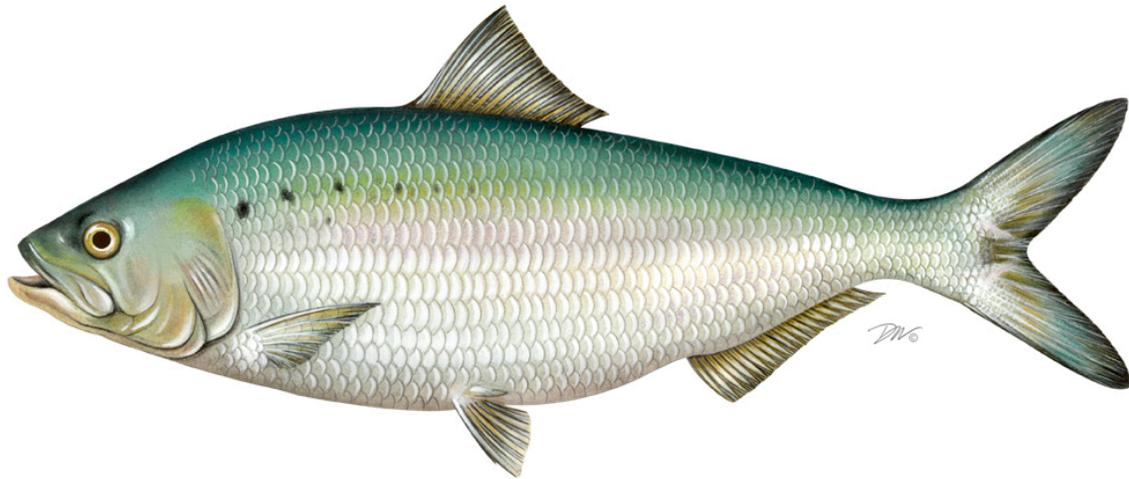


# *RECOVERY PLAN FOR HUDSON RIVER AMERICAN SHAD*

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March 2023



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New York State Department of Environmental Conservation  
Division of Marine Resources

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November 2022

Prepared by

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NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

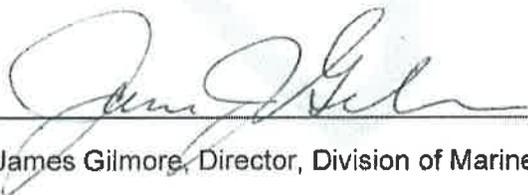
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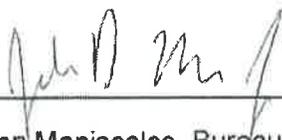
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## **FOREWORD**

“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**

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## LIST OF ABBREVIATIONS

A	annual mortality of adult females
ACCSP	Atlantic Coastal Cooperative Statistics Program
AIS	aquatic invasive species
ASMFC	Atlantic States Marine Fisheries Commission
C&R	catch-and-release
CEMR	Conditional Entrainment Mortality Rate
CRASC	Connecticut River Atlantic Salmon Commission
DE	Delaware
DEC	New York State Department of Environmental Conservation
IPCC	Intergovernmental Panel on Climate Change
IPEC	Indian Point Energy Center
ISFMP	Interstate Fishery Management Plan
JAI	juvenile abundance index
MA	Mid-Atlantic
MAFMC	Mid-Atlantic Fishery Management Council
NE	New England
NEFMC	New England Fishery Management Council
SAV	submerged aquatic vegetation
SD	standard deviation
SFMP	Sustainable Fishery Management Plan
SPDES	State Pollutant Discharge Elimination System
SSB	spawning stock biomass
USACE	U.S. Army Corps of Engineers
USCFF	United States Commission of Fish and Fisheries
YOY	young of year

## 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 (DEC). 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 short-term objective is to reopen the catch-and-release (C&R) fishery while supporting the long-term recovery objective of returning the stock to 1940s' levels. Gradual recovery should enable the future reopening of commercial and recreational harvest fisheries.

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 3 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.

DEC 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 since 1984 to sample the shad spawning stock, while beach seine surveys have been used since 1980 for young of year (YOY) sampling. 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.

Fishery-independent data are inadequate for modeling ideal conditions of a fully restored stock, so commercial landings have been used as 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' 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 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.

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Although all fisheries for American shad in the Hudson River are currently closed, we suggest reopening the recreational C&R fishery after some documented progress. 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 Catch-and-Release Threshold for three consecutive years and when 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 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 are supported by sufficient data.

## 1 INTRODUCTION

During the past 135 years, the Hudson River American shad (*Alosa sapidissima*) stock has 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 kilometers (km) from New York City to the Federal Dam at Troy (Appendix 1, Figure 1). American shad spawn in freshwater from Kingston, (river kilometer [rkm] 145) to Troy (rkm 244). Juveniles use the upper 150 km (Newburgh to Troy) of the estuary as a nursery area and migrate to the ocean from mid-summer to late fall/early winter. Once they mature between ages 3 and 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 lives. A more detailed description of American shad life history can be found in the most recent stock assessment conducted in 2020 by the Atlantic States Marine Fisheries Commission (ASMFC).

## 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 Hudson River American shad occurred in the 1860s. Following this perceived collapse (although no official records document the event), in 1868 the New York State legislature implemented gear restrictions, an escapement period, and fishing 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 Commission of Fish and Fisheries (USCFF) 1898 reports, the prevailing intent of the states, including New York, was not to interfere in any business, including fishing. It is clear that, although restrictions were implemented, fishing largely continued unabated. Some variation of these nineteenth-century rules existed until the fishery closed in 2010.

Following the perceived mid-1800s' collapse, the USCFF 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 attempts to restore stocks perceived to be exhausted. This so-called exhausted determination is questionable. From 1880 through 1901, the Hudson River stock produced the largest harvest in its recorded history, suggesting the spawning stock was large enough to quickly recover and 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 USCFF 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 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...[in] 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. Before, during, and after World War II, regulations were greatly relaxed, or abolished altogether. After almost 10 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 ASMFC was created to help ensure the continued harvest of United States fishery resources to supply troops during World War II. The ASMFC motto was “food will win the war” (ASMFC 1945). Regulatory management of Atlantic Coast shad stocks through ASMFC would wait another 42 years with adoption of the *Interstate Fishery Management Plan for Shad and River Herring* in 1985. Although the Interstate Fishery Management Plan (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), though an SFMP is not required for C&R fishing. 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 fishery to reduce river herring and shad bycatch, according to the Mid-Atlantic Fishery Management Council (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 American shad, commercial harvest continues along the Atlantic Coast as part of SFMPs approved for six Atlantic Coast states. Bycatch, or unintended harvest, of shad also occurs in several other fisheries in federal and 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.

Bycatch 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 has provided incidental catch estimates for various ocean gears since 1989. Total estimates of United States-based American shad bycatch 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 pounds (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 from the Hudson River is currently unknown and may be limiting recovery of the Hudson River stock.

In addition to ocean bycatch, 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 SFMP (Delaware River Sustainable Fishing Plan for American Shad 2022). 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 Delaware Bay. However, the Hudson River component from commercial fishery sampling in 2009 and 2010 was estimated to be 33–53% (Waldman et al. 2014).

## **Habitat Alteration**

The historical upstream limit for anadromous fish in the Hudson River was the natural falls at Fort Edward (Zeisel 1988). Natural falls at the confluence of the Mohawk and Hudson rivers prevented fish from moving into the Mohawk system. The rise in commercial shipping at the beginning of the nineteenth century led to a desire to connect ocean-going ships to midwestern states. The Erie Canal was completed in 1825, linking the Hudson River near Waterford (roughly 5 km north of Troy) 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 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 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, roughly 56 km 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 during the highest spring floods (Stevenson 1899). In 1915, the U.S. Army Corps of Engineers (USACE) replaced the old dam with a new concrete structure that 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 twentieth 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 9 additional kilometers, or 3.5% of habitat before the next lock and dam system (C1) on the upper Hudson River north of Waterford. Movement above the Federal Dam would expose adults and 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 rkm 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 River in Troy and the first barrier on the Rondout Creek in Eddyville), the lack of access to historic habitat did not cause the stock collapse. Furthermore, analysis presented in this plan suggests that most alosine 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 (SAV) may 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 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. 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 (rkm 190) was destroyed during this time. Another factor that has not been well researched is the effects of potential barriers posed by the railroads along both 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 remain accessible to American shad, unlike other Atlantic Coast systems, significant changes to 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). From 1830 through present day, at least 10 additional piscivores have been introduced to the Hudson, including voracious predators such as black bass, introduced in the 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 are much lower than surrounding waters (Strayer 2006), favoring species with high 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 (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 (AIS) 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. The canals subsequently allowed for easy movement of AIS 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 (Strayer 2016). There are many other AIS that have either recently entered 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 AIS 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, annual ichthyoplankton survey was conducted in the Hudson River Estuary from 1974–2016 by consultants under contract with Hudson River power-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 Conditional Entrainment Mortality Rate (CEMR) 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 1974–1997 (CHG&E et al. 1999). An estimated average of 20% CEMR was assumed for the period 1952–1973, 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, 10 are operating technologies to minimize fish mortality, 5 are currently reviewing options, and 2 have been designed and will be installed within the next 5 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 Generating uses a dry cooling system requiring no water from the Hudson River. Water withdrawal at Lafarge Cement Plant in Ravena 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. Albany Steam Station (now known as Bethlehem Energy Center) 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 April 2021, was permitted to use more than 2 billion gallons of water per day. Scheduled improvements will also have positive impacts for American shad. The Empire State Plaza operates a once-through cooling system at Albany, withdrawing approximately 90 million gallons per day for air conditioning purposes. A recently issued State Pollutant Discharge Elimination System (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; the salt front is advancing northward; water and air temperatures are increasing; and extreme precipitation is occurring more frequently, punctuated by interim periods of drought (Intergovernmental Panel on Climate Change 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). Climate change serves as a threat multiplier for American shad by exacerbating anthropogenic and ecological stressors; however, 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 disturbances 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 SAV (Hamberg et al. 2017). Floodwaters convey contaminants, which could have further impacted regeneration. These storms reduced SAV abundance in the Hudson River by more than 90% and made no appreciable recovery in 2012 or 2013 (Hamberg et al. 2017). SAV coverage increased by 126% in 2016 (from a 2014 baseline) but remains 19% less than pre-storm coverage (Carroll 2019). SAV 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, negative impacts to American shad are likely. In addition to habitat damage, Hurricane Irene and Tropical Storm Lee had acute but short-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 effects also threaten to negatively impact American shad. With sea level rise and more frequent storm events, humans will likely take aggressive steps 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 USACE sought to evaluate the impacts of a wide range of climate change mitigations, including a seawall and storm-surge barrier system that stretched across the entire mouth of the Hudson River from Far Rockaway, NY, to Long Branch, NJ (USACE 2019). 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 that the installation of structures in the main-stem Hudson River have the potential to be a threat to shad recovery. The owner of Green Island Hydroelectric Power Station at the Federal Dam in Troy has been required to install fish passage as part of the Federal Energy Regulatory Commission relicensing 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 Alteration" section beginning on page 8, analysis of the benefits of fish passage in the 2020 Shad stock assessment demonstrates only a 3% increase in spawner potential using "optimistic upstream and downstream passage rates." (ASMFC 2020). However, most fish passage installations for shad 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 threatens 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.

