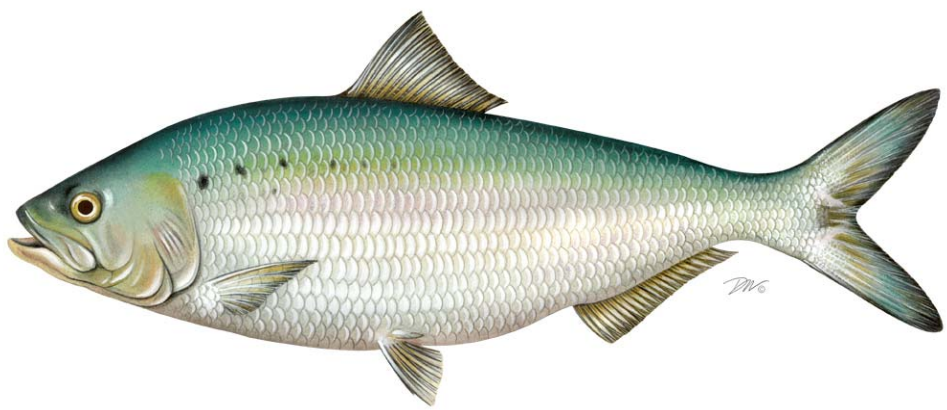
Stock Assessment Report No. 07-01
of the

Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report
to the American Shad Stock Assessment Peer Review



August 2007

Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

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to the American Shad Stock Assessment Peer Review

Conducted on
July 16-20, 2007
Alexandria, Virginia

Prepared by the
ASMFC American Shad Stock Assessment Peer Review Panel

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Preface

Summary of the ASMFC Peer Review Process

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Benchmark Stock Assessments: Data and Assessment Workshop and Peer Review Process report outlines options for conducting an external peer review of Commission managed species. These options are:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
2. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).
3. The Transboundary Resources Assessment Committee (TRAC) reviews stock assessments for the shared resources across the USA-Canada boundary and is conducted jointly through the National Marine Fisheries Service and the Canada Department of Fisheries and Oceans (DFO).
4. A Commission stock assessment Peer Review Panel conducted by 3-5 stock assessment biologists (state, federal, university). The Commission Review Panel will include scientists from outside the range of the species to improve objectivity.
5. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In July 2007, the Commission convened a Stock Assessment Peer Review Panel comprised of members with an expertise in stock assessment methods and/or anadromous species and their life history. The review for the American shad stock assessment was conducted at the Crowne Plaza Hotel in Alexandria, Virginia from July 16 - 20, 2007. Prior to the Review Panel meeting, the Commission provided the Review Panel Members with an electronic and hard copy of the 2007 American Shad Stock Assessment Report.

The review process consisted of an introductory presentation of the completed 2007 stock assessments by river system. Each presentation was followed by general questions from the Panel. The final two days involved a closed-door meeting of the Review Panel during which the documents and presentations were reviewed and a report prepared.

The report of the Review Panel is structured to closely follow the terms of reference provided to the stock assessment team.

Acknowledgements

The Atlantic States Marine Fisheries Commission thanks all of the individuals who contributed to the development of the American Shad Stock Assessment Report and the Terms of Reference and Advisory Report. The Commission extends its appreciation to the members of the American Shad Stock Assessment Peer Review Panel (Dr. Karin Limburg - Chair, State University of New York College of Environmental Science and Forestry; Dr. Jamie Gibson, Canada's Department of Fisheries and Oceans; Dr. Bill Pine, University of Florida; Dr. Terrance Quinn, University of Alaska; and Dr. Norma Jean Sands, National Marine Fisheries Service, Northwest Fisheries Science Center) for their efforts to evaluate the stock assessment and developing this Terms of Reference and Advisory Report.

The Commission and American Shad Peer Review Panel thank the ASMFC American Shad Technical Committee and Stock Assessment Subcommittee (SASC) members who developed the consensus stock assessment report, especially Andy Kahnle (New York Department of Environmental Conservation) for his dedication to the completion of the stock assessment, serving as Chair of the SASC, and presenting the report to the American Shad Peer Review Panel. We would also like to thank Russ Allen, New Jersey Department of Environmental Protection; Kathy Hattala, New York Department of Environmental Conservation; Michael Hendricks, Pennsylvania Fish & Boat Commission; Patrick Kilduff, Atlantic States Marine Fisheries Commission; John Olney, Virginia Institute of Marine Science; and Bob Sadzinski, Maryland Department of Natural Resources for their useful and clear presentations on the state-specific data and assessments.

The American Shad Peer Review Panel would like to thank Erika Robbins, Melissa Paine, Dr. Genny Nesslage, and Megan Caldwell from the ASMFC for logistical and administrative support during the peer review and preparation of the report.

Introduction

The American shad was, historically, one of the most important exploited fish species in North America (Stevenson 1899; Limburg et al. 2003). In the late 19th century, annual harvests reached over 50 million pounds (22.7 x 10^3 mt). Since then, the stocks declined due to a combination of overfishing, pollution, and habitat loss due to dam construction; over 4,000 km of spawning habitat have been lost (Limburg et al. 2003). In recent years, coastwide harvests are on the order of 500-900 mt, nearly two orders of magnitude lower than in the late 19th century.

The stocks of American shad in their native range along the North American East Coast are currently at all-time lows. The Shad and River Herring Technical Committee of ASMFC undertook the fourth assessment of American shad in 2007, through the Stock Assessment Subcommittee (SASC). Earlier assessments were conducted in 1984, 1988 and 1998 (ASMFC 1985, 1988, 1998).

The current assessment contains an extensive compilation of data from many sources and examines status at the river-stock level from some 30 different stocks. The SASC was mandated to use an inclusive, stakeholder-based approach. Hence, the SASC obtained its data from all local, regional, and federal management agencies, and used information from independently funded academic studies as well. The result was a 1,200+ page document; certainly one of the most comprehensive collections of fisheries related data ever assembled for this species.

This review contains a careful examination of eight Terms of Reference (TORs), i.e., information goals and analyses, to which the American shad SASC had committed. An Advisory Report follows our review of the TORs. We have included a new section in the Advisory Report called "Perspectives" because of the availability of long-term data and historical accounts that allow us to speculate on what the unexploited stocks may have looked like, and to help us interpret the "shifting baseline" (Pauly 1995) phenomenon as it applies to American shad. Several sentences found throughout the document are bolded to add emphasis.

The Review Panel commends the SASC for a well-organized, well-developed, and thoughtful report. The SASC worked hard to separate out "the hard facts" from more speculative analyses and more creative modeling. The members of the SASC are to be commended for their careful and cautious approach. The SASC is also to be commended for taking "the long view" where possible, in order to incorporate much historical information and give perspective to the current assessment.

American Shad Peer Review Panel:

Karin Limburg, State University of New York (Chair)
Jamie Gibson, DFO Canada
Bill Pine, University of Florida
Terry Quinn, University of Alaska – Fairbanks
Norma Jean Sands, NOAA Northwest Fisheries Science Center

Terms of Reference for the American Shad Stock Assessment Peer Review

A. Compile and determine adequacy of available life history data for each stock

The American Shad SASC compiled data from a wide range of state and federal sources. Life history and biological data included age, age-at-maturity, and number of previous spawnings (from scale analyses), length-at-age, weight-at-age, growth parameters (using von Bertalanffy or Gompertz models), fecundity (mostly from studies conducted in the 1950s), and natural mortality estimates. Other parameters included juvenile (mostly young-of-year, but also age-1) abundance indices and in some cases juvenile lengths. Table 1 lists some of the relevant indices that were compiled into the assessment report. Dams are noted because of their importance as an impediment to migration and also as a source of mortality, if passageways are in use.

The SASC did a highly commendable job at compiling the available data. It also scrutinized the data and commented on the quality of the data for each stock. The Panel did well with size-at-age analyses where the age data were reliable. The SASC also identified problems with sample size and design of monitoring, issues that are complicated because of shad's use of multiple spawning habitats along the length of natal river systems, and which can be further exacerbated by hydrology (floods and droughts).

A fundamental issue that hinders the assessments is that aging is very difficult for some of the American shad stocks. An ASMFC-sponsored scale aging workshop (using known-age scales from the Delaware River) revealed that scale readers with long experience tended to under-estimate the ages of older fish (McBride et al. 2005). Besides under-aging, scale erosion during the spawning run can sometimes extend back beyond previous spawning marks. Scales are metabolically active, and in cases where fish migrate long distances in unidirectional flows, such as the Delaware River, scales become quite eroded, presumably as they are "mined" for calcium.

The SASC and Technical Committee are well aware of the problem, and validation trials are in progress in a number of watersheds. The validations consist of marking otoliths of hatchery shad with oxytetracycline (OTC), releasing the fish, and monitoring for recaptures that occur several years later. This should be a substantial help in resolving some of the aging errors, and the Review Panel encourages as many such experiments as possible to be done, particularly in systems where scales are difficult to read. **Once reliable aging can be done, it will enable the use of better modeling methods for more stocks**.

