Greater Atlantic Region Policy Series [23-04]

# River Herring Habitat Conservation Plan

Benjamin German

Jonathan Watson

Matthew Best

# Abstract

This habitat conservation plan highlights the needs, opportunities, and challenges to restore river herring habitat and the populations they support throughout their U.S. Atlantic coast range. The executive summary included in this document outlines its contents in greater detail. Ultimately, by pursuing the plan goals, objectives, and actions, we seek to restore river herring throughout their native ranges to healthy, viable populations that support a broad array of social and ecological functions. The realization of this overall goal would include enhancing the productivity of spawning and rearing habitats such that it is not a significant factor limiting recovery.

## Keywords

River herring, habitat, conservation, restoration, anadromous, fish passage, climate change

**The Greater Atlantic Policy Series is a secondary publication series based in the NOAA Fisheries Greater Atlantic Regional Fisheries Office in Gloucester, MA. Publications in this series include works in the areas of marine policy and marine policy analysis. Please visit https://www.greateratlantic.fisheries.noaa.gov/policyseries/ for more information.**

**This document may be cited as:**
**German, B., Watson, J., Best, M., 2023. River Herring Habitat Conservation Plan. *Greater Atlantic Region Policy Series [23-04]. NOAA Fisheries Greater Atlantic Regional Fisheries Office - https://www.greateratlantic.fisheries.noaa.gov/policyseries/*347 *p.***

Acknowledgements

Significant contributions were provided by the following technical working group, which consisted of staff from NOAA Fisheries Restoration Center (RC), Southeast Region (SER), Greater Atlantic Region (GAR), and the Atlantic States Marine Fisheries Commission (ASMFC): Christopher Boelke (NOAA Fisheries GAR), James Boyle (ASMFC), John Catena (NOAA Fisheries RC), Twyla Cheatwood (NOAA Fisheries SER), Lou Chiarella (NOAA Fisheries GAR), Fritz Rohde (NOAA Fisheries SER), Howard Schnabolk (NOAA Fisheries RC), Caitlin Starks (ASMFC), and James Turek (NOAA Fisheries RC).

Additional contributors included: James Boyle (ASMFC), Steve Gephard (Connecticut Department of Energy and Environmental Protection, retired), Wilson Laney (North Carolina State University), Sean McDermott (NOAA Fisheries Alaska Region), Valerie Ouellet (Integrated Statistics), Bill Post (South Carolina Department of Natural Resources), Roger Rulifson (East Carolina University), Ken Sprankle (U.S. Fish and Wildlife Service), Tara Trinko-Lake (NOAA Fisheries Northeast Fisheries Science Center), and Alan Weaver (Virginia Department of Wildlife Resources). Several additional reviewers, including Alison Bowden (The Nature Conservancy), David O'Brien (NOAA Fisheries GAR), and Kate Swails (NOAA Fisheries) provided feedback that improved the quality of the manuscript.

Funding for this plan was made available by NOAA Fisheries Office of Habitat Conservation

Table of Contents

## List of Figures

## List of Tables

List of Acronyms and Initialisms

| | |
|---|---|
| **ACFHP** | Atlantic Coastal Fish Habitat Partnership |
| **AMP** | Alternative Management Plan |
| **AOP** | Aquatic Organism Passage |
| **APCC** | Association to Preserve Cape Cod |
| **APNEP** | Albemarle-Pamlico National Estuary Partnership |
| **ARRA** | American Recovery and Reinvestment Act |
| **ASMFC** | Atlantic States Marine Fisheries Commission |
| **BMPs** | Best Management Practices |
| **BRWC** | Blackstone River Watershed Council |
| **CBP** | Chesapeake Bay Program |
| **CCE** | Cornell Cooperative Extension |
| **CFRP** | Cape Fear River Partnership |
| **CN** | Canada |
| **CPUE** | Catch-per-unit-effort |
| **CRASC** | Connecticut River Atlantic Salmon Commission |
| **CRC** | Connecticut River Conservancy |
| **CRMC** | Coastal Resources Management Council |
| **CRT** | Coonamessett River Trust |
| **CRWA** | Charles River Watershed Association |
| **CTDEEP** | Connecticut Department of Energy and Environmental Protection |
| **CYCC** | Chequessett Yacht and Country Club |
| **DNA** | Deoxyribonucleic Acid |
| **DO** | Dissolved Oxygen |
| **DOC** | Dissolved Organic Carbon |
| **DOT** | Department of Transportation |
| **DRBC** | Delaware River Basin Commission |
| **DRBFWMC** | Delaware River Basin Fish and Wildlife Management Cooperative |
| **DU** | Ducks Unlimited |
| **DWCF** | Delaware Watershed Conservation Fund |
| **eDNA** | Environmental DNA |
| **EEP** | Ecosystem Enhancement Program |
| **EPA** | Environmental Protection Agency |
| **ESA** | Endangered Species Act |
| **FEMA** | Federal Emergency Management Agency |
| **FERC** | Federal Energy Regulatory Commission |
| **FFWCC** | Florida Fish and Wildlife Conservation Commission |
| **FMP** | Fishery Management Plan |
| **FPA** | Federal Power Act |
| **GAR** | Greater Atlantic Region |
| **GDNR** | Georgia Department of Natural Resources |
| **GIS** | Geographic Information Systems |
| **GOM** | Gulf of Maine |
| **HCD** | Habitat Conservation Division |

| | |
|---|---|
| **HCP** | [River Herring] Habitat Conservation Plan |
| **HREP** | Hudson River Estuary Program |
| **HUC** | Hydrological Unit Code |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **WQR** | Integrated Water Quality Report |
| **KHDG** | Kennebec Hydropower Developers Group |
| **LOMR** | Letter of Map Revision |
| **MADFW** | Massachusetts Division of Fisheries and Wildlife |
| **MAFMC** | Mid-Atlantic Fishery Management Council |
| **MCCF** | Maine Center for Coastal Fisheries |
| **MCHT** | Maine Coastal Heritage Trust |
| **MEDEP** | Maine Department of Environmental Protection |
| **MDIFW** | Maine Department of Inland Fisheries and Wildlife |
| **MDMF** | Massachusetts Division of Marine Fisheries |
| **MDMR** | Maine Department of Marine Resources |
| **MDNR** | Maryland Department of Natural Resources |
| **MHC** | Massachusetts Historical Commission |
| **Mid-A** | Mid-Atlantic |
| **MOA** | Memorandum of Agreement |
| **MRTC** | Maine Resources Technical Committee |
| **MSA** | Magnuson-Stevens Fishery Conservation and Management Act |
| **NAD 83** | North American Datum of 1983 |
| **NBEP** | Narragansett Bay Estuary Program |
| **NCDENR** | North Carolina Department of Environmental and Natural Resources |
| **NCDEQ** | North Carolina Department of Environmental Quality |
| **NCDMF** | North Carolina Division of Marine Fisheries |
| **NCDMS** | North Carolina Division of Mitigation Services |
| **NCDWR** | North Carolina Division of Water Resources |
| **NCSU** | North Carolina State University |
| **NE** | New England |
| **NEFMC** | New England Fishery Management Council |
| **NEFSC** | Northeast Fisheries Science Center |
| **NEPA** | National Environmental Policy Act |
| **NFPP** | National Fish Passage Program |
| **NFWF** | National Fish and Wildlife Foundation |
| **NGO** | Non-governmental Organization |
| **NHD** | National Hydrography Dataset |
| **NHFGD** | New Hampshire Fish and Game Department |
| **NHPA** | National Historic Preservation Act |
| **NID** | National Inventory of Dams |
| **NJDEP** | New Jersey Department of Environmental Protection |
| **NJF&W** | New Jersey Fish and Wildlife Service |
| **NLF** | Nature-like Fishway |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NPDES** | National Pollutant Discharge Elimination System |