Simulations for American shad in the Hudson River were conducted to assess the influence of passage performance standards on the abundance of spawners returning to the mouth of the river within the shadia package in R (Stich et al. 2022). These simulations assessed predicted population response to upstream passage by adults, downstream passage of juveniles, and downstream passage of adults through the Federal Dam at Troy and the Champlain Canal dams. Passage efficiency (upstream and downstream) was fixed to be the same across all dams considered. Simulations were run for both seasonal and daily upstream passage efficiencies. Seasonal passage efficiencies assumed a 20-day upstream migration window based on the average migratory window in the software package. All other model parameters were randomly sampled from distributions described in Stich et al. (2019) and updated following Gilligan (2020) and Gilligan-Lunda et al. (2021).

Five-thousand simulations were run (Appendix 1, Figure 2) and the code for seasonal passage efficiency simulations is in `sim_shad_seasonal.R`. All simulations used package version 2.1.0 available through the current master branch in the shadia GitHub repository (Stich et al. 2022).

Based on the results of these simulations and the goals and objectives of this plan (see Section 5), we recommend the following dam passage performance criteria:

1. Upstream adult passage minimum efficiency rate of 75%
2. Upstream adult passage time-to-pass of 48 hours or less
3. Downstream adult and juvenile passage efficiency and survival rate of 95%
4. Downstream adult and juvenile time-to-pass 24 hours or less

These passage performance criteria mirror requirements developed and implemented by the Connecticut River Atlantic Salmon Commission (CRASC) for shad passage in the *Connecticut River American Shad Management Plan* (CRASC 2017, 2020), and are supported by the simulations run for the Hudson River described above. Requiring these passage standards should ensure safe, timely, and effective upstream and downstream passage of both adult and juvenile shad. As models are refined, passage criteria may change to achieve the goals and objectives of this plan.

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, prompting some researchers to question the value of American shad culture (Hendricks 2003). Over half a 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 span 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 between 1899 and 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 again evaluate its effectiveness. Hasselman and Limburg (2012) state that stocking activities may be inadvertently 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 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, North Carolina) are iteroparous, returning to spawn in their natal rivers over multiple years. They have been documented in the Hudson River to return as many as eight times 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. Greater recovery potential would exist if American shad were allowed to reproduce naturally over the duration of the spawning run and throughout their lives (Hasselman and Limburg 2012).

Based on this information, we do not support the use of a stocking program to restore the Hudson River shad stock. Instead, we agree with the 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 National Marine Fisheries Service lab at Beaufort, North Carolina) 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, DEC formed the Hudson River Fisheries Unit to investigate 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 75–100 haul seine collections are made annually. Collections occur from April through the first week of June at sites located between rkm 88 and rkm 224. Biological and water quality data 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 is to capture and tag striped bass for coastwide mortality studies. However, this survey remains the longest-running survey to assess 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 SSB since 1984.

### **Young of Year Sampling**

Since 1980, DEC 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 fixed locations 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 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 JAI is derived from this beach seine survey because it represents our best understanding of American shad recruitment in the Hudson River since 1980.

## **4 CURRENT STOCK STATUS**

### **Mortality and Abundance Status**

Adult female mortality rates and adult abundance are described in the recent ASMFC stock assessment for American shad (ASMFC 2020). Female adult mortality is below the benchmark

threshold (see “Annual Adult Female Mortality Benchmark” for details (page 18). Juvenile mortality status is unknown due to a lack of data to make this determination. 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 juvenile mortality is occurring at unsustainable levels (ASMFC 2020).

Current abundance status is depleted as described in the recent ASMFC stock assessment (ASMFC 2020) due to the decline of in-river landings prior to closure in 2010 (Appendix 1, Figure 3). This is further supported by significant declining trends in female SSB and JAI during the same time period (Figure B and Figure C), followed by continued lack of stock response to management actions in 2005 (Atlantic Ocean closure) and 2010 (New York 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. As shown in Appendix 1, Figure 4, there is a significant declining trend in female mean length from 1988–2019 ( $\tau = -0.29$ ,  $p$ -value = 0.02). There is no trend in male mean length. As shown in Appendix 1, Figure 5, 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). There is no trend in male mean length at age.

Mean weight of females reflects SSB and thus some combination of fecundity and reproductive potential. As shown in Appendix 1, Figure 6, there is a significant declining trend in female mean weight from 1988–2019 ( $\tau = -0.29$ ,  $p$ -value = 0.02). 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 SSB. The recent ASMFC stock assessment indicated female mortality rates have fallen below the reference point and remained relatively stable since the mid-2000s. 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, and the highest reported landings occurred in 1889 (Appendix 1, Figure 3). The successive series of peaks and lows indicate that the Hudson stock lost its resilience to recover as the pattern of overfishing continued over the past 135 years. Each subsequent peak in landings is lower than the preceding one. This suggests 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 because sufficient time needs to be given 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 (Oregon/Washington) where the stock took approximately 20 years to recover after a period of overexploitation (Appendix 1, Figure 7). While each system has its own unique characteristics and challenges, the recovery in the Columbia River offers some insight on the time required for recovery.

## Long-term Objective

Our long-term recovery objective is a return of American shad stock abundance to the levels of the 1940s. We chose this time period as a long-term restoration objective because most habitat alteration ended prior to that 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 relative abundance of age-0 American shad (i.e., JAI) and SSB indices estimated for 1940–1950, calibrated using recent DEC beach seine and SSB indices.

## Short-term Objective

Ecosystem changes in the Hudson River and in the ocean may have made the long-term goal unrealistic in the short-term. 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 a 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 and 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:

- 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 DEC spawning stock sampling and methods described in Section 2.6 of the ASMFC American shad benchmark assessment (ASMFC 2020).
- 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 DEC 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-0 fish, or JAI: This index is a measure of annual recruitment or year class strength and is obtained through annual DEC YOY sampling by beach seine in the freshwater portion of the estuary.

No single index is adequate to evaluate progress toward 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 Recovery Targets and Limit Reference Points. Recovery Targets were developed with the goal of matching shad stock conditions from the 1980s. Limit Reference Points (Limits), developed for each index, represent an undesirable state of the fishery which management action should be taken in order to avoid further declines (Caddy and Mahon 1995). The current state of stock collapse has exceeded the Limits for two of the three benchmark indices. To enable recovery of Hudson River American shad, index values should not surpass the Limits set in this plan. If improvement continues, we will approach or exceed our short-term recovery objectives. In turn, controlled recreational and commercial fisheries can begin as we work toward our long-term recovery objective. See Section 7 for specifics on fishery reopening thresholds. To ensure public access to current stock status information about Hudson River American shad, DEC will publish data and recovery metrics at <https://www.dec.ny.gov/animals/62510.html> by August 1 of the calendar year for the previous year's survey data.

### Annual Adult Female Mortality Benchmark (A)

- Recovery Target: annual mortality rate (A) equal to 44%
- Limit Reference Point: 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 from 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 SSB and was not developed nor intended to grow or recover stocks. Given the Hudson River'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 previously. Therefore, we identified a more conservative total mortality rate of  $Z=0.80$ , equal to an annual mortality rate of 55%. This is a more appropriate Limit Reference Point, which will constrain mortality below the annual rates observed from 1993 through 1999—before the stock began its most recent collapse—and allow the stock to recover.