The SASC pointed out that American shad is a species well known for its life history variations with latitude (e.g., Leggett and Carscadden 1978, Limburg et al. 2003), but did not emphasize this in its report. The Review Panel felt that such information would have been useful to summarize, and to compare current parameters to historic data.

In summary, **the life history data compiled was sufficient for the assessment at hand**, and the study identifies areas of uncertainty where improvements can be made. Such improvements could lead to the development of stock-specific management plans where necessary for populations at various levels of abundance. Furthermore, improved data will enable the development of models and plans that may require other life history parameters, such as stock-recruit parameters, more detailed estimates of mortality (natural and human-driven), growth, maturity, counter-gradient growth variation, and ecosystem interactions.

Table 1. Summary of key biological, life history, and abundance indices reported for American shad, for the river/bay systems in the 2007 stock assessment. An "x" denotes the item was found in the report; "(x)" indicates data were considered unreliable by SASC & Panel; "●" was used by SASC to denote an index that went into the assessment, "○" denotes that an index was present, but not used, & "?" unreliable scales of Delaware River fish cast doubt upon age, maximum age, & repeat spawning estimates. *Z* = total mortality, *M* = natural mortality, FD = Fishery Dependent, FI = Fishery Independent, & JAI = Juvenile Abundance Indices.

State	River	Basic Biology				Relative Abundance Indices			
		Length	Weight	Sex	Age	FD Commercial	FD Recreational	FI Adult	JAI
ME	Merrymeeting Bay							○	○
	Kennebec								●
	Androscoggin	x		x	x				●
	Saco	x		x	x			●	
NH	Exeter	x		x	x			●	
MA	Merrimack	x	x	x	x			●	
RI	Pawcatuck	x		x	x			●	●
CT, MA	Connecticut	x	x	x	x	○	○	●	●
NY	Hudson	x	x	x	x	●	●	●	●
NY, PA, NJ, DE	Delaware River & Bay	x		x	(x)			●	●
MD	Nanticoke			x	x			●	●
PA, MD	Susquehanna River & Flats	x	x	x	x	○	○	●	●
MD, DC, VA	Potomac	x		x	x	●		●	●
VA	York	x		x	x	●	○	●	●
	James	x		x	x	●	○	●	●
	Rappahannock	x		x	x	●	○	●	●
NC	Albemarle Sound	x		x	x	●	○	●	○
	Roanoke	x		x	x		○	●	
	Tar-Pamlico	x		x	x	●	○	●	
	Neuse	x		x	x	●	○	●	
	Cape Fear	x		x	x	●	○	●	
SC	Winyah Bay					●			○
	Waccamaw	x		x	x	●		○	
	Great Pee Dee					●			
	Santee	x		x	x	●	●	●	○
	Cooper	x		x		●	●	○	
	Combahee					●			
	Edisto	x		x	x	●		○	○
SC, GA	Savannah					●	○		
GA	Altamaha	x	x	x	x	●		●	○
	Ogeechee					●	●		○
FL	St. Johns	x	x	x		○	●	●	

Table 1 (continued). Summary of key biological, life history, and abundance indices reported for American shad, for the river/bay systems in the 2007 stock assessment. An “x” denotes the item was found in the report; “(x)” indicates data were considered unreliable by SASC & Panel; “●” was used by SASC to denote an index that went into the assessment, “○” denotes that an index was present, but not used, & "?" unreliable scales of Delaware River fish cast doubt upon age, maximum age, & repeat spawning estimates. Z = total mortality, M = natural mortality, FD = Fishery Dependent, FI = Fishery Independent, & JAI = Juvenile Abundance Indices.

Jurisdiction	River	Life history variables						Dams
		Max Age	Repeat Spawning	Maturity	Fecundity	*Z*	*M*	
ME	Merrymeeting Bay							
	Kennebec							x
	Androscoggin							x
	Saco					x		x
NH	Exeter	x				x		x
MA	Merrimack	x	x			x		x
RI	Pawcatuck	x	x	x		z		x
CT, MA	Connecticut	x	x	?	x	x	x	x
NY	Hudson	x	x	x	x	x	x	
NY, PA, NJ, DE	Delaware River & Bay	?	?					
MD	Nanticoke	x	x			x		x
PA, MD	Susquehanna River & Flats	x	x	x		x		x
MD, DC, VA	Potomac	x	x			x		x
VA	York	x	x			x		
	James	x	x			x		
	Rappahannock	x	x			x		
NC	Albemarle Sound	x	x			x		
	Roanoke	x	x			x		x
	Tar-Pamlico	x	x			x		
	Neuse	x	x			x		x
	Cape Fear	x	x			x		
SC	Winyah Bay							
	Waccamaw	x						
	Great Pee Dee							
	Santee	x						x
	Cooper							x
	Combahee							
	Edisto	x						
SC, GA	Savannah							x
GA	Altamaha	x				x		x
	Ogeechee							
FL	St. Johns							

B. Compile and determine adequacy of available fishery-dependent and/or independent data as indices of relative abundance for each stock.

The SASC presented clearly which indices were available, compiled those indices, described their source, and identified the life stage to which each index applies. The indices included catch-per-unit-effort (CPUE) from various fisheries, direct counts (mostly at fish passageways), fishery-independent surveys, creel surveys for recreational fisheries, and juvenile abundance indices (JAIs). In some cases, where fish could be observed passing through a discrete area, an "area-under-the-curve" approach was used to index populations. This method, which integrates fish counts over time, was used in five river systems (Hudson, James, York, Rappahannock, and Altamaha Rivers). Every river system had at least one index available (Table 1), although the number of years of data varied considerably.

Trends in indices were compared within and between systems to evaluate the consistency of the indices. **The SASC and Review Panel noted the strong need to continue to collect and evaluate indices** such as counts at fish passage facilities, JAIs, etc., to determine the degree to which these inform and support estimates of adult abundance and reflect climatic factors, modifications in passage, and so on. It was noted that linkages between life stages and between indices could be improved in the future. Most shad do not mature before 5 years of age. Due to the resulting times lags and autocorrelation issues, long-term collections need to be put in place (or continued where they exist) once techniques have been worked out and accepted.

Indices were not synthesized using a single overall approach that could be used to develop population dynamics models. Such efforts could be conducted in the future as the time series become longer.

The Review Panel was concerned that very few estimates of uncertainty were presented with the index data. **The Panel encourages the SASC to produce and present uncertainty estimates (standard errors) for all indices.**

The Review Panel was also puzzled about what the JAIs were actually indexing. Seldom was there a direct relationship between a juvenile or other young-of-year (YOY) index (e.g., post yolk-sac larvae or PYSL) and an adult index. It is unclear whether this is because of the limitations of the time series, the way the data were collected, or because of other exogenous processes (e.g., an ocean intercept fishery). Most of the presented JAIs were calculated using data collected throughout the nursery areas and included YOY of varying sizes and ages. Abundance of YOY American shad is thought to be determined by a combination of density dependent and environmental factors acting within nursery areas, as well as the process of emigration to the sea (Crecco and Savoy 1988; Limburg 1996). When the JAI includes more than one life stage, thereby integrating over these processes, it becomes unclear whether it is intended to be an index of spawner abundance during that year, or an index of year class strength that is meant to index subsequent returns as the cohort matures. Collection and analysis of size and/or age data as part of the juvenile surveys may aid in determining the utility of these data series.

C. Determine most appropriate method of estimating natural mortality.

Natural mortality (*M*) remains one of the most important but difficult life history parameters to estimate for fish stocks (Vetter 1988). Direct estimates of *M* are sometimes possible when tagging or telemetry data are available (Hearn et al. 1998; Hightower et al. 2001), but most often *M* is approximated using some aspect of species life history and environment. The SASC chose Hoenig's method (Hoenig 1983), a widely used approach to estimate *M* from the longevity of the stock. The role that *M* plays in the assessment is primarily in the calculation of biological reference points; *M* is also used in combination with catch curves to partition total mortality into fishing mortality (*F*) and *M*. The SASC's rationale for using Hoenig's method was to use a simple, widely accepted approach for a group of geographic regions where longevity information was available. Natural mortality values were determined for New England (0.38), Hudson River (0.30), York River (0.35), and Albemarle Sound (0.42) stocks (Table 1.1.5-1 in the 2007 American Stock Assessment Report). Thus, as expected by the SASC, *M* increases from north to south due to the decrease in longevity and the decrease in repeat spawning frequency (the most southerly populations are semelparous).

In the previous assessment (ASMFC 1998), *M* was assumed to vary with age, with an *M* of 0.3 for ages 1-3, and with a range of higher values of *M* for older ages, under the supposition that mature fish would have higher mortality due to spawning. The higher values for the older aged fish were also different spatially for the Hudson River, northern rivers, and southern rivers (Table 1.1.5-1, 2007 American Shad Stock Assessment Report). The approach in the current assessment differs, because the SASC chose to perform a sensitivity study to assess how changes in *M* altered assessment outputs (see TOR-D). In this sensitivity analysis, four scenarios were examined, one where *M* changed over age, from 0.51 at age-1 to 0.19 at age-14 using a method from (Boudreau and Dickie 1989), and three other scenarios where *M* was held constant across ages at different values (*M*= 0.3, 0.5, and 0.7; Table 1.1.5-4, 2007 American Shad Stock Assessment Report).

