Introduction

This document presents a summary of the benchmark stock assessment for American shad. The assessment was prepared by the Atlantic States Marine Fisheries Commission's (Commission) Shad Stock Assessment Subcommittee (SAS) and peer-reviewed by an independent panel of scientific experts through the Commission's external review process. This assessment is the latest and best information available on the status of American shad stocks for use in fisheries management. The benchmark stock assessment report consists of two parts: sections 1-8, which include the initial stock assessment report that was provided to the Peer Review Panel prior to the Peer Review Workshop, and section 9, which provides details on additional analyses conducted during the Peer Review Workshop and final stock status determinations for stocks where determinations changed from the initial stock assessment report.

Management Overview

The Fishery Management Plan (FMP) for Shad and River Herring was one of the very first FMPs developed at the Commission. In 1994, the Shad and River Herring Management Board determined the FMP was no longer adequate for protecting or restoring the remaining shad and river herring stocks. Amendment 1 was adopted in 1998 and required specific American shad monitoring programs, as well as recommended fishery-dependent and fishery-independent monitoring programs for river herring and hickory shad, in order to improve stock assessment capabilities. In addition, Amendment 1 established a five-year phase-out of the ocean-intercept fishery for American shad by January 1, 2005.

In 2010, the Shad and River Herring Management Board approved Amendment 3, revising American shad regulatory and monitoring programs in response to the 2007 assessment, which found most American shad stocks were at all-time lows and did not appear to be recovering. The Amendment requires states and jurisdictions to develop sustainable fishery management plans (SFMPs), which are reviewed by the Technical Committee and approved by the Board, in order to maintain commercial and recreational harvest fisheries beyond January 2013. To date, the following states/jurisdictions have approved SFMPs for shad: Maine, Connecticut, Massachusetts, Delaware River Basin, Potomac River Fisheries Commission, North and South Carolina, Georgia and Florida.

Amendment 3 also requires states and jurisdictions to submit a habitat plan regardless of whether their fisheries would remain open to harvest. The habitat plans outline current and historical spawning and nursery habitat, threats to those habitats, and habitat restoration programs in each of the river systems. They provide a river system-specific, comprehensive picture of major threats to American shad in each state to aid in future management efforts, and include collaboration with other state and federal agencies (e.g., state inland fish and wildlife agencies, water quality agencies, U.S Army Corps of Engineers). The two largest threats identified in the habitat plans were barriers to migration and a lack of information on the consequences of climate change. A key benefit of the habitat plans is that each river system relevant to shad now has its threats characterized. The habitat plans are filed with the Federal Energy Regulatory Commission to ensure that shad habitat is considered when hydropower dams are licensed. They are also shared with inland fisheries divisions to aid in habitat monitoring and restoration efforts. A majority of the habitat plans were approved by the Board in February 2014, and it is anticipated that they will be updated in 2021. (Visit http://www.asmfc.org/species/shad-river-herring for more information on SFMPs and Shad Habitat Plans.)

What Data Were Used?

For this assessment, a combination of fishery-dependent and fishery-independent data from resource agency monitoring programs were included. Both types of data are limited, with only relatively short-term fishery-independent indices available for use and fishery-dependent data hindered by data gaps and a lack of river-specific information. Some new data collection programs have been added in recent years following the passage of Amendment 3 in 2010; these surveys should be useful in future assessments (five to ten years from now) if monitoring continues. In addition to the traditional fishery-dependent and fishery-independent data types used in stock assessment, this assessment also used habitat availability data for the first time.

Life History

American shad are an anadromous, pelagic, highly migratory, schooling species. The species spends most of its life in marine waters, with adults migrating into coastal rivers and tributaries to spawn. On average, American shad spend four to five years at sea, and some individuals from the southernmost range may travel thousands of miles during this time period. Additionally, rivers, bays, and estuaries associated with spawning reaches are used as nursery areas by young-of-year (YOY) American shad.