| | |
|---|---|
| **NRCM** | Natural Resource Council of Maine |
| **NRCS** | Natural Resources Conservation Service |
| **NRDA** | Natural Resource Damage Assessment |
| **NTU** | Nephelometric Turbidity Unit |
| **NYSDEC** | New York State Department of Environmental Conservation |
| **OHC** | Office of Habitat Conservation |
| **PAFBC** | Pennsylvania Fish and Boat Commission |
| **PCBs** | Polychlorinated biphenyls |
| **PFAS** | Per- and polyfluoroalkyl substances |
| **PIT** | Passive Integrated Transponder |
| **PRRP** | Penobscot River Restoration Project |
| **PRRT** | Penobscot River Restoration Trust |
| **RC** | Restoration Center |
| **RIDEM** | Rhode Island Department of Environmental Management |
| **RTRGC** | Roanoke-Tar River Gun Club |
| **SARP** | Southeast Aquatic Resources Partnership |
| **SAV** | Submerged Aquatic Vegetation |
| **SBU** | Stony Brook University |
| **SCDHEC** | SC Department of Health and Environmental Control |
| **SCDNR** | South Carolina Department of Natural Resources |
| **SAFMC** | South Atlantic Fishery Management Council |
| **SER** | Southeast Region |
| **SERC** | Smithsonian Environmental Research Center |
| **SES** | Social-Ecological System |
| **SFMP** | Sustainable Fishery Management Plan |
| **SNE** | Southern New England |
| **SRBC** | Susquehanna River Basin Commission |
| **SVCA** | Sheepscot Valley Conservation Association |
| **TEWG** | Technical Expert Working Group |
| **TNC** | The Nature Conservancy |
| **TOY** | Time-of-year |
| **TU** | Trout Unlimited |
| **UMCES** | University of Maryland Center for Environmental Science |
| **UNF** | University of Florida |
| **URI** | University of Rhode Island |
| **USACE** | United States Army Corps of Engineers |
| **USFWS** | United States Fish and Wildlife Service |
| **USGS** | United States Geological Survey |
| **VDWR** | Virginia Department of Wildlife Resources |
| **VDEQ** | Virginia Department of Environmental Quality |
| **VDHR** | Virginia Department of Historic Resources |
| **WC** | Woodwell Climate Research Center |
| **WHOI** | Woods Hole Oceanographic Institute |
| **WPWA** | Wood Pawcatuck Watershed Association |

## Executive Summary

### *Background – Stock Status, Threats, and Restoration*

River herring (alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis*, collectively) populations are at historic lows throughout most of their ranges (ASMFC 2017a). River herring are keystone species helping to support both marine and freshwater ecosystems. Although NOAA Fisheries recently determined that listing these two species under the Endangered Species Act (ESA) is not warranted at this time, the decision acknowledges the importance of restoring habitat and managing threats associated with climate change and harvest that are exacerbated by depressed abundance (84 FR 28630; June 19, 2019). NOAA Fisheries emphasizes that ensuring connectivity between ocean and freshwater habitats is vital to support the long-term sustainability and growth of river herring populations.

River herring population declines have been driven by a myriad of overlapping and interacting stressors including diminished connectivity between the ocean and spawning and rearing habitats, degraded freshwater and estuarine habitats, fisheries, and climate change. Barriers to fish passage created by dams, culverts, and other human infrastructure are among the most detrimental impacts. Over the past several decades, efforts have been made by many agencies and non-governmental organizations to reverse these declining trends. Persistent low river herring population levels indicate that additional measures are critically needed to restore these species to some semblance of historical abundance.

River herring were once broadly abundant in coastal watersheds, estuaries, and near-shore waters of the western North Atlantic Ocean. Their seasonal abundance, especially springtime fish runs in freshwater and estuarine habitats, supports a variety of vital ecosystem functions. Their migrations link coastal ocean waters with freshwater rivers, lakes, and streams. They serve as prey for many species of mammals, fish, birds, and other animals. Humans have exploited their seasonal abundance for millennia, first by Native Peoples and later, European colonists. These fish offered a source of readily-available protein and, as a result, influenced many social, economic, and cultural aspects of past cultures and communities. More recently, river herring supported extensive commercial and artisanal fisheries throughout their ranges before populations declined precipitously over the latter-half of the 20$^{th}$ century. Today, remnant herring runs provide a sense of place, a connection to the past, and local pride for many communities along the Atlantic coast. River herring stimulate economic vitality in coastal communities through tourism and recreational and commercial fisheries.

Restoration offers the opportunity for organizations and communities to prioritize river herring recovery at the river, watershed, and regional scale that will ultimately contribute to coastwide benefits to herring populations. The portfolio of approaches employed by restoration practitioners includes strategies such as increasing public education and awareness, removing passage barriers to re-establish connectivity to spawning and rearing habitats, improving water quality and other habitat conditions, and implementing science-based management measures, or more drastically, moratoria on fisheries throughout their ranges. To contribute to the effort to restore these iconic species, this River Herring Habitat Conservation Plan (HCP) is a NOAA Fisheries initiative to increase public awareness, stimulate increased impactful restoration and cooperative applied research, and inform efforts to improve both the quantity and quality of available spawning and rearing habitats throughout the range of each species. The HCP provides a review of a range of topics relevant to river herring restoration and management. Much of this information has been compiled from various state, federal, and regional documents with additional agency input. This plan seeks to consolidate this information into one source and provide a foundation for ongoing and future restoration actions. This plan presents this framework and content in a user-friendly format with the intent of fostering strong support from fishery scientists, resource managers, restoration practitioners, fishing communities, and the public. In support of these objectives, this plan focuses on the Atlantic coast range of river herring, approaching these topics at a regional (New England, Mid-Atlantic, Southeast) and watershed scale, with pertinent examples at finer geographic or contextual scales where information is available.

*HCP Overview*

The framework and content of this HCP are intended to take a holistic approach to the history, current status, and future of river herring throughout their estuarine and freshwater life stages. Focal topics seek to address past, present, and future contexts, and include: life history of the species, stock status and fisheries management, threats, information needs, social-ecological benefits of restoration, and an overview of the Atlantic coast watersheds where river herring are present. This HCP culminates with a section dedicated to goals, objectives, and recommendations related to river herring habitat conservation and restoration. Finally, a restoration showcase is included to provide the reader with concrete examples of previous restoration efforts, and the unique circumstances that led to successes (and obstacles) of a selection of projects scattered along the Atlantic coast. For a more in-depth description of the purpose, scope, methodologies, and the development of this plan, please *see Section 1.0 (Introduction to the Plan)*.

The highly-adaptive life history strategy of river herring leads to their capacity to occupy a variety of habitats throughout their expansive Atlantic coast ranges. They can be found at various life stages from the murky, sluggish coastal plain streams of the Southeast, to the fast-flowing rivers of the Northeast, inland lakes and ponds, estuaries, and the open ocean. *Section 2.0 (Life History, Distribution, and Ecological Considerations)* provides a review of the biology, life history, distribution, and related ecological considerations for both species of river herring.

River herring were once an abundant, commercially harvested resource before populations declined. As of 2012, river herring harvest was closed for all states[1] and jurisdictions without an approved sustainable fisheries management plan in place. *Section 3.0 (Stock Status, Fisheries, and Management History)* documents their current stock status, as well as contemporary directed fisheries, a timeline of federal management actions, and an overview of river herring management administered by the Atlantic States Marine Fisheries Commission (ASMFC).

River herring are subject to many threats due to their extensive geographic distribution and diversity of habitats. Many of these threats act synergistically, and several stand out from the long list, including climate change, lost connectivity or poor access to spawning and nursery habitats, poor water quality, at-sea mortality (including bycatch), and predation. These threats have varying degrees of impact based on locality and life stage; a detailed discussion of these factors can be found in *Section 4.0 (Threats to River Herring)*.

Gaps in our collective understanding of river herring throughout their native ranges highlights the need for further study to help mitigate threats and assist in the recovery of these species. These data gaps encompass a wide range of topics including climate change effects, ocean and river fisheries (both current and historical harvest), habitat condition, trophic-level and species

[1] Except ME, NH, and NY, where regulated harvest remained legal.

interactions, population dynamics, and life history strategies. For a summary of data gaps and research needs identified through this effort see *Section 5.0 (Data Gaps and Research Needs)*.