The Panel concurred with the SASC approach because the time-honored method of Hoenig is widely used, and more importantly, the SASC did a good job of examining the influence of *M* on the benchmarks that were calculated. **However, future efforts should focus on better determination of natural mortality, because biological reference points (BRPs) were very sensitive to the values of *M* used.** M is the population parameter that has the largest effect on benchmarks.

As a first step, the panel recommends that alternate life history methods should be investigated for the calculation of *M* (e.g., Alverson-Carney, Pauly, Gunderson; see Quinn and Deriso 1999, section 8.3), because these methods use additional life history information such as growth and reproduction and may help to expand or narrow the range of potential *M* values. Second, the SASC should consider whether field work could be done to determine *M* experimentally. A well-designed tagging program should be able to estimate a precise *M* value while also providing additional information of interest related to fishing mortality, age and growth, fish movement, and stock identification (see TOR-G). Third, the SASC should also consider a sensitivity scenario like that in the previous assessment, in which natural mortality increases with age.

It may also be interesting to consider a scenario in which M has a U-shaped distribution with age: high at younger and older ages and low at middle ages. This scenario would account for predation mortality at younger ages and spawning mortality at older ages.

In the current assessment, natural mortality is a parameter that encompasses various sources of mortality, including natural mortality (e.g., predation, disease), unmeasured fishing effects (e.g., bycatch, ocean fishery), and unmeasured anthropogenic effects (e.g., mortality due to dams and pollution). As the world moves to embrace ecosystem-based management, it will be necessary to separate natural and anthropogenic sources of mortality for better understanding the ecosystem. **The Panel recommends that the SASC move towards explicitly separating natural mortality M from mortality from anthropogenic sources** (Advisory Report, Section G).

D. Determine which assessment analyses are most appropriate to available data for each stock. Assessment methods will range from simple trend analysis to more complex models.

The SASC considered a variety of assessment approaches and ultimately used simple indices, catch-curve analyses, and biomass per-recruit models to assess American shad stocks. The core of the assessment is a comparison of catch-curve estimates of total mortality (Z) to benchmark Z values calculated by using a biomass-per-recruit model. Per-recruit models are widely used to estimate appropriate fishing mortality rates in conjunction with management goals. A key aspect of per-recruit models is that no knowledge of the stock-recruitment relationship is required for their calculations, because the model determines yield and biomass on a per recruit basis so harvest decisions are based on information once the fish have recruited. Data inputs for this type of model include an estimate of M, selectivity patterns, and information on weight-at-age and proportion mature-at-age. Key assumptions in per-recruit models are that fishing does not affect growth or recruitment, and that natural mortality and growth are constant with stock size (no compensation). The main output from a per-recruit model is a mortality target for the management objective, generally a level of F_{30}-F_{40} representing fishing mortality rates that would maintain biomass-per-recruit at the given percentage of the unfished stock (Quinn and Deriso 1999). Higher percentages represent more conservative fishing policies. In general, a per-recruit approach is an appropriate assessment technique for a coastwide evaluation where available data vary greatly.

The SASC's approach to per-recruit modeling differs somewhat from traditional approaches. The SASC chose to develop values of the maximum Z rather than for F. This was done because of uncertainty in the sources of mortality in American shad with hypotheses differing as to whether fishing mortality, other human-induced mortality, or changes in natural mortality are limiting American shad recovery. Benchmark values of Z_{30}, defined as the long-term total mortality rate that will preserve 30% of the biomass or egg production per recruit of an unexploited stock, were calculated for four regions to reflect differences in latitudinal differences in life history. Stock-specific estimates of Z from catch-curve methods were then compared to the Z_{30} level to assess total mortality status. Stocks where catch-curve mortality estimates exceeded Z_{30} level benchmarks were considered to have excessive total mortality.

The SASC did a good job of evaluating model sensitivity by building stock specific models where more data were available (e.g., Hudson River). As mentioned in TOR-C, the assessment showed how *F* benchmarks would vary across different levels of *M* using a range of age-variant and age-invariant *M* values. Benchmark *F* values from a per-recruit model are sensitive to *M* values and this sensitivity is acknowledged by the SASC in Tables 1.1.5-1 of the American Shad Stock Assessment Report. For the stock-specific benchmark calculations, different levels of *M* were used for each region based on known life history differences across the populations. Aging error is acknowledged as a major problem by the SASC. This source of error can have major implications in the use of the catch-curve analyses that are the core assessment for each stock. The authors do a good job pointing out the limitations related to the age validation work that has been done and studies are ongoing to aid in addressing the validation issues.

Catch-curve analysis has substantial limitations and should usually be avoided if reasonable alternatives are available (Quinn and Deriso 1999, chapter 8). Trends in recruitment cause biases in total mortality. For example, when there is a declining trend in recruitment, total mortality is underestimated. This can lead to underestimating fishing mortality, which is not precautionary. Furthermore, the trend in recruitment is completely confounded with total mortality, such that using catch-curves can not simply be validated by inspecting the slope for a linear relationship between $\log_e(N)$ and age.

The use of catch curves requires the SASC to specify the range at which full vulnerability is achieved. In the case of American shad, age frequencies in the catch curve are low and the range of ages is limited to as few as 4 cohorts. Consequently, the standard error of the catch curve is undoubtedly high, yet these standard errors are not reported nor are uncertainties in the catch-curve considered. **Future assessments should report the standard error.** The SASC also fitted catch-curves using data only to the right of the peak in the catch-age plots. The biological samples are collected in-river, and as a result the abundance of age classes that are not fully mature is underestimated (because these cohorts are not in the river where the samples are taken), which can lead to mortality estimates that are biased low. Where the data were available, the SASC did estimate *Z* from catch curves based on number of previous spawnings, an approach that uses abundance of mature fish only. For some populations, the estimates from the two methods were in good agreement, whereas in some other populations they were not. *Thus, catch curve analysis for American shad may be both inaccurate and imprecise.*

Given these caveats, the Panel accepts the use of catch curve analysis in this assessment, because sensitivity analyses suggest that the results presented are robust to the assumptions that were made in using the catch-curves. Nevertheless, the focus of future assessments should be the development of more modern models of age-structured populations that integrate data sources and knowledge about American shad. Age-structured models have been developed for anadromous *Alosa* that incorporate both age and previous spawning history in the catch-at-age array. Chaput et al. (2001) described a tuned VPA used for assessment of anadromous alewife in the Margaree River, Nova Scotia, and Gibson and Myers (2003) presented a statistical catch-at-age model adapted to four alewife populations in eastern Canada. Rather than tracking only abundance at age, cohorts are partitioned into sub-cohorts based on the age-at-maturity. These models preclude the need to specify maturity schedules in age-structured models and address issues of variability in maturity schedules in the assessment models. When vital rates are held constant over sub-cohorts, estimation uncertainty can be evaluated because multiple estimates of different parameters (i.e., fishing mortality) are obtained in each year. Other alternative modeling approaches are discussed in TORs E and G.

A potential assessment framework that the ASMFC may wish to consider is one modeled after the framework used for many North Pacific salmonid stocks. For populations where data sources are limited, simple models with very conservative input parameters are used such that a highly precautionary, risk-adverse harvest policy is developed. In areas where more information is available, more in-depth models are developed which often allows greater flexibility in the management plans and potentially higher harvests in some years. Similarly, the North Pacific Fishery Management Council has a tier system for groundfish assessment based on the amount of available information. The tiers range from stocks with sufficient information to establish maximum sustainable yield (MSY), to stocks for which per recruit analyses can be conducted, to stocks for which only historical catch information is available. **These tiered systems** for being precautionary in data-poor situations, and more active in managing harvest in more data-robust environments, **could potentially be implemented for American shad along the U.S. East Coast**.

E. Estimate biological reference points for each stock where possible.

The SASC developed a benchmark total mortality rate, Z_{30}, defined as the long-term total mortality rate that would preserve 30% of the spawning biomass produced per recruit (BPR) in an unexploited population. In future assessments, the Panel recommends labeling this spawner-biomass-per-recruit (SPR) rather than biomass per recruit (BPR) to avoid confusion with *total* biomass per recruit. This reference point is analogous to the SPR fishing mortality rates (e.g., F_{30}, F_{40}) widely used as reference points in fisheries around the world when spawner-recruit relationships are uncertain (Quinn and Deriso 1999). The origin of the choice of F_{30} for American shad populations dates back to the stock assessment of 1998 (ASMFC 1998). The Panel was unable to find any rationale for the choice of the value of 30 (versus 35 or 40) and requests that future stock assessments reveal this rationale and investigate whether the choice of the value of 30 is sufficiently conservative.

