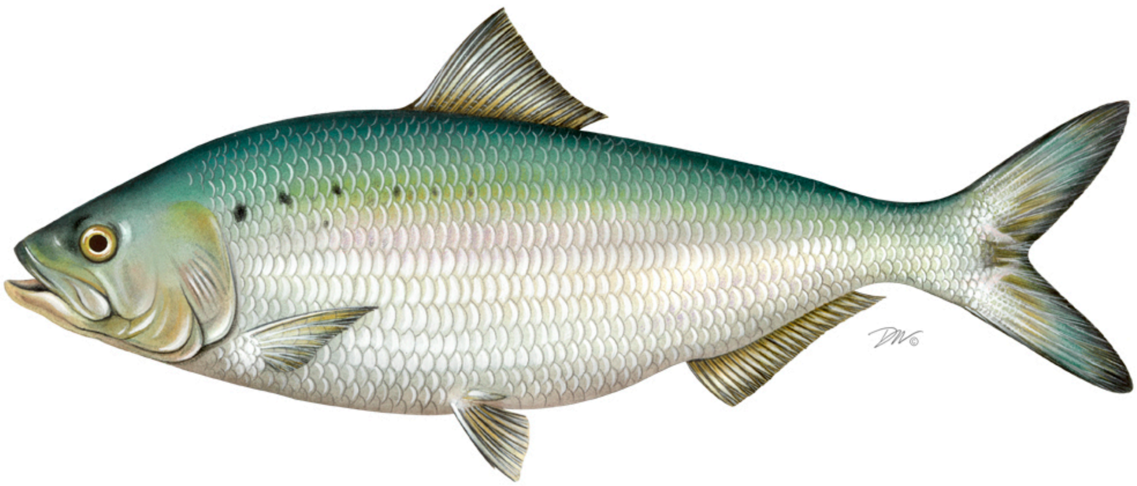
Recovery Plan for Hudson River American Shad

March 2022



Wes Eakin, Gregg Kenney, ElizaBeth Streifeneder

New York State Department of Environmental Conservation
Division of Marine Resources

FOREWORD

"When the situation was manageable it was neglected, and now that it is thoroughly out of hand we apply too late the remedies which then might have effected a cure. There is nothing new in the story. It is as old as the sibylline books… Want of foresight, unwillingness to act when action would be simple and effective, lack of clear thinking, confusion of counsel until the emergency comes, until self-preservation strikes its jarring gong–these are the features which constitute the endless repetition of history."
Winston Churchill, 1935

Acknowledgements

We wish to thank the following individuals for providing their expertise to the development of this plan: Kathy Hattala, Robert Adams, Brian DeGasperis, Sarah Fernald, Rich Pendleton, Dan Stich, Libby Zemaitis, Kim McKown, John Maniscalco, Carol Hoffman, Chris VanMaaren, and Kelsey Gustafson.

EXECUTIVE SUMMARY

This document provides a brief history of the Hudson River stock of American shad *(Alosa sapidissima)* and describes the long-term goals for its recovery, established by the New York State Department of Environmental Conservation (NYSDEC). Per Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring (2010), commercial and recreational shad harvest is prohibited in state waters unless states have an approved sustainable Fishery Management Plan. American shad fisheries have been closed in the Hudson River since 2010 following several years of recruitment failure resulting in unsustainable conditions. However, as this plan outlines, the long-term recovery objective is to return the stock to 1940s levels and enable the reopening of commercial and recreational fisheries in the future.

Anecdotal accounts of the once-robust Hudson River shad fisheries suggest that by the mid- to late-1800s, intense harvesting pressure led the stock nearly to collapse, initiating legislative action by New York State in 1861. Over the next 150 years, the Hudson River shad stock recovered and then went through a steep decline three more times. Each time, the peak of recovery was lower than the last recovery.

Early management guided fishing methods but maintained a relatively passive approach to limiting fishing effort. Managers instead focused on restoration through stocking with hatchery-reared shad, which diminished in practice by the early to mid-1900s until a resurgence in the past two decades. For the Hudson River stock, the adverse effects of stocking may outweigh potential benefits, so it is not considered a viable recovery strategy: efforts should focus instead on reducing mortality and enhancing natural reproduction. Causes of mortality unrelated to fishing have also exacerbated the Hudson River shad stock decline. These include reduced juvenile shad recruitment from piscivorous invasive species; impingement and entrainment of fish by water cooling intakes of industrial energy-generating facilities; habitat destruction and decreased resiliency from climate change-induced extreme weather events; and blocked access for shad spawning migrations by dams.

NYSDEC conducts annual monitoring of American shad and associated habitat data to gather information about the stock and inform fishery management decisions. Haul seine surveys have been conducted to sample the shad spawning stock since 1984, while beach seine surveys have been used for young of year (YOY) sampling since 1980. These data show the stock status is near its all-time historic low, characterized by declining spawning stock biomass and poor recruitment, as determined by a low juvenile abundance index (JAI).

Fishery-independent data are inadequate for modeling ideal conditions of a fully restored stock, so commercial landings have been used has a proxy for historical stock status. Over the past 135 years, oscillations in landings with an overall decreasing trend in peak landings suggest that the stock has lost resiliency to overfishing events. As such, it may take years or decades for the stock to recover to 1940s stock conditions. As a first step toward the goal, the short-term objective is to reach conditions observed in the 1980s, which will be determined using three benchmarks: total annual mortality of adult females (A), spawning stock biomass (SSB), and the juvenile abundance index (JAI).

For each benchmark, we developed Recovery Targets that mirror 1980s conditions, and Limit Reference Points to set levels under which the stock levels should not drop. The targets and limits for each benchmark were calculated from data during selected years when the stock exhibited positive trends that illustrate stability and resilience.

Although all fisheries for American shad in the Hudson River are currently closed, we suggest reopening the recreational catch and release fishery after some documented progress, as this would increase public awareness for a historically significant species, cause minimal mortality, and allow the stock to continue recovering. Reopening may occur upon maintaining a Catch and Release Threshold for three consecutive years and either the five-year running average SSB benchmark or JAI benchmark exceed the Limit Reference Points.

Significant actions have been taken to improve the Hudson River shad stock since we closed the New York fisheries for shad, including reduced mortality at industrial water intakes and ocean bycatch catch caps. However, conservative management and considerable patience are needed to return the Hudson River shad stock to levels with enough resilience for commercial and recreational harvest. Reaching that status will take years or decades, and additional time may be required at steps throughout the reopening process. While working toward the long-term objective, we will continue to gather data, identify challenges, and take management actions that are in line with our recovery priorities and supported by sufficient data.

1 INTRODUCTION

Over the past 135 years, the Hudson River American shad (*Alosa sapidissima*) stock experienced a series of overfishing events that caused a once thriving anadromous run to collapse by the turn of the twenty-first century. The repeated overfishing events, coupled with habitat loss and degradation, created unacceptable conditions for the future of the Hudson River American shad stock. In March 2010, New York State closed all fisheries for American shad in the Hudson River, and marine waters of the state.

Given the long history of overfishing, recovery of this signature Hudson River species may require many years. We suspect that nearly all of the stock's resilience has diminished. We recommend a cautious and conservative approach to managing the fishery if the stock is to recover at all.

Life History

American shad of the Hudson River Estuary are anadromous, spending most of their lives in the near-shore Atlantic Ocean from Virginia to Maine before returning to the river and its tributaries each spring to spawn. The Hudson River Estuary extends 245 km from New York City to the Federal Dam at Troy (Appendix 1, Figure 1). American shad spawn in freshwater from Kingston (km 145) to Troy (km 244). Juveniles use the upper 150 km (Newburgh to Troy) of the estuary as a nursery area and emigrate to the ocean from mid-summer to late fall/early winter. Once they mature between age-3 and age-7, American shad return to the Hudson to spawn for the first time. Shad in the Hudson River stock exhibit iteroparity and return annually to spawn for the remainder of their life. A more detailed description of American shad life history can be found in the most recent Stock Assessment (ASMFC 2020).

2 CAUSES OF DECLINE

Overfishing

During the nineteenth century, New York State was solely responsible for regulating the shad fishery within its waters. An anecdotal article in Harper's Weekly (1872) suggested a serious decline of the Hudson River American shad occurred in the 1860s. Following this "collapse" (although no official records document this event), in 1868 the New York State legislature implemented fishing net restrictions, an escapement period, and open/closed seasons to control fishing on the Hudson. These restrictions generally defined fishing practices of the time, setting the season to coincide with the period that shad were in the river. According to United States Fish Commission Reports (USCFF 1898), the prevailing intent of the states, including NY, was not to interfere in any business, including fishing. It is clear, that although restrictions were implemented, fishing effort and practices largely continued unabated. Some variation of these nineteenth century rules existed until the fishery closed in 2010.

Following the perceived mid-1800s collapse, the United States Fish Commission and the New York Board of Fish Commissioners began stocking the Hudson River with American shad fry and fingerlings (Cheney 1900). So began New York's legacy, along with many other east coast states, of shad hatchery production and an attempt to restore stocks perceived to be exhausted. This "exhausted" condition is questionable. From 1880 through 1901, the Hudson stock produced the largest harvest in its recorded history. This suggests the spawning stock was large enough to quickly recover to produce two successive, historically high peaks in harvest within 30 years. The supposed need for hatchery supplementation was due to management trends at the time. Most other east coast shad stocks, primarily the Susquehanna and other Chesapeake stocks, were being severely depleted (Talbot 1954). Leaders of the US Fish Commission relied heavily on hatchery production rather than fishing curtailment as a solution. Shad stocking continued in New York for nearly 50 years (Talbot 1954), decreasing steadily, as the focus of fish culture shifted to other species of more interest for recreational fisheries. After 1920, mention of shad hatchery production no longer appeared in New York State Commission reports.

Studies conducted by the United States Bureau of Fisheries (USCFF 1939) indicated that:

> "although pollution and obstruction of rivers have doubtless contributed to the failure of reproduction…of many Atlantic coast shad streams, the decline in yield has not been limited to polluted or obstructed streams…some unpolluted rivers (Edisto) have been severely depleted, yet a fine recovery has been observed in the polluted Hudson. This recovery is attributed to regulations limiting fishing to four nights a week and closing spawning areas to fishing."

This recovery did not last very long. During the years leading up to, during, and after World War II, regulations were greatly relaxed, or abolished altogether. After almost ten years of continuous, unabated fishing at near record levels, the Hudson River stock experienced a collapse in the early 1950s from which it never recovered (Walters 1995). The high fishing rate continued to remove fish faster than the stock could replace itself.

In 1942, the Atlantic States Marine Fisheries Commission (ASMFC) was created with the objective to help ensure the continued harvest of US fishery resources to supply troops during WWII: its motto "food will win the war" (ASMFC 1945). Regulatory management of the Atlantic coast shad stocks through ASMFC would wait another 42 years with adoption of an Interstate Fishery Management Plan (ISFMP) for Shad and River Herring in 1985. Although the ISFMP contained many strong recommendations, following the plan was voluntary. This changed in 1993 with the passage of the Atlantic Coastal Fisheries Cooperative Management Act, which mandated compliance by federal law. In 1998, Amendment 1 to the ISFMP included the first interstate regulation to close the mixed-stock ocean fisheries for shad by 2005. In 2010, Amendment 3 to the ISFMP prohibited commercial and recreational harvest of shad in state waters, unless a state has an approved Sustainable Fishery Management Plan (SFMP). In the same year, New York State closed all recreational and commercial fishing in the Hudson River. In 2014, river herring and American shad catch caps were implemented in both the Atlantic Mackerel and Herring fisheries to reduce river herring and shad bycatch (MAFMC 2014).

Harvest Continues (In spite of depleted status)

While the requirements of Amendments 1 and 3 to the ISFMP have limited the ability to harvest of American shad, commercial harvest continues along the Atlantic Coast as part of SFMPs approved for six different Atlantic Coast States. Incidental catch, or bycatch, of shad also occurs as part of several other fisheries that take place in federal waters as well as in Canadian waters. Shad from the Hudson River stock are harvested in several of these fisheries, although the magnitude of the harvest of Hudson shad is unknown.

Incidental harvest from federal waters is landed in several Atlantic States, according to the Atlantic Coastal Cooperative Statistics Program (ACCSP). State specific information is not available for this report and is reported inconsistently in the 2020 ASMFC Stock Assessment. The Northeastern Fisheries Observer Program (NEFOP) has provided incidental catch estimates for various ocean gears since 1989. Total estimates of U.S. based American shad incidental catch in federal waters were developed as part of Amendment 14 to the Atlantic

Mackerel, Squid and Butterfish Fishery Management Plan (MAFMC 2014), which provides detailed methodology and results. From 1989-2017, the total annual incidental catch of American shad ranged from 92,594 to 577,611 lbs., averaging 141,095 lbs. since the closure of the Hudson River shad fisheries (2010). Harvest occurred at significant rates by both the Mid-Atlantic and New England fleets (the only fleets surveyed). More than 10% of the total incidental catch was caught by the following gears: small mesh bottom trawls, New England mid-water trawls, and large mesh gill nets. The gill nets captured adult fish, while both trawls captured adult and juvenile American shad. The proportion of this mixed-stock harvest that is Hudson River stock is currently unknown and may be limiting recovery of the Hudson River stock.