During final revisions of this plan, an error in annual mortality (A) in 2018 was identified. Due to a transcription error, the previously reported A in 2018 of 77% should have been 62%.

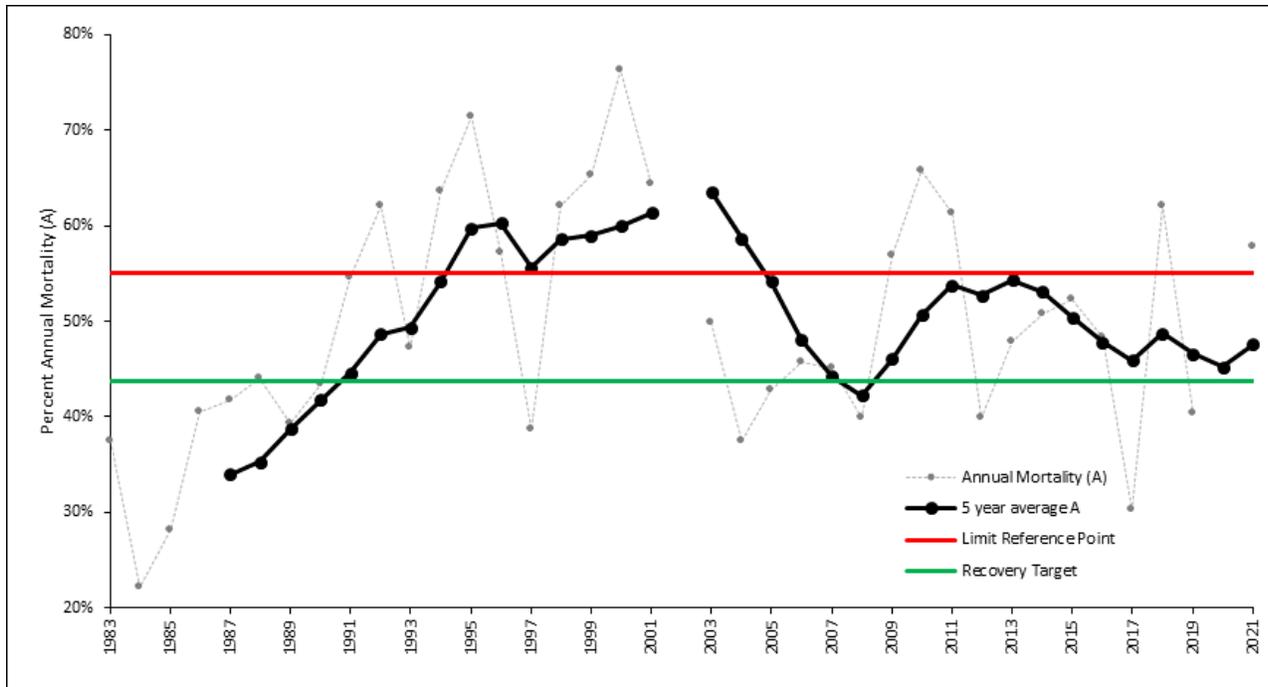


Figure A. Annual mortality of Hudson River adult American shad females. Includes Recovery Target and Limit Reference Point.<sup>1</sup>

### Annual Adult Female Spawning Stock Biomass Benchmark

- Recovery Target: SSB index value equal to 57.39
- Limit Reference Point: SSB index value equal to 30.61

We identified a Recovery Target for annual adult female SSB that is consistent with the short-term objective identified previously. Specifically, our Recovery Target, equal to 57.39, is the mean SSB from 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, the years from 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 kilograms) was the best metric to reduce the influence of outlier years.

<sup>1</sup> As noted in the text under the subheading Annual Adult Female Mortality Benchmark (A), during final revisions of this plan, an error in annual mortality (A) in 2018 was identified. Due to a transcription error, the previously reported A in 2018 of 77% should have been 62%.

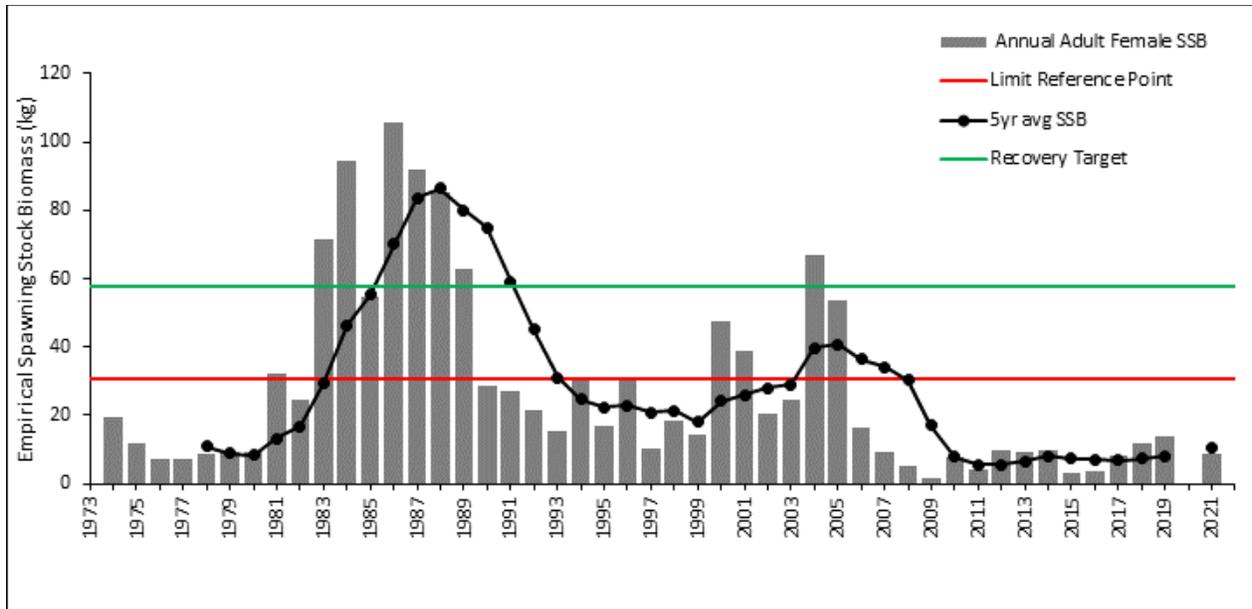


Figure B. Spawning stock biomass of Hudson River adult American shad females. Includes Recovery Target and Limit Reference Point.

**Annual Juvenile Abundance Index Benchmark**

- Recovery Target: JAI equal to 28.28 fish/haul
- Limit Reference Point: JAI equal to 8.32 fish/haul

We identified a Recovery Target for the 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 from 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 recur. 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 before the stock collapse, from 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.

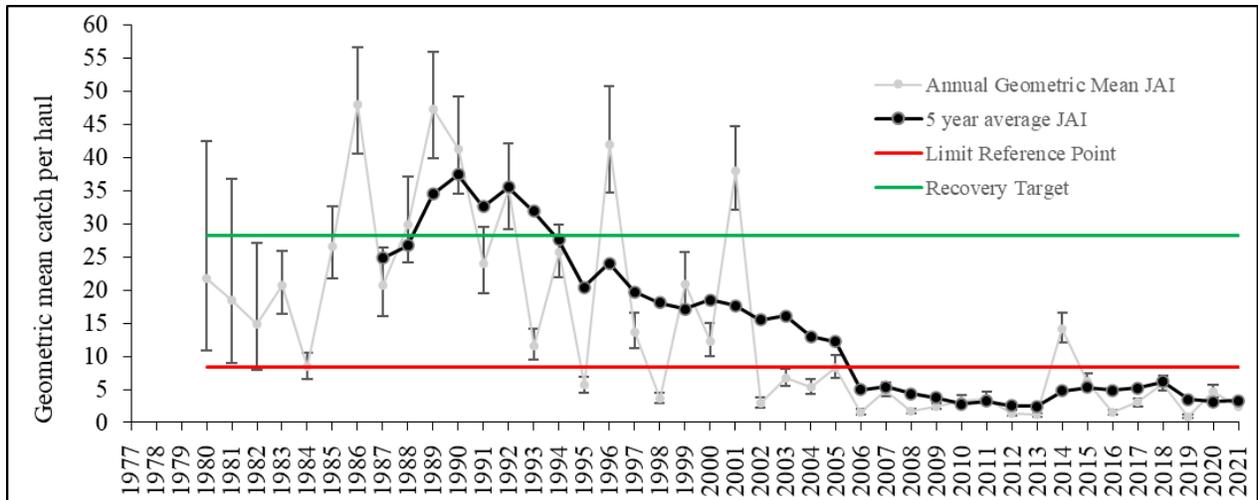


Figure C. JAI for Hudson River YOY American Shad. Includes Recovery Target and Limit Reference Point.

## 7 HUDSON RIVER FISHERIES AND REOPENING 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 with 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 pastime 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 2010, in response to the troubling results of the 2007 American shad ASMFC stock assessment, the DEC closed all fishing for American shad. All commercial and recreational fisheries, C&R angling, were prohibited in the Hudson River and tributaries.

### Recreational Catch-and-Release

C&R recreational angling is the fishery that poses the least threat to the recovery of American shad, and it does not require ASMFC approval to implement. There is no current 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 C&R shad fishing is perceived to be low, perhaps as low as 1.65% (Millard et al. 2003). Regardless, all fisheries—including C&R—were closed in 2010 to maximize the pace of recovery for American shad.