The SASC chose to develop a benchmark rate for Z rather than for F because there are many competing theories about the causes of mortality in Atlantic coastal American shad stocks. This does not eliminate the issue of partitioning mortality into F and M in modeling, but it does avoid an emphasis on F when comparing the results to observed estimates of Z. A regional approach was used to estimate reference points because most individual stocks did not have all of the needed stock specific data. Z_{30} values were calculated for New England, Hudson River, York River and Albemarle Sound. The reference point could not be calculated for the most southerly populations that spawn only once and then die. For these populations, a method similar to that for Pacific salmon, also semelparous, could be explored (NMFS 2004).

Inputs to the model are natural mortality, maximum age, proportion mature-at-age, biomass-at-age, and the selectivity of fishing gear. The SASC conducted thorough sensitivity analyses of the Z_{30} values to the model inputs. Additionally, for the Hudson River population, they augmented the basic biomass-per-recruit (BPR) calculations by also determining egg production-per-recruit (EPR) after including fecundity-at-age. Egg production is more closely tied to the regenerative capacity of the population than spawning biomass, though rarely are there large differences in results. Because there is variation in the timing of the fisheries relative to natural mortality, the SASC calculated Z_{30} values for both Type 1 (fishing and natural mortality occurring at separate times) and Type 2 (fishing and natural mortality both occurring year round) fisheries. The resulting values were thought to bracket the range of expected Z_{30} values for fisheries harvesting American shad.

The Review Panel agreed that Z_{30} is an appropriate benchmark for overall use at the current time, given differences in both the biology and the types of data available for the many populations included in the assessment. However, the Review Panel identified two problems with the calculations used that were corrected at the meeting by two members of the SASC in order that the assessment could proceed. Below, our report refers to these as "revised" values of Z_{30}.

First, in the Type 1 calculation, only mature fish were vulnerable to the fishery, but the survivorship calculation included fishing mortality for both mature and immature fish. The second issue was that gear selectivity (termed a "partial recruitment vector") had also been included in the survivorship calculation. Because the Z_{30} reference point was the benchmark against which Z values calculated from catch curves were being compared, gear selectivity needed to be set equal to one for all ages, if the two values were to be comparable. This results from the implicit assumption that Z is the same for all ages when estimated from a catch curve using linear regression.

Because shad are diadromous, the effect of increasing total mortality on spawner biomass depends on how that mortality is distributed throughout the population. In-river fisheries typically harvest mature fish just prior to spawning, whereas both mature and immature fish are vulnerable to fisheries in the ocean. In-river fisheries affect populations just before spawning, whereas adult turbine mortality affects a population after reproduction has occurred. In each case, the effect of increasing mortality on spawning biomass-per-recruit may differ between these two types of fisheries, even if the increase in (annual) mortality is the same.

The Review Panel agreed with the SASC that the effects of in-river fisheries could be modeled as a Type 1 fishery, and that the effects of marine fisheries could be modeled as a Type 2 fishery. For both fisheries, Z_{30} is found by calculating spawning BPR for a range of fishing mortalities and finding the fishing mortality that reduces the BPR to 30% of its value in the absence of fishing.

The order of mortality events is an important consideration when developing BPR models. For a Type 1 in-river fishery, N_a is the number of fish at age a (mature and immature combined) at the time when the mature fish component first enters the river. These fish are assumed to be fished after river entry, but before spawning. Given this order of events, the spawning biomass per recruit for a given level of F, BPR$_F$, is given by:

$$BPR_F = \sum_a N_a (1-u_a) m_a w_a \ ,$$

where m_a, w_a and u_a are the age-specific maturity probabilities, weights, and exploitation rates, respectively. The abundance N_1 at age 1 is set to a constant value (say 1,000) to obtain a per-recruit value. The number of fish at age a+1 is given by:

$$\begin{aligned} N_{a+1} &= N_a m_a e^{-M}(1-u_a) + N_a(1-m_a)e^{-M} \ . \\ &= N_a e^{-M}(1-m_a u_a) \end{aligned}$$

The first term on the right side of the first line of the equation is the number of surviving mature fish and the second term is the number of surviving immature fish. The second line is the equation reduced. In this equation, fishing mortality is only applied to mature fish, because immature fish are largely absent from the river system. If selective gear is used, age-specific gear selectivity, v_a, can be included in the model in the calculation of u_a:

$$u_a = (1-e^{-v_a F}) \ .$$

Note that the assumption $v_a = 1$ was used here so that the Z_{30} and catch curve Z values would be comparable. Additionally, the partial recruitment vectors from the original assessment were not used in the revised Z_{30} values, because there is uncertainty about their connection to gear selectivity. Given the variability in gears used to capture shad, and the fact that other in-river sources of mortality were being included, the Review Panel considered this assumption appropriate for the current wide-scale assessment, but recommends that gear selectivity be investigated further in stock-specific assessments where fisheries or other sources of mortality are known to be selective. Gear selectivity determines how mortality is distributed over ages. As a result, the reference Z_{30} values will change if selectivity is included and will be specific to the gear.

For a Type 2 at-sea fishery (in which natural and fishing mortality operate concurrently and both mature and immature fish are vulnerable to the gear), BPR_F, is given by:

$$BPR_F = \sum_a N_a m_a w_a$$

because the start of the year is when mature fish are found at the mouth of the river system, after at-sea fisheries and just before spawning.

In this situation, N_{a+1} is calculated as:

$$N_{a+1} = N_a e^{-M}(1-u_a) \ ,$$

because both mature and immature fish experience natural and fishing mortality.

The exploitation fraction $\underline{u}_a$ is approximated by the standard Baranov equation:

$$u_a = \frac{v_a F}{Z_a}\left(1 - e^{-Z_a}\right), \text{ where } Z_a = v_a F + M \ .$$

The Review Panel then considered how to parameterize the BRP model for a Type 2 fishery. Were young fish vulnerable to the ocean fisheries? Can the very limited stock information from tagging and genetics be used to establish reference points? How much variability is there in gear selectivity by age? Are there sex-specific differences? Is it defensible to ignore the river mortalities here? The Review Panel could not resolve any of these issues with the scientific information at hand. Therefore, the Review Panel did not ask the SASC members to provide revised values from the Type 2 fishery, because of uncertainties in the ocean fisheries related to stock, age, and sex composition.

Results from the revised per recruit procedure are contrasted with the SASC stock assessment results from 1998 and this year in Table 2. The revised benchmark calculations resulted in higher Z_{30} values than were initially estimated by the SASC. This is the expected outcome because the revised results have less total mortality on immature shad, thus allowing higher mortality on mature shad. The revised results are lower than the comparable Z_{30} values used in the last region-wide shad assessment (ASMFC 1998), because natural mortality for older ages was much higher in the previous assessment.

Biological reference points are indices based on the biological characteristics of a fish stock and the characteristics of its fisheries or other human interactions. They are used to gauge whether specific management objectives are being achieved and provide both the link between stock assessment and management objectives (Caddy and Mahon 1995), and a basis for risk analysis of management actions (Punt and Hilborn 1997). **Although the Review Panel considered the Z_{30} benchmark sufficient for the region-wide comparisons presented in this assessment, this reference point is not directly linked to the management issues for many of these populations and the Review Panel encourages the development of population-specific reference points appropriate for the alleviation of the threats that exist for many of these populations.** Where abundance is sufficient to support fisheries, fishery-type reference points are appropriate, but for populations under restoration or rebuilding, reference points must also be appropriate for assessing the effectiveness of recovery activities. Human activities impact anadromous fish populations in many ways (e.g., fishing, dams and turbine mortality, habitat degradation), and where populations that are fished are under stress from other human activities, fishery reference points may need to be adjusted to compensate for the reduced productivity resulting from these other activities. For populations with low freshwater productivity, meeting the Z_{30} criterion will not ensure population recovery, as it does not explicitly account for this reduced production. The Review Panel notes that rebuilding targets are being developed for many of these populations and that in many instances, such as the Susquehanna River population, the SASC provided these targets in its report.

Table 2. Initial and revised benchmark total mortality rates (Z_{30}) for each region for a Type 1 (T1) fishery. Initial values came from the original stock assessment produced by the SASC; revised values (in bold) were provided by SASC members as requested by the Review Panel. The Panel recommends that the revised values be used. Values used in the last assessment (ASMFC 1998), and corresponding F_{30}s for the York River are provided for comparison.