The annual return of river herring to coastal waterways has significant social and economic influence on coastal communities throughout human history, although presently the commercial components have been greatly diminished. *Section 6.0 (Social-Ecological Benefits of River Herring Restoration)* discusses the current and historical socio-ecological benefits associated with river herring.

Effective habitat conservation, enhancement, and restoration actions are framed by historical and current conditions that may be specific to each watershed. Each watershed (or sub-watershed) can present a distinct combination of threats or obstacles to river herring and unique challenges for restoration that should be considered during planning efforts. *Section 7.0 (Watershed Overview and Evaluation of River Herring Restoration Potential)* provides an overview of watersheds that support spawning and rearing habitats for river herring.

*HCP Goals*

The ultimate goal is to restore healthy, sustainable Atlantic coast river herring populations that support a broad array of social and ecological services and functions, with stocks that are no longer designated depleted by ASMFC. In support of this goal, the purpose of the HCP is to serve as a compendium of information on river herring, their varied threats, information gaps, and approaches to management (including conservation and restoration) to enable managers to more effectively increase stock size and genetic diversity while minimizing sources of mortality throughout their coastwide ranges. This document outlines four high-level goals, which were established to provide a framework of recommendations that guide efforts to restore, maintain, and enhance river herring habitats and the populations they support:

- Goal 1: Improve connectivity of river herring habitats throughout the species ranges.
- Goal 2: Assess and enhance spawning and rearing habitats for river herring throughout their coastwide ranges.
- Goal 3: Establish and strengthen partnerships among state and federal agencies, non-governmental organizations (NGOs), tribes, and other river herring stakeholders.

- Goal 4: Address information gaps and research needs where applied research is needed to expand knowledge of river herring related topics.

This plan is focused on near-term management (10-15 years) and the goals and recommendations will be reevaluated and updated as appropriate and as resources allow. River herring habitat conservation goals and recommendations are described in greater detail, with accompanying objectives and action items, in *Section 8.0 (River Herring Habitat Conservation Goals, Objectives, and Recommendations)*.

*Restoration Showcase*

In instances where diadromous fish stocks such as river herring are reduced or depleted, restoration provides opportunity to both restore runs of fishes and the economic and cultural benefits supported by well-functioning ecosystems. The Restoration Project Showcase (see: *Appendix C: Restoration Project Showcase: Techniques, Successes, and Lessons Learned*) describes a collection of restoration projects implemented along the Atlantic coast that demonstrate various approaches for restoring river herring habitat and re-establishing connectivity. The projects were selected in an attempt to represent the diversity of techniques, site conditions, and issues addressed in different regions. This section is designed to provide the reader with successful project examples including techniques used, funding sources, and "lessons learned" that can inform future restoration efforts.

*Conclusion*

In summary, this HCP provides a framework to inform and support efforts for restoring alewife and blueback herring populations throughout their native ranges with a focus on their spawning and rearing habitats. This plan combines information regarding life history, stock status, threats, and data gaps to inform a series of goals and objectives for the recovery of these species. It also collates references for regional/local management plans and describes several restoration project case studies to further inform future initiatives to conserve and enhance river herring populations. Due to the current state of river herring stocks, immediate and strategic action is necessary to restore populations in the face of multiple overlapping threats and challenges. This HCP marks another step in this much needed effort to conserve these important fishes.

## 1.0 Introduction to the Plan

The ultimate goal for river herring is to restore healthy, sustainable Atlantic coast river herring populations that support a broad array of social and ecological services and functions, with stocks that are no longer designated depleted by ASMFC. In support of this goal, through the Habitat Conservation Plan (HCP) we seek to increase public awareness, stimulate cooperative research, and inform efforts to help restore river herring (collectively, alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis*) populations throughout much of their Atlantic coastal ranges. The HCP takes a necessarily broad perspective to describe the suite of issues river herring face and to consider measures or strategies to assist in their recovery. The plan builds upon previous and ongoing efforts to further river herring conservation, catalogues ongoing activities, and incorporates past information provided by the Technical Expert Working Group (TEWG).

### 1.1 Purpose and Need

The purpose of the HCP is to serve as a compendium of information on river herring, their varied threats, information gaps, and approaches to management (including conservation and restoration) to enable managers to more effectively increase production, and minimize sources of mortality throughout their coastwide ranges. It is intended to align management approaches and efforts for these species on a coastal scale, encouraging conformity among various managers and synergizing management strategies. The wide geographic range that river herring inhabit throughout the Atlantic coast results in a significant number of supporting habitats, stakeholders, and resource management agencies. This plan focuses on the interactions of river herring with these systems during their freshwater and estuarine life stages. Each state, and in some instances municipality, faces a unique set of management concerns and employs a variety of approaches to address them.

While it is unlikely that a single document could capture all of the management considerations for these species, particularly at the sub-regional or local scale, one of the benefits of a coastwide plan is the high-level consolidation of common threats, opportunities, and recommendations. The overarching need for a coastwide plan stems from the rapid decline in river herring stocks since the 1970s (ASMFC 2012b), due in large part to compounding factors such as at-sea mortality and stressors they experience during their spawning and early life stages (84 FR 28630). The following sections describe specific management needs this plan seeks to address.

### 1.1.1 Promote habitat conservation and restoration

Degradation and lack of accessibility to habitats that historically supported river herring at various stages of their life histories are fundamental contributing factors to the precipitous declines documented throughout the nineteenth and twentieth centuries. This HCP documents challenges and opportunities for habitat conservation and restoration that may facilitate their recovery.

### 1.1.2 Support collaboration for habitat conservation and research efforts

As a repository for contemporary research and conservation efforts, this plan is intended to facilitate collaboration across various agencies and organizations engaged in river herring habitat restoration and conservation. Identifying both common and diverging approaches to conservation as well as associated outcomes will help to inform future management decisions and encourage consistency across management units. Similarly, identifying common research and monitoring approaches as well as highlighting most critical resource management needs will inform coastwide priorities.

### 1.1.3 Highlight habitat conservation and research opportunities

One of the objectives of this HCP is to identify areas or projects that could benefit restoration or research efforts. This plan includes a comprehensive list of current and past examples where habitat conservation and river herring restoration were successful, in order to provide resource managers of other systems a template for success. This plan identifies potential research opportunities to further advance the knowledge necessary to properly restore river herring habitat.

### 1.1.4 Expand outreach for river herring

Public visibility and understanding of the resource(s) are fundamental to spurring conservation actions in social-ecological systems. Despite traditionally playing a central role for coastal communities, river herring currently do not benefit from the attention provided to other species (e.g., sport fish). This lack of visibility is further compounded by their historically-low abundance, especially near populated coastal areas. The objective of expanded outreach is to convey the historical and cultural importance of river herring along with their current status, restoration approaches, and recovery challenges to a broad array of audiences to further encourage public engagement and support for habitat restoration actions.

## 1.2 Goals for River Herring Habitat Conservation

In support of the ultimate goal (see *Section 1.0*) to restore river herring stocks coastwide through habitat conservation and restoration, the HCP presents several focused goals. In association with each focused goal, we developed several supporting objectives and recommended actions (see *Section 8.0*). The goals are as follows:

1. Improve connectivity of river herring habitats throughout the species ranges.
2. Assess and enhance spawning and rearing habitats for river herring throughout their coastwide ranges.
3. Establish and strengthen partnerships among state and federal agencies, NGOs, tribes, and other river herring stakeholders that seek to conserve, restore, and manage river herring.
4. Address information gaps and research needs where applied research is needed to expand knowledge of river herring related topics (see *Section 5.0* for further detail on these topics)

## 1.3 Geographic Scope

This HCP covers the entire range of alewife and blueback herring on the Atlantic coast of the United States. In this HCP, watersheds are described according to the Hydrological Unit Code (HUC) system described by Seaber et al. (1987). Sixteen states contain either all, or portions of the 24 four-digit HUC (HUC4) watersheds that drain to the Atlantic Ocean and support populations of river herring (Table 1; Figure 1). The states from north to south are: Maine, New Hampshire, Vermont,[2] Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida.

