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Evaluating the Current Status of American Shad Stocks in Three Virginia Rivers

Robert J. Latour,* Eric J. Hilton, Patrick D. Lynch, Troy D. Tuckey, Brian E. Watkins, and John E. Olney[1]
Virginia Institute of Marine Science, College of William and Mary, Post Office Box 1346, Gloucester Point, Virginia, 23062, USA

Abstract

Directed commercial fisheries for American shad *Alosa sapidissima* in the primary Virginia tributaries of the Chesapeake Bay have been under moratorium since 1994. Monitoring of adult American shad within these rivers has been ongoing since 1998 through a cooperative program involving commercial fishers. The monitoring program is designed to mimic traditional commercial fishing practices so that stock status can be inferred by comparing contemporary catch-per-unit-effort levels with those derived from historic logbooks. In this paper, we present analyses of the available monitoring and historic catch rate data along with updated stock status information for American shad in the James, York, and Rappahannock rivers. Two analytical methods were used to derive annual indices of relative abundance; both methods yielded very similar patterns for each river system. Comparisons of contemporary and historic indices of relative abundance suggest that American shad in the James and York rivers continue to persist at low levels of abundance. Measures of stock abundance in the Rappahannock River have been higher than the logbook reference value for much of the monitoring period. However, current moratoria and restoration strategies, which include hatchery releases of fry, the removal of obstructions blocking spawning and nursery habitat, and reductions in bycatch from other fisheries, should continue into the foreseeable future.

The American shad *Alosa sapidissima* is an obligate anadromous clupeid native to estuarine and coastal waters of eastern North America from Canada to Florida. American shad stocks along the Atlantic coast exhibit varying life history strategies that are both fascinating and complex. These fish spend most of their life at sea and migrate into the freshwater components of coastal river systems to spawn. Emigration from natal rivers to oceanic waters occurs during the first year of life, although the exact timing of this movement process is variable across stocks (Limburg 1996).

Historically, American shad supported vibrant fisheries in both coastal and estuarine environments. During the latter half of the 1800s, American shad were an important food resource and among the top three species harvested along the Atlantic coast (U.S. Fish Commission 1872–1881, ASMFC 2007). Total coastwide landings peaked in 1896 at slightly less than 23,000 metric tons (mt) but consistently declined in subsequent decades to averages of 3,465 and 1,635 mt for the periods of 1950–1969 and 1970–1989, respectively (NMFS annual commercial landings statistics). Total landings from American shad fisheries in Virginia tracked the coastwide statistics fairly closely, dropping to mean levels of 1,188 and 549 mt for the aforementioned time periods (NMFS annual commercial landings statistics). Although fisheries still exist for some American shad stocks, most have either been significantly reduced or closed. Since 1994, in-river harvest of American shad has been prohibited in the Chesapeake Bay and its tidal tributaries in Virginia (Virginia Marine Resources Commission [VMRC] Regulation 450-01-0069);

Subject editor: John Waldman, Queens College, Flushing, New York, USA

*Corresponding author: latour@vims.edu
[1]Deceased.
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directed coastal mixed-stock fisheries were more recently phased out, with full closure in December 2004 (ASMFC 1999). However, fishing mortality for Virginia American shad stocks is not zero due to allowable harvest by Native Americans, minimal permitted bycatch by fishers targeting striped bass *Morone saxatilis* in the tributaries of the Chesapeake Bay, minor takes from a few small recreational fisheries in rivers outside of the Chesapeake watershed (e.g., the Nottoway and Blackwater rivers), unknown losses from catch-and-release mortality of recreational fisheries within tidal rivers, and unknown losses from bycatch of other fisheries operating along the U.S. East Coast.

Following the moratorium on in-river fisheries for American shad in Virginia, a variety of restoration activities were initiated in an effort to rebuild depleted stocks. These included annual releases of hatchery-reared larvae in some rivers, construction of fish passage facilities, and removal of dams to restore access to historic spawning habitat (Hendricks 2003; Olney et al. 2003; Weaver et al. 2003). In 1997, commercial American shad fishers asked the VMRC to consider lifting the in-river moratorium, although no information on adult stock abundance or spawning run strength was available to evaluate the stock status or provide harvest reference points. As a result, fisheries-independent monitoring of adult American shad abundance began in 1998 for stocks in three primary tributaries of the Chesapeake Bay: the James, York, and Rappahannock rivers (Olney and Hoenig 2001). While obtaining contemporary stock-specific adult abundance information was viewed as necessary, equally important was the need to develop an objective framework that would allow this information to be interpreted relative to historic levels. The only available historic fisheries data for American shad in Virginia, other than landings, were catch rates obtained from logbooks voluntarily provided by a subset of commercial fishers. These logbooks provided information on the daily effort and catch of females from 1980 to 1992. Additional daily catch rates were obtained from archived microfilm from the 1950s. As a result, the current spawning stock monitoring program was designed to mimic commercial fishing practices as closely as possible, so that progress toward restoration could be measured by relating contemporary catch rates to those obtained from the logbooks.