Region	Model	Max. age	M [1]	Z_{30}		F30
				EPR [2]	BPR [3]	
New England	T1	11	0.38	-	0.64	
	revised T1	11	0.38		**0.98**	
Hudson River, NY	T1	14	0.30	0.52	0.54	
	revised T1	14	0.30	**0.68**	**0.73**	
York River, VA	T1	12	0.35	0.64	0.63	0.28
	revised T1	12	0.35	**0.85**	**0.85**	**0.50**
Albemarle Sound, NC	T1	10	0.42	-	0.76	
	revised T1	10	0.42		**1.01**	
ASMFC 1998						
All rivers	1-3		0.3			
Hudson	4-10		0.6		0.99	0.39
Northern rivers (NC-ME)	4-10		1.5		1.93	0.43
Southern rivers (SC-FL)	4-8		2.5		2.98	0.48

[1] assumed instantaneous natural mortality
[2] eggs per recruit
[3] biomass per recruit

The Z_{30} benchmarks could not be developed for the most southerly populations because they are semelparous. First, the Review Panel suggests that reference points for these populations be determined using surplus production, biomass dynamics, or delay-difference models, as shown in Hilborn and Walters (1992) and Quinn and Deriso (1999). Although at present the Panel does not know whether this approach will provide plausible reference points, testing the approach would also evaluate the utility of the data in this type of model. These kinds of models can be used with age-structured populations that do not have reliable age data for catch and abundance. Second, it may be possible to develop management benchmarks from standard semelparous spawner-recruit analysis (Quinn and Deriso 1999, chapter 3). Here an index of recruitment (from juvenile surveys) would be compared with an index of spawners (from river surveys) in order to establish F_{msy} reference points. This approach is widely used with Pacific salmon populations (NMFS 2004). This may also be the solution to the problems in the Delaware River, for which aging accuracy is suspect. The above models could possibly be derived using the Lewis haul seine (adult) time series and the JAI in an age-aggregated modeling approach.

F. Determine current status of each stock where possible.

The SASC provided information for American shad populations in a total of 64 rivers in 16 states/jurisdictions; assessment was conducted for 31 of these populations (Table 1.2 of 2007 American Shad Stock Assessment Report). Stock assessments based on trend analyses using fisheries-independent and/or fisheries-dependent index time series, were presented for 23 of these populations (Table 3). For 16 of these populations, comparisons of total mortality rates to benchmark total mortality rates (Z_{30}) were provided.

Given the wide variety of data types available for each population, coupled with differences in the biology, fisheries, and human and non-human induced factors that differentially affect shad population dynamics on a river by river basis, the SASC opted to assess Atlantic coastal shad stocks on an individual basis. **The Review Panel agreed that as an anadromous species, American shad should be assessed and managed by river system.** American shad spawn in rivers along the entire U.S. Atlantic coast and there are gradient (latitudinal) differences among river systems in life history attributes as well as river-specific factors such as the presence of dams (with and without fish passage), water quality problems, and estuarine and in-river fisheries that can lead to river-specific variation in patterns of abundance and in restoration potential.

The SASC used a simple index-based approach in its assessment for several reasons. These included the complexities of modeling oceanic and estuarine mixed-stock fisheries as well as river-specific commercial and recreational fisheries, particularly when few of the mixed-stock fisheries are adequately monitored, but there is almost no information about how to allocate the mixed-stock harvest among stocks. Additionally, few long-term, fishery-independent indices exist, except on rivers with fish passage, and the SASC identified uncertainties about the age data.

The SASC acknowledged that the assessment would not provide definitive answers to all the questions plaguing management of Atlantic coastal American shad. However, it did expect the assessment to give insight to managers on the complexity of the issues facing American shad in order to assist them in their decision-making as well as laying the foundation for future assessments in terms of data sources and methods.

The Review Panel found that, with some exceptions, the SASC was able to determine the current status of many of the stocks, an impressive result given existing data uncertainties and limited resources. From river to river, the basis for this assessment ranged from appropriate qualitative statements about status where populations were extirpated or are near extirpation to assessments of trends in abundance indices and total mortality. Where data were limiting or contradictory, the SASC appropriately stated that stock status was unknown. The Review Panel anticipates that the summaries provided by the SASC estimates will be particularly informative for prioritizing research and management actions as it relates to restoration of populations and preventing further declines.

Table 3. The 2007 assessed status (recent trend) of American shad populations compared with earlier 1998 assessment. A "?" in the status column indicates that either there was insufficient data or the various data analyses gave conflicting indications of trend.

State	River	Benchmark	*Z*	2007 Status	1998 Status
ME	Merrymeeting Bay			declining	
	Kennebec	0.98			
	Androscoggin	0.98			
	Saco	0.98	0.8-1.6		
NH	Exeter	0.98	0.3-2.1	Declining	
MA	Merrimack	0.98	0.4-2.4	Stable	Stable
RI	Pawcatuck	0.98	0.7-2.0	Declining	Stable
CT, MA	Connecticut	0.98	0.7-3.0	Stable	Stable
NY	Hudson	0.73	0.4-1.4	Declining	Declining
NY, PA, NJ, DE	Delaware River & Bay	0.85		Stable	Stable
MD	Nanticoke	0.85	0.1-1.6	Stable	Increasing
PA, MD	Susquehanna River & Flats	0.85	1.0-3.5	Declining	
MD, DC, VA	Potomac	0.85	0.6-1.5	Increasing	
VA	York	0.85	0.4-1.4	Increasing	Declining
	James	0.85	0.7-1.4	Declining	Stable
	Rappahannock	0.85	0.3-1.4	Stable	Stable
NC	Albemarle Sound	1.01	0.3-2.4	Stable	
	Roanoke	1.01		Stable	
	Tar-Pamlico	1.01	0.9-2.0	?	
	Neuse	1.01	0.2-2.0	?	
	Cape Fear	1.01	0.5-2.0	?	
SC	Winyah Bay	None		Stable	
	Waccamaw	None		?	
	Great Pee Dee	None		?	
	Santee	None		?	Increasing
	Cooper	None		Stable	
	Combahee	None		?	
	Edisto	None		Declining	Stable
SC, GA	Savannah	None		Stable	
GA	Altamaha (+ Ocmulgee)	None		Declining	Increasing
	Ogeechee	None			
FL	St. Johns	CPUE		Stable	

In general, as summarized by the SASC, American shad stocks have substantially declined from historic levels (see "Perspectives" section). The coastwide stock has experienced overfishing during at least three time periods over the 150 years of record. During these time periods, landings and likely fishing intensity have varied through time such as low landings during World War I, when fishing was thought to have declined, and high landings during World War II, when fishing increased. Major changes in recruitment have also historically occurred due to in-river modifications (dams, dredging, pollution, etc.). Recently, potentially large reductions in fishing mortality have also likely occurred due to the closure of the ocean-intercept fisheries. This closure may expedite stock recovery, but the time period since closure in 2005 and this assessment in 2007 has not been long enough to detect a response from the resource. Recreational fishing appears to be highly variable across the coast, but trends in recreational fishing are generally not well known. While habitat related improvements are being made as part of ongoing river restoration programs (e.g., up-stream passage, improvements in water quality), the Peer Review Panel suggested substantial improvements to both upstream and downstream fish passage as an area requiring remediation and research. Finally, bycatch in shad and other fisheries is almost totally unknown and needs expedited investigation in future assessments.

The Review Panel appreciated the efforts of the SASC to provide historical landings data that at times dated back into the 1800s. While historical landings data cannot be used to estimate virgin biomass prior to exploitation, they do provide indications of stock potential which aid in the interpretation of the low but stable abundances reported for some rivers. There also appear to be latitudinal differences in stock status, with northern stocks having experienced larger declines and apparently slower recovery to historical overfishing than more southern stocks.

While the available data, trend analyses, and benchmark Z_{30} comparisons carried out by the SASC were sufficient to provide an overview of status of shad populations in many rivers, the Review Panel recommends the development of population-specific assessment approaches that can be used to address management questions relevant to the specific population. Guidance on this recommendation is provided in TOR-G.

G. Develop recommendations for needed monitoring data and future research.

The Panel reviewed the SASC recommendations on page 154 of its report. **The Panel thought that the SASC captured most of the important points and decided to use these recommendations as the basis for its own.** The Panel made changes to SASC recommendations 1, 2, 6, 9, 10, and 12 and added one additional recommendation about modeling.

Recommendations for Fisheries and Fishery Assessments:

1. Due to the poor condition of many shad populations, future management actions to reduce total mortality are needed.
2. Develop a management recovery plan for those populations where current total mortality is above the Z_{30} benchmark. Components of this plan could include reductions in commercial or recreational fishery mortalities, reductions in bycatch, habitat restoration, improvements in upriver and downstream fish passage, or some combination. All stocks should have management plans that describe fishery and habitat goals and objectives for both the short term and long term. These plans should be reviewed and updated on a regular basis.
3. Identify all fisheries where bycatch occurs, then quantify the amount and disposition of bycatch. In fisheries where bycatch is allowed, quantify the discards.
4. Employ observer coverage to verify the reporting rate of commercial catch and harvest, as well as bycatch and discards.

5. Identify directed harvest and bycatch losses of American shad in all fisheries. In particular, the ocean and bay waters of Atlantic Maritime Canada should be included in this investigation.

6. Future assessments will need to better separate ocean and river fishing mortality in historical data. The problem is that data from the now-closed ocean fishery are limited in regard to stock origin, age composition, and maturity of fish. There is need for better identification of stock composition in mixed stock harvest using microchemistry techniques, genetics, and/or tagging. Modeling may help to account for ocean mortality, and efforts to locate age composition and maturity information.

7. Spatially delineate between mixed stock and Delaware stock areas within the Delaware River system.

8. Collect annual estimates of recreational catch, total harvest, CPUE, age, size, and sex composition of fish in each fishery.