Portions of an additional HUC4 — the St. John watershed which is divided among northern Maine and Quebec and New Brunswick, Canada — was identified as a focus for future

[2] Vermont is the only state in the Atlantic coast region that is not part of the Atlantic States Marine Fisheries Commission

restoration efforts. While river herring currently pass the Mactaquac Dam in Keswick Ridge, New Brunswick, Canada, via a trapping facility, this run is likely well below the carrying capacity of this system and it is unclear whether they migrate far enough up the mainstem to enter tributary habitat in the U.S. For this reason, we note that the watershed has been identified as a future focus, particularly in the Meduxnekeag and Aroostook rivers[3]; however, it was not included in the more detailed analysis (see *Section 7.0*) performed for the other 24 HUC4 watersheds where river herring are currently present and managed in U.S. waters. The St. John is included in Table 1 and Figure 1 for reference.

Table 1 – HUC4 Watershed Metrics.

| HUC4 ID | NHD HUC4 Number | NHD HUC4 Name | Drainage Area (square miles) | Acres | State/Province |
|---|---|---|---|---|---|
| 1 | 0101 | St. John | 14,087 | 9,015,710 | ME/NB,QC |
| 2 | 0102 | Penobscot | 8,611 | 5,510,768 | ME |
| 3 | 0103 | Kennebec | 5,903 | 3,778,001 | ME |
| 4 | 0104 | Androscoggin | 3,528 | 2,257,874 | ME,NH |
| 5 | 0105 | Maine Coastal | 11,567 | 7,402,612 | ME/NB |
| 6 | 0106 | Saco | 4,853 | 3,105,641 | MA,ME,NH |
| 7 | 0107 | Merrimack | 5,004 | 3,202,287 | MA,NH |
| 8 | 0108 | Connecticut | 11,264 | 7,209,005 | CT,MA,ME,NH,VT/QC |
| 9 | 0109 | Massachusetts-Rhode Island Coastal | 7,103 | 4,545,992 | MA,RI |
| 10 | 0110 | Connecticut Coastal | 4,850 | 3,104,260 | CT,MA,NY,RI |
| 11 | 0202 | Upper Hudson | 12,665 | 8,105,456 | MA,NJ,NY,VT |
| 12 | 0203 | Lower Hudson-Long Island | 7,328 | 4,689,812 | CT,NJ,NY,RI |
| 13 | 0204 | Delaware-Mid Atlantic Coastal | 18,023 | 11,534,902 | DE,MD,NJ,NY,PA,VA |
| 14 | 0205 | Susquehanna | 27,500 | 17,599,860 | MD,NY,PA |
| 15 | 0206 | Upper Chesapeake | 5,872 | 3,757,932 | DE,MD,PA |
| 16 | 0207 | Potomac | 14,679 | 9,394,592 | DC,MD,PA,VA,WV |
| 17 | 0208 | Lower Chesapeake | 20,684 | 13,237,535 | DE,MD,VA,WV |
| 18 | 0301 | Chowan-Roanoke | 19,062 | 12,199,819 | NC,VA |
| 19 | 0302 | Neuse-Pamlico | 14,280 | 9,139,228 | NC |
| 20 | 0303 | Cape Fear | 9,207 | 5,892,756 | NC |
| 21 | 0304 | Pee Dee | 18,864 | 12,073,036 | NC,SC,VA |
| 22 | 0305 | Edisto-Santee | 23,698 | 15,166,695 | NC,SC |
| 23 | 0306 | Ogeechee-Savannah | 16,914 | 10,824,778 | GA,NC,SC |
| 24 | 0307 | Altamaha-St. Marys | 20,862 | 13,351,520 | FL,GA |
| 25 | 0308 | St. Johns | 12,185 | 7,798,584 | FL |

[3] Within the St. John watershed, the HUC8 Aroostook River (HUC# 01010004), Becaguimec Stream-Saint John River (HUC# 01010010), Meduxnekeag River (HUC# 01010005), and Keswick River- Saint John River (HUC# 01010011) was identified as a focus for river herring for future potential restoration actions, though whether either species was historically present in the Aroostook, Becaguimec, and Meduxnekeag is unknown.

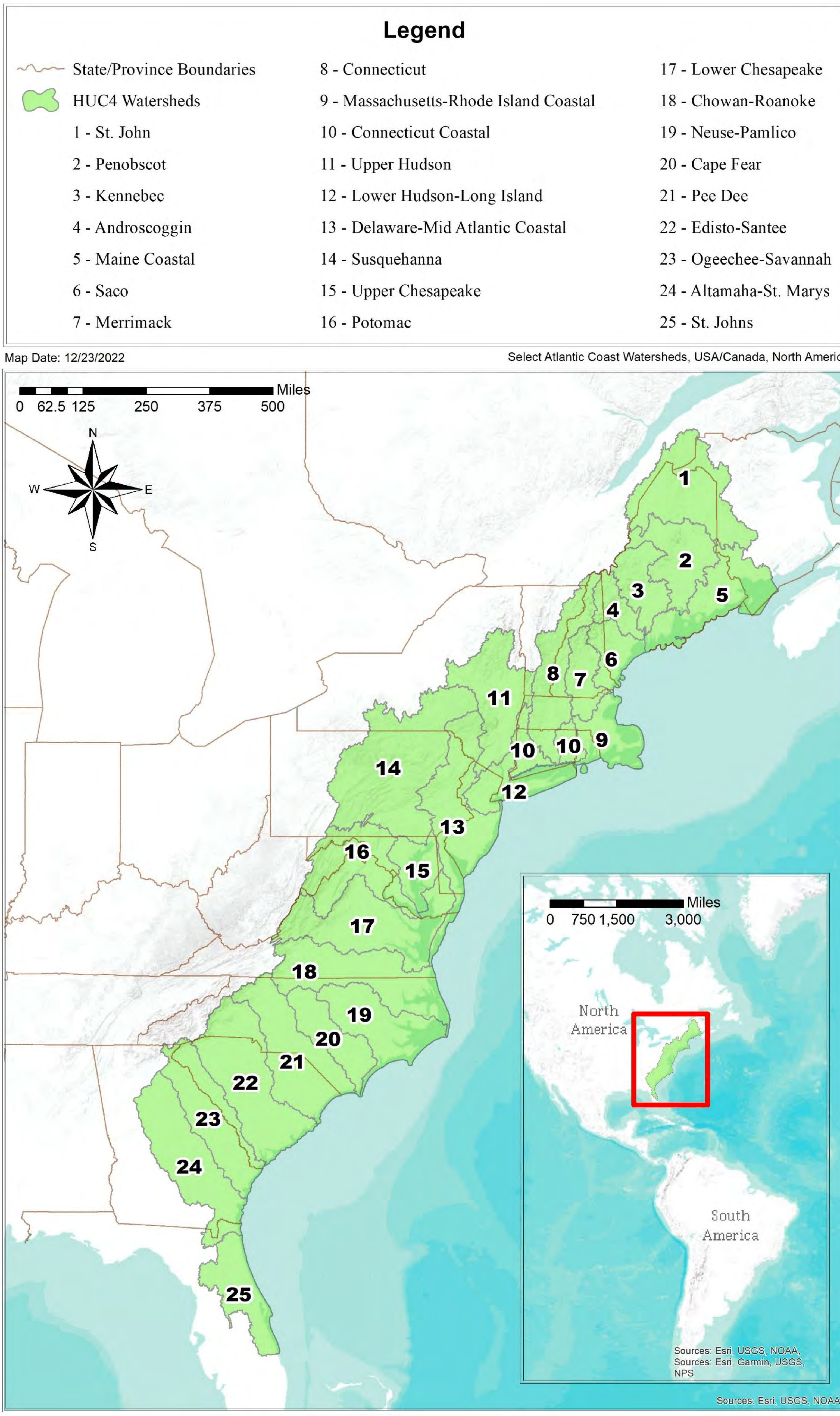


Figure 1 – Atlantic Coast HUC4 Watersheds Considered in the HCP.

