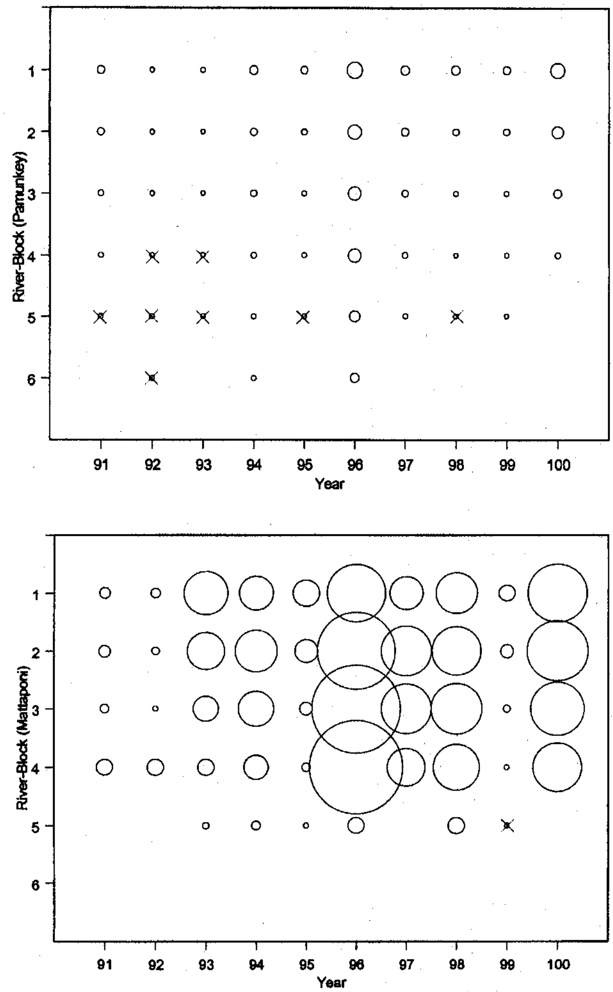

Figure 4.—Spatial distribution of catches of juvenile American shad in the Pamunkey and Mattaponi rivers, 1991–2000. Bubble size is proportional to area-under-the-curve estimates of cruise-specific catch rates versus day of the sampling season; x denotes sampling yielded no juveniles. River block 1 is river km 124–130 on the Pamunkey River and river km 104–111 on the Mattaponi River.

their proximity, we conclude that the York River JAI is more heavily influenced by the abundance of American shad in the Mattaponi River than in the Pamunkey River.

Recommendations

Presently, there are insufficient data on spawning run size to relate the York River JAI to subsequent recruitment of adult cohorts. We recommend the continuation of the JAI until the time series of adult abundance is sufficient to test the validity of either juvenile survey (push net or seine). Rigorous validation studies for all JAIs of American shad that have not yet been validated are strongly encouraged. We do not recommend continuation of the maximum catch rate (MGM) for this or other like surveys. The remaining forms of the index perform similarly; thus, the current ASMFC (1999) requirement to report juvenile abundance as a geometric mean may be unnecessary. The seine survey is used in most participating states to monitor the relative abundance of shad and may be a less expensive alternative to the push-net survey in the York River. In addition, use of the seine may allow sampling farther upstream than the present push-net survey. Since abundance of juvenile

Table 3.—Regression equations ($y = mx + b$), R^2 values, and p-values for comparisons of forms of an index of abundance of juvenile American shad in the York River. Juvenile abundance monitoring changed after 1989 by increasing effort (number of cruises) and standardizing the time between cruises (6 d). Current monitoring occurs from June–August, which is less protracted in time than past monitoring (spring–early fall). MGM = maximum geometric mean; RM = areal mean; GM = geometric mean; and AM = arithmetic mean.