We propose to re-open the C&R 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 5-year average annual mortality (A) must be less than 49.5% for 3 consecutive years. This C&R 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 5-year average JAI value must exceed 8.32 fish/haul or the running 5-year average SSB value must exceed 30.61 kg. By meeting this combination of stock indicators, the population will be able to continue recovering despite any modest increase in mortality caused by a C&R fishery.

**Recreational Catch-and-Release Reopening Criteria:**

- 5-year average annual mortality (A) < the C&R Threshold (49.5%) for 3 consecutive years
- 5-year average female SSB > 30.61 or 5-year average JAI > 8.32 fish/haul

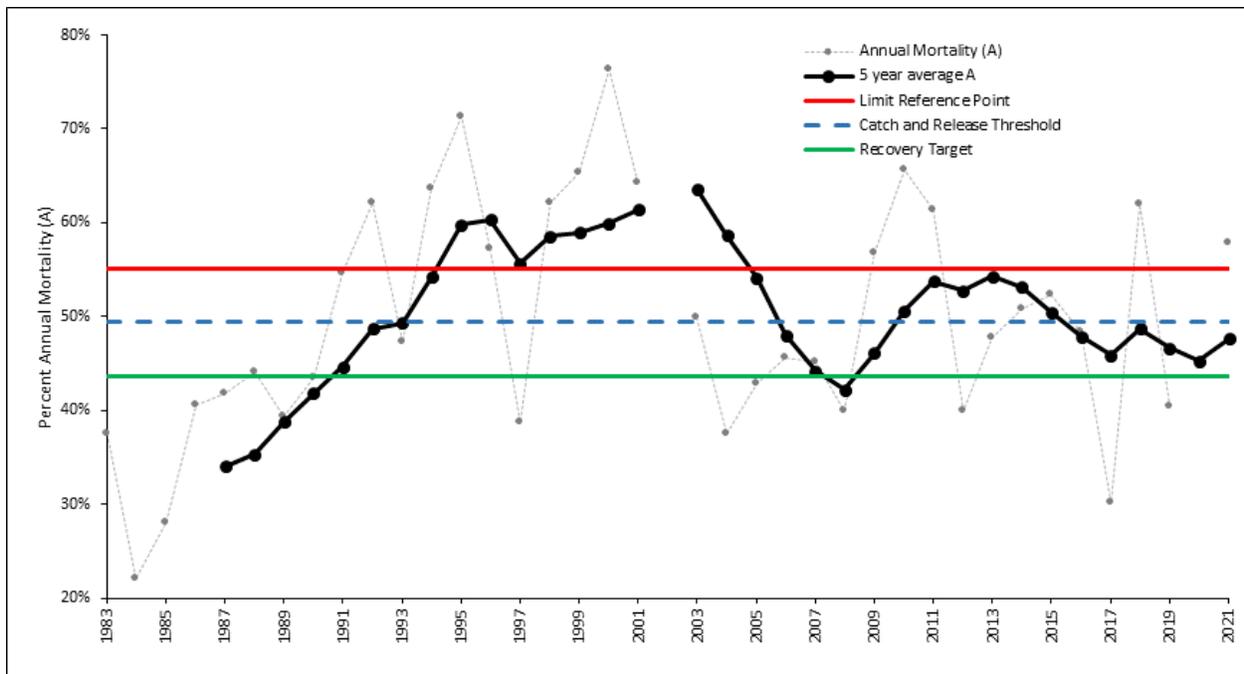


Figure D. Annual mortality of Hudson River adult American shad females. Includes Recovery Target, Limit Reference Point and Catch-and-Release re-opening Threshold. To re-open C&R fishery, the running five-year average annual mortality rate must be below the Catch-and-Release Threshold for three consecutive 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 we feel it is important to specify when harvest would again be appropriate.

Carefully monitored recreational and commercial harvest of American shad in the Hudson River can begin when all three benchmarks reach the Recovery Target.

Recreational and Commercial Harvest Reopening Criteria:

- 5-year mean annual mortality (A) < 44%, and
- 5-year mean SSB > 57.39, and
- 5-year mean JAI > 28.28 fish/haul

We propose that any reopened portion of the fishery can remain open as long as these reopening criteria for that fishery 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 or processing problems will have to be considered on a case-by-case basis.

Prior to any recreational or commercial harvest of shad in the Hudson River, New York State 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 an SFMP and submit it 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, such as 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 river's shad fisheries and through reduced mortality at 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 River 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 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.

### **A. MAINTAIN HUDSON RIVER MONITORING PROGRAMS**

Implementation of the Hudson River shad fishery management strategy requires that DEC 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 for the adaptive management of this stock.

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

**ACTION:** Conduct annual DEC sampling and support other programs to monitor the JAI, spawning stock demographics, and adult mortality rate of American shad. DEC will publish data and recovery metrics at <https://www.dec.ny.gov/animals/62510.html> by August 1 of the calendar year for the previous year's survey data.

## **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 historically taken in directed commercial fisheries from New England to Virginia. It is not known to what extent 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 ASMFC, the New England Fishery Management Council (NEFMC), and the MAFMC 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 River 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 and NE large mesh gill nets, and Delaware Bay large mesh gill nets.

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

**ACTION:** Incorporate recent genetic studies into the development of future Delaware River SFMPs 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 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 Federal 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 while requiring minimum passage standards mentioned in Section 2, or—if passage standards cannot or are not achieved—by preventing access of American shad to the structures.

### **F. HABITAT RESTORATION**

DEC published the *American Shad Habitat Plan for the Hudson River* in 2021, as required by the ASMFC. 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:** Better understand and mitigate impacts of climate change on the Hudson River American shad stock.

*RECOVERY PLAN FOR HUDSON RIVER AMERICAN SHAD*

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

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 impacts of disease and pathogens.

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## APPENDIX 1. ADDITIONAL TABLES AND FIGURES

### Tables

Table 1. Annual and multiyear mean measures of adult Hudson River American shad female mortality and spawning stock biomass, and juvenile abundance

Year	Adults				Juveniles	
	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	62%	49%	11.84	7.20	5.87	6.15
2019	40%	47%	13.76	8.02	0.92	3.50
2020		45%			4.59	3.19
2021	58%	48%	8.58	10.54	2.36	3.35
Recovery Targets		44%		57.39		28.28
Limit Reference Points		55%		30.61		8.32