In this paper, we provide indices of relative abundance derived from catch-per-unit-effort (CPUE) data collected for adult American shad in the James, York, and Rappahannock rivers of the Chesapeake Bay in an effort to evaluate progress toward stock rebuilding. Our specific objectives were to (1) evaluate the current status of American shad stocks in three Virginia rivers through comparisons of adult abundance indices from the standardized monitoring program (1998–2011) with those calculated from logbook data (1980–1992 for all rivers and 1953–1957 for the York River) and (2) assess the relative accuracy of a nonparametric approach and a parametric approach for the quantification of trends in the relative abundance of American shad.

METHODS

Field sampling and laboratory processing.—Staked gill nets were used in the current adult American shad monitoring program and constructed to closely match traditional commercial gear specifications. All activities associated with erecting the net stand and fishing the gear were conducted cooperatively with fishers that formerly harvested American shad commercially to closely mimic historical fishing practices. In each river, a single staked gill-net stand was fished on two succeeding days (two 24-h sets) each week between late February and early May and then hung in a nonfishing position until the next sampling event; surface water temperature and salinity were recorded at each sampling event. The locations for each staked gill net were based on those associated with the historic logbook data, and stand locations were selected to approximate the "average" logbook catch so as not to bias recent catch rate estimates. Scientists from the Virginia Institute of Marine Science (VIMS) were present for each sampling event, and all American shad captured were returned to the laboratory for further processing.

The exact gear dimensions associated with the logbook data from the James and York rivers differed slightly from those of the logbook data from the Rappahannock River. Sampling in the James and York rivers was conducted using a 273-m staked gill net (9.1-m panel length) located at river miles 10 (36°59.0′N, 76°28.8′W) and 14 (37°20.8′N, 76°37.7′W), respectively (Figure 1). In the Rappahannock River, a 277-m staked gill net (14.6-m panel length) was located at river mile 36 (37°55.9′N, 76°50.4′W). The nets in the York and James rivers were constructed of 12.4-cm stretched-mesh monofilament netting, while the net used in the Rappahannock River was constructed of 12.7-cm netting.

In the laboratory, all adult American shad collected from the monitoring sites were measured (fork length to the nearest millimeter) and weighed (total weight to the nearest gram) on a Limnoterra FMB IV electronic fish measuring board interfaced with a Mettler PM 30000-K electronic balance. All individuals were dissected for sex determination, and the ovaries of females were staged macroscopically following the criteria described by Olney et al. (2001). Index of relative abundance calculations were based only on those fish staged as maturing, hydrated, or running.

Index calculations.—For each stock, indices of relative adult abundance were generated for all available years using a nonparametric index estimator defined to be the area under the curve (AUC) and a parametric approach using a generalized linear model (GLM). Since the historic American shad fishery targeted prespawned females for roe, all indices of relative abundance were expressed as kilograms of females$\cdot$m$^{-1}\cdot$ d^{-1}. Daily catches of adult female American shad in the York River during the 1950s were multiplied by 2.16 to adjust for changes in fishing efficiency due to differences in material (multifilament versus monofilament) and mesh sizes (12.06-cm mesh