		1979–2000			1979–1987			1991–2000		
x	y	$mx + b$	R^2	p	$mx + b$	R^2	p	$mx + b$	R^2	p
MGM	RM	$35.6x - 217.6$	0.92	<0.001	$33.6x - 110.3$	0.85	<0.001	$36.3x - 317.9$	0.91	<0.001
MGM	GM	$0.2x - 0.8$	0.84	<0.001	$0.1x + 0.8$	0.67	0.008	$0.2x - 1.9$	0.84	<0.001
RM	GM	$0.004x + 0.2$	0.91	<0.001	$0.002x + 2.0$	0.35	0.091	$0.005x - 0.5$	0.94	<0.001
AM	GM	$0.2x - 0.7$	0.96	<0.001	$0.2x - 0.4$	0.91	<0.001	$0.2x - 1.5$	0.96	<0.001
AM	RM	$47.8x - 150.4$	0.97	<0.001	$44.9x - 86.9$	0.55	0.022	$48.0x - 173.8$	0.99	<0.001
AM	MGM	$1.3x + 4.3$	0.94	<0.001	$1.5x - 2.0$	0.81	<0.001	$1.2x + 8.0$	0.94	<0.001

Table 4.—Indices of abundance of juvenile American shad collected in beach seine surveys (1980–1999). Indices are calculated for the Mattaponi, Pamunkey, and York rivers.

	Mattaponi		Pamunkey		York	
Year	Index	SD	Index	SD	Index	SD
1980	1.75	1.06	0.44	0.68	1.12	0.97
1981	0.74	0.78	0.58	0.67	0.65	0.72
1982	9.11	1.28	0.40	0.51	3.33	1.42
1983	1.64	1.01	0.77	0.78	1.22	0.93
1984	11.56	1.37	0.33	0.52	3.79	1.56
1985	7.21	1.37	0.56	0.63	3.03	1.38
1986	1.24	0.98	0.05	0.05	0.62	0.84
1987	0.12	0.40	0.00	0.00	0.07	0.31
1988	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.75	0.95	0.00	0.00	0.38	0.77
1990	0.05	0.20	0.00	0.00	0.03	0.15
1991	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.23	0.54	0.00	0.00	0.13	0.42
1994	1.39	1.02	0.09	0.26	0.70	0.88
1995	0.04	0.15	0.00	0.00	0.02	0.12
1996	15.04	1.37	1.29	0.89	5.97	1.53
1997	1.71	1.10	0.30	0.51	0.98	0.96
1998	2.38	1.40	0.04	0.16	1.04	1.21
1999	0.14	0.41	0.00	0.00	0.08	0.32

Table 6.—Ratios (Mattaponi/Pamunkey) of juvenile abundance index values for American shad. Ratios less than 1 are in bold italics. AM = arithmetic mean; GM = geometric mean; MGM = maximum geometric mean; and RM = areal mean.

Year	AM	GM	MGM	RM
1979	***0.9***	1.4	***0.8***	1.2
1980	5.1	5.6	5.3	5.0
1981	1.7	1.1	4.1	3.2
1982	9.7	7.7	4.9	10.1
1983	2.2	2.2	2.1	2.9
1984	15.6	12.7	14.6	16.8
1985	2.0	3.2	2.6	4.1
1986	3.6	3.5	5.9	5.3
1987	50.0	14.0	19.3	48.2
1991	***0.7***	***0.8***	1.1	***0.7***
1992	23.2	17.9	11.0	21.0
1993	79.0	69.0	43.9	88.5
1994	5.7	6.8	5.4	6.2
1995	5.0	4.7	2.9	3.1
1996	4.8	6.0	4.6	5.8
1997	9.6	12.3	11.7	12.4
1998	17.4	26.6	22.0	28.4
1999	5.2	3.7	5.4	4.4
2000	4.1	6.6	4.4	6.4

American shad on the Mattaponi River drives the York River JAI, sampling could be limited to this tributary to further decrease the costs of the annual survey on the York River.

Table 5.—Regression equations ($y = mx + b$), R^2 values, and p-values for comparisons of an index of abundance of juvenile American shad from independent surveys monitoring juvenile abundance on the York (Y), Mattaponi (M), and Pamunkey (P) rivers (1991–1999). GM = geometric mean.

Pushnet (x)	Seine (y)	$mx + b$	R^2	p
GM_Y	GM_Y	$0.18x - 0.28$	0.98	< 0.001
GM_M	GM_M	$0.17x - 1.15$	0.94	< 0.001
GM_P	GM_P	$0.09x - 0.08$	0.98	< 0.001

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