## Figures

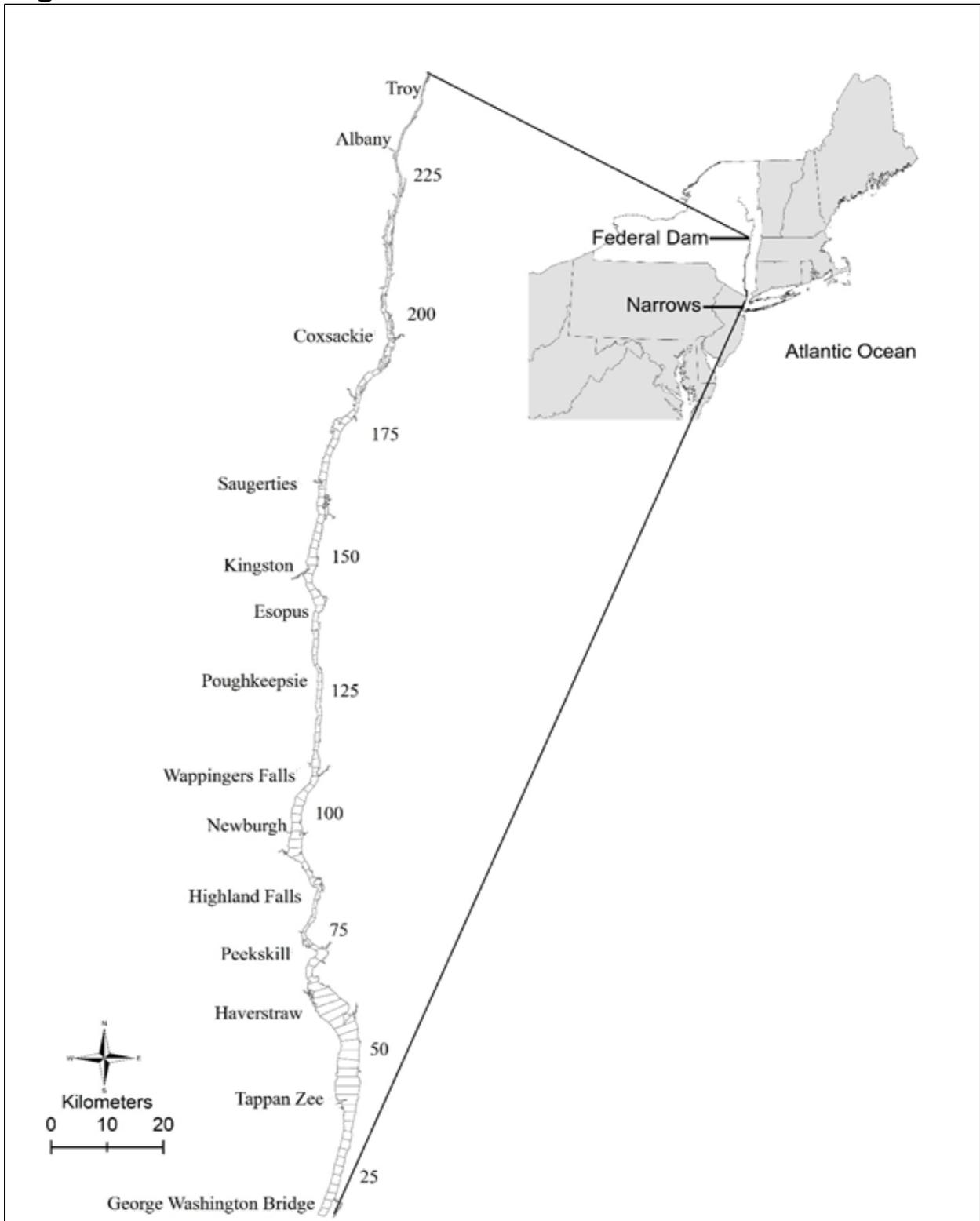


Figure 1. Hudson River Estuary, New York

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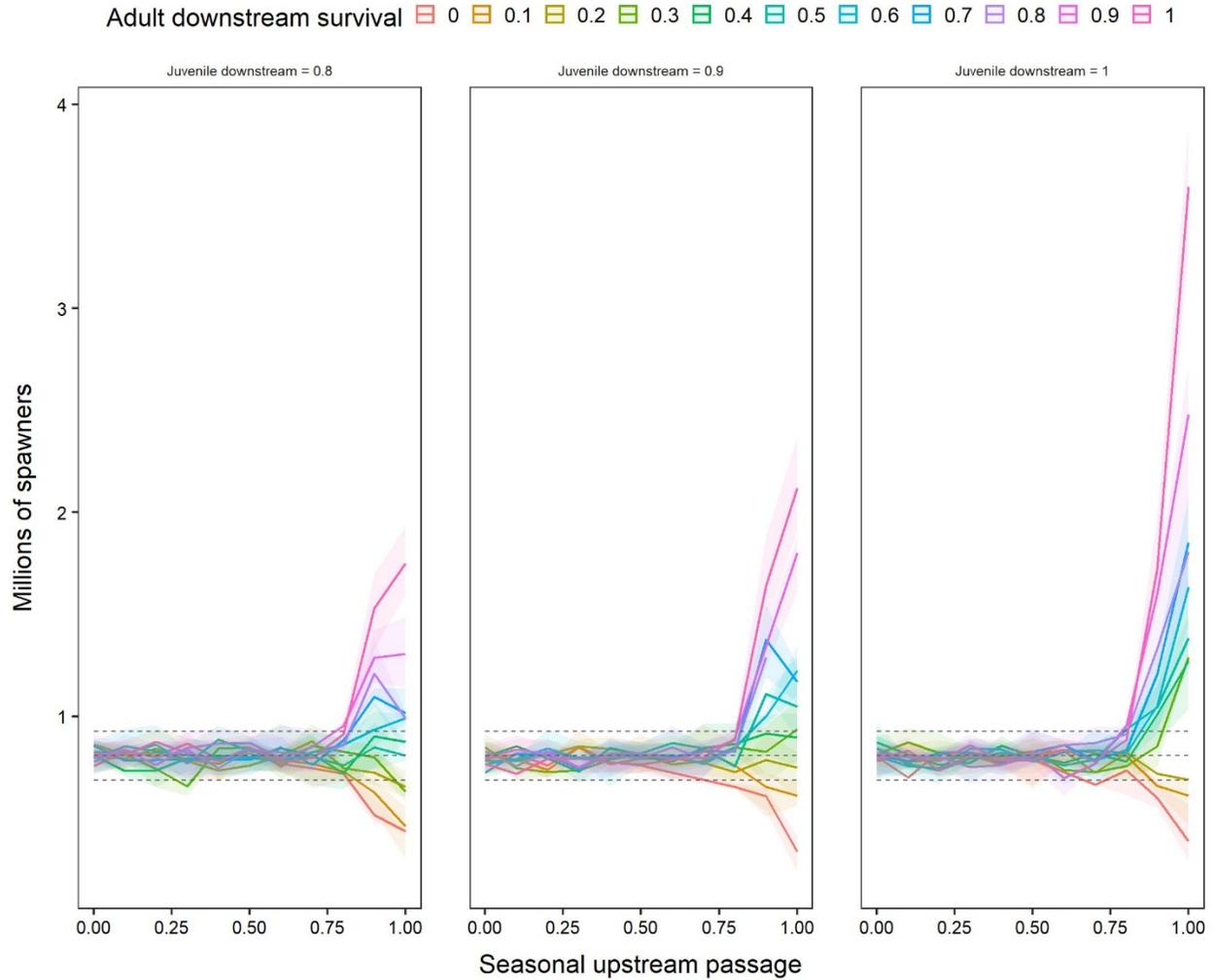


Figure 2. Predicted spawner abundance as a function of upstream seasonal (20-d) passage rates, and downstream survival of adults and juveniles through dams. The middle dashed line indicates the average predicted population size in the absence of upstream fish passage and outer dashed lines are 95% confidence intervals. The solid, colored lines are mean predicted abundance for each scenario, and the semi-transparent polygons are 95% confidence intervals across all runs for each combination of parameters.

RECOVERY PLAN FOR HUDSON RIVER AMERICAN SHAD

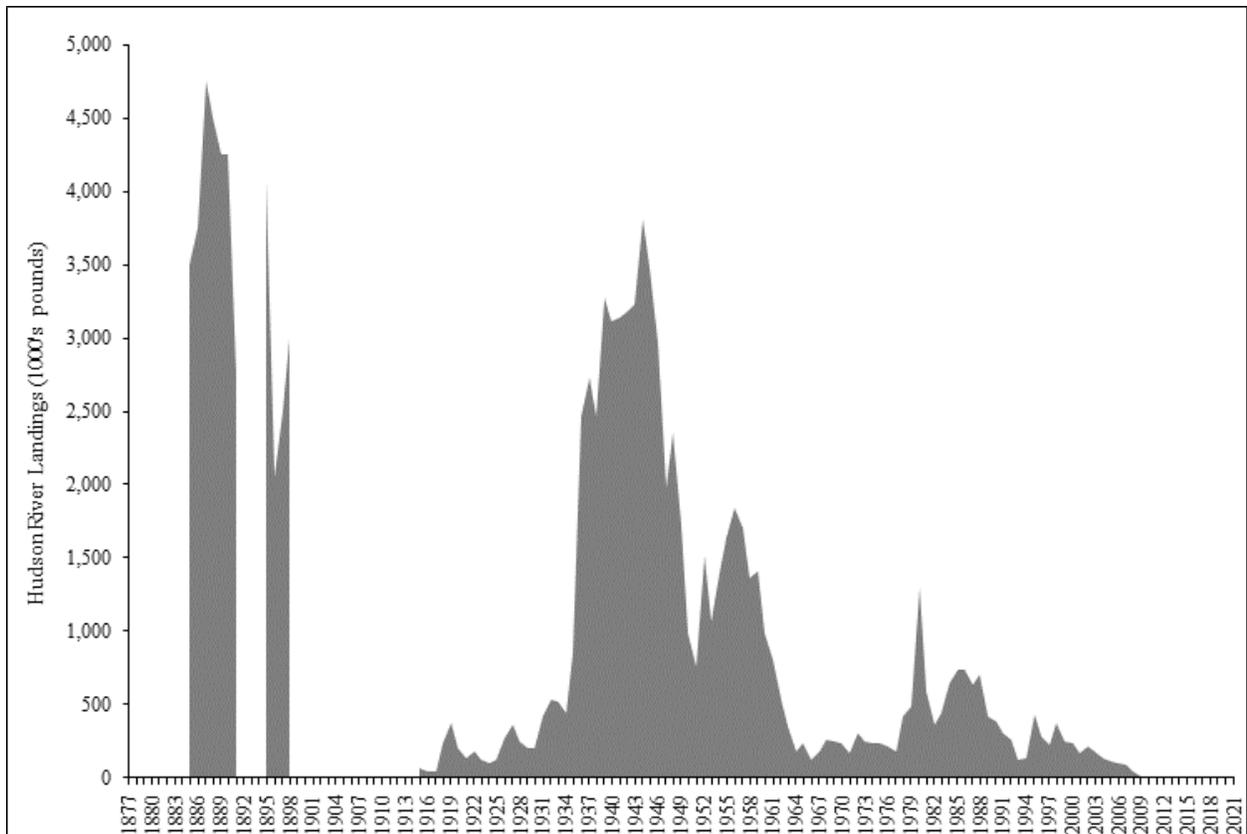


Figure 3. Historic commercial fishery landings of American shad in the Hudson River Estuary, 1880–2019. Fishery closure 2010–present.