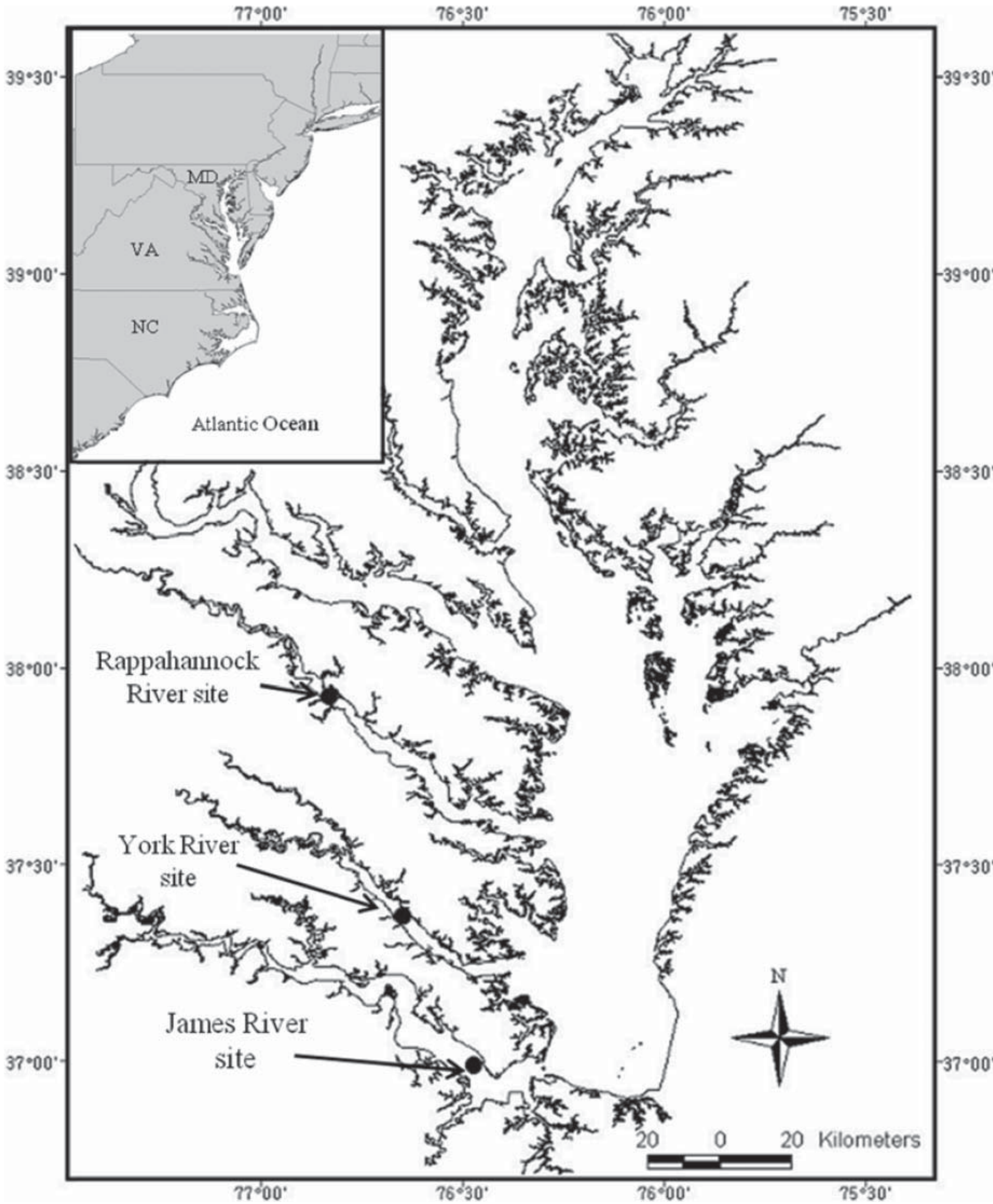

FIGURE 1. Locations of staked gill-net American shad monitoring sites on the James, York, and Rappahannock rivers based on historical locations associated with commercial logbook daily catch data.

versus 12.4-cm mesh) between older and contemporary staked gill nets (Olney and Hoenig 2001; Maki et al. 2006). Reference index values for stock status determination in each river system were calculated as the mean catch rate from 1953 to 1957 for the York River stock and that from 1980 to 1992 for the James and Rappahannock River stocks. Given the long coastwide exploitation history of American shad and the systematic decline in landings over the past century, these reference values are likely best interpreted as first-level metrics of stock rebuilding rather than absolute thresholds of sustainability.

The AUC estimator, which originated with Pacific salmon *Oncorhynchus* spp. escapement studies (Ames and Phinney 1977; Neilson and Geen 1981; English et al. 1992), has traditionally been used to summarize fisheries-independent catch rate information collected for adult female American shad stocks in Virginia (Olney and Hoenig 2001). The method is based on the trapeziodal rule applied to CPUE versus time, that is,

$$AUC_y = \frac{1}{2}\sum_{i=1}^{n-1} D_i(R_i + R_{i+1}), \qquad (1)$$

where y denotes the index year, D_i is the number of days between sampling events i and $i+1$, n is the total number of sampling events, and R_i is the CPUE for sampling event i (Wilhite et al. 2003). The AUC does not require CPUE observations to follow any particular probability distribution and has the attractive characteristic that zero catch rate observations do not affect the index value. For an anadromous species that may exhibit yearly variation in the timing of the spawning run, zero catches can occur if sampling takes place too early or too late relative to run timing. In this case, zero observations truly indicate that no fish are available for sampling and thus should not negatively affect the index value.

The AUC estimator lacks an obvious and rigorous method for quantifying the uncertainty in annual index values. We elected to use a bootstrap procedure (Efron and Tibshirani 1993; Parken et al. 2003) to estimate annual coefficients of variation (CV) for the AUC indices of American shad. Annual CV estimates were calculated as

$$CV_y = \frac{SD_y}{AUC_y},$$

where AUC_y is the annual index value calculated from equation (1) and SD_y is the estimated year-specific standard deviation of 2,000 nonparametric bootstrap-sampled AUC_y estimates. Each data set derived in the bootstrap procedure was constructed by assigning those days actually fished a randomly chosen CPUE value (with replacement) from those observed in the associated month of sampling. This approach was taken to preserve the fairly well known intra-annual patterns in daily CPUE across the spawning run (Nichols and Massmann 1963).

Application of a GLM was motivated by the notion that parametric estimators are generally more efficient than nonparametric estimators and because GLMs allow for the inclusion of explanatory variables beyond just a year effect. A GLM is defined by the underlying statistical distribution for the response variable (daily CPUE in this case) and how a set of linearly related explanatory variables correspond to the expected value of the response variable (Maunder and Punt 2003). The linear relationship between explanatory variables and some function of the expected value of the response variable is given by

$$g(\mu_i) = \mathbf{x}_i^{\mathrm{T}}\boldsymbol{\beta}, \qquad (2)$$

where $\mu_i = E(Y_i)$ (with Y_i being defined as the ith response variable), $\mathbf{x}_i$ is the vector of explanatory variables, $\boldsymbol{\beta}$ is a vector of parameters, and g is the differentiable monotonic link function that governs the relationship (linear or nonlinear) between the random (μ_i) and systematic ($\mathbf{x}_i^T\boldsymbol{\beta}$) components of the model (McCullagh and Nelder 1989; Maunder and Punt 2003).