The historical range of American shad extended from Sand Hill River, Labrador, Newfoundland, to Indian River, Florida, in the western Atlantic Ocean. The present range extends from the St. Lawrence River in Canada to the St. Johns River in Florida. Scientists estimate that this species once ascended at least 130 rivers along the Atlantic coast to spawn, but today spawning runs occur in fewer than 70 systems. Most American shad return to their natal rivers and tributaries to spawn, with a small percentage (3%) straying to non-natal river systems. Due to this life history, each river system represents a separate stock of American shad. All stocks along the coast are considered part of a larger metapopulation, or a spatially-structured population comprising subunits (river-specific stocks for American shad) that interact with each other but are distinct.

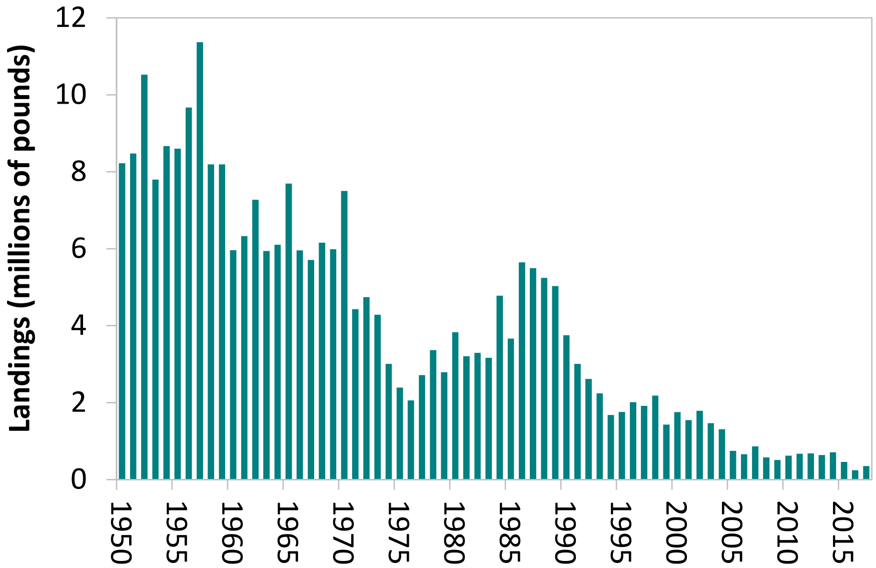
In the spring, American shad spawning migrations begin in the south and move gradually north as the season progresses and water temperatures increase. Spawning runs typically last two to three months, but may vary depending on weather conditions. Male American shad arrive at riverine spawning grounds before females. Upstream migration distance varies depending on the river system and has shifted over time. While it is not unusual for American shad to travel 25 to 100 miles upstream to spawn, some populations historically migrated over 300 miles upstream. In the 18th and 19th centuries, American shad runs were reported as far inland as 451 miles along the Great Pee Dee and Yadkin Rivers in North Carolina and over 500 miles in the Susquehanna River.

American shad spawning frequency also varies regionally. Generally, American shad that spawn north of the Cape Fear River in North Carolina are iteroparous (spawn more than once), while American shad spawning south of the Cape Fear River are semelparous (spawn once and then die). Semelparity in the southern stocks may be due to the physiological limits of the long oceanic migrations or higher southern water temperatures. Research suggests southern stocks produce more eggs per unit of body weight than northern populations to compensate for not spawning repeatedly.

Fishery-Dependent Data

American shad are caught in a number of different fisheries, both as a target species and as bycatch. The assessment included commercial landings data by river, where available, and in aggregate from all rivers and estuaries along the coast and the ocean (Figure 1). Commercial landings in Canadian waters were also included in the assessment based on research that indicates U.S. stocks migrate to these waters and are vulnerable to Canadian marine fisheries. Landings have declined since the 1950s by more than an order of magnitude, from as high as 11 million pounds in 1957 to less than a quarter of million pounds in 2016. Though changes in landings in recent years are influenced by regulations that affect fishing effort, such as moratoria on riverine fisheries, the long-term decrease in landings reflects declines in abundance effort. Data from fishery observers were used to estimate bycatch in estuarine and ocean fisheries. This bycatch occurs primarily in bottom trawl and gill net fisheries targeting other species and may be retained or discarded.