In addition to ocean incidental harvest, directed commercial gill net fisheries of mixed stock American shad are permitted by the states of Delaware and New Jersey in Delaware Bay through an ASMFC approved Sustainable Fishery Management Plan (DE River Basin SFMP 2016). From 1985 to 2019, the peak annual mixed stock landings from these fisheries was approximately 125,000 lbs. Since 2007, annual landings of mixed stock shad have averaged less than 10,000 lbs. The Hudson River component of the mixed stock harvest likely varies annually and spatially within the Delaware Bay. However, in sampling of the commercial fishery in 2009 and 2010, the Hudson River component was estimated to be 33-53% (Waldman et al. 2014).

It is not known if shad are taken by recreational fishing while in ocean waters, or if they are taken in combination with, or mistaken for, hickory shad.

Habitat Alteration

The historical upstream limit for anadromous fish in the Hudson River was the natural falls at Fort Edward, NY (Zeisel 1988). Natural falls at the confluence of the Mohawk River and the Hudson prevented fish from moving into the Mohawk System. With the rise in commercial shipping at the beginning of the 19th century, there was a desire to connect the ocean-going ships to Midwestern states. The Erie Canal was completed in 1825, linking the Hudson River near Waterford, NY (roughly 5 km north of Troy, NY) to the Great Lakes through a series of locks mostly within the Mohawk River system. Today the Erie Canal consists of 34 locks from Waterford to the Niagara River. In addition, six hydropower facilities are now in operation along the Mohawk corridor.

During the same time period as the Erie Canal construction, there was a push to move timber and other commodities from Canada and northeastern states to New York and then on to Midwestern states. The Champlain Canal was finished in 1823 linking the upper Hudson River to Lake Champlain. The current Champlain Canal consists of 11 locks operated from Waterford, NY to Whitehall in Lake Champlain.

At the downstream end of the Erie and Champlain navigation corridors, a 3-meter high dam was constructed in 1826 at Troy, NY, roughly 56 kilometers downstream of the traditional head of tide at Fort Edward. This dam was made of log cribwork and filled with stone; likely impassable for shad at all but the highest spring floods (Stevenson 1899). In 1915, the US Army Corps of Engineers replaced the old dam with a new concrete structure, which included a lock. In 1921, a hydropower unit was fitted to the dam. Undoubtedly, American shad spawning and nursery habitat was lost after the construction of the Federal Dam at Troy. In the latter half of the 20th century, dams have been removed and fish passage systems have been constructed as a way to enable access to spawning areas for migratory species. However, any passage or improved passage of fish above this dam would provide just under nine additional kilometers, or 3.5% of habitat before the next lock and dam system (C1) on the upper Hudson River north of

Waterford, NY. Movement above the Federal Dam would expose adults and young of year (YOY) shad to mortalities associated with both upstream and downstream passage at the hydropower facility, a cost that may outweigh the benefits of a minimal increase in habitat. Furthermore, the huge commercial landings reported in the late 1800s as well as the 1930s and 1940s indicate that spawning and nursery habitats in the 245 river kilometers below the Federal Dam are enough to support a large population of American shad.

Several models showing the impacts of dams on the availability of spawning habitat and spawner potential were included in the most recent coastwide stock assessment (ASMFC 2020; Stich et al. 2019; Stich et al. 2020). The installation of dams coastwide, particularly in the northern range, resulted in significant habitat loss, blocking nearly 40% of total habitat once used by American shad. Removing dams, although sometimes impractical, could restore much of the lost habitat and spawner potential. Fish passage alone will not restore the lost habitat. It is estimated that even with extensive fish passage efforts, dams represent a fixed constraint of about 37% of the fishery potential of American shad (ASMFC 2020).

Fortunately, dams have a relatively small impact on American shad in the Hudson River. While shad are prevented from reaching nearly 40% of their historic habitat coastwide, the Hudson stock has lost access to just 9% of historic habitat (ASMFC 2020). Although the removal of several key dams would undoubtedly benefit shad in the Hudson River (notably, the Federal Dam on the main stem Hudson in Troy, NY and the first barrier on the Rondout Creek in Eddyville, NY), the lack of access to historic habitat did not cause the stock collapse. Furthermore, Stich et al. 2022 (*manuscript in prep*) suggests that most passage scenarios, with the exception of 95-100% upstream and downstream adult and juvenile survival, would result in populations lower than scenarios where no passage was allowed, indicating that the amount of available habitat is likely not limiting recovery. While we do not feel access to historical habitat is limiting recovery, we believe that improvements to habitat quality such as water quality, restoration of back channels and tidal wetlands, and submerged aquatic vegetation will result in improved recruitment of juvenile shad, a crucial component needed for stock recovery.

In addition to the habitat changes presented by the creation of locks and dams in the uppermost portion of the estuary, shad habitat was also affected by the increased use of shipping traffic and development of infrastructure along the banks of the tidal river. Through the middle of the nineteenth century, the northern third of the estuary below the Federal Dam at Troy, NY was a braided river-channel system dominated by vegetated shallows and intertidal wetlands. Side channels in this section provided important shallow water and intertidal habitats that were isolated from the higher energy regime of the main channel. Unfortunately, these habitats were largely altered by the early twentieth century due to the dredge and fill activities associated with construction and maintenance of the federal navigation channel that allowed ocean vessels to reach Albany. Miller et al. (2006) approximates 57% of the braided, intertidal shallow water habitat (1,821 hectares) found north of the City of Hudson (km 190) was destroyed during this time period. Another factor that is not well researched or understood is the potential barriers posed by the railroads along both the east and west sides of the Hudson River. Tributaries once flowed freely, with unobstructed hydraulics, from the upland valley to the wide estuary. While these connections still exist, they are much different today than they were historically. Tributaries are forced through bridge and culvert constrictions under the tracks as they make their way to the Hudson River. The impact of this funneling effect on water quality and access from the Hudson into tidal tributary mouths is not well understood.

In summary, while much of the spawning and nursery grounds in the Hudson River remains accessible to American shad, unlike other Atlantic Coast systems, significant changes to the habitat quality and river morphology may reduce the success and productivity of this shad stock.

Other Causes and Potential Future Threats

Invasive Species

Five piscivores are native to the freshwater, tidal Hudson River (Daniels et al. 2011). Beginning in 1830 through present day, at least 10 additional piscivores have been introduced to the Hudson, including voracious predators such as black bass (introduced in 1830s), Northern pike (1840s), walleye (1890s), and channel catfish (1976) (Daniels et al. 2005). The addition of these piscivores has likely impacted the recruitment of alosines including American shad; however, the magnitude and rate of predation by these species on juvenile and adult alosines in the Hudson River has yet to be fully explored.

Water chestnut, an ornamental macrophyte native to Eurasia, was introduced to the Hudson River Estuary in the 1930s (Strayer 2006). This plant outcompetes native macrophytes such as water celery, forming expansive, dense mats in most of the shallow water embayments in the tidal freshwater portions of the river. Sedimentation and turbidity within these mats are much higher and the dissolved oxygen levels within the mats is much lower than surrounding waters (Strayer 2006), favoring species with wide tolerances for unfavorable environmental conditions (Schmidt and Kiviat 1988). The establishment of these immense water chestnut mats each summer significantly reduces the amount of near-shore nursery habitat available to YOY alosines, cutting off areas that would likely have remained more productive with native macrophyte beds.

The introduction of zebra mussels in the Hudson in 1991, and their subsequent explosive growth in the river, quickly caused pervasive changes in the phytoplankton (80% drop) and micro- and macro-zooplankton (76% and 50% drop respectively) communities (Caraco et al. 1997). Water clarity improved dramatically (up by 45%) and shallow water zoobenthos increased by 10%. Given these massive changes, Strayer et al. (2004) explored potential effects of zebra mussel impact on YOY fish species. Most telling was a decrease in observed growth rates and abundance of YOY fishes, including open-water species such as alewife and blueback herring. A decade later, Strayer et al. (2014) reported on the improvement in zooplankton and macrobenthos inhabiting deep water, indicating that abundance of juvenile alewives increased during the late zebra mussel invasion period while post-yolk sac larval abundance did not. The abundance of post-yolk sac and juvenile American shad and post-yolk sac river herring declined during the early to later zebra mussel invasion period. It is not yet clear how this constraint affects survival and subsequent recruitment.

The Hudson River is particularly susceptible to threats from aquatic invasive species because of its connection to the Erie and Champlain Canals. These canals were built in the early 1800s and breached the natural watershed divide of the Hudson River Estuary and allowed for easy movement of aquatic invasive species from the Great Lakes, Lake Champlain, and any connected tributary. The canal system is the likely source of many non-native fish, bivalves, and snails in the Hudson River, including the zebra mussel, described above (Strayer 2016). There are many other invasive species that have recently or are poised to enter the Hudson River including Round Goby, Silver Carp, Bighead Carp and a wide variety of invertebrates (Strayer 2016). The major disruption to the ecology of the Hudson River from these species, as seen first-hand with the invasion of the zebra mussel, will continue to threaten the recovery of American shad as long as the invasive aquatic species can easily navigate through the Erie and Champlain Canals.

Water Withdrawals

American shad, and other fish, are negatively impacted by water withdrawals on the Hudson River. Shad are killed both by impingement on intake screens and by entrainment through the cooling water systems of electric plants. Steam electric plants alone are permitted to use nearly 5 billion gallons of Hudson River water per day. A river-wide ichthyoplankton survey occurred annually in the Hudson River Estuary through 2016, conducted by consultants under contract with the Hudson River Generating companies. To better define impacts of the once-through cooling systems on fish, estimates of mortality on various ichthyoplankton life stages were calculated using two models, the Empirical Transport Model and the CEMR (Conditional Entrainment Mortality Rate) model. Detailed methodology for both models can be found in CHG&E et al. (1999). Estimates of mortality are expressed as conditional entrainment mortality rates, or the percent reduction in a year-class that would be due to mortality from entrainment through once-through cooling water systems if no other causes of mortality operated. Loss estimates for the Hudson River Estuary include one major office complex air conditioning unit, two nuclear plants, one waste-fuel plant, and five fossil-fuel power plants located throughout the Hudson Valley north of New York City. CEMR at these facilities combined has ranged from 16% to as high as 52% during the period 1974 to 1997 (CHG&E et al. 1999). An estimated average of 20% CEMR was assumed for the period 1952 to 1973 when major power plant once-through cooling systems came online (CHG&E et al. 1999).

In years since the 1999 study, impacts of water withdrawals on year-classes of American shad have probably been reduced due to changes at a variety of locations. As part of the Clean Water Act, in New York State, all existing industrial facilities using water from the Hudson River must install and operate technologies on their cooling water intakes that will minimize impingement and entrainment. Of the 17 industrial facilities known to use Hudson River water for cooling, ten are operating technologies to minimize fish mortality; five are currently reviewing options; and two have been designed and are to be installed within the next five years. Several plants (i.e., Bowline, Danskammer, and Roseton) operated at less than 30% of capacity for most of the period from 2010-2016. Athens Generator uses a dry cooling system requiring no water from the Hudson River. Water withdrawal at Lafarge Cement Plant in Bethlehem is in the area of the river most vulnerable for developing shad larvae. Water withdrawal at this site is 25% of what it was in the late 1990s and impingement and entrainment have been effectively eliminated using wedgewire intake screens. The Albany Steam Electric Plant (now called Bethlehem Energy) was repowered and uses a hybrid closed cycle cooling system with a water intake fitted with wedgewire screens. This has nearly eliminated the impingement and entrainment of fish at this location. Indian Point Energy Center (IPEC) closed in April of 2021, which was previously permitted to use more than 2 billion gallons of water per day. Scheduled improvements will also have positive impacts for American shad. The Empire Plaza operates a once-through cooling system at Albany, withdrawing approximately 90 million gallons per day for air conditioning purposes. A recently issued SPDES permit requires the intake to be fitted with a wedgewire screen system, which will eliminate impingement and nearly eliminate entrainment at this site.

Climate Change

Climate change is affecting the Hudson River Estuary on a local level. Sea level is rising, water and air temperatures are increasing, and extreme precipitation is occurring more frequently, punctuated by interim periods of drought (IPCC, 2014). These changes influence fish and wildlife distribution, migration patterns, and spawning phenologies. (Horton et al. 2014, Nack et al. 2019, Pirani and Boicourt 2018, Reidmiller et al. 2018, Rosenzweig et al. 2011). The onset of spawning for American shad was earlier in 2012 relative to 1976, and by the 2090s, the shad spawning season is predicted to begin 15 days earlier and be shortened by 4 days (Nack et al. 2019). It is unknown how these changes will affect the existing American shad ecology, including the availability of plankton to developing shad, changes to predator-prey interactions, and the iteroparity of the stock.