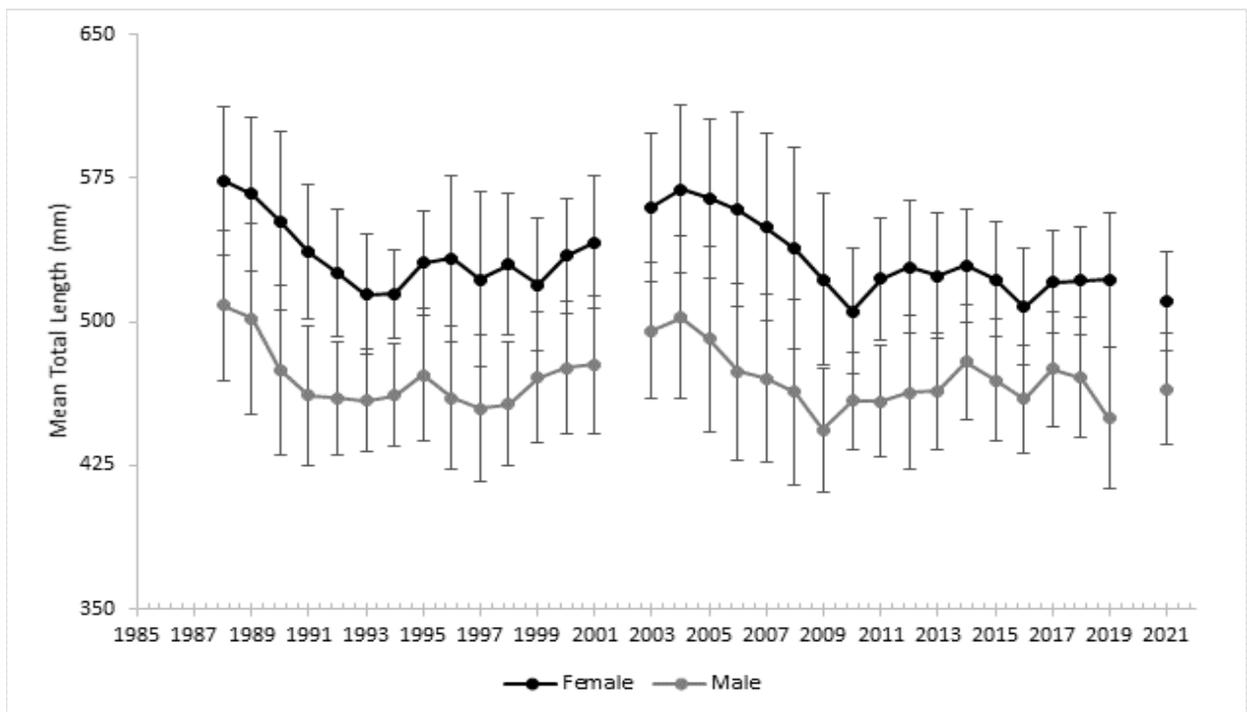


Figure 4. Mean total length of American shad collected in the Hudson River during fisheries independent sampling. Error bars  $\pm$  1 SD

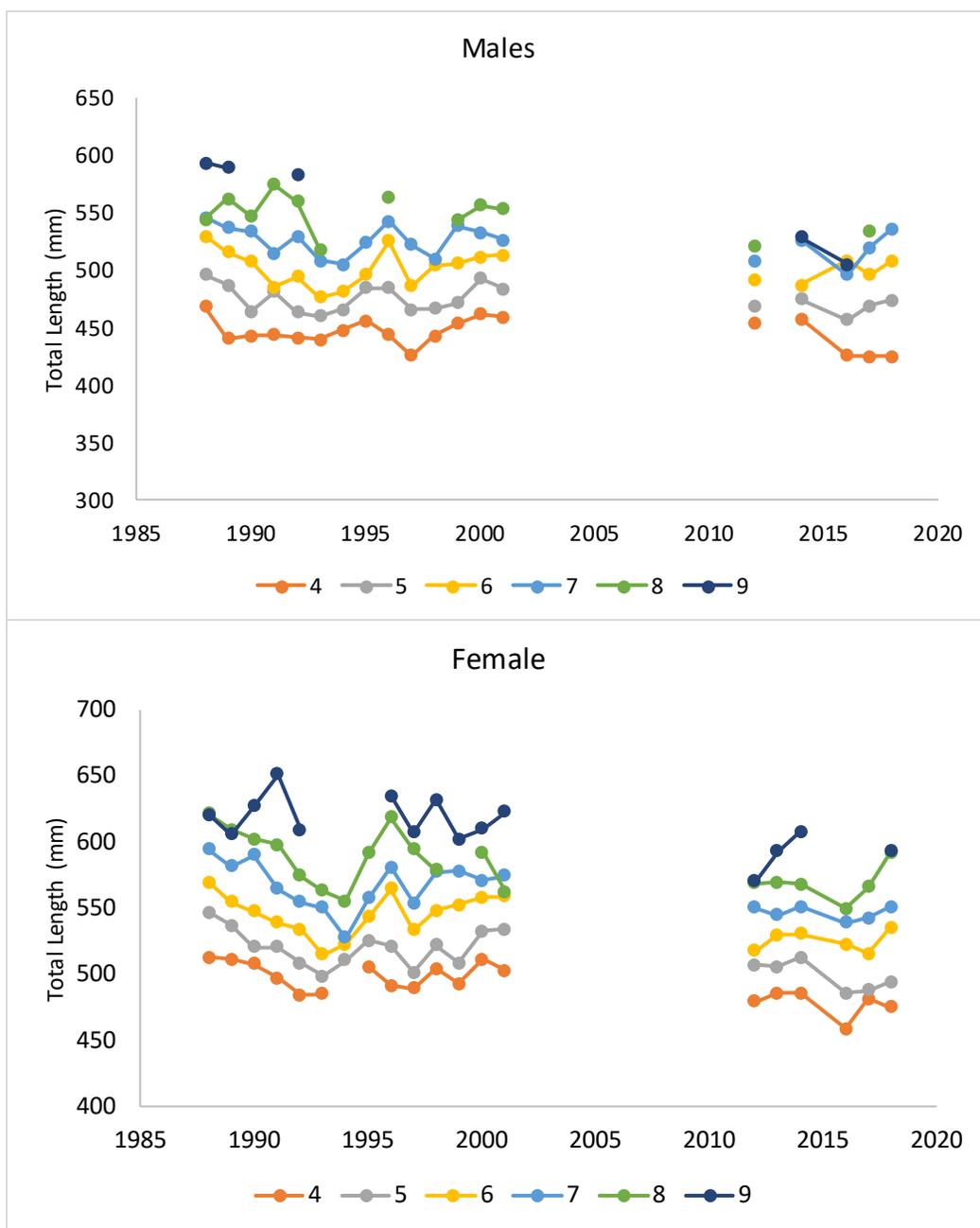


Figure 5. Mean total length at age for ages 4 to 9 of male (top) and female (bottom) American shad collected in the Hudson River during fisheries independent sampling. Ages less than 4 and greater than 10 excluded due to low sample sizes.

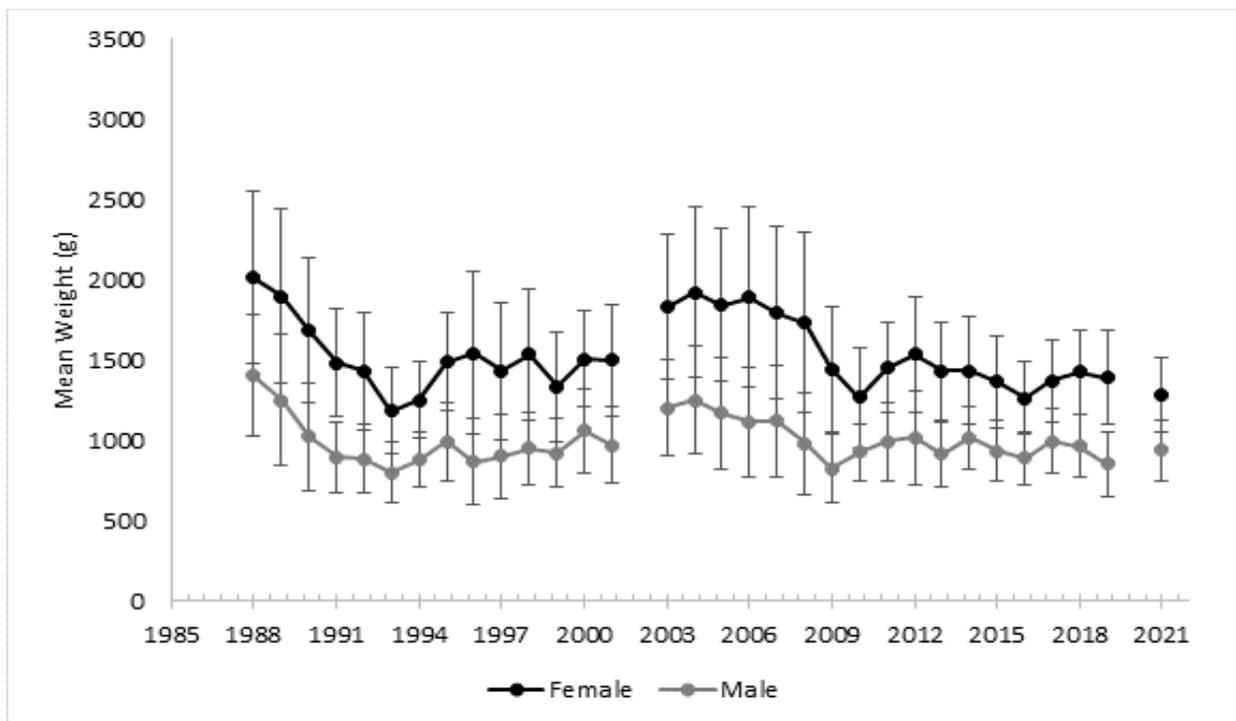


Figure 6. Mean total weight of American shad collected in the Hudson River during fisheries independent sampling. Error bars  $\pm$  1 SD