## 1.4 Methodologies and Source Material

*Watershed Delineation*

We describe each watershed using the HUC system. We focused on the HUC4 watersheds (n=24)[4] along the U.S. portion of the Atlantic coast that support populations of anadromous river herring (see *Section 2.4 Distribution and Potential Habitat*). To increase resolution, HUC8 watersheds (n=233) that comprise the focus HUC4 watersheds were also evaluated. All HUC data and polygons were downloaded from the National Hydrography Dataset (NHD), which is produced and maintained by the United States Geological Survey (USGS). Area calculations were performed using the North American Datum of 1983 (NAD 83) under the Albers Equal Area Conic projection.

*River Mile Calculations*

We used the USGS's NHD (or NHDPlus – a related dataset offering high-resolution products) to analyze and enumerate lotic features using the geometric river network feature class (Hydronetwork). We used the Utility Network Analyst or the select by attribute/location tools in Esri's GIS mapping software, ArcMap (v10.7), to select reaches for analysis, and the associated attribute table(s) to calculate metrics. As with area calculations, lotic feature metrics were calculated using the NAD 83 under the Albers Equal Area Conic projection.

*River Herring Distribution*

Range data from the Nonindigenous Aquatic Species Database administered by USGS (Daniel and Neilson 2020) were used to generate figures in this HCP, as well as to inform focus areas based on historical presence of the species. There were areas where river herring have been introduced outside of the 24 HUC4s considered for both species within this dataset, but these were excluded from analysis based on the goals of this HCP.

*Barrier Description*

The figures in this HCP used point data for dams retrieved from the National Inventory of Dams[5] (NID). The Northeast Region Freshwater Network Barrier Prioritization Tool (Martin and Levine

[4] The St. John was not included in this analysis, as noted in Section 1.2
[5] This dataset is provided and maintained by the U.S. Army Corps of Engineers (USACE).

2017) and the Comprehensive Southeast Aquatic Barrier Prioritization Tool (SARP 2022) were used to describe barrier severity and number of barriers within individual HUC4 watersheds.

*Restoration Showcase Project Selection*

Restoration projects highlighted in *Appendix C* were selected through a voting and ranking process within the working group (1.7.1). The list of contemporary restoration efforts was compiled through research and outreach efforts. For a full list of restoration efforts considered in this process refer to Appendix Table B 7–Table B 9. From this list, a smaller subset of approximately 25 projects was presented to the working group to be further narrowed down. Preference was given to recent efforts (i.e., completed within the past 10 years) as well as those that displayed a diverse set of techniques or approaches. The three to four projects that best demonstrated the variety of habitats and techniques employed within each region (i.e., New England, Mid-Atlantic, and Southeast) were selected.

## 1.5 NOAA Fisheries

The National Marine Fisheries Service, also known as NOAA Fisheries, is an office of the National Oceanic and Atmospheric Administration (NOAA) within the U.S. Department of Commerce. NOAA Fisheries is responsible for the stewardship of the nation's ocean resources and their habitats. NOAA Fisheries provides vital services for the nation: productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems. Each of these services is built upon the foundation of a scientifically informed, ecosystem-based management approach.

U.S. fisheries are among the world's largest and most sustainable. The goal of the U.S. fishery management process is to ensure that all seafood harvested from U.S. federally-managed fisheries is sustainable. The Magnuson-Stevens Fishery Conservation and Management Act (MSA) established eight regional fishery management councils and mandated that they work in partnership with NOAA Fisheries to assess and predict the status of fish stocks, set catch limits, ensure compliance with fisheries regulations, reduce bycatch, and designate essential fish habitat.

The resilience of our marine ecosystems and coastal communities depends on healthy marine species including diadromous species. Under the MSA, the Federal Power Act (FPA), the Fish and Wildlife Coordination Act, and the Endangered Species Act (ESA), NOAA Fisheries works to conserve and restore public trust resources, and recover protected marine species, while promoting economic and recreational opportunities.

### 1.5.1 NOAA Fisheries Habitat Divisions

There are two regional NOAA Fisheries offices within the ranges of river herring – Greater Atlantic Region (GAR) and Southeastern Region (SER). Each regional office contains a division responsible for fish habitat conservation through protection and restoration – Habitat and Ecosystem Services Division (HESD) in GAR and Habitat Conservation Division (HCD) in SER. These divisions support a vision for healthy and self-sustaining marine, estuarine, and riverine habitats that support vital ecosystem services, including abundant living marine resources, diverse human uses, and resilient coastal communities. Staff within these offices work to protect and restore habitats that sustain fisheries, assist in the recovery of protected species, and maintain resilient coastal ecosystems and communities.

### 1.5.2 NOAA Fisheries Restoration Center

The Restoration Center (RC) invests in habitat restoration across the country where our nation's fisheries and protected resources need it most. In collaboration with its broad reaching network of local, regional, and national partners, the RC contributes and leverages funding, provides technical support, and completes high-quality restoration projects to help recover threatened and endangered species, support sustainable fisheries, offset damages from oil spills and other contaminant releases, and strengthen coastal habitat and community resilience.

## 1.6 The Atlantic States Marine Fisheries Commission

In the early 1940s, the 15 Atlantic coast states formed, through an Interstate Compact,[6] the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC was organized recognizing that coastal fishes do not adhere to political boundaries and that sound management required coordinated effort. For over 70 years, the ASMFC has served as a deliberative body, coordinating the conservation and management of state-shared nearshore fishery resources – marine, shell, and diadromous – for sustainable use.

ASMFC member states are (from north to south) Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, North

[6] Congress ratified the Compact in 1942 through Public Law 539 of the 77th Congress.

Carolina, South Carolina, Georgia, and Florida, encompassing the entirety of the river herring range in the U.S (except Vermont). Each state is represented by three commissioners: the top official (or a designee) for the state's marine fisheries management agency, a state legislator, and an individual appointed by the governor. Commissioners participate in the deliberations of the Commission's main policy arenas: interstate fisheries management, fisheries science, habitat conservation, and law enforcement. The one-state one-vote concept allows commissioners to address stakeholder-resource balance issues at the state level.

The mission of the ASMFC as stated in its 1942 Compact is:

"To promote the better utilization of the fisheries, marine, shell and anadromous, of the Atlantic seaboard by the development of a joint program for the promotion and protection of such fisheries, and by the prevention of physical waste of the fisheries from any cause."

The ASMFC recognizes the importance of habitat to the success of its mission and vision. As part of their management approach, the ASMFC has established a Habitat Committee which prepares and updates the habitat section of each Fisheries Management Plan (FMP), and may comment on particular threats to ASMFC-managed resources. Habitat loss and degradation have been identified as significant factors affecting the long-term sustainability of the nation's fisheries. Many forms of habitat conservation are beyond the operational jurisdiction of the federal and state fisheries agencies. This poses challenges for fisheries managers within the ASMFC in maintaining vital fish habitat, lacking specific regulatory authority for habitat conservation, restoration, or protection. This plan will provide a framework for fishery managers to identify and assess opportunities for restoration in freshwater habitats, promoting synergistic management between the marine and freshwaters habitats.

## 1.7 Development Committees

Two collaborating committees were organized to facilitate development of the HCP: a working group composed of NOAA Fisheries and ASMFC staff, and a steering committee of regional agency and academic representatives from the Northeast, Mid-Atlantic and Southeast Atlantic Coast regions.

### 1.7.1 Working Group

The working group was assembled to review and compile available data, draft the outline of the HCP, decide on the appropriate topics, information, and analyses to include, and to provide initial review of these materials once they reach draft form. The ten members that comprised the working group represented the NOAA Fisheries Greater Atlantic Region (GAR) and Southeast Region (SER) with regional staff from the RC along with the Fishery Management Plan Coordinators for shad and river herring from the ASMFC. Working group meetings were held on a routine basis throughout the development process. Additional periodic meetings were also held to collaborate with the steering committee to communicate plan progress, direction, and to secure invaluable input from these regional experts on various river herring topics.