Sea-level rise and flooding are likely to affect the estuary's tidal marshes and shallows. It remains to be seen whether marshes can fully recover after disturbance from extreme weather events. In 2011, Hurricane Irene and Tropical Storm Lee carried huge volumes of sediment in the estuary, where it hindered the growth of submerged aquatic vegetation (SAV) (Hamberg et al. 2017). These storms, in 2011, reduced submerged aquatic vegetation abundance in the Hudson River by more than 90% and made no appreciable recovery in 2012 or 2013 (Hamberg et al. 2017). Submerged aquatic vegetation coverage has since increased by 126% in 2016 (from a 2014 baseline), but remains 19% less than pre-storm coverage (Carroll 2019). Submerged aquatic vegetation is an important habitat for the development of young shad (Ross et al. 1997). If the frequency of SAV damaging storms increases in future years, there will likely be negative impacts on the recruitment of American shad. In addition, Hurricane Irene and Tropical Storm Lee had acute but shorter-term direct impacts on fish. For example, a sonic tagged, and otherwise resident, cohort of striped bass exhibited a novel migration pattern after the storms and left the estuary for the ocean (Bailey and Secor 2016).

In addition to the ecological shifts expected from climate change, the human responses to climate change impacts also threaten to negatively impact American shad. With sea level rise and more frequent storm events, humans will likely take aggressive steps (or may begin to take drastic measures) in the future to prevent flooding and protect infrastructure. The suite of potential options that may be considered include shoreline structures, beach nourishment, levees, floodwalls, seawalls and storm-surge barriers. A recent study by the Army Corps of Engineers (USACE 2019) sought to evaluate the impacts of a wide range of climate change mitigations, including a sea wall and storm-surge barrier system that stretched across the entire mouth of the Hudson River from Far Rockaway, NY to Long Branch, NJ. The impacts of such a major in-water infrastructure project on habitats used by American shad would be a significant threat to their recovery. Strong consideration must be given to the impacts of this and other in-water infrastructure projects to minimize or eliminate negative effects on anadromous fishes.

Fish Passage Structures and Stocking Efforts

While fish passage structures are typically listed in recovery plans as a means to improve shad stocks, we believe it is more appropriate to list fish passage as a threat to shad recovery in the Hudson River. The owner of the Green Island Hydropower facility at the Federal Dam in Troy, NY has been required to install fish passage as part of the FERC re-licensing process. It is not yet known what the upstream and downstream mortality rates will be resulting from the operation of this passage structure. As stated in the Habitat Alterations section, analysis of the benefits of fish passage in the 2020 Shad Stock Assessment demonstrate only a 3% increase in spawner potential using "optimistic upstream and downstream passage rates." (ASMFC 2020). However, most fish passage installations do not operate at "optimistic" passage rates (Haro and Castros-Santos, 2010). Downstream mortality of adult and juvenile shad passing through turbines at the Federal Dam threaten to make this project an additional source of mortality on the Hudson River shad stock. These circumstances underscore the crucial need for constant evaluation of upstream and downstream passage efficacy to ensure that fish passage structures scheduled to be in operation within the next few years do not negatively impact shad recovery.

Stocking of hatchery-reared fish is a method used by fisheries managers to restore depleted American shad spawning runs in the United States. However, despite the millions of American shad stocked in various rivers along the Atlantic coast of the United States, spawning populations continue to decline in abundance, prompting some researchers to question the value of American shad culture (Hendricks 2003). In fact, over a half century ago, Mansueti and Kolb (1953) opined that "no competent fishery biologist has advocated the stocking of [American] shad fry as a successful [rehabilitation] measure." (Hasselman and Limburg 2012). While stocking has been a method advocated for restoration dating back to the 1800s, it has also been suggested during the same length of time that the most promising restoration measures are proper conservation and improvement of spawning habitat (Moss 1950).

A massive stocking effort in the Hudson River occurred following a collapse in the mid-1800s. Stocking of American shad began in 1869 with peak hatchery production occurring between 1899-1901 averaging just under 15 million fry released per year. Despite the large numbers of fry produced, Talbot (1954) reported "It can be stated definitively that the peak hatchery production in 1899, 1900, and 1901 did not maintain the [Shad] runs". By the mid-1940s, support for shad stocking waned and the Hudson River shad hatchery, along with many others along the Atlantic coast, ceased operations (Talbot 1954).

A resurgence of stocking as a means of restoration has occurred over the last couple of decades, leading fisheries managers to once again evaluate its effectiveness. Hasselman and Limburg (2012) state that stocking activities may be inadvertently (and ironically) hindering restoration success. Specifically, stocking practices may only yield short-term gains in abundance at the ultimate expense of population fitness and may jeopardize the genetic integrity of distinct stocks (Lynch and O'Hely 2001). In other words, stocking can alter the genetic diversity of shad, which makes them less resilient to threats such as changing environmental conditions due to climate change.

Stocking also requires the inefficient strip spawning of females (Talbot 1954) resulting in death following the collection of a single batch of eggs. American shad exhibit batch spawning (Olney and McBride 2003; Hyle et al. 2014; McBride et al. 2016) meaning that they spawn multiple batches of eggs during one spawning season. McBride et al. (2016) reported female shad in the Connecticut River averaged 6.7 batches with an average of 45,950 eggs per batch resulting in an estimated 311,500 eggs per spawning season. In addition, American shad in their northern range (North of Cape Fear, NC) are iteroparous, returning to spawn in their natal rivers over multiple years, and have been documented in the Hudson River to return as many as eight times over in a lifetime. Sacrificing shad for hatchery production results in a net loss of reproductive potential; from approximately 20,000-50,000 eggs for hatchery production versus 300,000-2,400,000 eggs from natural reproduction. Thus, greater recovery potential would exist if American shad were allowed to reproduce naturally over the duration of the spawning run and throughout their lifetime (Hasselman and Limburg 2012).

Based on the information above, we do not support the use of a stocking program to restore the Hudson River shad stock. Instead, we agree with recommendations of Moss (1950) and Hasselman and Limburg (2012) that restoration efforts should focus on habitat restoration while mitigating other factors hindering recovery such as ocean bycatch mortality and harvest of Hudson River shad in other directed mixed stock fisheries.

3 ANNUAL MONITORING

When Talbot (1954) documented the major decline that occurred in the years following World War II, little biological data on stock condition existed, with the exception of commercial fishery landings. Talbot and the biologists at the Federal Biological Lab (now NMFS lab at Beaufort, NC) Shad Program wrote many papers on developed methods of sampling and aging fish (Wolfe 2000). These studies initiated the collection of biological data on shad stocks coastwide.

In 1979, the New York State Department of Environmental Conservation (NYSDEC) formed the Hudson River Fisheries Unit to investigate the stock characteristics and status of important anadromous striped bass and American shad stocks that use the Hudson as their spawning area. Management of these species, and other diadromous fish such as river herring, are shared resources along the coast and are managed jointly by coastal states through the ASMFC. Annual data are collected, summarized (Appendix 1, Table 1) and used to continually update species' status. Without these annual data, changes in the stocks would be difficult to detect and may impede science-based decisions in the management forum.

Data Collection and Analysis

Spawning Stock Sampling

Since 1984, spawning populations of American shad have been sampled by haul seines, which exhibit relatively low size selectivity in sampling fish when compared to other gear types (Kahnle et al. 1988). The fish sampled in this program best represent the spawning stock, or production portion of the population which has escaped coastal directed, coastal intercept, and in-river commercial fisheries (ASMFC 2007). From 1984-1988, a 305-meter haul seine was the primary gear. Beginning in 1988, a 152-meter haul seine was used and has continued to be the main gear used in this survey. Sampling is concentrated near known spawning areas and at beaches where adults are susceptible to capture by shore gear. Approximately 75 to 100 haul seine collections are made annually. Collections occur from April through the first week of June at sites located between km 88 and 224. Captured fish are transferred to a floating live car after which they are identified to species, sexed, measured and weighed; and scale samples taken. Water quality data such as temperature, salinity, pH, dissolved oxygen, conductivity and total dissolved solids are taken at each station.

Catch rates from the haul seine survey have not been used in previous assessments to track spawning stock abundance since there was no other adult abundance measure to validate the estimates. There was also concern that the survey methods may not be appropriate for abundance estimation, since the primary objective of the survey to capture and tag striped bass for coastwide mortality studies. However, this survey remains the longest running survey to capture the spawning stock in the Hudson; the gear used is non-size selective; and the survey covers a large portion of the spawning reach. Catch rates from this survey were once again evaluated in the 2020 Stock Assessment for American Shad (ASMFC 2020) and were approved to be used when considering spawning stock abundance. An evaluation of the data, model outputs, and caveats are detailed in the Stock Assessment (see Section 3.5.6.1 of ASMFC 2020).

For this Recovery Plan the most appropriate spawning stock index is derived from this haul seine survey, as it represents our best understanding of the Hudson River spawning stock biomass (SSB) since 1984.

Young of Year (YOY) Sampling

Since 1980, the NYSDEC has sampled YOY American shad in the Hudson River Estuary with a 30.5-meter by 3.1-meter beach seine with 0.64 cm stretch mesh. Sites are sampled during the day at approximately 28 standard sites in the freshwater tidal reaches of the Hudson River. Captured fish are transferred to a bucket after which they are enumerated by species and life stage (YOY or older). Water quality data such as temperature, salinity, pH, dissolved oxygen, conductivity, and total dissolved solids are documented at each station. In addition, prevailing conditions such as wind speed, wave height, cloud cover and vegetative cover are recorded at each seine event. This survey provides a relative juvenile abundance index (JAI) for YOY American shad in the freshwater tidal section of the Hudson River. The nominal index is an annual geometric mean catch per haul that encompasses the entire time series and incorporates all hauls. For this Recovery Plan, the most appropriate juvenile abundance index is derived from this beach seine survey (see section 3) because it represents our best understanding of American Shad recruitment in the Hudson River since 1980.

4 CURRENT STOCK STATUS

Mortality and Abundance Status

Juvenile mortality status is unknown due to a lack of data to make this determination. Female adult mortality is below the benchmark threshold (see details below in Annual Female Adult Mortality Benchmark). Though adult mortality is below the benchmark threshold, it is important to note that maintaining female adult mortality below the benchmark threshold will not result in favorable abundance status if the previously mentioned unknown juvenile mortality is occurring at unsustainable levels (ASMFC 2020).

The current abundance status is depleted as described in recent ASMFC stock assessment (ASMFC 2020) due to the decline of in-river landings prior to the closure in 2010 (Appendix 1, Figure 2). This is further supported by the significant declining trends in the female spawning stock biomass and JAI during the same time period (Figure B and Figure C), followed by a continued lack of stock response to management actions in 2005 (Ocean closure) and 2010 (NY closure).

Mean Length, Mean Length at Age, and Mean Weight

Mean total length and mean length at age reflects age structure of the population and thus some combination of recruitment and level of total mortality. There is a significant declining trend in female mean length from 1988-2019 (tau = -0.29, p-value = 0.02) (Appendix 1, Figure 3). There is no trend in male mean length. Significant declining trends were also detected for mean length at age for age 4 females (tau = -0.49, p-value = 0.00), age 5 females (tau = -0.39, p-value = 0.02), age 7 females (tau = -0.44, p-value = 0.01), and age 8 females (tau = -0.44, p-value = 0.01) (Appendix 1, Figure 4). There is no trend in male mean length at age.

Mean weight of females reflects spawning stock biomass and thus some combination of fecundity and reproductive potential. There is a significant declining trend in female mean weight from 1988-2019 (tau = -0.29, p-value = 0.02) (Appendix 1, Figure 5). There is no trend in male mean weight.

Summary

Hattala and Kahnle (ASMFC 1998; ASMFC 2007) twice documented overfishing of the Hudson River shad stock. It should be noted that “current” stock data covers only the past 35 years since 1980. Data were collected before, during, and after stock collapse with the stock currently near its all-time historic (since 1880) low. The rise in mortality in the early 1990s coincided with a decrease in mean length, mean length at age, and female spawning stock biomass. The recent ASMFC stock assessment indicated female mortality rates have fallen below the reference point and stabilized since the mid-2000s, however; in the recent years (2017-2019) mortality has increased. Recruitment remains poor and well below the recruitment failure threshold.