Histograms of raw adult CPUE data by year for each stock were consistently positively skewed, which provided evidence that the CPUE data are lognormally distributed. Therefore, a lognormal GLM with categorical year and month fixed effects was used to model adult CPUE for each river system (a gamma GLM with the same categorical fixed effects was also considered but is not described here since it yielded results that were virtually indistinguishable from those of the lognormal model for each river system). A constant of 10^{-3} was added to all daily CPUE values to adjust for zero values while maintaining the relative scale and the distributional shape of the data. The exact model structure was as follows:

$$\log_e(\mathrm{CPUE} + 10^{-3})_{ym} = mean + year_y + month_m + \varepsilon_{ym}, \qquad (3)$$

where y and m denote the index year and month, respectively. The GLM model fits were evaluated primarily through visual examination of quantile-quantile (QQ) plots of normality and plots of residuals versus predicted values (Zuur et al. 2010). Annual CVs were calculated as

$$CV_y = \frac{SD_y}{GLM_y},$$

where GLM_y is the bias-corrected year-specific index value based on equation (3) and SD_y is the square root of the estimated year-specific variance (see Lo et al. 1992 for details on bias correction and variance calculation). All statistical analyses (including the simulation described below) were performed with the software package R version 2.11.0 (R Development Core Team 2010).

Simulation.—Given that the two index estimators applied to the adult American shad CPUE data have very different statistical foundations, it is reasonable to assume that they will provide different patterns in relative abundance and interpretations of progress toward restoration. Therefore, we evaluated the performance of the AUC and GLM approaches in a simulation context to gain insight about which more accurately reflects the trends in actual biomass. The simulation was structured to produce CPUE data similar to those recorded by the American shad monitoring program by specifying a temporally varying and stochastic trend in the population biomass available for sampling along with an assumed staked gill-net catchability coefficient. Known catch data were generated as

$$C_{d,y} = qE_{d,y}(p_d B_y)e^{\varepsilon_{d,y}}, \quad (4)$$

where $C_{d,y}$ is the simulated catch for sampling day d in year y, q is the catchability coefficient for a staked gill net (assumed to be 1.5×10^{-6} because it yielded daily CPUE values similar in scale to those obtained from the standardized monitoring program), $E_{d,y}$ is the effort for day d in year y, p_d is the proportion of the total biomass present in the river during sampling day d, B_y is the biomass of the stock in year y, and $\varepsilon_{d,y}$ is a random deviation in catch for each day d in year y such that $\varepsilon_{d,y} \sim N(0, 0.5)$. Time series for B_y were generated by specifying an initial biomass (1×10^5) and setting subsequent biomasses to that of the previous year adjusted by a random deviation derived from a normal distribution with a randomly chosen mean value (between -10^4 and 10^4) for each simulation to establish directionality in the biomass trend, and a standard deviation of 10^4. Also, a minimum threshold biomass (100) was imposed to ensure that the simulated stock never became extirpated. Simulated effort was determined by specifying a random number of sampling days per year (20–24), with sampling always beginning in February and ending in May. Daily effort was multiplied by a constant (273) to reflect the meters of staked gill net fished per day. Finally, p_d was specified to increase then decrease linearly, with a peak roughly in the middle of the sampling season.

The simulation was executed iteratively to produce 5×10^4 time series of catch data 13 years in length. Relative indices of abundance were then estimated for each catch series using the GLM (assuming lognormally distributed errors and categorical fixed effects for year and month of sampling) and the AUC estimators. Since the true biomass underlying the simulated catch data was known, the indices of abundance were scaled and yearly percent differences from the true biomass were calculated for each approach. The results from the GLM and AUC approaches were compared using median percent difference (MPD) for each estimated time series of relative abundance.

RESULTS

Trends in Adult Relative Abundance

The annual indices of relative abundance for American shad based on the AUC and GLM showed very similar patterns within each river system. In terms of numerical scale, the estimated annual catch rates from the James and York rivers were similar to but often an order of magnitude larger than those from the Rappahannock River. The relative abundance based on monitoring data from the James and York rivers was below the reference index value from their respective logbook reference periods for all years (the exception being the 2003 James River index value from the AUC; Figure $2a_1$–c_1). The 2011 James River AUC index value is the second highest in the monitoring time series and is slightly less than the reference value. The Rappahannock River monitoring index showed promising signs of stock rebuilding during the first six years of the time series (1998–2003), as it peaked at a value substantially above the logbook mean value. However, the index declined to a value below (GLM) or near (AUC) the logbook reference value by 2010, followed by a high value in 2011. The basic trends in the James and Rappahannock River monitoring indices were similar, while the York River index showed a variable but generally decreasing pattern throughout the time series.

The precision of the indices was generally good for all stocks regardless of the analytical method used since most CV values were between 0.1 and 0.3 (Figures $2a_2$–c_2). The GLM index for the Rappahannock River had the highest CVs, with values consistently between 0.3 and 0.4. Across river systems, the CV values associated with the AUC estimator tended to be lower than those associated with the GLM, which may have been due to the methodological differences in the calculations of these measures of variation. Observational comparisons of the CV values derived from the logbook data with those obtained from the monitoring program data showed no obvious differences or patterns for either analysis method.