Figure 1. American Shad Commercial Landings



Fishery resource agencies collect biological and effort data from some fisheries, which are used to characterize the age structure (catch-at-age) and catch-per-unit-effort (CPUE). Age structure can be analyzed to estimate mortality and CPUE can be analyzed to track changes in abundance over time.

Recreational fishing for American shad occurs in some rivers, but data from these fisheries are limited. Some of these fisheries are only open for catch and release, but impacts of these fisheries are unknown due to the lack of total catch and release mortality information. NOAA Fisheries' Marine Recreational Information Program, which tracks coastal recreational catch and effort, rarely encounters anglers fishing for American shad and, as a result, its estimates of recreational catch and effort are highly uncertain and were not used in the assessment.

Fishery-Independent Data

Fishery resource agencies along the coast conduct surveys that encounter American shad in river systems and marine environments. These surveys provide indices of abundance and biological data to track changes in relative abundance through time and characterize population attributes such as age structure and average size. In-river surveys encounter YOY fish moving to estuarine and marine environments in the fall and adults returning to rivers to spawn in the spring. Marine surveys encounter juvenile and adult fish that come from different rivers, and then mix and migrate together in the ocean. Due to a lack of genetic data, fish captured by these marine surveys cannot be traced back to their river-specific stocks; this prevents a complete understanding of trends in abundance, or biological attributes of river-specific American shad stocks from marine surveys. In addition to typical fishery-independent surveys, fish counts and biological sampling of American shad passing dams are also used as indices of abundance and to characterize population attributes. Fishery-independent data sets represent a relatively short time series compared to the long history of American shad fisheries and do not provide information on the historical productivity of stocks, making it difficult to determine abundance status from these data sets alone. Shad biologists from along the coast also provided data on historical spawning habitat area and dams, which were used to determine currently unobstructed spawning habitat.

What Models Were Used?

The assessment evaluated Atlantic coastal stocks on an individual river system basis when data were available and also as a coastwide metapopulation with data sets that could not be attributed to system-specific stocks. Twenty three system-specific stocks had data available for assessment. Due to data limitations, regional metapopulations were defined to share life history data (growth and natural mortality rates) among system-specific stocks within each regional metapopulation. The northern iteroparous metapopulation included stocks north of the Hudson River to the U.S.-Canadian border, the semelparous metapopulation included stocks north of the Cape Fear River to the Hudson River. As an anadromous metapopulation, ideally American shad should be assessed and managed by individual river systems. However, the majority of the life history of shad is spent in the marine environment where factors influencing survival likely have impacts upon multiple river stocks when they mix during marine migrations. This complex life history complicates assessment as it is difficult to separate in-river factors from marine factors governing population dynamics. Also complicating the assessment is the variability in data quantity and quality among rivers along the coast.

A combination of assessment approaches was used to assess the status of American shad stocks due to the variation in data availability across individual systems. The year 2005 was selected as a reference point for abundance trend analyses based on a coastwide management change (i.e., closure of the ocean-intercept fishery) to assess response in abundance to this change. An **autoregressive integrated moving average (ARIMA) analysis of** abundance indices was used to compare current abundance to reference abundance levels in 2005. **Mann-Kendall trend analysis** was used to detect trends in each abundance index since 2005 and to detect trends in mean length and mean length-at-age over time.

To establish total mortality (*Z*) biological reference points (BRPs), the assessment used a modified **Thompson-Bell spawning biomass per recruit (SBPR) model**. The threshold for total mortality was set at $Z_{40\%}$, which is the total mortality that produces 40% of the spawning biomass that would be produced under natural mortality levels (*M*).The assessment used **total mortality estimators** (i.e., catch curves) to estimate annual total mortality of spawning adults. Recent mortality (averages during 2015-2017) was compared to $Z_{40\%}$ thresholds to assess whether the total mortality of stocks is sustainable.