5 STOCK RECOVERY GOALS

Independent data on the Hudson River stock of American shad are not adequate to model the conditions of a hypothetical, fully restored stock. The current detailed data series begins in 1974, after the stock had already experienced several large overfishing events. In the absence of fishery-independent data, we used commercial landings as a proxy for stock size and examined the historical landings pattern to choose a time period to best represent characteristics of a “restored” stock. Commercial harvest records began in the late 1800s, with the highest reported landings occurred in 1889 (Appendix 1, Figure 2). The successive series of peaks and lows, described above, indicated that the Hudson stock lost its resilience to recovery as the pattern of overfishing continued over the past 135 years. Each subsequent peak in landings is lower than the preceding one. This suggests that the stock was never fully able to recover during the interim periods. With this in mind, we suggest a conservative approach to address stock recovery; sufficient time needs to be given to the stock to achieve even the most modest goals. One example of the potential amount of time required for American shad stock recovery is in the Columbia River (OR/WA) where it took approximately 20 years to recover after a period of extensive over exploitation (Appendix 1, Figure 6). While each system has its own unique characteristics and challenges, the recovery in the Columbia River offers some insight on the expectations of the time requirement for recovery.

Long-term Objective

Our long-term recovery objective is to return American shad stock abundance to levels that occurred in the 1940s. We chose this time period as a long-term restoration objective because most habitat alteration ended prior to that time period and habitat conditions (filled areas) have remained somewhat stable since then. Quantitative targets for the long-term objective will be monitored once our short-term objective is reached. Metrics include (1) relative abundance of age zero American shad (JAI) and (2) SSB indices estimated for 1940-1950, calibrated using recent NYSDEC beach seine and SSB indices.

Short-term Objective

Ecosystem changes both in the Hudson River and the ocean may have made the long-term goal unrealistic in the short-term. Moreover, very little information is currently available on stock condition for use in setting long term restoration targets. Consequently, we set a short-term restoration goal based on stock conditions during the recent period of landings in the mid-1980s, for which there are more reliable data. Although this is the lowest peak of the time series, achieving even these conditions might be difficult because of ecosystem changes along with historically low stock size.

Our short-term objective is to restore the Hudson River American shad stock abundance to levels observed in the mid-1980s. We chose several measures, or benchmarks, to assess stock status as we move toward our objectives. These include:

- Rates of total annual mortality (A) of mature females. This is defined as that fraction of females present at the start of the calendar year that die during the year. The rate is estimated from data obtained by annual NYSDEC spawning stock sampling and methods described in Section 2.6 of the ASMFC American shad benchmark assessment (ASFMC 2020).

- Spawning stock biomass, or SSB. This is a relative annual index of total weight (biomass) of mature female shad and is a measure of spawning potential, i.e. high abundance of large female shad equals high spawning potential, resulting in increased stock resiliency. This is obtained by annual NYSDEC spawning stock sampling. SSB is calculated as:

$$SSB_y = \sum_a N_{a,y} * W_{a,y}$$

  where $N_{a,y}$ is the abundance in numbers at age (*a*) and year (*y*) and $W_{a,y}$ is the mean weight by age (*a*) and year (*y*) from biological data collected during fisheries independent sampling.

- Annual index of relative abundance of age zero fish, or juvenile abundance index (JAI). This index is a measure of annual recruitment or year class strength and is obtained through annual NYSDEC YOY sampling by beach seine in the freshwater portion of the Estuary.

No single index is adequate to evaluate progress towards our objective because each index responds at a different rate to different influences on the stock. For example, the JAI usually responds to changing early life survival while SSB responds most quickly to changing adult survival. A healthy sustainable fish stock needs good recruitment, adequate spawning stock size to assure future production, and reasonably low adult mortality rates. The use of all three indices addresses these needs and creates the most robust approach to setting recovery targets.

6 RECOVERY BENCHMARKS

For each of the benchmarks, we developed both Recovery Targets and Limit Reference Points. The Recovery Targets were developed with the goal of matching shad stock conditions from the 1980s. We also developed Limit Reference Points (Limits) for each index. These Limits represent an undesirable state of the fishery which management action should be taken to avoid (Caddy and Mahon 1995). In our current state of stock collapse, we have exceeded the Limits for two of the three benchmark indices. As the recovery of Hudson River American shad begins, however, we will return to the desirable side of the Limits. If improvement continues, we will approach or exceed our short-term recovery objectives. In turn, limited recreational and commercial harvest can begin as we work toward our long-term recovery objective. See section 7 for specifics on fishery re-opening thresholds.

Annual Adult Female Mortality Benchmark (A)

Recovery Target: An annual mortality rate (A) equal to 44%.
Limit Reference Point: An annual mortality rate (A) equal to 55%

We identified a Recovery Target for adult female mortality (A) that is consistent with the short-term objective identified above. Specifically, our Recovery Target, equal to 44%, is the mean mortality rate during the time period 1983-1994.

To establish a Limit Reference Point for annual mortality rate (A), our starting point was the ASMFC total instantaneous mortality (Z) benchmark calculated in the coastwide 2020 stock assessment. Z was determined using a Thompson-Bell yield per recruit model with inputs specific to the Hudson River stock. The rate was set to Z=0.92; equal to an annual mortality rate

(A) of 60%. However, the yield per recruit model used in the recent stock assessment (ASMFC 2020) was developed to assess the amount of additional mortality (beyond natural mortality) a stock can experience without reducing spawning stock biomass and was not intended to grow or recover stocks. Given the Hudson's depleted stock status and abundance being at or near historic lows, a more conservative annual mortality benchmark is necessary to achieve the objectives described above. Therefore, we identified a more conservative total mortality rate of Z=0.8; equal to an annual mortality rate of 55% is a more appropriate Limit Reference Point, which will constrain mortality below the annual rates observed from 1993 through 1999 when the stock began its most recent collapse and allow the stock to recover.

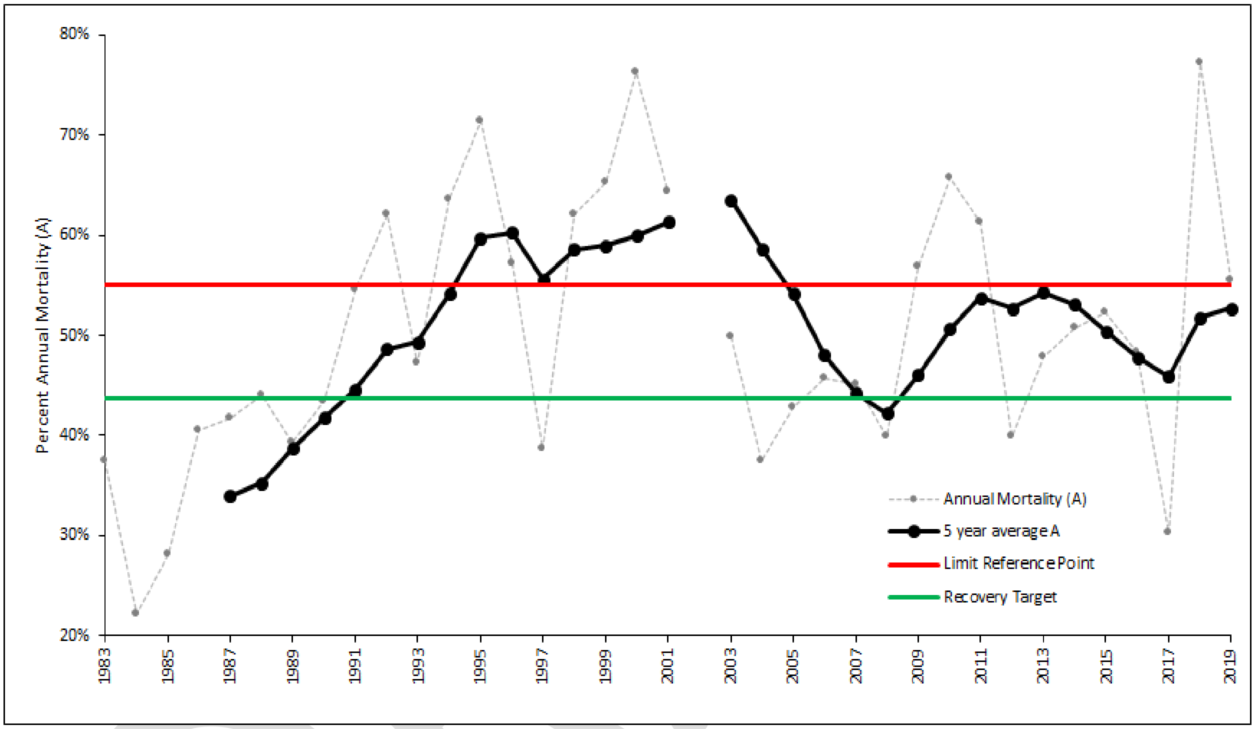


Figure A. Annual mortality of Hudson River adult American shad females. Includes Recovery Target and Limit Reference Point.

Annual Adult Female Spawning Stock Biomass Benchmark (SSB)

Recovery Target: A Spawning Stock Biomass index value equal to 57.39.
Limit Reference Point: A Spawning Stock Biomass index value equal to 30.61.

We identified a Recovery Target for annual adult female Spawning Stock Biomass (SSB) that is consistent with the short-term objective identified above. Specifically, our Recovery Target, equal to 57.39, is the mean SSB during the time period 1983-1994, which we aim to replicate for the Hudson River American shad stock.

When establishing a Limit Reference Point for SSB we sought to identify a level where the stock had historically been able to be resilient to stressors and avoid complete collapse. The SSB is currently near the lowest levels observed in the time series and must be allowed to recover to a level that can withstand all sources of mortality, natural and anthropogenic. Therefore, a Limit Reference Point for SSB must be at a level where the stock can be resilient to stressors. Of the current dataset, years 1983-2005 best reflect a time where stock levels went through growth and contraction without collapse. For the Limit Reference Point, we felt the median SSB (30.6 kg) was the best metric to reduce the influence of outlier years.

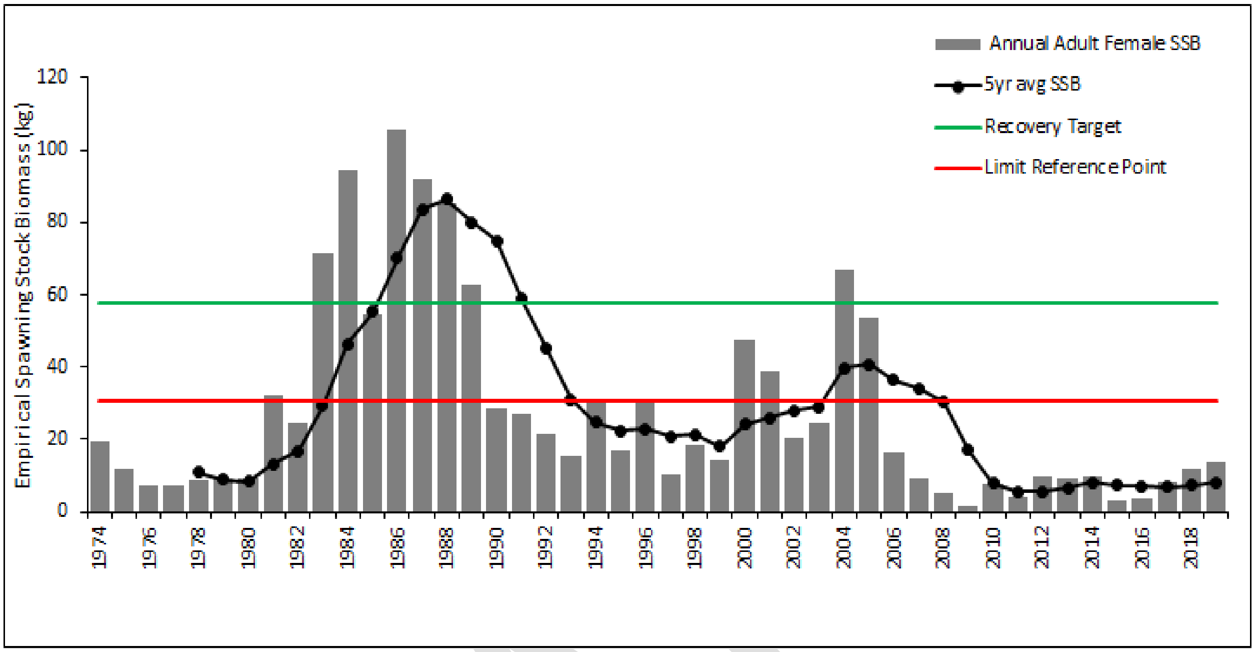


Figure B. Spawning stock biomass of Hudson River adult American Shad females. Includes Recovery Target and Limit Reference Point.

Juvenile Annual Index Benchmark (JAI)

Recovery Target: A Juvenile Annual Index equal to 28.28 fish/haul.
Limit Reference Point: A Juvenile Annual Index equal to 8.32 fish/haul.

We identified a Recovery Target for the Juvenile Annual Index (JAI) that is consistent with the short-term objective identified above. Specifically, our Recovery Target, equal to 28.28 fish/haul, is the mean JAI during the time period 1983-1994, which we aim to replicate for the Hudson River American shad stock.