9. If in-river tagging programs (conducted in Georgia, South Carolina, and Maryland) used to estimate exploitation and population size are continued, then assumptions must be verified. Issues related to reporting rate, tag mortality and loss, and movement (fallback), which are needed to estimate exploitation, need to be addressed.

10. Improve analyses of mark-recapture data by using modern methods (e.g., those contained in program MARK; Williams et al. 2001) to estimate survival.

11. Monitor juvenile production in semelparous stocks. Such monitoring may indicate when recruitment failure has occurred.

12. Accurate and precise aging is a critical underpinning of shad stock assessment and a prerequisite to any substantial improvement. Validation of aging procedures using either scales or otoliths is greatly needed for most shad stocks. These methods should allow for age and year-class identification in mature fish. To validate otoliths, it would be desirable to mark stocked larvae with OTC, alizarin, or thermal marking.

13. Characterize passage-associated efficiency, mortality, migration delay, and sub-lethal effects on American shad at hydroelectric dams.

14. Annually update all summary data tables of on-going data collection for use in the next assessment in the format used in this stock assessment for use in ASMFC stock assessments only.

15. Shad population modeling must be vastly expanded in the future. First, age-structured assessment models are needed to integrate the various sources of information available for shad stocks. These models have largely supplanted catch-curve analyses around the world. Second, models that incorporate predator-prey interactions should be examined. Shad are consumed by striped bass (e.g., in Connecticut), seals, sharks, other fishes, and birds. Little is known about these effects. If statistical multi-species models cannot be developed, then perhaps Ecopath may provide some insight. Third, the ultimate goal of stock assessment of shad should be to develop a life history model that accounts for all major factors that affect the mortality, recruitment, and reproduction of shad. This model would include factors in

the ocean environment such as ocean fishing, fisheries bycatch, and oceanographic processes. This model would include factors in the freshwater environment, including fish passage and related mortality, commercial and recreational fishing mortality, habitat changes, and environmental factors. Such a model would be useful to help understand which processes are most important in the sustainability of shad populations.

Recommendations for Habitat

1. Develop safe, timely, and effective upriver and downriver passage for adults and downriver passage for juvenile at all barriers that limit access to spawning reaches.
2. Maintain water quality and suitable habitat for all life stages of American shad in all rivers with shad populations. Refer to Amendment 1 for habitat issues pertaining to American shad and the ASMFC Anadromous Species Habitat Source Document (*in prep*).
3. In rivers with flow regulation, maintain flows at levels that ensure adequate fish passage, water quality, and habitat protection.

H. Describe the locations and amounts of shad and river herring bycatch in commercial fisheries for mackerel, sea herring, and other pelagic species and estimate the contribution of that bycatch to fishing mortality.

The SASC members were unable to complete this task at the time of the review. The data sources are widely dispersed and not readily available. This task remains a high priority for the SASC, as bycatch could potentially represent a significant and unknown source of mortality.

Advisory Report

A. Stock status

The stock assessment report identifies that all the stocks are highly depressed from historical levels. Current status, i.e., whether the stocks are currently improving or not, was identified for most stocks (Table 3). Declines in American shad in recent years were indicated for Maine, New Hampshire, Rhode Island, and Georgia stocks, and for the Hudson, Susquehanna, James and Edisto Rivers. Low and stable, but often highly variable, stock abundance was indicated for Massachusetts, Connecticut, Delaware, Chesapeake, Rappahannock, some South Carolina, and Florida stocks. Stocks showing some rebounding in recent years include the Potomac and York stocks. Data limitations and conflicting data precluded the report from saying much about the current status or trend of stocks from North or South Carolina (see Table 3).

The status of stocks as reported in the 1998 stock assessment report was based on 1992-1996 trends. Many of the stocks exhibited stable or positive trends during this time and these trends seem to continue until around 1999-2000, as indicated by the current assessment. The current assessment shows declines for several of these stocks from the turn of the century (Pawcatuck, Chesapeake Bay, James, Edisto rivers). The Panel report from the last assessment (1998) stated that: "*These trends in abundance over the 1992-1996 period may reflect natural variability, changes in fishing pressure, or both. The short time series is of limited applicability in analyzing the long term health of American stocks.*" This comment is still relevant and the changes in short term trends seen for American shad just reemphasize this. Only two stocks show some signs of increasing recent trends, i.e., York and Potomac Rivers. The Potomac was not assessed in the last review and the York showed a decline in that review. **Taken in total, American shad stocks do not appear to be recovering. Current restoration actions need to be reviewed and new ones need to be identified and applied.** These include fishing rates, dam passage (and survival there from), stocking, and habitat restoration.

B. Stock Identification and Distribution

East Coast stocks of American shad have distinct phylogenetic structure due to their natal homing behavior (Bentzen et al. 1989; Nolan et al. 1991; Brown et al. 1996) and are known to mix along their migration routes. Direct evidence comes from tagging experiments (e.g., Talbot and Sykes 1958; Dadswell et al. 1987; Jesien et al. 1992) and is also inferred from natural genetic composition (Brown et al. 1996, 2000) and from biogeochemical signatures in otoliths (Thorrold et al. 1998; Walther 2007).

In the current stock assessment, the SASC discussed at length the impacts of the ocean-intercept fishery on American shad (Section 1.5.1, Part A). Using a combination of artificial tagging and genetic data, the SASC attempted to parse out the percentages of mixed stock ocean (including Delaware Bay) harvests that individual stocks composed. Heaviest mixed stock exploitation was estimated to derive from North and South Carolina, and from the Delaware, Hudson, and Connecticut Rivers. For the Hudson River, where more data are available, the losses attributed to the ocean-intercept fishery appear to be reasonable.

As pointed out in Brown et al. (2000), shad marine migration paths are likely to vary from one year to the next due to changes in climate and possibly other ecological factors. Hence, mixed stock ocean fisheries are likely to intercept different stocks at different rates across time. The uncertainty that arises lends support to the precautionary measure of closing down the ocean-intercept fishery.

The SASC pointed out that further methods development is needed to resolve the mixing of American shad stocks. The Review Panel concurs, and recommends both the implementation of archiving programs (for DNA and otoliths) and more research on otolith chemical markers.

C. Management Unit

Management units of individual river stocks appear appropriate and are supported by the genetic evidence (Brown et al. 2000; Waters et al. 2000). Additional assessment approaches may require combining information from multiple stocks to create regional models supported by life history differences in the stocks, such as a southern stocks (South Carolina, Georgia, and Florida) Mid-Atlantic, and North Atlantic stocks.

D. Landings

The SASC has done an excellent job compiling landings statistics from a variety of state and federal sources across about a 150-year time period (and in the case of the Potomac River, back to 1814). These landings statistics provide useful information to infer stock potential for restoration purposes.

E. Data and Assessment

This is addressed in TOR-D.

F. Biological Reference Points

This is addressed in TOR-E.

G. Fishing Mortality

Most of the mortality estimates presented were in terms of *Z* calculated from catch-curve methods. Partitioning of mortality into estimates of *F* requires additional assumptions related to *M*. Because of uncertainty in *M*, estimates of *F* were not presented. There is also some debate on the SASC about what is included as *F* or *M*. Generally in most fisheries stock assessments, *F* would include all anthropogenic sources or mortality. For example in these stocks, this would include mortality associated with fishing (directed commercial, commercial bycatch, and recreational) and adult dam passage mortality. Natural mortality sources would include fish that die due to any non-anthropogenic source including predation, old age, or spawning associated mortality.

The SASC and individual managers expressed interest in developing approaches to partitioning mortality into different sources. We have provided some guidance related to this in TOR-G. Most management actions are directed at regulating *F*. The SASC's approach of presenting mortality in terms of total mortality assumes that *M* has remained constant across the time series where *Z* values were presented for each stock in order to evaluate trends in *F*. Using this approach, the SASC is monitoring trends in *Z* for responses to recent fishery management actions such as closure of the ocean-intercept fishery. If the assumptions of the catch-curve methods are met, then this approach is likely reasonable. However, by not partitioning mortality, the SASC needs to address other hypotheses of interest such as changes in natural mortality related to ecosystem changes (e.g., increases in striped bass abundance) which may lead to increased predation on American shad. The exception is for the York River where benchmark guidelines are presented for F_{30} levels as well as Z_{30} levels.

The SASC's recommendation to continue the use of Brownie type survival models (Brownie et al. 1985) is a good recommendation to estimating total mortality from tagging data. Estimates of reporting rate are required to partition mortality into component parts. Lack of knowledge about reporting rates is possibly why survival estimates from the Brownie models in the Hudson River are not partitioned into component parts. The SASC's decision to exclude other tagging based exploitation estimates (e.g., South Carolina) because of uncertainty in reporting rate and mixing of marked and unmarked fish is appropriate. However, properly designed tagging programs conducted over multiple years could provide annual estimates of fishing mortality for use in assessing stock status and evaluating factors limiting recovery. Jiang et al. (2007) provide an example of using a tagging program to estimate *F* and *M* for striped bass in the Chesapeake Bay.