### 1.7.2 Steering Committee

All Atlantic coast regions (New England, Mid-Atlantic, Southeast) were represented on the steering committee by professionals from agencies and academic institutions including the NOAA Fisheries  Northeast Fisheries Science Center, U.S. Fish and Wildlife Service (USFWS), Virginia Department of Wildlife Resources (VADWR), South Carolina Department of Natural Resources (SCDNR), North Carolina State University (NCSU), the State University of New York College of Environmental Science and Forestry, and East Carolina University, among others. The steering committee was tasked with advising and providing input on plan content and direction, enhancing regional context of the document, and providing constructive document review to support the working group. Meetings were held on an as-needed basis (generally every 1–2 months) throughout plan development.

## 1.8 Alignment with ASMFC Fishery Management Plans

River herring, American shad, and hickory shad are jointly managed by the ASMFC under Amendment 2 (ASMFC 2009) to the FMP for Shad and River Herrings (ASMFC 1985). The management goal outlined in ASMFC (2009) is to:

Protect, enhance, and restore East Coast migratory spawning stocks of American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), alewife, and blueback herring in order to achieve stock restoration and maintain sustainable levels of spawning stock biomass.

Additionally, Amendment 2 outlines five objectives designed to support the goal:

1. Prevent further declines in river herring (alewife and blueback herring) abundance.
2. Improve our understanding of bycatch mortality by collecting and analyzing bycatch data.
3. Increase our understanding of river herring fisheries, stock dynamics and population health through fishery-dependent and independent monitoring, in order to allow for evaluation of management performance.
4. Retain existing or more conservative regulations for American shad and hickory shad. Requirements for American shad and hickory shad regulations and monitoring are detailed in Amendment 1 to the Shad and River Herring FMP (ASMFC 1999).
5. Promote improvements in degraded or historical alosine critical habitat throughout the species ranges.

The goals and recommendations of the HCP align with and are designed to support the ASMFC's approach to river herring management.

## 1.9 Atlantic Coast River Herring Collaborative Forum

The Atlantic Coast River Herring Collaborative Forum (River Herring Forum) is an information exchange venue to bring together river herring practitioners, managers, researchers, and community groups from across the species ranges. This forum is co-chaired by NOAA Fisheries and ASMFC staff. The purpose of the River Herring Forum is to promote the conservation of the species, support information exchange, and encourage collaboration.

The River Herring Forum is a renaming of the River Herring TEWG that began working on river herring conservation issues in spring 2014. The TEWG was a committee established by NOAA Fisheries and the ASMFC to address data needs associated with river herring, and support the development of a river herring conservation plan. The river herring conservation plan was released in 2015 with the goals of increasing public awareness of the river herring species, stimulating cooperative research efforts, addressing data gaps, and coordinating efforts to enhance the conservation of these species.

After completion of the 2015 river herring conservation plan, the TEWG remained active to support continued collaboration and information exchange. This refined focus warranted a new name to reflect the group's continued role in supporting river herring conservation. After many alternatives were considered, the River Herring Forum was chosen. This new name reflects the species and their ranges, as well as the purpose of the venue. In addition to the name change, NOAA Fisheries' collaboration with the ASMFC led to improvements in the meeting format and organization. The goal for the River Herring Forum is to attract a diverse audience interested in engaging in meaningful discussions pertaining to river herring science, management, conservation, and restoration. This Forum also serves to connect watershed-based practitioners across regions. This structure, which connects regional and watershed-based practitioners through a centralized network, is needed to enhance the conservation, management, and restoration of river herring (Kritzer et al. 2022).

## 2.0 Life History, Distribution, and Ecological Considerations

### 2.1 River Herring Overview

River herring is a term used to collectively refer to two species in the Clupeidae family – alewife and blueback herring. These congeneric, anadromous fishes have a collective range extending from Atlantic Canada to the St. Johns River in Florida (Greene et al. 2009). While these species co-occur throughout a considerable amount of their coastal ranges, alewife are typically more abundant than blueback herring in the northern portion of the range, and blueback herring outnumber alewife in the mid-coast and southern portions of the range (Schmidt et al. 2003). In the Southeast, alewife do not range as far south as blueback herring; although historical information indicates its distribution extended as far as South Carolina (Leim and Scott 1966), more recent work suggest they are no longer found beyond North Carolina (Rulifson et al. 1982; Rulifson et al. 1994). River herring spend the majority of their lives at sea where they travel in schools. Once they reach maturity (typically 3-6 years), they return to freshwater streams to spawn in the springtime (Collette and Klien-MacPhee 2002) at water temperatures from 13 to 27°C (Mansueti and Hardy 1967; Loesch 1969).

Figure 2 – Underwater photo of adult river herring migration. Credit: NOAA Fisheries.

Recent investigations suggest that individuals within each species exhibit a diverse range of life history strategies. For example, in the Penobscot River (Stevens et al. 2021), several otolith microchemistry studies (Gahagan et al. 2012; Payne Wynne et al. 2015) strengthen evidence for prolonged or recurrent use of fresh water for juvenile river herring. Adults of both species exhibit iteroparity[7] and typically return annually to the same river system for spawning (Fay et al. 1983), though adults have been documented to stray to other rivers (Loesch 1987). Even though river herring are capable of repeat spawning over multiple years, mortality during spawning runs is common and freshwater mortality rates of adults vary annually depending on in-river and regional conditions, such as river flow. For example, Havey (1973) estimated that, on average, 90.7 percent of spawning adult alewife accessing Love Lake, Maine do not survive the first spawning migration. In contrast, Kissil (1974) estimated that 48.6 – 57.4 percent of adult alewife experienced mortality during their spawning run into Bride Lake, CT. Ogburn et al. (2017) note that mortality on the spawning ground can be difficult to estimate in dynamic riverine settings

[7] Iteroparity is defined as more than one reproductive event in an individual's lifetime, colloquially referred to as repeat spawning.

and observed that downstream run counts were 24 – 28 percent of upstream counts in a Chesapeake Bay tributary. Spawning-related mortality is highest for southern populations such that many populations of blueback herring with natal rivers south of North Carolina are considered semelparous[8] (ASMFC 2009). In contrast, clinal trends for alewife spawning mortality are less well-studied (Greene et al. 2009). The close relation and number of similarities between alewife and blueback herring often result in grouped management strategies; however, there are important diverging life history characteristics between these two species that are important to consider for effective management and restoration actions.

### 2.1.1 Alewife

#### 2.1.1.1 Characteristics and Life History

Alewife are morphologically similar to blueback herring. Despite similarities in appearance, several characteristics can be used to differentiate them. Adult alewife are distinguished by comparatively larger eyes, which generally have a diameter larger than snout length. The lining of the abdominal cavity (peritoneum) in alewife has a pale, pinkish coloration whereas blueback herring have a dark, pigmented peritoneum. Scale imbrication pattern and meristics can also be used to separate alewife from other clupeids (Fay et al. 1983).

Alewife exhibit countershading, with dorsal surfaces colored dark grey or green, grading through silver or tan on the flanks to white on the ventral surface. Adult alewife are generally 11-12inches in total length, though occasionally larger individuals (up to around 14in) have been observed (Fay et al. 1983). In some systems (e.g., Connecticut River – Davis and Schultz 2009), recent declines in average body size of migrating alewife have been over time have been documented.

Alewife typically reach sexual maturity by ages 3–5 (ASMFC 2017a). Spawning adults are generally ages 3–9 with up to four repeat-spawning marks, though older individuals with a greater number of repeat-spawning marks have been documented in a few cases (ASMFC 2017a). The maximum age of spawning alewife is generally nine years, with maximum ages of 6–8 being common in most rivers; maximum age of spawning adults has declined in several rivers over the past several decades (ASMFC 2017a). The recent benchmark stock assessment

[8] Semelparous is defined as reproducing or breeding only once in a lifetime.

and update (ASMFC 2017b, 2017b) also noted that mean size for male and female alewife declined in approximately 40 and 60 percent of rivers evaluated, respectively. Females produce between 60,000 and 100,000 eggs during their spawning season, which are scattered over sand, gravel or vegetated substrates in quiet areas of lotic or lentic waters (Werner 2004). Eggs hatch in 2-15 days, depending on ambient water temperature during incubation (Fay et al. 1983).