The assessment also used several classes of population models to assess the status of individual stocks depending on data availability. **Delay-difference models** used total catch data and indices of abundance to track changes in biomass and exploitation rates. The exploitation rate that results in maximum sustainable yield (U_{MSY}) was compared to recent exploitation rates to assess whether exploitation is sustainable. **Statistical catch-at-age models** used catch-at-age data and indices of abundance to track the decline in abundance of each year class in the population due to mortality. Recent mortality was then compared to $Z_{40\%}$ thresholds as was done with total mortality estimators. Finally, a **population simulation model** that linked shad life history characteristics to spawning habitat availability was used to estimate spawner potential. The analysis compared spawner potential under three scenarios: (1) historic, undammed spawning habitat, (2) spawning habitat with no fish passage at dams, and (3) spawning habitat with an optimistic estimate of “current” fish passage at barriers (Figure 2).

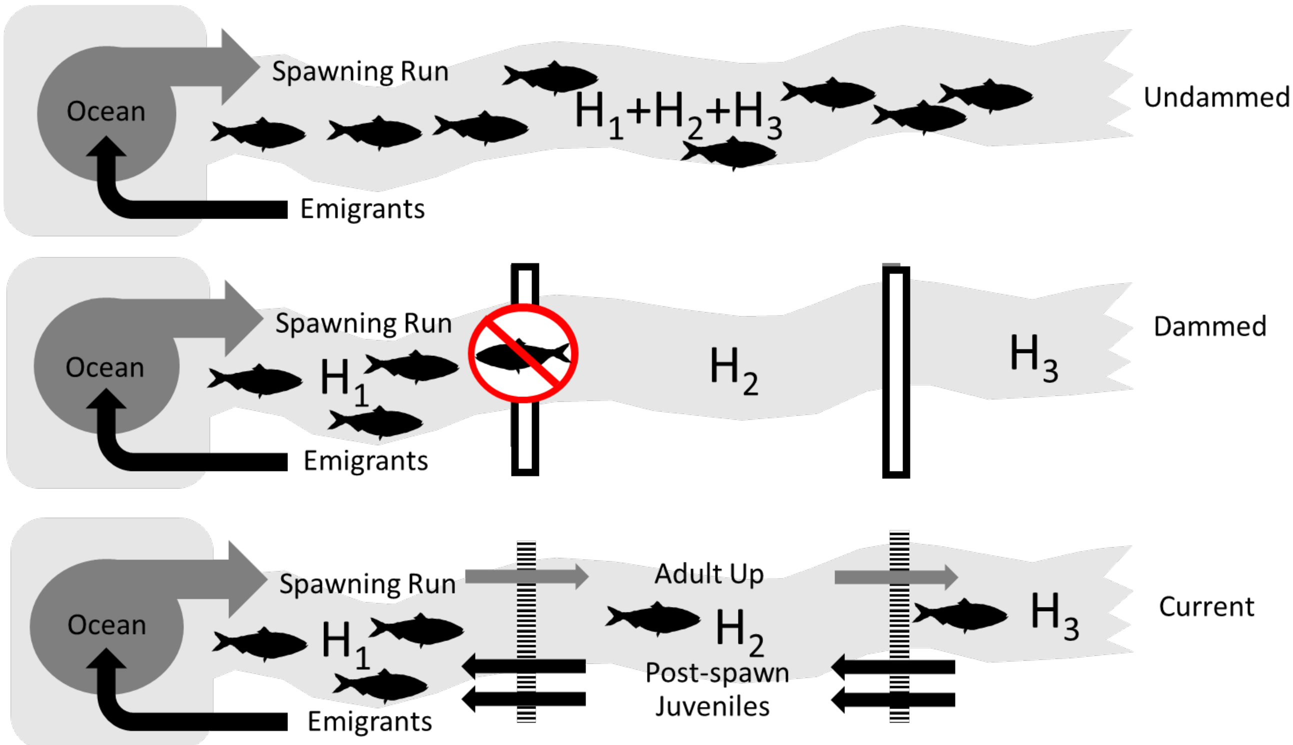


Figure 2. The habitat assessment and simulation model to estimate spawner potential under 3 different scenarios (from top to bottom): (1) historic, undammed spawning habitat, (2) spawning habitat with no fish passage at dams, and (3) spawning habitat with an optimistic estimate of "current" fish passage at barriers. Image © Mike Bailey.

What is the Status of the Stock?