Progress toward the logbook-based reference index values for each stock expressed as proportions was highly variable both within the monitoring period of each stock and across stocks (Figure 3). Summaries of the proportional differences (mean [SD]) for each estimator across stocks are as follows: GLM: James (0.36 [0.22]), York (0.32 [0.18]), and Rappahannock (1.84 [0.98]); AUC: James (0.58 [0.29]), York (0.43 [0.24]), Rappahannock (1.95 [1.03]). In general, the mean proportional differences from the AUC were higher than those of the GLM for each stock, which suggests that the AUC index provides a more optimistic outlook on progress toward the logbook reference values.

Simulation

Simulated catch data facilitated a comparison of the two approaches (AUC and GLM) used to derive the relative abundance indices for American shad stocks monitored in Virginia. The MPD between the estimated biomass and the true (specified) biomass for each simulation indicated that both the AUC and GLM are accurate most of the time (overall median MPD = 8.4 and 8.0 for the AUC and GLM, respectively). However, on several occasions when American shad stocks were simulated to experience a systematic decline in abundance, the MPD was high for both methods (maximum MPD = 1,110.0 and 1,512.0 for the AUC and GLM, respectively). These inaccuracies were found to correspond to simulated population crashes (i.e., true biomass reached the lower threshold [100] for several years). When this occurred (4,033 of the 5×10^4 simulations), neither the AUC nor the GLM was able to accurately estimate the biomass trend at the lower threshold. The removal of the runs corresponding to these biomass trajectories resulted in more accurate estimates of relative biomass for both methods irrespective of the true underlying biomass trend (median MPD = 8.2 and 7.8, and maximum MPD = 22.3 and 21.4 for the AUC