H. Recruitment

The Panel feels that the SASC did an excellent job compiling the existing recruitment indices. Juvenile recruitment data are often lacking in many fisheries assessments and efforts to monitor recruitment should continue for each stock. The Panel feels that additional effort should be made to determine how JAIs compare to estimates of adult abundance, both in terms of run size that produced a particular year class and how well strong year classes detected in the JAI programs persist in the adult stock. This would aid in evaluating recruitment responses to climatic events, such as droughts and flooding, or changes in dam management operations related to enhancing upstream and downstream passage capabilities at dams.

I. Spawning Stock Biomass

No estimates of spawning stock biomass (SSB) were presented. However, historical landings data do provide some insight into the potential spawning stock biomass, indicating that SSB is likely much lower currently than in previous time periods (Figure 1). Recent indices of adult abundance also demonstrate large reductions in stock biomass for the northern stocks (Maine through Rhode Island). The Connecticut stock shows variable but stable indices of adult returns, the Hudson River stock shows decline, and the more southern stocks show mixed signals or a stable trend with high variability. However, all abundance indications show low spawning abundance compared with historical levels, assuming that the high historical landings correlate with high historical spawning levels.

J. Bycatch

This is addressed in TOR-H above.

K. Other Comments

Throughout the SASC report there is little discussion on the amount of uncertainty associated with data used in the assessment, particularly in the indices such as annual variance in JAIs. The Panel would like to again make the same recommendation as in the 1998 American shad stock assessment to present uncertainty in model inputs whenever possible instead of assuming that values are known. This allows managers not only to evaluate the uncertainty in the input data, but also to evaluate the uncertainty associated with model results and to aid in research planning by identifying areas where sampling variability is high or model outputs are highly sensitive to uncertain data inputs. These recommendations follow guidelines highlighted in the 1998 NRC report, *Improving Fish Stock Assessments*, which encourages all stock assessments to "*present realistic measure of the uncertainty in model outputs whenever feasible*" (NRC 1998).

L. Perspectives

The world is a rapidly changing place, as the impact of humanity becomes ever more pervasive. Historical ecology has become one means to study and evaluate this impact (e.g., Jackson et al. 2001; Briggs et al. 2005). The current American shad stock assessment explicitly incorporated historical perspectives, by compiling catch data as far back in time as the early 1800s. Throughout the stock assessment report, time series of harvests from a number of states and river systems are presented along with the corresponding state or system summary. The Panel brings these data together in a slightly different way by (a) putting all the time series data onto the same temporal scale, with different scales on the y-axis, in order to examine temporal trends, and (b) putting all the data on the same scales on both axes, in order to examine the magnitude of these trends. The Panel normalized the catch data to the distances of available river kilometers that shad would have traversed during different time periods, following Limburg et al. (2003). This allows us to compare catches among river systems. The Panel notes that the un-normalized trends show similar patterns.

In addition, the Panel can comment on some of the past characteristics of American shad as listed in newspaper accounts from the New York Times Archive, and make note of other past information. The New York Times had many articles about the shad fishery. Archives are available online dating back to 1851 (www.nytimes.com).

Historical Time Series of Catches

Long-term data were available from the American shad stock assessment report for the states of Maine, Massachusetts, Rhode Island, Connecticut, New York (Hudson River), Maryland (mostly upper Chesapeake), the Potomac River, North Carolina, South Carolina, and the Savannah River, which borders South Carolina and Georgia. These data were normalized by dividing the catches by the amount of available river and estuary kilometers that shad would have traveled to reach their spawning grounds (Figure 1-A). Mostly the river/estuary distances declined over time, unless a dam passageway was built or a dam was removed. The periods of the two World Wars are included in Figure 1-A to help guide the eye.

Fisheries peaked at different times over the past 120 years, with highest harvests in the 1880s and 1890s in the Hudson River, Maryland, and North Carolina, but peaking later in Maine (1912), Massachusetts (1957), and Connecticut (1946). Considerably lower catches per km were recorded for Rhode Island, South Carolina, and the Savannah River. Catches increased in both Connecticut and New York during the Depression and remained high throughout the post-WWII period, but declined (or possibly collapsed) shortly thereafter.

The Potomac River has data going back to 1814; the maximum harvest from extant records was in 1832, with a total catch of 51,136,364 kg (167,112 kg per river km). If the average shad caught then weighed five pounds (2.27 kg), this amounted to over 10 million fish; if the average shad weighed four pounds (1.82 kg), this would have been over 12 million fish caught in one system in one year. Indeed, it was thought that 22.5 million fish could be caught "in a good year" (Tilp, 1978, cited in the ASMFC report). Later the Potomac fishery peaked in 1898, but as in some other systems, went through a serious of gradual "fishing up" and collapse episodes. Today, that fishery is limited to bycatch and recreational landings, and a stocking program is in place to supplement the remnant population.

If all the time series are placed on one graph with arithmetic axes (Figure 1-B), the scale of the early Potomac fishery to subsequent ones is startling. Log-transforming the landings axis (Y-axis) permits all the time series to be viewed. On this scale, the long-term decline is exponential with a slope of -0.035 yr^{-1} with all the data (R^2 = 0.33, $p < 10^{-5}$), or -0.033 yr^{-1} if the early Potomac landings are excluded (R^2 = 0.26, $p < 10^{-5}$).

American Shad in the 19th Century

There is a large gap in data from 1832 until the 1880s, but the Panel does know from historical and contemporary accounts that the shad fisheries were already in decline by the mid-19th century. Fishing regulations had already gone into effect in the 18th century in New England, and net lift periods were put in place in the Hudson River in the 1870s.

During this period, the field of scientific aquaculture grew into a major tool that federal and state resource commissions used to enhance flagging fisheries. Seth Green began experimenting with shad culture in 1867 in the Connecticut River, and by 1870 shad eggs were being hatched both in the Connecticut and Hudson Rivers (NYT 1874). Green and his colleagues transported shad to the West Coast by rail (Boyle 1969) and attempted to establish populations in the Great Lakes and Mississippi River (NYT 1874). The American Fish Culturists' Association, which evolved into the American Fisheries Society (AFS), was founded in 1870 and had an initial focus on shad, salmon, and trout. The first scientific report in the Transactions journal was on American shad culture (Clift 1872). By the turn of the century, major aquaculture facilities were in place along several rivers.

Difficult as it is to believe today, American shad were dramatically important as a food source through the 19th century and into the early 20th century. "*Its* [shad] *abundance in the early history of the country was such as to excite the unbounded astonishment of those who beheld it for the first time*" (NYT 1874). Charles Minor Blackford wrote in 1916 that, "*…there is probably no fish on earth that surpasses the shad in all the qualities that go to make up an ideal food fish…*" (Blackford 1916). There are many 19th century newspaper accounts of the toothsome flavor and appeal of shad. It is no mystery why so much effort was put into its propagation.

Why did American shad catches decline so precipitously in the early 20th century? Although it may never be known definitively, there is ample evidence that raw sewage and other noxious pollution became severe and persistent in the period of the 1890s through the 1920s. For example, in November, 1916 the New York Times ran the note:

"*Shad are reported in the Hudson River. They are not many, and they are not edible, tasting of sludge and oil too much. It is not known certainly what is the explanation of their unseasonable appearance, but it serves to recall the time when the shad fisheries of the Hudson were worth as many hundreds of thousands as in recent years they have been worth thousands*" (NYT 1916).

Nineteenth century accounts document repeatedly that American shad were larger and weighed more in the early and mid-century than later. A 1611 account from the Potomac River was of shad measuring a yard long (91 cm) (Tilp 1978, cited in the ASMFC stock assessment). In 1903, the New York Times reported that: "*A few years ago, eleven, twelve, and even fourteen pound shad were not uncommon in the Hudson, but very little is heard of shad of that sort today. The average weight for both sexes, according to the figures of the United States Fish Commission, is between three and four pounds*" (NYT 1903).

Finally, linkages with marine ecosystems were also apparent and in decline in the late 19th and early 20th centuries. Future ecosystem models that include shad could use some of the historic accounts as a starting point. For example, shad were known to be preyed upon by marine species. "*In the deep sea the horse mackerel, kingfish, and shark work dreadful havoc with the adults. Even the porpoise pursues the shad to shore and devours him just as he reaches the haven of river water*" (NYT 1903). Stevenson (1899) was acutely aware of the linkages between continental watersheds and coastal marine fisheries, and wrote in his monograph on the state of shad fisheries that:

"*The relationship between the different species of fish in the economy of nature is not very well understood, but sufficient is known to indicate that the valuable shore fisheries on the New England coast are intimately associated with the run of shad and similar species up the rivers of that section. Seventy years ago the run of fish up the rivers of the New England States was very much greater than at present, and after the parent fish had disappeared the waters swarmed with the young, which later in the year descended to the sea in enormous schools, attracting the cod, haddock, and other offshore species, which were caught in great abundance within a short distance of the coast, rendering unnecessary the expensive and hazardous trips to distant banks. But with the depletion of shad, alewives, salmon, and kindred species came a corresponding diminution in the number of cod, haddock, etc. near the coast. And it appears that any measures tending to restore the anadromous fishes to their former abundance will also improve the coast fisheries.* (pp. 104-105)"

Shifting Baselines and Lost Connectivity

American shad has lost its place as a dominant species in East Coast estuaries and rivers, and has dropped out of commonplace memory in America. Historical reconstructions may help to establish a baseline and benchmarks against which to measure recovery. The late 19th century harvests have been suggested as a baseline, but there is evidence that even these fisheries were conducted on depleted populations. In the 21st century, American shad could become a bellwether of ecosystem health, managed not only for fisheries, but also to indicate the status of the connectivity and environmental quality of watersheds and coastal oceans.