When establishing a Limit Reference Point for the JAI we carefully considered the fact that the Hudson stock collapsed due to recruitment overfishing. In other words, removals of adults were too high for the stock to replace itself, driving production to very low levels. If the stock is not given sufficient time to grow, then events of the past could quickly relapse. Because this index has been used in several ASMFC stock assessments and Fishery Management Plans, we thought it appropriate to use a common recruitment failure metric of the 25th percentile of values in time period before the stock collapse, 1983-2005. These data are recent and span a long time period, where the stock levels went through growth and contraction without collapse. This is the same time period we used when generating the SSB Limit Reference Point.

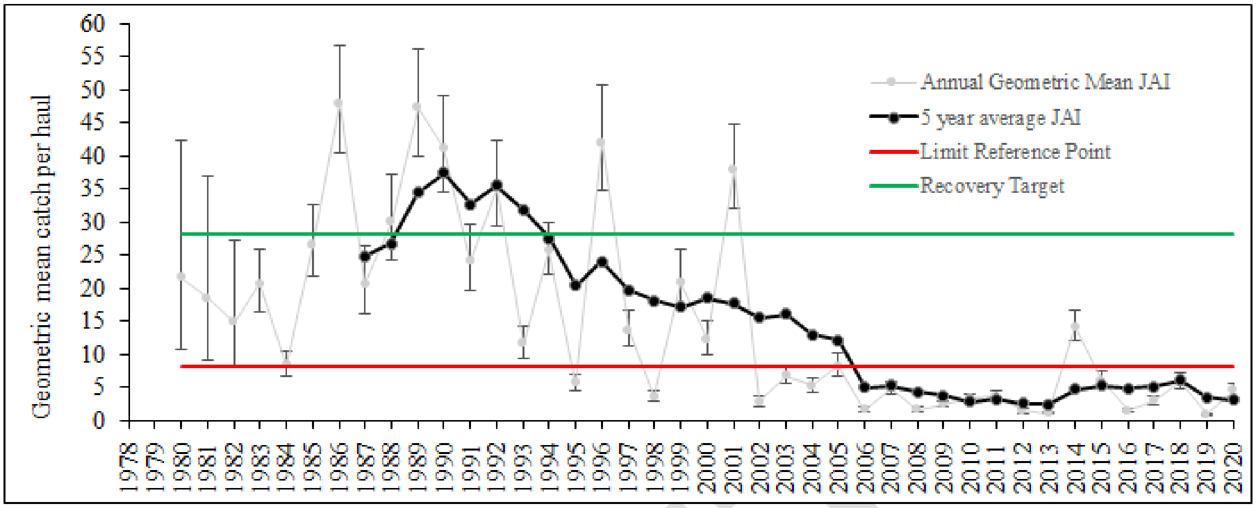


Figure C. Juvenile annual index for Hudson River young-of-year American Shad. Includes Recovery Target and Limit Reference Point.

7 HUDSON RIVER FISHERIES AND RE-OPENING THRESHOLDS

Shad Fisheries on the Hudson River

Commercial and recreational fisheries for American shad have a long history on the Hudson River. It is likely that Native Americans and early European settlers of the Hudson Valley fished for shad, using them for both food and fertilizer. Landings from early commercial fisheries documented significant harvest from stake gill nets in the late 1800s.

In more recent history, commercial fishing continued throughout the river. Generally, in the mid-1990s – 2000s, commercial fishing in the lower river occurred in the Tappan Zee and Haverstraw bays primarily using fixed gill nets averaging approximately eight active fishers per year. In this same period, commercial fishing by drift gill nets occurred between Newburgh Bay and Catskill averaging roughly 22 active fishers per year.

Recreational fishing for shad was also a popular past time in the 1990s – 2000s. Regular, comprehensive data are unavailable for this fishery but, anecdotally, recreational shad fishing with light tackle was popular from Coxsackie to Troy. A Hudson River creel survey conducted in 2001 (Normandeau 2003) estimated that nearly 20,000 American shad were caught that spring with roughly one third of those catches coming from shore-based anglers. Overall, the retention rate of American shad was about 7%.

In 2009, in response to the troubling results of the 2008 American Shad ASMFC stock assessment, the NYSDEC closed all fishing for American shad. All commercial and recreational fisheries, including catch and release by angling, were prohibited in the Hudson River and tributaries.

Recreational Catch and Release

Catch and release (C&R) recreational angling is the fishery that poses the least threat to the recovery of American shad. Obviously, there is no harvest of shad in a C&R fishery; however, C&R does contribute to the mortality of American Shad through latent discard mortality. Discard mortality for catch and release shad fishing is low, perhaps as low as 1.65% (Millard et al.

2003), regardless all fisheries including C&R were closed in 2009 in order to maximize the pace of recovery for American Shad.

We propose to re-open the catch and release fishery for Hudson River American shad when mortality levels are at a point where we expect the stock to be able to grow AND when either the SSB or the JAI benchmarks are above the Limit Reference Point. Specifically, the running five-year average annual mortality (A) must be less than 49.5% for three consecutive years. This Catch and Release Threshold was set as the mid-point between the Recovery Target and the Limit Reference Point and should allow the stock to continue to grow. IN ADDITION, either the running five-year average JAI value must exceed 8.33 fish/haul OR the running five-year average SSB value must exceed 30.61kg/haul. By meeting this combination of stock indicators, the population will be in a position to continue its rebound, despite any minor increase in mortality through a catch and release fishery.

Recreational Catch and Release Re-opening Criteria:

- **Five year average annual mortality (A) the Catch and Release Threshold (49.5%) for three consecutive years.**
- **Five year average female spawning stock biomass (SSB) > 30.61 OR Five year average juvenile annual index (JAI) > 8.325 fish/haul.**

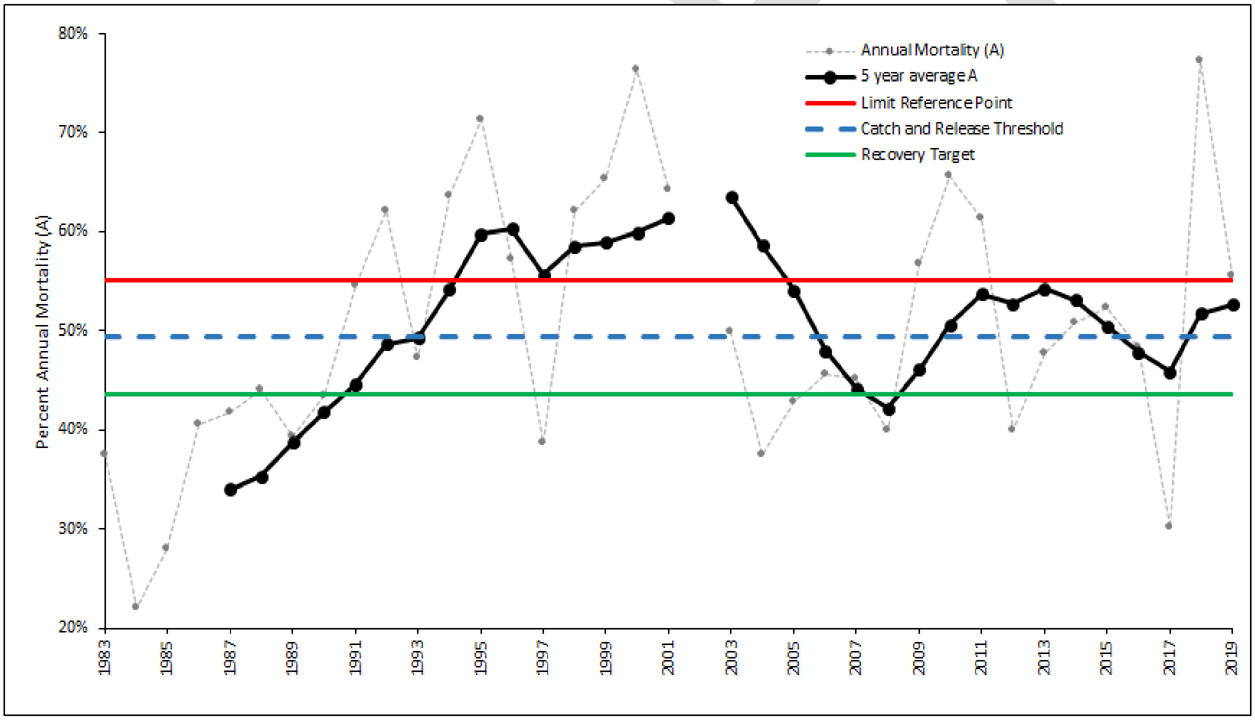


Figure D. Annual mortality of Hudson River adult American shad females. Includes Recovery Target, Limit Reference Point and Catch and Release re-opening Threshold. To re-open Catch and Release fishery, the running five-year average annual mortality rate must be below the Catch and Release Threshold for three consecutive years AND the five-year running average for the SSB OR JAI must exceed one of their respective Limit Reference Points.

Recreational and Commercial Harvest

Our goal is to recover the Hudson River shad stock to levels where it once again has the resilience to withstand directed commercial and recreational harvest in the Hudson. We recognize that with the current pace of recovery this will take many years, but feel it is important to specify when harvest would again be appropriate.

Briefly, carefully monitored recreational and commercial harvest of American shad in the Hudson River can begin when all three benchmarks reach the recovery target. Specifically,

Recreational and Commercial Harvest Re-opening Criteria:

- **Five-year mean annual mortality (A) < 44%, AND**
- **Five-year mean female spawning stock biomass (SSB) > 57.39, AND**
- **Five-year mean juvenile abundance index (JAI) > 28.28 fish/haul**

We propose that any reopened portion of the fishery can remain open as long as the reopening criteria for that fishery, as listed above, are still met. Should any of the criteria not be met for a given fishery, then that fishery should be closed until reopening criteria have again been achieved. If any of the three recovery criteria cannot be calculated due to unforeseen data collection or processing problems, then the remaining index may need a longer time period to ensure stock resiliency to allow any fishing. Any changes as a result of data collection of processing problems will have to be considered on a case-by-case basis.

It is also important to note that prior to any recreational or commercial harvest of shad in the Hudson River, New York is required under Amendment 3 of the ASMFC Shad and River Herring Interstate Fisheries Management Plan to submit a Sustainable Fisheries Management plan (SFMP) demonstrating that any fishery will not prevent future stock production and recruitment (ASMFC 2010). Once recovery targets are met, staff will develop a SFMP and submit for approval by the ASMFC Shad and River Herring Management Board. This new plan will consider all new developments in our understanding of American shad biology, for example, newly described oscillating movements in the Hudson (Higgs et al. 2022, *manuscript in review*) Once approved, the sustainability benchmarks identified in the SFMP will supersede the recovery targets.

8 RECOMMENDATIONS FOR STOCK RECOVERY

Since the collapse of the Hudson River American shad stock in the mid-2000s, a number of steps have been taken to improve the chances of recovery. Hudson River shad mortality has been reduced through the closure of the Hudson River shad fisheries and reduced mortality at Hudson River water intakes.

There have also been fishery management changes that have, or may, further reduce mortality. The most significant fishery management change was the improved bycatch monitoring and river herring and shad bycatch caps that were implemented in the New England and Mid-Atlantic Mackerel and Atlantic Herring fisheries in 2014. These caps triggered fishery closures in 2018 and 2019, potentially reducing harvest of Hudson shad in those years. More importantly, these catch caps are structured in a way that encourages commercial operators to avoid harvesting their target species in the times and places where one would expect shad bycatch. This change to fishing behavior should provide a reduction in mortality of shad for as long as the caps stay in place; even if the caps are not reached. Additionally, a Fishery Management Plan threshold benchmark for mixed-stock American shad was implemented in the Delaware Bay in

2016. While this benchmark has not yet been reached, it should afford some protection to Hudson River shad as populations begin to recover.

While we remain hopeful that the changes that have already taken place will allow for Hudson River American shad to recover with time, we continue to identify, and complete actions that will improve the chances of stock recovery. Priority recovery actions are outlined below. More detail on the threats that require the actions described below can be found in the Threats section of this document, beginning on page 8.

A. MAINTAIN HUDSON RIVER MONITORING PROGRAMS

Implementation of the above fishery management scheme requires that the NYSDEC annually monitor the JAI, adult spawning stock, and adult mortality rate of American shad. Continued monitoring is critical to measuring progress and to adjusting management measures, as necessary, for the adaptive management of this stock.

OBJECTIVE: Continue Hudson River Monitoring Programs to collect necessary data to assess progress towards recovery goals.

ACTION: Conduct annual DEC sampling to monitor the JAI, spawning stock age structure, and adult mortality rate of American shad.

B. REDUCE FISHING MORTALITY

The most important and meaningful action that we can take is to reduce mortality on all life stages as quickly as possible. American shad from the Hudson River Estuary were taken in directed commercial fisheries from New England to Virginia; it is not known to what extent that adult fish continue to be taken. Knowledge of bycatch characteristics (quantity, location, and time of year) allows us to evaluate the impact of bycatch and to reduce it where needed through regulation in New York state waters and through action at the Atlantic States Marine Fisheries Commission, the New England Fishery Management Council, and the Mid-Atlantic Fisheries Management Council for fisheries in waters of other states and in federal waters. Since shad from many stocks are taken as ocean bycatch, we will also need to develop a method to identify that part of the bycatch from the Hudson River. This will allow New York to focus regulatory protection on those fisheries most affecting Hudson shad.