Adult mortality for the coastwide metapopulation is unknown, but was determined to be unsustainable for some system-specific stocks, indicating the continued need for management action to reduce adult mortality. Specifically, adult mortality was determined to be unsustainable for three stocks (Connecticut, Delaware, and Potomac) and sustainable for five stocks (Hudson, Rappahannock, York, Albemarle Sound, and Neuse). Though adult mortality was determined to be sustainable for some system-specific stocks, it is important to note that maintaining sustainable adult mortality will not result in favorable abundance status if juvenile mortality is unsustainable. Unfortunately, data are not being collected in any system to determine juvenile mortality status and, without these determinations, a significant uncertainty remains in assessment advice for the management of American shad.

Abundance status is unknown for most systems due to data limitations, so trends in YOY and adult abundance are provided for information on abundance changes since the 2005 closure of the ocean-intercept fishery (see Table on next page). For YOY indices, two systems experienced increasing trends while one system experienced a decreasing trend since 2005. All other systems experienced either no trend (eight systems), conflicting trends among indices (one system), or had no data (11 systems). For adult indices, four systems experienced increasing trends while no systems experienced decreasing trends since 2005. All other systems experienced either no trend (11 systems), conflicting trends among indices (seven systems), or had no data (one system). Trend analyses also indicate a continued lack of consistent increasing trends in coastwide metapopulation abundance since 2005. Abundance status was determined to be depleted for one system (Hudson) and not depleted for one system (Albemarle Sound). Despite the finding that the Albemarle Sound abundance status is not depleted, the coastwide metapopulation abundance was determined to

Summary of American Shad Stock & Habitat Conditions				
System	Historic Riverine Habitat Currently Unobstructed	Abundance Trends (2005-2017)	Adult Status*	
			Total Mortality Rate	Abundance
Merrymeeting Bay	50.02%	YOY: No trend Adults: No data	Unknown	Unknown
Merrimack	17.83%	YOY: No data Adults: Increasing trend	Unknown	Unknown
Pawcatuck	19.21%	YOY: No data Adults: Increasing trend	Unknown	Unknown
Connecticut	45.19%	YOY: No trend Adults: Conflicting trends between indices (1 increasing, 1 no trend)	Unsustainable	Unknown
Hudson	89.24%	YOY: No trend Adults: No trend	Sustainable	Depleted
Delaware	72.05%	YOY: No trends (2 indices) Adults: Conflicting trends between indices (1 increasing, 1 no trend)	Unsustainable	Unknown
Nanticoke	100%	YOY: Declining trend Adults: No trends (2 indices)	Unknown	Unknown
Susquehanna & Upper Chesapeake	4.38%	YOY: No trend Adults: No trends (2 indices)	Unknown	Unknown
Patuxent	100%	YOY: No data Adults: No trend	Unknown	Unknown
Potomac	90.02%	YOY: No trend Adults: No trends (2 indices)	Unsustainable	Unknown
Rappahannock	95.98%	YOY: Increasing trend Adults: No trends (2 indices)	Sustainable	Unknown
York	87.42%	YOY: Conflicting trends between indices (1 increasing, 2 no trends) Adults: No trend	Sustainable	Unknown
James	72.77%	YOY: No trend Adults: No trends (2 indices)	Unknown	Unknown
Albemarle Sound	58.92%	YOY: Increasing trend Adults: Conflicting trends between indices (2 no trends, 1 increasing)	Sustainable	Not overfished
Tar-Pamlico	75.68%	YOY: No data Adults: No trend	Unknown	Unknown
Neuse	90.05%	YOY: No data Adults: Conflicting trends between indices (1 increasing, 1 no trend)	Sustainable	Unknown
Cape Fear	46.59%	YOY: No data Adults: Increasing trends (2 indices)	Unknown	Unknown
Winyah Bay	73.13%	YOY: No data Adults: Conflicting trends (1 increasing, 2 no trend)	Unknown	Unknown
Santee-Cooper	20.95%	YOY: No data Adults: Conflicting trends between indices (1 increasing, 2 no trend)	Unknown	Unknown
ACE Basin	82.28%	YOY: No data Adults: No trend	Unknown	Unknown
Savannah	59.19%	YOY: No data Adults: No trends (2 indices)	Unknown	Unknown
Altamaha	82.24%	YOY: No data Adults: Conflicting trends between indices (1 increasing, 1 no trend)	Unknown	Unknown
St Johns	90.04%	YOY: No trend Adults: Increasing trend	Unknown	Unknown
Coastwide	55.42%	YOY: NA Adult: Conflicting trends between indices	Unknown	Depleted