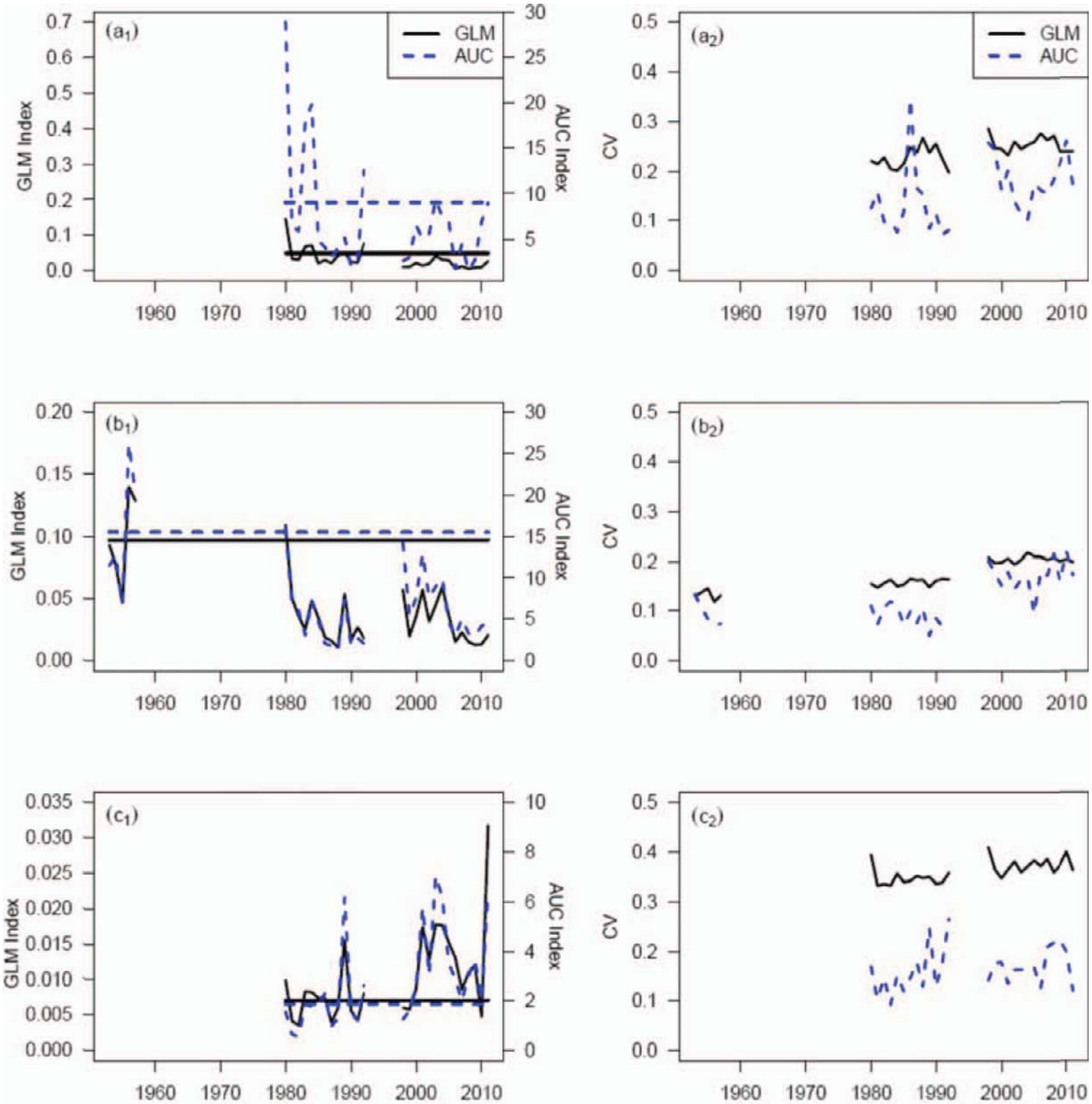

FIGURE 2. Annual indices of relative abundance and the associated coefficients of variation (CVs) for American shad collected from the **(a)** James, **(b)** York, and **(c)** Rappahannock rivers based on area-under-the-curve (AUC; blue lines) and generalized linear model approaches (GLM; black lines). All monitoring indices correspond to the years 1998–2011. The horizontal lines represent the logbook-based restoration index values, which are means from 1980–1992 for the James and Rappahannock rivers and 1953–1957 for the York River.

and GLM, respectively). Overall, the GLM performed slightly better than the AUC; despite this difference, however, when three random biomass trajectories were compared with the estimated biomass, it was clear that both the AUC and the GLM captured the general pattern in the true abundance whether it was increasing, decreasing, or stable over time (Figure 4).

DISCUSSION

Virginia stocks of American shad remain at or near historically low levels of abundance despite a nearly complete in-river fishing moratorium since 1994. Regardless of the analytical method used to estimate adult relative abundance (AUC or GLM), the trends in the indices generally showed a declining pattern for virtually all (York River) or fairly large portions (4–5 consecutive years, James and Rappahannock rivers) of the monitoring period. The relative abundance of American shad in the James and York rivers has been consistently below logbook reference levels, and the Rappahannock River index dropped from 2003 to 2010 despite efforts to remove obstructions within the river and increase available habitat. In February 2004,

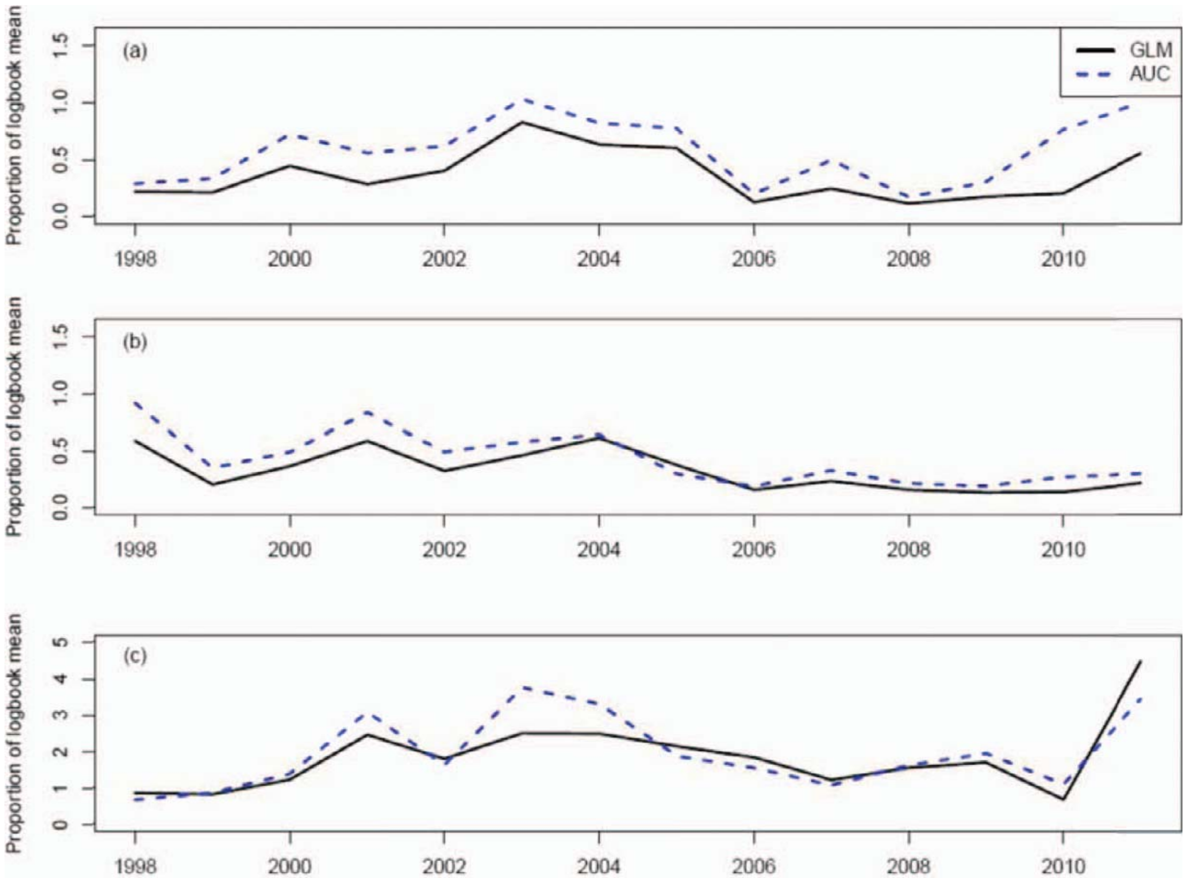

FIGURE 3. Proportional differences of the monitoring indices from 1998 to 2011 relative to the respective restoration reference index value for American shad in the **(a)** James, **(b)** York, and **(c)** Rappahannock rivers based on area-under-the-curve (AUC; blue lines) and generalized linear model approaches (GLM; black lines).