OBJECTIVE: Prevent an increase in Hudson River American shad harvest before recovery occurs.

ACTION: Maintain the 2010 moratorium on harvest from New York State waters; Maintain ocean intercept fishery closure implemented by ASMFC in Amendment 1 to the Shad and River Herring Interstate Fisheries Management Plan (ASMFC 1999).

OBJECTIVE: Identify and mitigate all sources of American shad fishing mortality, beyond known fisheries.

ACTION: Maximize observer coverage and port-side sampling of all fishery types (all gears, all waters) throughout the range of American shad.

OBJECTIVE: Determine Hudson River stock component of fisheries with significant American shad harvest. There are currently several fleets/fisheries that land significant numbers of American shad: Mid-Atlantic (MA) and New England (NE) small-mesh bottom trawls, NE mid-water trawls, MA+NE large mesh gill nets, Delaware Bay large mesh gill nets.

ACTION: Collect shad tissue samples from fisheries with significant interactions with American shad and determine what proportion of the American shad vulnerable to the fisheries are composed of Hudson River stock.

ACTION: Incorporate recent genetic studies into the development of the 2021 Delaware River Sustainable Fishery Management to make sure the mixed-stock benchmark accurately accounts for the harvest of Hudson River American shad.

ACTION: Develop a strategy to engage the appropriate Fishery Management Council or Commission to reduce mortality of American shad from significant fisheries that encounter high proportions of Hudson River shad.

C. REDUCE MORTALITY FROM OTHER SOURCES

The most important and meaningful action that we can take is to reduce mortality on all life stages as quickly as possible.

OBJECTIVE: Identify and mitigate all additional anthropogenic sources of mortality experienced by American shad.

ACTION: Work collaboratively with academia, state and federal resource agencies to identify, quantify and mitigate mortality due to additional anthropogenic causes (e.g. turbine mortality at hydroelectric facilities).

D. WATER INTAKES

OBJECTIVE: There has been significant improvement in the protection of American shad at water intakes in the Hudson River. We recommend continued diligence by regulatory agencies to improve protection at all water intakes in the Hudson River that may impact American shad, including new proposals.

ACTION: Ensure that new and existing water intakes proposed and installed in the Hudson River include provisions that are protective of American shad.

ACTION: Quantify the number of existing water intakes in the Hudson River, particularly those in the vicinity of American shad spawning habitat, that do not include provisions that are protective of American shad.

E. FISH PASSAGE STRUCTURES

OBJECTIVE: Minimize mortality of American shad at fish passage structures.

ACTION: Assess the impacts of upstream and downstream mortality of adult and juvenile American shad at the Troy Dam and all other accessible passage structures in the Hudson and Mohawk rivers.

ACTION: Reduce mortality at passage structures negatively impacting American shad. This may be accomplished by either improving the design of passage structures or preventing access of American shad to the structures.

F. HABITAT RESTORATION

The NYSDEC developed an American Shad Habitat Plan in 2021, as required by the Atlantic States Marine Fisheries Commission. Objectives and actions related to American shad habitat restoration, including habitat restoration opportunities related to invasive species prevention, are included in that document.

G. CLIMATE CHANGE

OBJECTIVE: Mitigate impacts of climate change on the Hudson River American shad stock.

ACTION: Continue to monitor climate change impacts to the Hudson River and American shad to identify and implement opportunities to adaptively manage and minimize adverse impact.

ACTION: Explore the implications to migratory fish of differential warming rates between the Atlantic Ocean and the Hudson River Estuary.

ACTION: Evaluate impacts of Northwest Atlantic Ocean heatwaves on the ecology of American Shad, including the timing and location of seasonal movements, impacts on prey abundance and availability, and disease and pathogens.

9 REFERENCES

Atlantic States Coastal Cooperative Statistics Program (ACCSP). https://safis.accsp.org/accsp_prod/f?p=1490:1:12007459682654

ASMFC (Atlantic States Marine Fisheries Commission). 2020. American Shad 2020 Stock Assessment Report. Washington, DC, USA.

ASMFC (Atlantic States Marine Fisheries Commission). 2010. Amendment 3 to the Interstate Fishery Management Plan for Shad and River Herring. Washington, DC, USA.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. Stock assessment of American shad, Stock Assessment Report Number 07-01. Washington, DC, USA.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring. Fishery Management Report No. 35. Washington, DC, USA.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. American shad stock assessment peer review report. Washington, DC, USA.

ASMFC (Atlantic States Marine Fisheries Commission). 1945. 4th Annual Report of the Atlantic States Marine Fisheries Commission to the Congress of the United States and to the Governors and Legislatures of the 14 member states, New York NY, USA.

Bailey, H. and D.H. Secor. 2016. Coastal evacuations by fish in extreme weather events. Scientific Reports 6, 30280; doi: 10.1038/srep30280.

Caddy, J.F., and R. Mahon. 1995. Reference points for fisheries management. FAO Fisheries Technical Paper #347.

Caraco, N.F., J.J. Cole, P.A. Raymond, D. L Strayer, M.L. Pace, S.E.G. Findlay and D.T. Fischer. 1997. Zebra mussel invasion in a large turbid river: phytoplankton response to increased grazing. Ecology 78:588-602.

Carrol, S.M. 2019. Spatial analysis of the recovery of submerged aquatic vegetation in the Hudson River Estuary following the 2011-2012 hurricane seasons. Montana State University, Masters Thesis.

CGH&E et al. (Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York Inc, New York Power Authority, and Southern Energy New York) 1999. Draft environmental impact statement for the State Pollutant Discharge Elimination System Permits of Bowline Point, Indian Point 2&3 and Roseton Steam Electric Generating Stations. Poughkeepsie, New York.

Cheney, A.N. 1900. Shad Culture in the Hudson River. In Fifth Annual Report of the Commissioners of Fisheries, Game and Forests of the State of New York., pp. 241-247.

Crecco, V., T. Savoy, and J. Benway. 2007. Stock assessment of American shad in Connecticut. Pages 347-402. In ASMFCa. Atlantic States Marine Fisheries Commission. 2007. Stock assessment of American shad, Stock Assessment Report Number 07-01. Washington, DC, USA.

Daniels, R.A., R.E. Schmidt, and K.E. Limburg. 2011. Hudson River fisheries: once robust, now reduced. In R.E. Henshaw, editor. Environmental History: Human Uses that Changed Ecology; Ecology that Changed Human Uses. SUNY Press., pp. 27-40.

Daniels, R.A., K.E. Limburg, R.E. Schmidt, D.L. Strayer, and R.C. Chambers. 2005. Changes in fish assemblages in the tidal Hudson River, New York. In Historical changes in large river fish assemblages of America. American Fisheries Society. Bethesda, Maryland., pp. 471-503.

Delaware River Basin Fish and Wildlife Cooperative, 2016. Delaware River Sustainable Fishing Plan for American Shad. 27pp.

Hamberg, J., Findlay, S.E.G., Limburg, K.E. and Diemont, S.A.W. (2017), Post-storm sediment burial and herbivory of Vallisneria americana in the Hudson River Estuary: mechanisms of loss and implications for restoration. Restor Ecol, 25: 629-639. https://doi.org/10.1111/rec.12477

Haro, A. and T. Castro-Santos. 2012. Passage of American Shad: Paradigms and Realities. Marine and Coastal Fisheries 4(1): 252-261.

Harpers Weekly 1872. Seth Green's Shad Nursery, April 27, 1872, page 325. Harper's Weekly Newspaper, New York, NY.

Hasselman, D. J and K. E. Limburg. 2012. Alosine Restoration in the 21st Century: Challenging the Status Quo. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 4: 174-187

Hendricks, M. L. 2003. Culture and transplant of alosines in North America. Pages 303–312 in K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Higgs, A. L., P. C. Perry, C. R. Standley and D. Fox. 2021. Fine Scale Oscillatory Behavior and Migration Patterns for Multi-Year Tagged Anadromous American Shad (*Alosa sapidissima*) in the Hudson River, New York: Management Implications for the Future. (*manuscript in review*)

Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz, 2014: Ch. 16: Northeast. In Climate Change Impacts in the United States: The Third National Climate Assessment. J.M. Melillo, T.C. Richmond, and G.W. Yohe, Eds. U.S. Global Change Research Program, pp. 371-395, doi:10.7930/J0SF2T3P.

Hyle, A.R., R. S. McBride, and J. E. Olney. 2014. Determinate Versus Indeterminate Fecundity in American Shad, an Anadromous Clupeid, Transactions of the American Fisheries Society, 143:3, 618-633.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kahnle, A., D. Stang, K. Hattala, and W. Mason. 1988. Haul seine study of American shad and striped bass spawning stocks in the Hudson River Estuary. New York State Department of Environmental Conservation, Summary report for 1982-1986, New Paltz.

Lynch, M., and M. O' Hely. 2001. Captive breeding and the fitness of natural populations. Conservation Genetics 2:363–378.

Mansueti, R. J., and H. Kolb. 1953. A historical review of the shad fisheries of North America. Chesapeake Biological Laboratory, Publication 97, Solomons, Maryland.

McBride R. S., R. Ferreri, E. K. Towle, J. M. Boucher, and G. Basilone. 2016. Yolked Oocyte Dynamics Support Agreement between Determinate and Indeterminate-Method Estimates of Annual Fecundity for a Northeastern United States Population of American Shad. PLoS ONE: 11(10)

Mid-Atlantic Fisheries Management Council (MAFMC 2014). Amendment 14 of the Mackerel, Squid and Butterfish Fisheries Management Plan https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/53e3d5fbe4b0e88e72d231c6/1407440379012/Am14FEIS.pdf

Millard, M.J., J. Mohler, A. Kahnle, K. Hattala, W. Keller, and A. Cosman. 2003. Mortality Associated with Catch and Release Angling of Striped Bass and American Shad in the Hudson River. Final Report to: NY Department of Environmental Conservation, Hudson River Fisheries Unit, New Paltz, NY

Miller, D.E., J. Ladd and W.C. Neider. 2006. Channel morphology in the Hudson River Estuary: historical changes and opportunities for restoration. American Fisheries Society Symposium 51, pp 29-37.

Moss, D. D. 1950. The Connecticut River shad. Connecticut State Board of Fish and Game, Mimeo Report, Hartford.

Nack, Christopher C., Dennis P. Swaney and Karin E. Limburg. 2019. Historical and Projected Changes in Spawning Phenologies of American Shad and Striped Bass in the Hudson River Estuary. Marine and Coastal Fisheries. Volume11, Issue3, Pages 271-284

National Marine Fisheries Service (NMFS) http://www.st.nmfs.noaa.gov/ecosystems/ebfm/index

Normandeau, 2003. Assessment of Hudson River Recreational Fisheries. Contract Number C004005. Prepared for the NYSDEC. 342 pp.

Olney, J. E., and R. S McBride. 2003. Intraspecific variation in batch fecundity of American shad: revisiting the paradigm of reciprocal latitudinal trends in reproductive traits. Pages 185-192 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Pirani, R and Boicourt, K., 2018. Climate Change; And its Impact on the NY-NJ Harbor & Estuary Program, Hudson River Foundation. New York, NY.

Reid H. A., R. S. McBride and J. E. Olney. 2014. Determinate Versus Indeterminate Fecundity in American Shad, an Anadromous Clupeid, Transactions of the American Fisheries Society, 143:3, 618-633

Reidmiller, D. R., C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment vol II (Washington, DC: U.S. Global Change Research Program)

Rosenzweig, C., W. Solecki, and A. DeGaetano, 2011: ClimAID: Integrated assessment for effective climate change adaptation strategies in New York State. In Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change

Adaptation: Technical Report. C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, and P. Grabhorn, Eds. New York State Energy Research and Development Authority, pp. 1-14

Ross, R.M., Bennett, R.M. and Johnson, J.H. 1997. Habitat Use and Feeding Ecology of Riverine Juvenile American Shad. North American Journal of Fisheries Management, 17, 964-974.

Schmidt, R.E. and E. Kiviat. 1988. Communities of larval and juvenile fish associated with water chestnut, watermilfoil, and water-celery in the Tivoli Bays of the Hudson River. Report to Hudson River Foundation, New York, NY. 35 pp.

Stich, D.S., Gilligan, E., and Sperhac, J.M. 2020. shadia: American shad dam passage performance standard models for R, version 1.8.2. url: https://github.com/danStich/shadia.

Stich, D.S., Sheehan, T.F., and Zydlewski, J.D. 2019. A dam passage performance standard model for American shad. Can. J. Fish. Aquat. Sci. 76(5): 762-779.