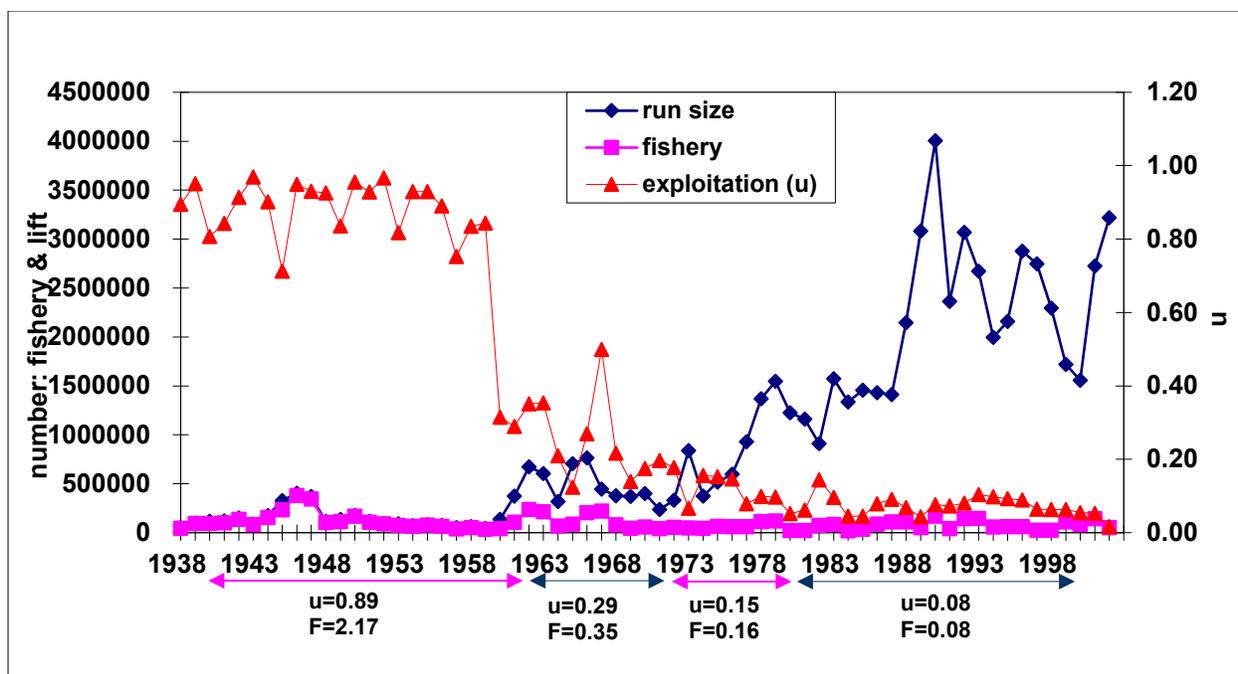


Figure 7. Comparison of fisheries harvest versus run size of American shad in the Columbia River, Oregon/Washington (from ASMFC, 2007a).

## APPENDIX 2. SUMMARY OF COMMENTS RECEIVED ON THE DRAFT RECOVERY PLAN FOR HUDSON RIVER AMERICAN SHAD

DEC received written comments from 9 individuals and organizations and comments by phone from 2 individuals during the 60-day public comment period (March 2–May 2, 2022). Availability of the draft plan was announced via DEC press release, DEC website, the statewide Environmental Notice Bulletin, and social media. All comments received were either addressed in the revised plan or are responded to below.

Most comments expressed general support for restoring the Hudson River American shad stock. We reviewed the content of each comment, grouped similar comments, and organized them by issue. Most responses below are in reply to unique comments from individual commenters. Topics or comments repeated by multiple people are otherwise noted. Editorial comments were also incorporated into the final draft, and these changes are summarized at the end of the appendix.

### Habitat Connectivity and Fish Passage

Comment Summary: Remove dams on tributaries to the Hudson River, namely the Eddyville dam on the Rondout Creek, to improve habitat connectivity and access to spawning grounds for migratory fish.

Response: DEC’s Hudson River Estuary Program and the New York State Water Resources Institute have conducted studies to inform local dam removal efforts in the Hudson River watershed. These projects are ongoing, as DEC and collaborators actively work to improve habitat connectivity through the removal of dams with willing dam owners and with ecological and societal benefits. Removal of the Eddyville Dam is known to be a priority restoration project, and was considered as part of the USACE Hudson River Habitat Restoration Recommended Projects feasibility report and environmental assessment. Removal of Eddyville Dam on the Rondout Creek was removed from the recommended plan after substantial public feedback and owner disinterest (2020).

Comment Summary: The position DEC takes regarding fish passage at the Green Island Hydropower facility (Hydroelectric Station) is too narrow, and the associated Recommendations exclude consideration of benefits of fish passage to other species. Instead of recommending passage be prevented, the Plan should recommend efficient passage and include fishway performance standards necessary to realize benefits for the shad population.

Response: This recommendation was written specifically regarding American shad passage at the Federal Dam and was based on high downstream mortality rates from the 2020 stock assessment. To clarify this point and avoid the erroneous assertion that all fish passage structures have adverse impacts on fish recovery, the language was modified accordingly and additional information about alosine passage standards was incorporated.

### Historical Data and Shad Decline:

Comment Summary: Two commenters mentioned that data for 2020 are not shown in the figures for annual mortality or spawning stock biomass, and 2021 data are not shown in any figures. Understanding trends in the stock are not possible without all the information.

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Response: Due to the COVID-19 pandemic, the adult spawning stock survey did not occur in 2020, so data are unavailable for that year. The Alosine Beach Seine survey did take place in 2020 and values are shown in Figure C. Data from 2021 were not yet analyzed by the draft publication date of March 2, 2022, but all 2021 data are now available and are shown in the figures and content of the revised plan.

Comment Summary: Nutrient loads from sewage releases in the current Hudson River system are far less than in the early 20th century and even the late 1900s when shad recruitment was higher and the spawning stock was more abundant. Since the Hudson River cannot return to its former state with higher nutrient loading from sewage and more shad, it should be managed like other rivers in clearer systems.

Response: Primary production in the Hudson River depends on several environmental variables beyond nutrient loads, including freshwater discharge, water residence time, and turbidity from clay and silt. Although nutrients from sewage have decreased in the past several decades, the Hudson has a unique combination of physical, chemical, and geomorphological characteristics that contribute to primary productivity, as well as a unique trophic system susceptible to unknown impacts by encroaching or newly established invasive species. To ensure the most successful recovery of the Hudson River American shad stock, management will continue to carefully consider the individual impacts to this unique stock. To improve our understanding of relationships between nutrient loads and shad recruitment, this topic may be the focus of future DEC research.

Comment Summary: Predation by other fish appears to be the leading cause of shad decline based on a lack of an obvious relationship between SSB and JAI shown in the figures, so a stocking effort may be one of the last remaining options to bolster stock recovery.

Comment Summary: Stocking should be prohibited as a method to re-establish shad populations because it would be detrimental to the genetic integrity of the stock, for reasons such as introducing maladaptive traits, reducing disease resistance, and producing fish that are ill-equipped to withstand predation in the natural environment.

Response: Although predation on juvenile shad by other species is a source of American shad mortality, insufficient data are available to quantify its magnitude relative to the impact of other issues at the juvenile life stage (nursery habitat availability, food availability, etc.). Regardless of the amount of predation on juveniles, stocking would pose further complications for the stock as described in the “Fish Passage Structures and Stocking Efforts” section. Because the stock is in a depleted state, hatchery spawning and ultimately sacrificing adult shad will reduce genetic diversity and remove individuals from the spawning stock that could otherwise repeatedly spawn in future years in the Hudson River.

### Recovery Planning and Tracking

Comment Summary: DEC and ASMFC actions to reduce shad bycatch in mixed stock fisheries and utilize genetic techniques to understand stock structure and natal fidelity are appropriate for shad recovery planning.

Response: Noted.

Comment Summary: Recovery planning for the Hudson River American shad stock should not be based on arbitrary numerical targets for the population because it doesn't necessarily

account for genetic health of the population. Managers should use the most sophisticated scientific techniques available to assess the health of the stock.

Comment Summary: The modelling and threshold statistics used in this plan for reopening the Catch and Release fishery are unnecessarily complicated for what would be a small fishery with low mortality.

Response: The metrics used in this plan for shad recovery are also used in many recent stock assessments and fishery management plans by ASMFC, MAFMC, NEFMC, Pacific Fishery Management Council, Northwest Atlantic Fisheries Organization, and Western Central Atlantic Fishery Commission. DEC will continue to monitor and develop the most effective monitoring and management methods and will apply them to American shad management as appropriate.

Comment Summary: Explain the manner and frequency that future data for the Hudson River shad stock will be presented, and whether it will be conducted independently of the coastwide stock assessments.

Response: DEC will calculate the three recovery metrics outlined in the plan on an annual basis. These metrics are all calculated using data collected by DEC. This will happen independently of stock assessments conducted coastwide through the ASMFC. DEC will publish data and recovery metrics at <https://www.dec.ny.gov/animals/62510.html> by August 1 of the calendar year for the previous year's survey data.

#### Reopening of Catch-and-Release Fishery

Comment Summary: Explain the justification for closure of the Catch and Release (C&R) shad fishery, what management objectives have been accomplished since then, and whether or not continued closure is warranted.