Embry Dam was breached to open 170 km of spawning and nursery habitat in the Rappahannock River for American shad, river herring (blueback herring *Alosa aestivalis* and alewife *Alosa pseudoharengus*), and many other resident and migratory fishes. As the maturation of Rappahannock River shad peaks at ages 4–5 (Maki et al. 2001; Tuckey and Olney 2010), the 2009 to 2011 indices of adult relative abundance should include fish produced in the absence of Embry Dam. While it is recognized that the fish fauna in the Rappahannock River will likely need decades to fully realize the effects of the removal of the dam, perhaps the elevated 2011 index value represents the beginning of the anticipated benefits.

In 1992, efforts began to rebuild American shad stocks in Virginia through the release of hatchery-produced fry from a cooperative agreement between the U.S. Fish and Wildlife Service and the VMRC. Stocking has occurred in the James River since the beginning of the hatchery program, whereby scientists from the Virginia Department of Game and Inland Fisheries (VDGIF) annually collect gametes from wild adult American shad in the Pamunkey River (part of the York River system) and release reared fry with marked otoliths from antibiotic immersions within the upper portion of the river. Stocking efforts expanded in 2003 to include the release of marked fry in the Rappahannock River based on the capture of wild adult American shad from the Potomac River. Modest numbers of marked fry have also been introduced into the York and Potomac rivers, primarily to offset the adult takes supporting hatchery activities. The numbers of fry released in the two targets systems have varied over time without a clear pattern and largely in response to available operational resources (Dean Fowler, VDGIF, personal communication). Nevertheless, hatchery-produced American shad fry likely represent an important aspect of the observed trends in adult relative abundance derived from the monitoring program. Olney et al. (2003) created some optimism about the effectiveness of the hatchery program by showing a positive relationship between the prevalence of hatchery-derived fish captured by the monitoring program and the overall adult monitoring index values for the James River. To date, however, a similar analysis for the Rappahannock River has not yet been conducted, so it is not possible to make inferences about the impact of hatchery fry on the stock