Yolk-sac larvae generally range from 0.1-0.2in (2.5-5.0 mm) in length at hatch, and fully absorb the yolk sac in a few days (Fay et al. 1983). The larval stage begins at yolk sac absorption, and lasts until the larvae transform into juveniles, which typically occurs around 0.8in (20 mm) in total length. Juveniles may exhibit upstream movement during development and typically remain in freshwater/estuarine rearing areas through the early fall, followed by emigration to the mouths of large estuaries (Stevens et al. 2021) or the inshore waters of the Atlantic continental shelf (Fay et al. 1983).

Alewife are generally considered zooplanktivores; however, in some areas or among larger individuals, eggs (fish, crustacean, and insect), larval and adult insects, as well as small fish can be significant dietary components (Collette and Klien-MacPhee 2002). As soon as larval alewife develop a functional mouth (typically around 6 mm in total length), they begin feeding on zooplankton; small cladocerans and copepods are targeted at first, with larger zooplankton and benthic amphipods incorporated into their diets as they grow (Norden 1968; Nigro and Ney 1982).

Figure 3 – Juvenile river herring schooling in the Damariscotta fishway with adults below (lower right) in the Damariscotta River, Maine Credit: NOAA Fisheries.

#### 2.1.1.2 Habitat

Alewife are documented to occur from South Carolina and north to the Gulf of St. Lawrence, with the highest run counts found from the Chesapeake Bay to New Brunswick, Canada (Berry 1964; Winters et al. 1973; Loesch 1987; Greene et al. 2009). They use a diverse array of freshwater, estuarine, and marine habitats depending on the season and life stage. The HCP is focused on conserving and restoring coastal and inland habitats that serve as critical migration corridors, as well as spawning and rearing areas. Habitat requirements have been described and inferred through studies completed throughout their range, which were cataloged in detail by Greene et al. (2009) and Able and Fahay (2010).

Alewife undertake extensive upstream spawning migrations and are relatively strong swimmers; using bursts of speed to ascend river reaches of rapid flow. However, they lack upstream migration strategies such as leaping or climbing over obstacles. One implication of this is that relatively low-head dams, which may be passable by other migratory fishes such as Atlantic salmon (*Salmo salar*) or American eel (*Anguilla rostrata*), can represent a complete barrier for river herring. USFWS (2019) suggests that although alewife are capable of burst speed of around 6 feet per second in areas of high velocity flow, burst swimming is limited to very brief periods, and resting pools and eddies are essential for fish to recovery from fatigue and successful passage.

Figure 4 – Alewife spawning behavior in still-water reaches of the lower Susquehanna watershed in Maryland Credit: CBP/Will Parson.

Alewife frequently choose lakes or ponds for spawning, often traveling far upstream to reach these habitats (Loesch 1987). Spawning alewife may also select sluggish reaches of streams or larger rivers to lay their eggs (Figure 4); here they often concentrate near the bank where the water can be less than one foot deep (Jones et al. 1978). In watersheds impacted by large dams, spawning may occur in impounded reaches above dams (if upstream passage is provided), or in eddies/pools below dams (Loesch and Lund 1977; Flagg 2007). Alewife have also been documented utilizing ocean-connected brackish coastal ponds or freshwater coves landward of barrier beaches in New England and Nova Scotia for spawning (Loesch 1987; Collette and Klien-MacPhee 2002). Eggs are broadcast over a wide variety of substrates such as gravel, sand, detritus, or submerged aquatic vegetation (Edsall 1964; Mullen et al. 1986), although Boger (2002) noted an affinity for coarse substrate in Virginia.

In areas of sympatry, alewife typically spawn several weeks earlier than blueback herring; however, migration timing and spawning overlap are common (Loesch 1987; Ogburn et al. 2017). Spawning may occur throughout the day, but low-light and night spawning are more common (Richkus 1974; Greene et al. 2009). More recently, Ogburn et al. (2017) noted that upstream migration peaked in the afternoon/evening early in the season, when alewife dominated the run, but also observed upstream movement throughout the night. O'Connell and Angermeier (1997) observed in a Mid-Atlantic watershed that alewife and blueback herring used temporal rather than spatial separation for spawning habitat which was hypothesized to minimize competition between the two species. After spawning, spent adults move quickly downstream and return to the ocean (Collette and Klien-MacPhee 2002), with downstream movement likely driven by temperature and discharge (Ogburn et al. 2017). Once back in the ocean, post-spawn river herring commonly aggregate nearshore in large schools (Kircheis et al. 2004).

Eggs are associated with freshwater spawning areas and are initially demersal (Mansueti 1956; Fay et al. 1983). Larvae are also typically found in the vicinity of these freshwater spawning areas (Able and Fahay 2010), although they have been documented around the freshwater-saltwater interface (Campfield and Houde 2011; Able et al. 2020). Juvenile alewife occupy a variety of habitats during their first year, including freshwater ponds, large rivers, tidal freshwaters, submerged aquatic vegetation (SAV) and other estuarine habitats (Greene et al. 2009; Able and Fahay 2010). Their outmigration to estuarine/coastal waters is protracted throughout the summer and often occurs in distinct waves or pulses (Richkus 1974; Kosa and Mather 2001; Gahagan et al. 2010). Increased river discharge is thought to be a major cue for emigration from freshwater rearing habitat (Richkus 1974; Yako et al. 2002; Gahagan et al. 2010), although other factors (e.g., water temperature, moon phase, interspecific competition) have also been implicated in triggering outmigration (Greene et al. 2009). In some instances, young-of-the-year alewife may remain in their natal ponds until there are sufficient flows to flush the waterbody. Juveniles also use estuarine waters as rearing habitat, more notably in the southern portion of their range (Murdy et al. 1997; Turner and Limburg 2016; Able et al. 2020). They occupy a wide range of habitats in the estuary, although they are typically associated with intermediate salinities (Able and Fahay 2010). Juvenile alewife have been typically found near the surface during summer months, followed by a shift to deeper waters in the fall prior to their winter out-migration (Warriner et al. 1970; Able and Fahay 2010). Once they emigrate from their rearing habitats, juvenile alewife typically spend their first winter in coastal waters near their natal river (Milstein 1981, Limburg 1998; Able and Fahay, 2010). They have also been documented to spend their first winter in deep waters of large rivers and estuaries (Able and Fahay 2010) and move back into shallower/upstream estuarine waters in the following spring (Marcy Jr. 1969; Milstein 1981). Overwintering has been documented in tidal reaches of rivers including the Hudson (Limburg 1998), Penobscot (Stevens et al. 2021), and in deep estuarine waters of the Delaware (Smith 1971) and Chesapeake (Hildebrand and Schroeder 1928) bays.

### 2.1.2 Blueback Herring

#### 2.1.2.1 Characteristics and Life History

Adult blueback herring are distinguished from alewife by comparatively smaller eyes with a diameter less than snout length. They typically have more rays in the dorsal fin (16-18 compared to 12-16 in alewife) and have a dark peritoneum (Hildebrand and Schroeder 1928; Werner 2004). Scale imbrication pattern and meristics can also be used to separate blueback herring from other clupeids. Blueback herring exhibit countershading, with dorsal surfaces colored bluish black or blue green, grading through tan or silver on the flanks to white on the ventral surface. Adult blueback herring are generally 11-12inches in total length, and generally have comparable length at age values to alewife (Fay et al. 1983).