Response: As described in the plan, in 2010 the recreational and commercial shad fisheries in New York closed due to the collapse of the stock and to prevent further decline of the Hudson River stock. Since 2010, annual shad monitoring in the Hudson River has continued alongside additional initiatives, including improved bycatch monitoring and bycatch caps in coastal fisheries, genetic studies to better understand Hudson River shad stock origins, and reduced juvenile mortality at industrial cooling facilities along the river. These actions have bolstered our understanding of the stock and reinforced the need for continued C&R closure until there are improvements in the indices generated through routine monitoring.

Comment Summary: Three commenters explained that DEC should open the C&R Fishery immediately because shad mortality from C&R fishing would be very low and the stock recovery goals are unrealistic because the river has changed in the past 100 years. Establishing the thresholds as described in the plan amounts to preventing the C&R fishery from ever reopening, thereby keeping the public from engaging with what could be a beneficial and sustainable shared resource.

Comment Summary: One commenter said that the C&R fishery should not be reopened after limited metrics of recovery. There are better ways to increase public engagement with shad than allowing fishing, for example social media and community science, as this would create more widespread awareness without harming shad.

Response: A priority for DEC is to open a C&R fishery once reopening criteria are met, as described in the plan in Section 7. To date, those criteria have not been met.

American shad not only serve a crucial ecological role in the Hudson River Estuary but also as a highly sought-after fish by recreational anglers. It is the DEC's responsibility to consider all stakeholders and user groups during the development of the American shad recovery plan. This means developing recovery targets and reopening criteria that will allow for stock recovery while providing recreational anglers the opportunity for a sustainable C&R fishery. We feel once C&R reopening criteria are met, any mortality associated with a C&R fishery will not diminish or hinder stock recovery goals as described in Section 5.

Comment Summary: Catch and Release fishing is problematic for shad, and should remain prohibited, for the following reasons:

- Proper handling and release of fish is impossible to standardize.
- Release mortality is likely higher than reported in the Millard et al. study because of issues with the experimental design and statistical analysis.
- Handling stress from capture during migration could induce skipped spawning in shad.

Comment Summary: Shad angling mortality is so low that reopening the Catch and Release fishery immediately is justified. Using a scenario where the 2001 and 2005 shad recreational fisheries were conducted under Catch and Release fishery rules and the discard mortality rate of 1.6% holds true (from Millard et al. 2003), the Catch and Release fishery would have resulted in a negligible level of shad mortality at 132 shad each year.

Response: A priority for DEC is to open a C&R fishery once reopening criteria are met as described in Section 7 of the plan. To date, those criteria have not been met.

While mortality rates in historic studies suggest that C&R mortality is less than 3% (Millard et. al 2003), we feel this is likely an underestimate due to issues encountered during the study. The main issue is that the study ended in early May (due to equipment failures associated with holding tanks) while water temperatures were still relatively low. Additionally, the authors noted that all observed mortalities occurred in the latter half of the study when water temperatures exceeded 12 degrees Celsius (C). American shad are very sensitive to stress of any kind and that sensitivity increases with increasing water temperature. Therefore, had the study continued to adequately cover the entirety of the fishing season (April–early June) when water temperatures frequently exceed 17 degrees C, the C&R mortality would likely have been greater than reported. Based on the rationale above and given the current stock status described in Section 4, we do not support adding additional sources of mortality until reopening criteria are met.

Comment Summary: Threshold measures for recovery and recent trends in the data suggest fishery closure has not helped Hudson River shad recovery to date. How will keeping the C&R fishery closed do anything to help?

Response: A Hudson River American shad C&R fishery will likely result in a relatively small amount of additional mortality on the Hudson River stock of American shad. However, given the current status of the stock, as outlined in Section 6: Recovery Benchmarks, we do not support adding additional sources of mortality at this time. This plan outlines the recovery metrics required to reopen a C&R fishery. Generally, this

includes a sustainable mortality rate and an improvement in spawning stock biomass or recruitment (See Section 6, Figures A and B).

Comment Summary: Require barbless hooks upon reopening of the C&R Fishery to reduce mortality.

Response: Barbless hooks minimize handling stress and reduce release mortality and will be considered as a viable regulatory measure to improve survival if the C&R fishery reopens in the future.

Comment Summary: Make it clear that C&R does not require an ASMFC-approved sustainable fishery management plan.

Response: The description of C&R fishery reopening requirements was expanded to clarify this point in Section 2, "Causes of Decline."

Plan Content

Comment Summary: Some of the background information has appeared in previous plans for American shad in the Hudson River. One commenter suggested moving background information to an appendix or link on the DEC website.

Response: Because literature relevant to American shad has been updated and expanded since previous plans were written, relevant background information will remain included to make this plan accessible to all readers whether or not they are familiar with previous American shad plans.

Comment Summary: Change title from Hudson River to Hudson Estuary.

Response: Although American shad migrate through the tidal Hudson Estuary, the plan name will remain "Hudson River" for consistency with other DEC American shad management plans, including the American Shad Habitat Plan for the Hudson River.

**Log of Changes:**

<b>Page</b>	<b>Section</b>	<b>Change</b>
4	Executive Summary	Added "the short-term objective is to reopen the catch-and-release (C&R) fishery"
7	Overfishing	Added "though an SFMP is not required for C&R fishing"
8	Harvest Continues	Updated Delaware River Sustainable Fishing Plan for American Shad reference from "2016" to "2022"
9	Habitat Alteration	Changed "Stich et al. 2022 (manuscript in prep)" to "analysis presented in this plan"
11	Climate Change	Added "the salt front is advancing northward"
12	Climate Change	Added "Climate change serves as a threat multiplier for American shad by exacerbating anthropogenic and ecological stressors"

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Page	Section	Change
12	Climate Change	Added “Floodwaters convey contaminants, which could have further impacted regeneration” and in “negative impacts to American shad <i>are likely</i> . In addition to <i>habitat damage...</i> ”
12	Fish Passage and Stocking Efforts	Added “we believe that the installation of structures in the main-stem Hudson River have the potential to be a threat to shad recovery”
13	Fish Passage and Stocking Efforts	Added passage performance standards assessment section beginning with “Simulations for American shad” and ending with “passage criteria may change to achieve the goals and objectives of this plan.”
15	Spawning Stock Sampling	Changed “km” to “rkm” and changed “capture” to “assess.”
15	Young of Year Sampling	Changed “standard” to “fixed.”
16	Current Stock Status	Shifted appendix figure numbers up by one (e.g. changed “Figure 2” to “Figure 3”, etc.).
16	Current Stock Status: Summary	After reviewing recent mortality data, a transcription error was identified for the 2018 mortality estimate. As a result “in recent years (2017–2019 and 2021) mortality has increased” changed to “remained relatively stable since the mid-2000s.”
18	Recovery Benchmarks	In sentence “Limit Reference Points (Limits) ,” added “further declines.” To final sentence of the paragraph, changed “recreational and commercial harvest” to “controlled recreational and commercial fisheries.”
19-21	Recovery Benchmark Figures	Data from 2021 annual monitoring were not available when the Draft Recovery Plan was published, but was added to each recovery benchmark figure and associated text.
18-19	Annual Adult Female Spawning Stock Biomass Benchmark	Added explanation of data modification to text (p.18) and footnote (p.19): “During final revisions of this plan, an error in annual mortality (A) in 2018 was identified. Due to a transcription error, the previously reported A in 2018 of 77% should have been 62%.”
20	Recovery Benchmarks	Added DEC website link where annual monitoring survey results can be found
21	Shad Fisheries on the Hudson	Corrected reference of ASMFC American Shad stock assessment to “2008” to “2007” and adjusted DEC shad fishery closure from “2009” to “2010” for clarity, as the closure approval in late 2009 applied to what would have been the 2010 shad fishing season.
21	Recreational Catch-and-Release	Added to opening statement about catch-and-release “...it does not require ASMFC approval to implement.”
21	Recreational Catch-and-Release	Added “perceived to be.”
22	Recreational Catch-and-Release	Changed “2009” to “2010” for clarity regarding the closure of shad C&R fishery. The closure, approved in

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Page	Section	Change
		late 2009, applied to what would have been the 2010 shad fishing season.
22	Recreational Catch-and-Release	Modified wording of last sentence to clarify plan objective related to reopening the C&R fishery: "By meeting this combination of stock indicators, the population will be able to continue recovering, despite any modest increase in mortality caused by a catch-and-release fishery."
22	Recreational Catch-and-Release	Added "<" to Recreational Catch and Release Reopening Criteria, where symbol was missing: Five-year average annual mortality (A) < the Catch and Release Threshold (49.5%) for three consecutive years.
24	Recommendations: A	In action, changed "age structure" to "demographics."
24	Recommendations: A	Added DEC website link where annual monitoring survey results can be found.
25	Recommendations: B	In second action, changed "the 2021" to "future," as the incorporation of genetic studies to the Delaware River Sustainable Fishery management are ongoing.
25	Recommendations: E	In second action, expanded explanation of passage standards: "This may be accomplished by either improving the design of passage structures while requiring minimum passage standards mentioned in Section 2, or—if passage standards cannot or are not achieved—by preventing access of American shad to the structures."
26	Recommendations: G	In objective, added "Better understand and mitigate."
27-32	References	Added additional and newly published references associated with editorial changes made since release of draft plan.