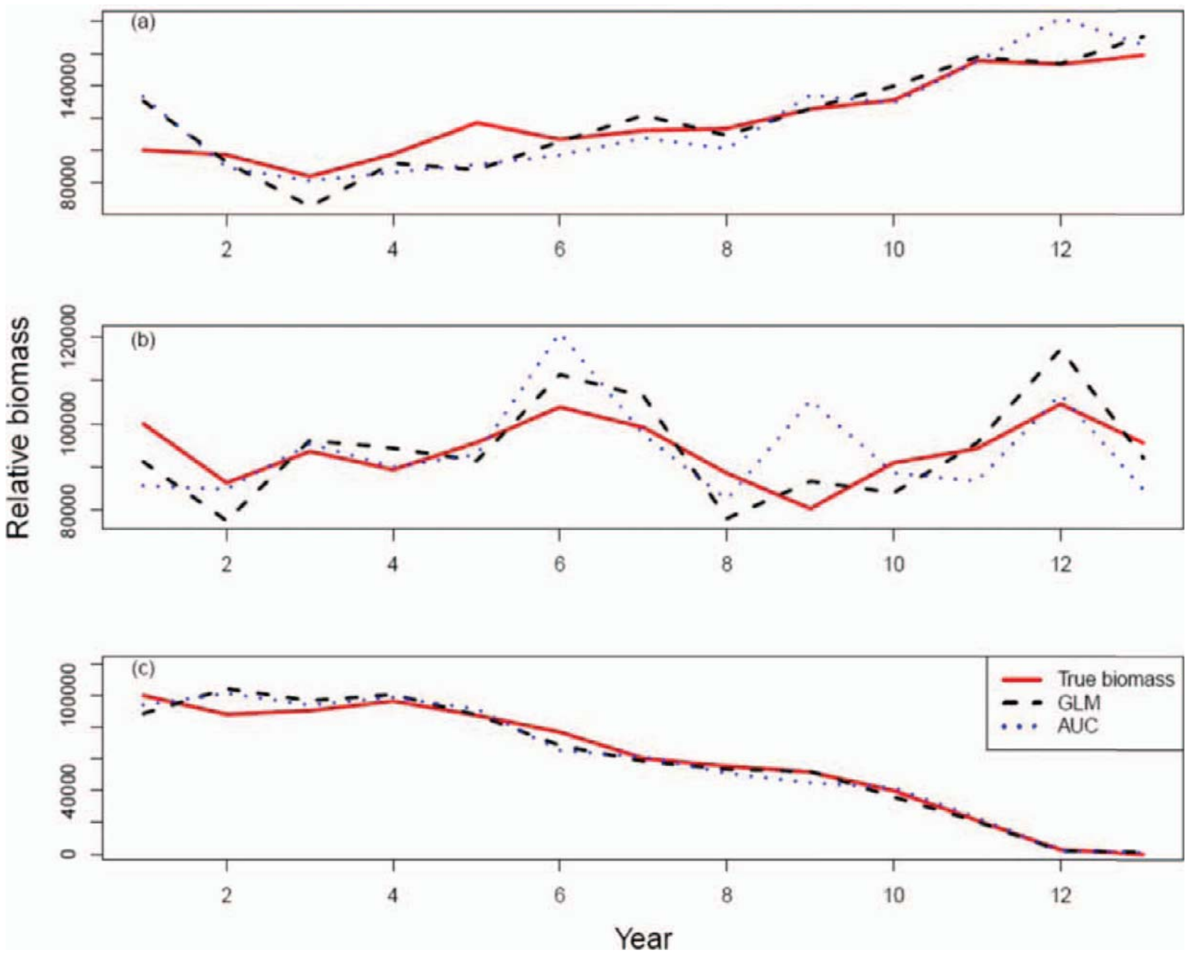

FIGURE 4. Comparison of the true biomass (red lines) simulated for American shad in Virginia and the biomass estimated by area-under-the-curve (AUC; blue lines) and generalized linear model approaches (GLM; black lines) for **(a)** increasing, **(b)** stable, and **(c)** decreasing scenarios of true biomass.

dynamics of American shad in this river system. The role of hatchery inputs and their correlation with adult spawning stock strength in Virginia waters is an important and fertile area for future research.

There are no obvious explanations for the consistent declining trend in the relative abundance of American shad in the York River. Harvest by Native Americans has legally persisted on this stock at unknown levels that are thought to be negligible. However, if the total stock size is critically low, it is possible that harvest levels traditionally viewed as insignificant comprise appreciable proportions of stock abundance. Additional sources of loss for York River and other Virginia American shad stocks include catch-and-release mortality from recreational fisheries within tidal rivers and bycatch by other fisheries operating along the U.S. East Coast. However, virtually no information exists to quantify stock-specific or mixed-stock mortality rates for the American shad captured by these fisheries. Other possible explanations for the declining catch rates of adults in the York River include increased mortality during early life, habitat limitations for larval and juvenile growth, reduced water quality, and altered freshwater flow regimes. There have been no known changes to water quality, flow regimes, or the amount of rearing habitat in the York River, and the data available to address the possibility of increasing mortality rates during residence in the nursery are insufficient. In many respects, the lack of signs of recovery in the relative abundance of the York River stock is a mystery.

Comparisons of current catch rates with those obtained during the commercial fishery provide an important reference point for evaluating progress toward stock rebuilding. Although the monitoring program relies on staked gill nets positioned at locations that provided “average” commercial catches of American shad from the logbook periods, it is important to note that several hundred staked gill nets were in operation within each river system during the commercial fishery. Therefore, the interaction effects of multiple stands on daily CPUE levels from a single location are unknown and could compromise direct comparisons across time periods. For the James River, the interaction effects are believed to be minimal since the monitoring staked gill net is located near the river’s mouth and, based on our understanding of historical fishing locations, very few staked gill nets were erected down river from the monitoring location. However, interaction effects could be of concern for the York and Rappahannock rivers, since the monitoring locations are centrally located and considerable commercial fishing effort was directed downriver of these sites. It is also recognized that use of a single staked gill net in each river does not permit detection of the variation in the within-river migratory pathways used by American shad. That is, slight deviations in directional movements along the river's axis (perhaps due to annual variation in environmental conditions) may have significant impacts on the CPUEs of the monitoring program and how those indices reflect the patterns in true abundance.

The goal of the simulation was to gain insight regarding the accuracy of the AUC and GLM estimators in order to more precisely characterize stock status relative to reference levels derived from logbooks. The primary and somewhat surprising result from the simulation was that both the AUC and GLM estimators performed well in terms of yielding patterns of relative abundance reflecting the patterns in absolute abundance. For simulation runs in which the true population biomass did not crash, the median and maximum MPDs were slightly smaller for the GLM than the AUC but not enough for one to conclude that the GLM is superior to the AUC. In scenarios in which a population crash was simulated (i.e., biomass reached the lower threshold for multiple years), the MPD for the estimated biomass trajectories tended to be high. However, this phenomenon is likely related to the metric used for evaluation and does not necessarily indicate that the estimators do not perform well when the stock becomes extirpated. When the true biomass reached the lower threshold for several years, the estimated index of abundance captured this trend (e.g., Figure 4c), but scaled estimates of biomass during the population crash remained slightly higher than the true biomass. Since biomass was low during this period, relatively small absolute differences resulted in relatively large percentage differences, thereby inflating the overall MPD.

All stock assessments require reference points in order to draw conclusions regarding stock status. For American shad stocks in Virginia, these reference points are average CPUE values derived from logbook data associated with commercial fishing activities in the not-so-distant past. It is recognized that the logbooks themselves come from time periods when American shad stocks were depressed and likely only remnant populations. Therefore, the logbook-based reference points are best interpreted as first-level milestones toward stock rebuilding rather than absolute thresholds for differentiating stocks that are overfished from those that are not. In-river fisheries for Virginia American shad should not be contemplated until monitoring CPUEs consistently maintain levels that are substantially larger than the logbook reference values.

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