* The status determinations identified in the table for total mortality and abundance are for adults only. System-specific data on juvenile American shad as they transition from young-of-the-year (YOY) to mature spawning adults are unavailable, which can impact overall status determinations.

be depleted based on the decline in coastwide landings since the 1950s by more than an order of magnitude and the lack of consistent increasing trends in abundance indices since the decline in landings.

There may still not have been enough time for coastwide abundance to respond to the 2005 closure of the ocean intercept fishery, given various factors impeding rebuilding among systems. In fact, the assessment finds that shad rebuilding is limited by restricted access to spawning habitat. Current barriers partly or completely block 40% of historic shad spawning habitat (including Canada), which may equate to a loss of more than a third of spawning adults. Optimistic fish passage rates only provide a modest increase (4%) in spawner potential relative to no fish passage.

The decline of American shad is not unique; declines of many other diadromous species have been observed in the North Atlantic basin. Multiple factors are likely responsible for shad decline such as overfishing, inadequate fish passage at dams, predation, pollution, water withdrawals, channelization of rivers, changing ocean conditions, and climate change. It is not possible to separate out impacts of each factor with available data to evaluate their relative contributions to abundance decline. Thus, the recovery of American shad will need to address multiple factors including improved monitoring (see below), anthropogenic (human-caused) habitat alterations, predation by non-native predators, and exploitation by fisheries.

Data and Research Needs

Efforts to assess the status of American shad on the Atlantic coast are hampered by a lack of data and the complex stock structure. Several high priority research needs were identified during the benchmark stock assessment to improve future stock assessments.

Stock composition data (e.g., genetic samples, tagging studies) are essential to understand mixed-stock fishery impacts on American shad stocks. These data are needed for both mixed-stock fishery catches as well as mixed-stock fishery-independent surveys (e.g., coastal trawl surveys).

American shad are relatively difficult to age, and scales continue to be used for age and repeat spawn data in several monitoring programs despite these data generally being less reliable than age data from otoliths. Monitoring programs should use otoliths for age data. Scales should be collected for repeat spawn marks which are not made on otoliths. Rigorous protocols for ageing need to be used that include collection of supplementary data to evaluate error such as repeated, independent reads of age and spawn marks from age structures and continued collection of known-age fish.

All systems with fisheries should be monitored with comprehensive fishery-independent monitoring programs that collect data on relative abundance and biological attributes and fishery-dependent monitoring programs that collect data on all fishery catch (including discards), effort, and biological attributes.

Existing riverine surveys only encounter mature fish and marine surveys only encounter immature fish of unknown stock origin, making stock-specific maturity determination challenging. Maturity studies designed to accommodate this unique challenge posed by American shad reproductive behavior need to be conducted.

More widespread research on fish passage at barriers is needed for adult upstream and downstream migration and YOY downstream migration.

Whom Do I Contact For More Information?

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Glossary

Anadromous – Migrating from marine, saltwater environments to freshwater environments to spawn.

Catch-at-age – The number of fish of each age that are removed in a year by fishing activity.

Depleted – Reflects low levels of abundance though it is unclear whether fishing mortality is the primary cause for reduced stock size

Iteroparous – The characteristic of spawning more than once throughout a species' life.

Metapopulation – A spatially-structured population with subunits (river-specific stocks for American shad) that interact with each other but are distinct.

Semelparous – The characteristic of spawning once before dying.

Sustainable – Amendment 3 defines sustainable fisheries as those that demonstrate their stock could support a commercial and/or recreational fishery that will not diminish the future stock reproduction and recruitment. In the assessment, the mortality status of a system was defined as sustainable if mortality was less than or equal to the reference point or unsustainable if mortality was greater than the reference point.

Total mortality (*Z*) – The rate of removal of fish from a population due to both fishing and natural causes.

Young-of-year (YOY) – An individual fish in its first year of life; for most species, YOY are juveniles.

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