Strayer, D.L. 2016. The Mohawk River and Erie Canal as a Corridor for Biological Invasions. Presented at the Hudson River Environmental Society Symposium, New Paltz, NY.

Strayer, D.L. 2006. Alien Species in the Hudson River. In Levinton and Waldman (Eds.), The Hudson River Estuary, pp 296-312. Cambridge University Press.

Strayer, D.L., K.A. Hattala, A.W. Kahnle and R.D. Adams. 2014. Has the Hudson River fish community recovered from the zebra mussel invasion along with its forage base? Canadian Journal of Fisheries and Aquatic Sciences 71:1-12.

Strayer, D.L., K.A. Hattala and A.W. Kahnle. 2004. Effects of an invasive bivalve (*Dreissena polymorpha*) on fish in the Hudson River Estuary. Canadian Journal of Fisheries and Aquatic Sciences 61:924-941.

Stevenson, C.H. 1899. The shad fisheries of the Atlantic Coast of the United States. In U.S. Commission of Fish and Fisheries, Part XXIV. Report of the Commissioner for the year ending June 30, 1898. Government Printing Office, Washington, D.C., pp. 101-269.

Talbot, G. 1954. Factors associated with fluctuations in abundance of Hudson River shad. US Fishery Bulletin 101(56): 373-413.

USACE (United States Army Corps of Engineers). 2019. New York – New Jersey Harbor and tributaries coastal storm risk management feasibility study. Interim report. 136 pp.

USCFF (US Commission of Fish and Fisheries). 1871-1940. Reports of the Commissioner. USCFF. https://library.noaa.gov/Collections/Digital-Documents/Fish-Comm-Annual-Rep.

Waldman, J., D. Hasselman, P. Bentzen, M. Dadswell, L. Maceda and I. Wirgin. 2014. Genetic Mixed-Stock Analysis of American Shad in Two Atlantic Coast Fisheries: Delaware Bay, USA, and Inner Bay of Fundy, Canada, North American Journal of Fisheries Management, 34:6, 1190-1198, DOI: 10.1080/02755947.2014.954067

Walters, C. 1995. Estimation of historic stock size and recruitment anomalies form relative abundance time series. Can. J. Aquat. Sci. 52:1523-1534.

Wolfe, D. A. 2000. A History of the Federal Biological Laboratory at Beaufort, North Carolina, 1899-1999. US NOAA.

Zeisel, W.N. 1988. A History of Recreational Angling on the Hudson River. Final report to the Hudson River Foundation. 310 pp.

APPENDIX 1. ADDITIONAL TABLES AND FIGURES

Tables

Table 1. Annual and multi-year mean measures of adult Hudson River American shad female mortality and spawning stock biomass; and juvenile abundance.

	Adults				Juveniles	
Year	Annual Mortality (A)	5 Yr Mean A	Empirical Spawning Stock Biomass (ESSB)	5 Yr Mean ESSB	JAI	5 Yr Mean JAI
1974			19.40			
1975			12.00			
1976			7.40			
1977			7.20			
1978			8.80	10.96		
1979			9.00	8.88		
1980			9.20	8.32		
1981			32.20	13.28		
1982			24.60	16.76		
1983	37%		71.20	29.24	20.68	
1984	22%		94.40	46.32	8.38	
1985	28%		54.37	55.35	26.64	
1986	41%		105.78	70.07	47.95	
1987	42%	34%	91.84	83.52	20.67	24.86
1988	44%	35%	85.32	86.34	29.96	26.72
1989	39%	39%	62.96	80.05	47.30	34.50
1990	43%	42%	28.58	74.90	41.24	37.42
1991	55%	45%	27.13	59.17	24.05	32.64
1992	62%	49%	21.22	45.04	35.17	35.54
1993	47%	49%	15.30	31.04	11.64	31.88
1994	64%	54%	30.61	24.57	25.68	27.56
1995	71%	60%	17.07	22.27	5.64	20.44
1996	57%	60%	30.48	22.94	42.00	24.03
1997	39%	56%	10.22	20.74	13.68	19.73
1998	62%	59%	18.63	21.40	3.66	18.13
1999	65%	59%	14.30	18.14	20.88	17.17
2000	76%	60%	47.39	24.20	12.28	18.50
2001	64%	61%	38.63	25.83	37.97	17.69
2002			20.46	27.88	2.91	15.54
2003	50%	64%	24.63	29.08	6.71	16.15
2004	37%	59%	66.98	39.62	5.33	13.04
2005	43%	54%	53.44	40.83	8.27	12.24
2006	46%	48%	16.25	36.35	1.61	4.97
2007	45%	44%	9.15	34.09	4.86	5.36
2008	40%	42%	4.94	30.15	1.70	4.35
2009	57%	46%	1.56	17.07	2.45	3.78
2010	66%	51%	7.82	7.94	3.34	2.79
2011	61%	54%	4.07	5.51	3.70	3.21
2012	40%	53%	9.80	5.64	1.45	2.53
2013	48%	54%	9.45	6.54	1.17	2.42
2014	51%	53%	9.65	8.16	14.15	4.76
2015	52%	50%	3.16	7.23	6.16	5.33
2016	48%	48%	3.39	7.09	1.54	4.89
2017	30%	46%	7.96	6.72	3.02	5.21
2018	77%	52%	11.84	7.20	5.87	6.15
2019	56%	53%	13.76	8.02	0.92	3.50
Recovery Targets		44%		57.39		28.28
Limit Reference Points		55%		30.61		8.32

Figures

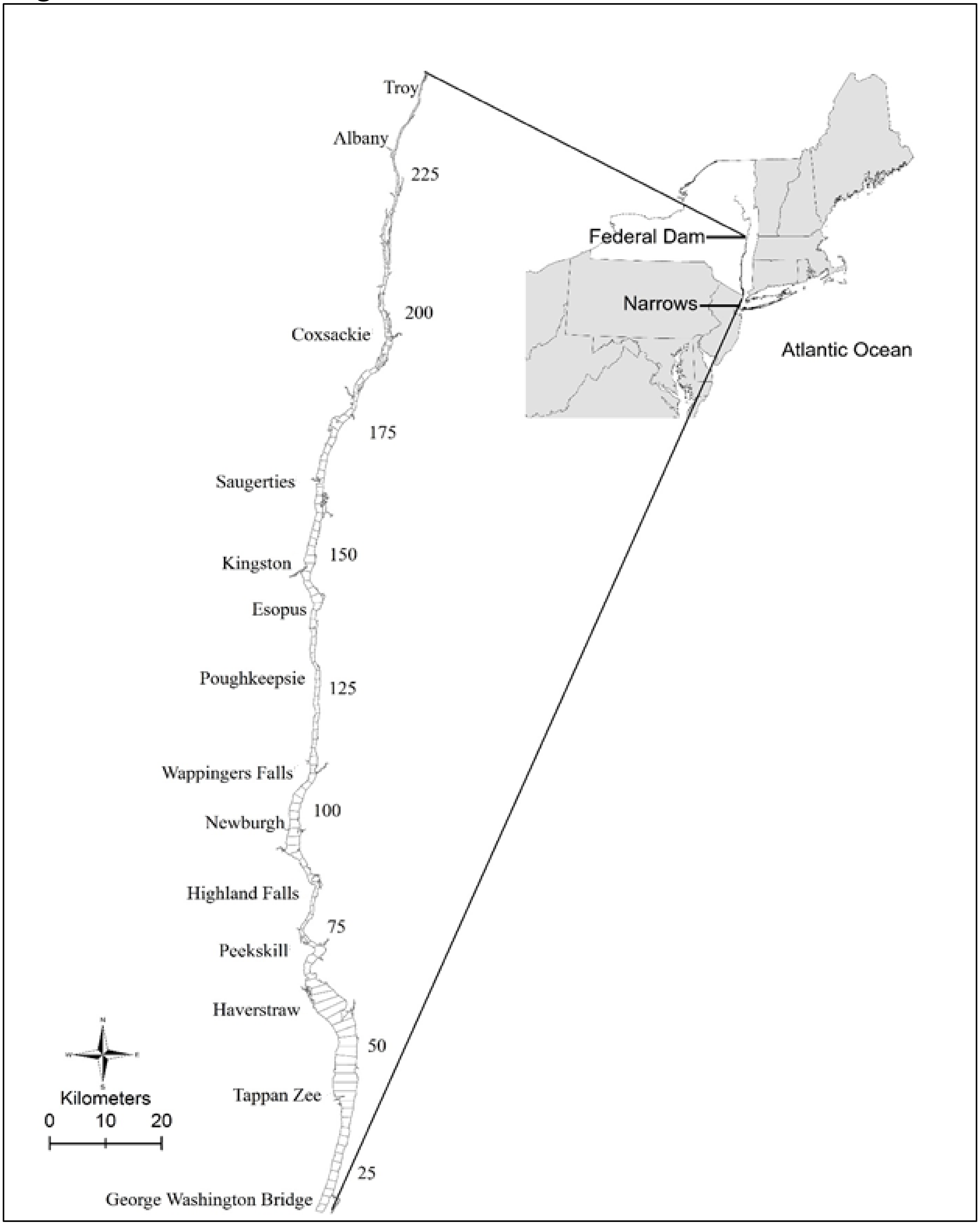


Figure 1. Hudson River Estuary, New York.

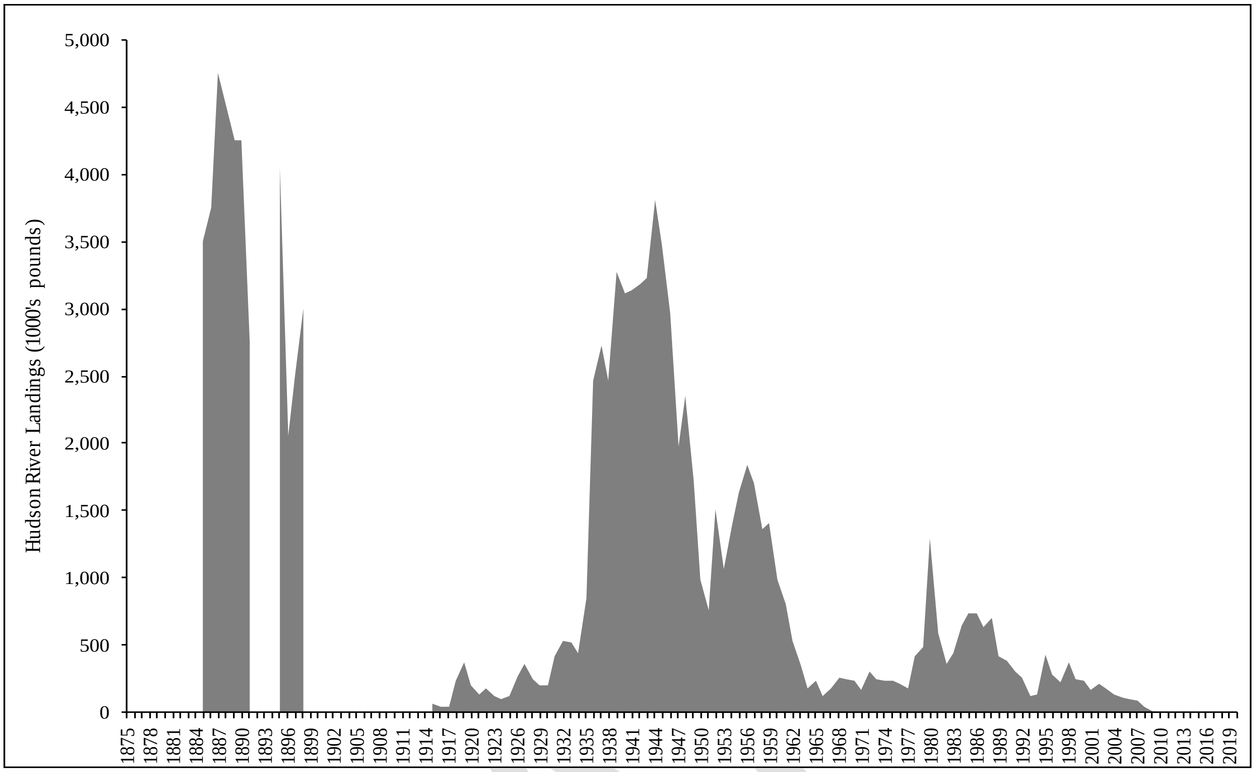


Figure 2. Historic commercial fishery landings of American shad in the Hudson River Estuary, 1880-2019. Fishery closure 2010-present.