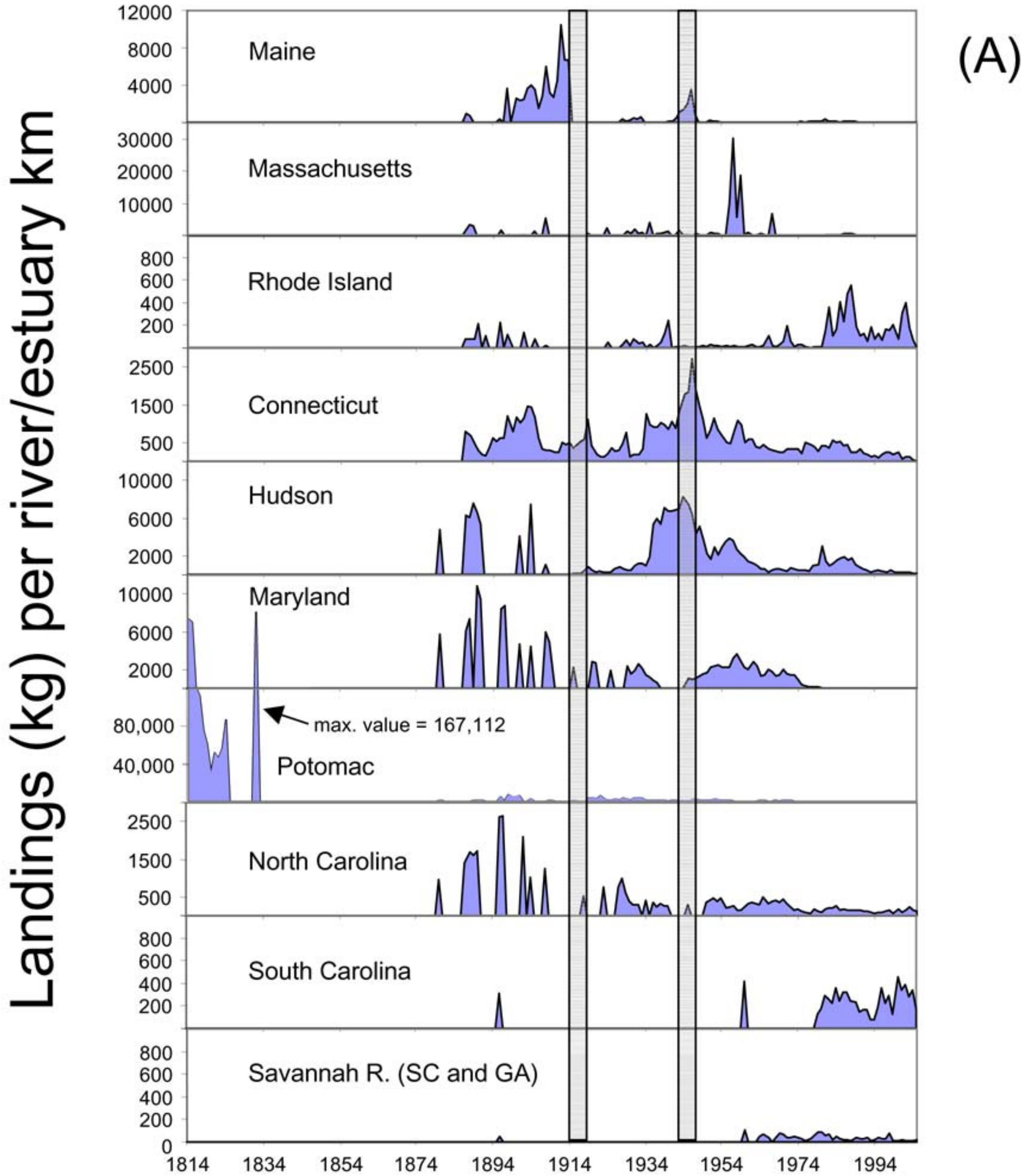
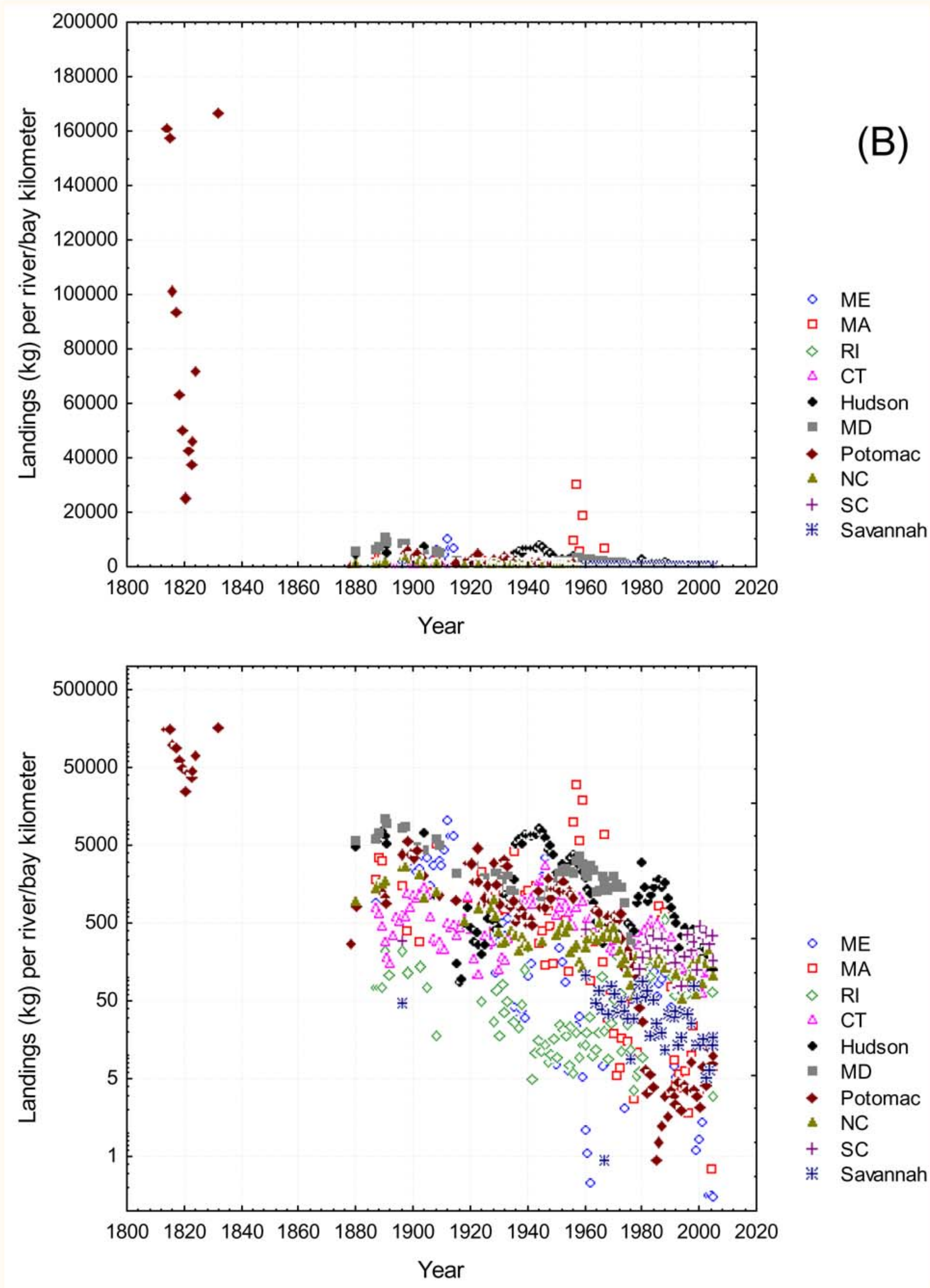


Figure 1. Time trends of American shad landings for selected rivers. Landings have been normalized by dividing by the distance inland that shad could migrate through estuaries and rivers from the sea. (A) Trends shown by individual state or river system; note the differences in y-axis scales. The two World Wars are shown as light gray bars. (B) Trends placed on the same y-axis: arithmetic scale (top) and logarithmic scale (bottom).



(B)
Landings (kg) per river/bay kilometer
Year
ME
MA
RI
CT
Hudson
MD
Potomac
NC
SC
Savannah

M. Sources of information (Literature Cited)

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