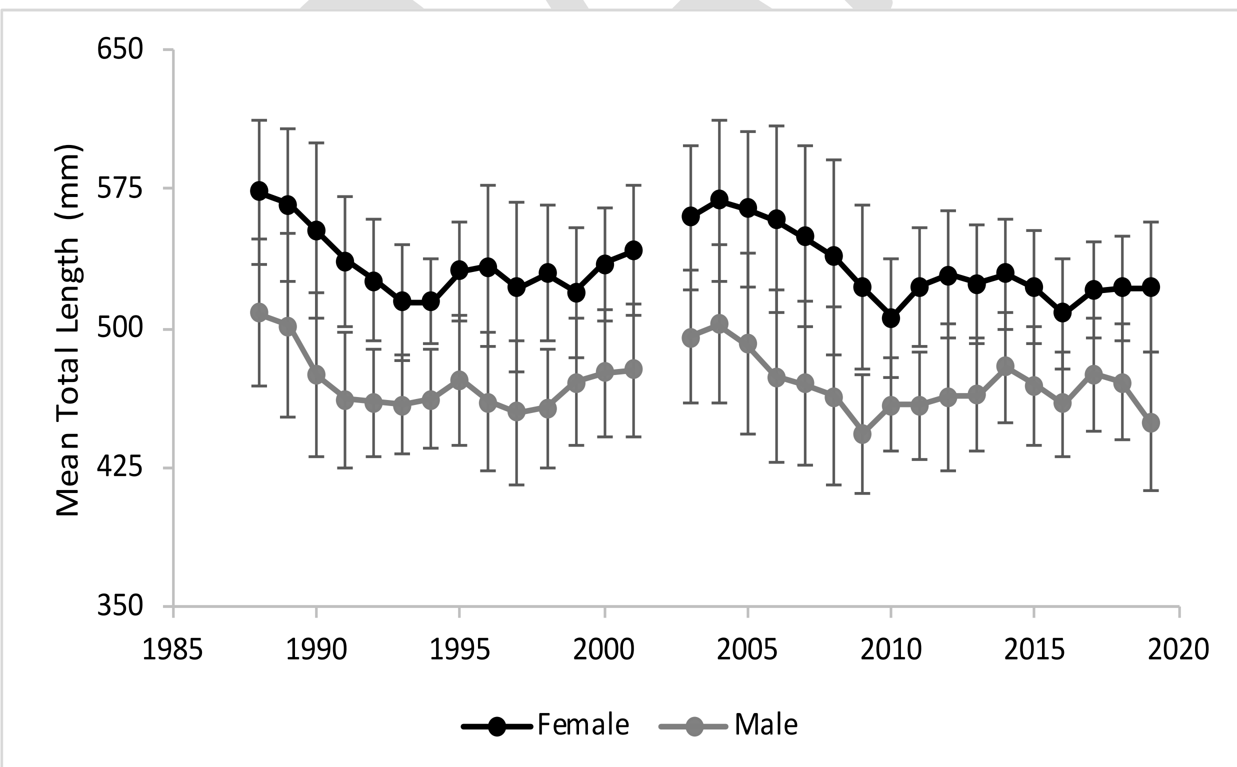


Figure 3. Mean total length of American shad collected in the Hudson River during fisheries independent sampling. Error bars ± 1 SD

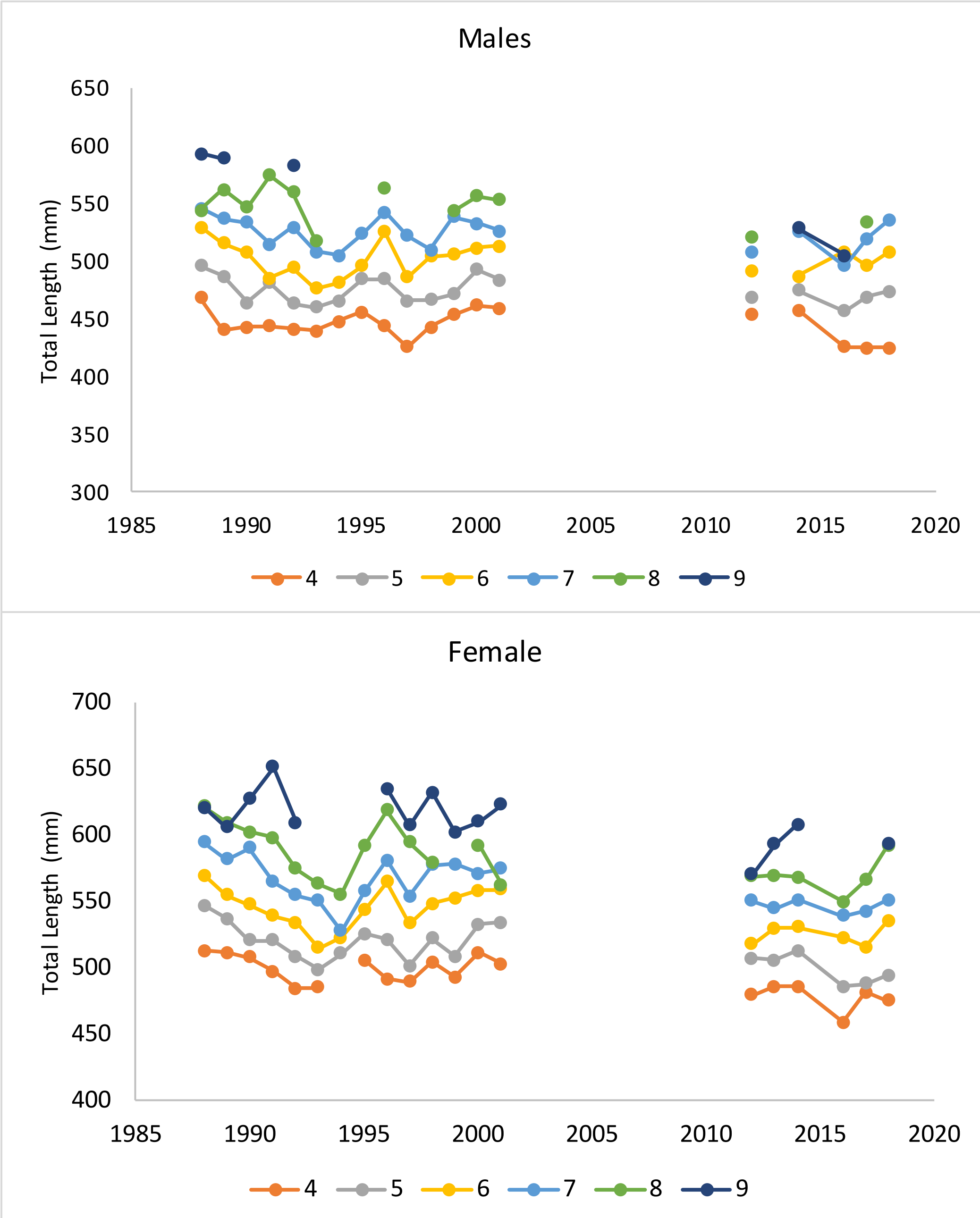


Figure 4. Mean total length at age for ages four to nine of male (top) and female (bottom) American shad collected in the Hudson River during fisheries independent sampling. Ages less than four and greater than 10 excluded due to low sample sizes.

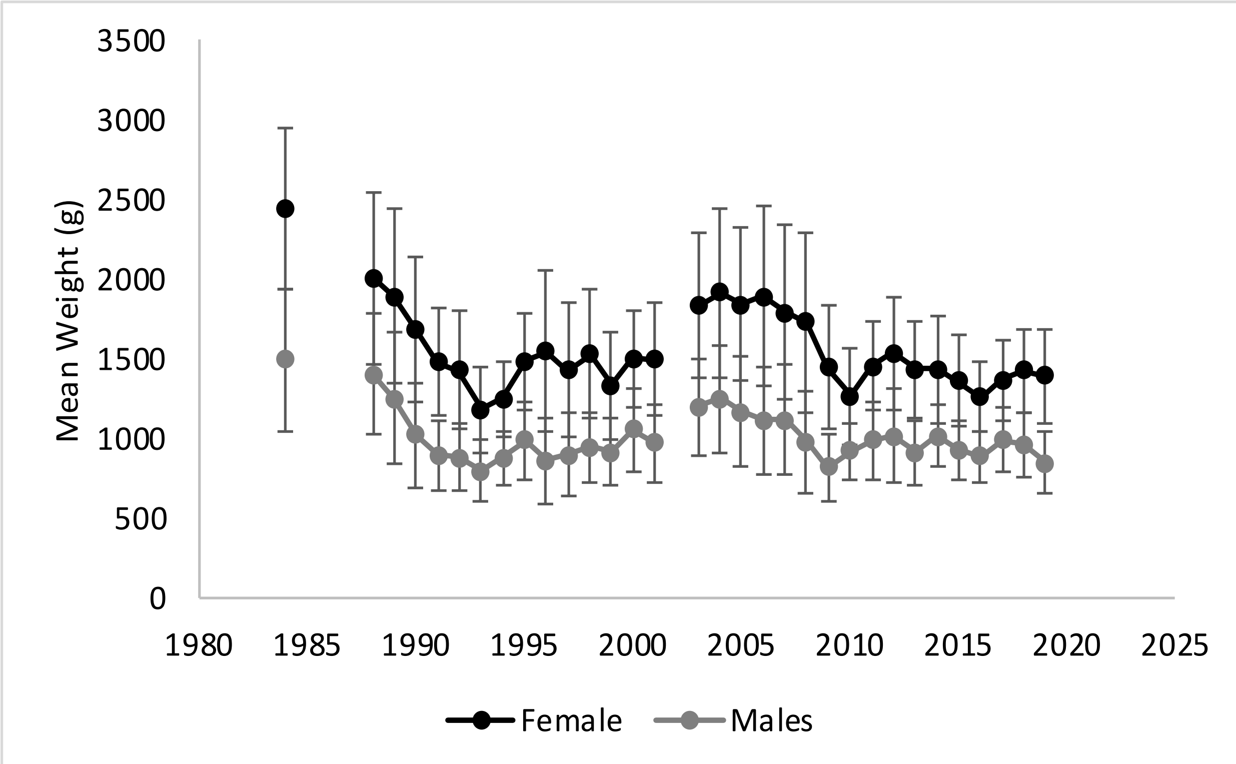


Figure 5. Mean total weight of American shad collected in the Hudson River during fisheries independent sampling. Error bars ± 1 SD

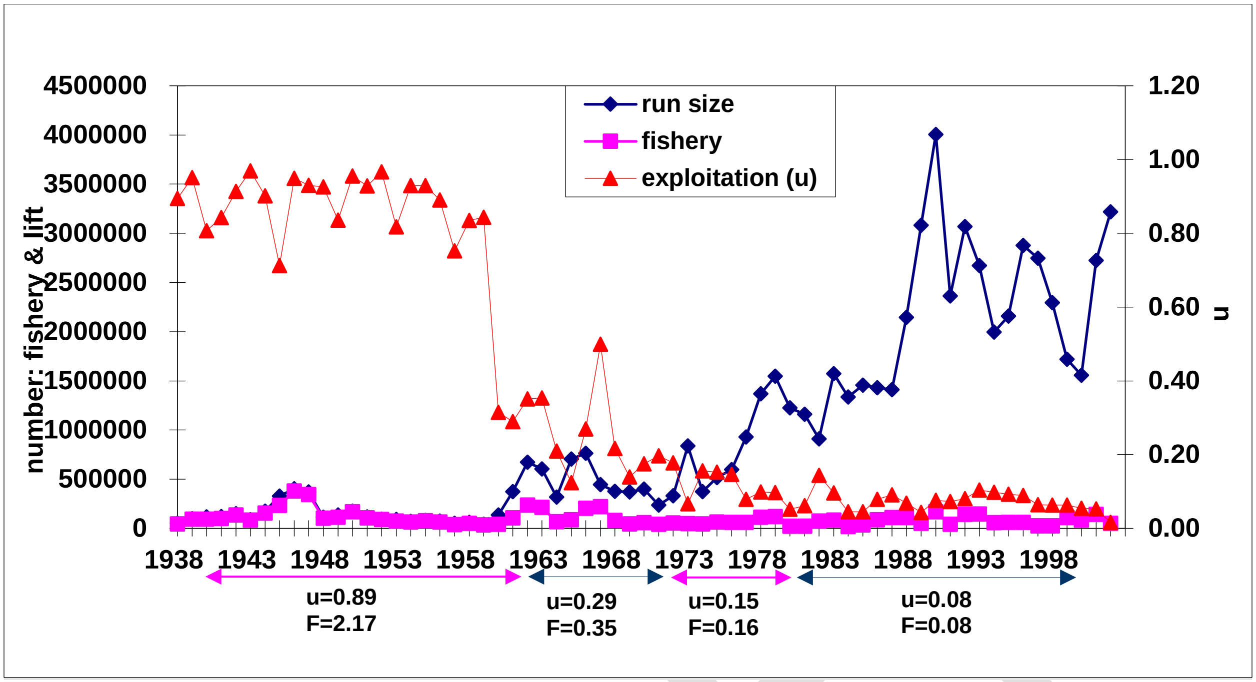


Figure 6. Comparison of fisheries harvest versus run size of American shad in the Columbia River, OR/WA (From ASMFC, 2007a).