Blueback herring exhibit similar maturation rates to alewife, typically reaching sexual maturity at ages 3–6, with age 4 fish being most common for first-time spawners (Messieh 1977; Loesch 1987). Repeat spawners are typically age 3–9, generally with up to four repeat-spawning marks (ASMFC 2017a). Maximum age of spawning adults has decreased in many rivers, with current ranges typically between age 5–7 (ASMFC 2017b). Similarly, mean length at age of spawning blueback herring has decreased significantly in several rivers for both sexes, especially when data are available prior to 1990 and most consistently in younger (e.g., ages 3–6) spawning age classes (ASMFC 2017b). Blueback herring are typically more fecund than alewife, with females producing between 50,000 and 350,000 eggs (Werner 2004). During spawning, eggs are released over sand and gravel substrates in larger rivers or tributaries with relatively swift flow; tending to avoid sluggish or still water areas (see review by Greene et al. 2009).

Yolk-sac larvae generally range from 0.1-0.2inches (2.5-5.0 mm) in length at hatch, and fully absorb the yolk sac in a few days (Fay et al. 1983). The larval stage begins at yolk sac absorption, and lasts until the larvae transform into juveniles in approximately 25-35 days, which typically occurs around 0.8inches (20 mm) in total length (Watson 1970). Young blueback herring typically remain in freshwater rearing areas through the early fall, followed by emigration to the ocean (Fay et al. 1983; Able and Fahay 2010). Several studies suggest that, like alewife, blueback herring exhibit a diversity of life history patterns and may be found in freshwater habitats up to their second year (Limburg 1998; Stevens et al. 2021).

Blueback herring are size-selective zooplankton feeders (Collette and Klien-MacPhee 2002). Their diet consists of invertebrates including ctenophores, calanoid copepods, amphipods, mysid and other pelagic shrimps, or small fishes. In nursery areas, juvenile blueback herring feed primarily on zooplankton including cladocerans and copepods as well as benthic organisms such as dipteran larvae (Greene et al. 2009).

#### 2.1.2.2 Habitat

Similar to the alewife, blueback herring utilize a diverse suite of freshwater, estuarine, and marine habitats depending on the season and life history stage. While they are documented to occur north to Nova Scotia and New Brunswick in Canada, blueback herring comprise a relatively larger proportion of the overall river herring spawning runs in the Mid-Atlantic and southeastern United States (Schmidt et al. 2003). Habitat requirements have been described and inferred in studies completed throughout their range, which were cataloged in detail by Greene et al. (2009) and Able and Fahay (2010).

Blueback herring undertake spawning migrations into coastal river and tributaries. They have been described to exhibit shorter upstream migrations relative to alewife (Hildebrand and Schroeder 1928; Able and Fahay 2010), although others such as Loesch (1987) and O'Connell and Angermeier (1997) have questioned the veracity of this claim. This may point to different regional migration tendencies or reflect sampling effects. Regardless, blueback herring are relatively strong swimmers and, like other alosines, they lack the ability to leap or climb over obstacles and instead use bursts of speed to ascend areas of rapid flow. In general, blueback herring and alewife have comparable swimming abilities, and clupeids typically require similar passage parameters based on morphometric characteristics (Castro-Santos 2006; Turek et al. 2016; USFWS 2019).

In areas of sympatry with alewife, blueback herring tend to select lotic[9] areas for spawning, while in their allopatric range (south of Cape Hatteras, generally) they tend to spawn in lentic habitats to a greater extent (Loesch 1987). Spawning blueback herring generally prefer runs of streams or larger rivers to lay their eggs (Greene et al. 2009). In watersheds impacted by large dams, where river herring are forced to spawn in the same vicinity, blueback herring and alewife have been hypothesized to select discrete spawning sites to reduce overlap and competition (Loesch 1987; Greene et al. 2009).

In watersheds that support populations of both species, blueback herring typically spawn a few weeks later than alewife; however, overlap is common (Loesch 1987). Blueback herring tend to be more selective than alewife with spawning sites, preferring to release eggs over hard substrate in areas with relatively fast flow (Loesch and Lund 1977; Mullen et al. 1986). Spawning occurs primarily at night and has been observed at temperatures above 14°C, with 21–24 °C being ideal (Klauda et al. 1991). After spawning, spent adults move quickly downstream and return to the ocean (Collette and Klien-MacPhee 2002). Near-shore aggregations of adult river herring are common following outmigration after spawning (Kircheis et al. 2004).

Blueback herring eggs and larvae generally remain in the vicinity of the freshwater habitats into which they are spawned (Able and Fahay 2010). Juveniles are found throughout most freshwater tidal areas and into mesohaline estuaries where they show affinity for shoreline habitats during their first growing season (Able and Fahay 2010). In certain systems, they show a preference for low salinity (e.g. 0-5 ppt) habitats (Greene et al. 2009). In tidal freshwater rearing areas, juveniles are typically surface-oriented (more so than alewife) with a moderate shift to mid-water depths (15 m) at night in the early fall (Warriner et al. 1970). Decreasing water temperature is thought to be a major cue for emigration from freshwater rearing areas, although other factors (e.g., precipitation, light intensity) have also been implicated in triggering outmigration (see review by Greene et al. 2009). Juveniles emigrate to overwinter in coastal waters, generally near their natal estuary (Limburg 1998; Able and Fahay 2009). Similar to alewife, juveniles have been documented to overwinter in deep waters of large rivers (Limburg et al. 1998; Stevens et al.

[9] Lotic refers to bodies of water with flow or running water like rivers and streams. Lentic bodies of water are still with minimal flow, like lakes and ponds.

2021). Age–1 individuals have been documented to return to shallower waters of their natal estuaries the following spring (Hildebrand and Schroeder 1928; Able and Fahay 2010).

### 2.1.3 Hybridization

Alewife and blueback herring are capable of hybridization despite estimated species divergence occurring around one million years ago (Faria et al. 2006). While competition between alewife and blueback is largely moderated by spatial/temporal habitat partitioning (Greene et al. 2009), interactions between the two species may be of concern to fisheries managers in certain settings. Hybridization between alewife and blueback herring has been documented and is considered common by some researchers (McBride et al. 2014; Reid et al. 2018). Barriers to natal spawning grounds can force an overlap of spawning habitat between these two species, which can increase the likelihood of hybridization. It has been suggested that altered habitat formed from dams favors alewife-introgressed hybrids due to impounded environments (Hasselman et al. 2014). However, the lentic or lotic preferences for these species tends to differ on a coastwide-scale. Additional information regarding hybridization is presented in *Section*.

## 2.2 Trophic Interactions

Alewife and blueback herring are subject to predation during all life stages and in each habitat they occupy, from nursery grounds in freshwater systems to the open ocean. They are an important prey source for many fish and wildlife species, including predatory game fishes, mammals, reptiles, and birds of prey (Hall et al. 2012; MDMR 2016). Here, we focus on notable interactions with other state and federally-managed fisheries. Additional information regarding the ecological importance of river herring to various food webs can be found in *Section 6.3*.

River herring are a keystone species (Able et al. 2020) because they influence the movements and abundance of their predators, including commercially and recreationally valuable fish species. In freshwater and estuarine settings, striped bass (*Morone saxatilis*) is a major predator of both river herring species (Walter et al. 2003). Striped bass movements have been inferred to mirror the migratory patterns of river herring, reflecting their importance as prey (Ng et al. 2007). Predation pressure by striped bass has been hypothesized to influence population size of river herring in some river systems. For example, Savoy and Crecco (2004) speculated that an increase in the number of striped bass in the Connecticut River may have contributed to a decline in river herring numbers. Similarly, at least two studies (Juanes et al. 1993; Creaser and Perkins

1994) noted that age–0 river herring were prevalent in the diet of age-0 bluefish (*Pomatomus saltatrix*) in two different estuaries (Hudson River in New York and Marsh River in Maine, respectively). Finally, river herring have also played an important role supporting marine fisheries. Historically, they were used extensively as bait in the American lobster (*Homarus americanus*) and Atlantic cod (*Gadus morhua*) fisheries of New England (Ames 2004; Hall et al. 2012; Ames and Lichter 2013). Restoration of river herring to coastal rivers has the potential to support the restoration and sustainability of these fisheries that were once commercially-significant at the coastal scale (McDermott et al. 2015).

River herring can influence the trophic structure of freshwater systems (see *Section 6.0*) and may compete with residential freshwater species for food in certain settings. However, studies evaluating interspecific competition are limited. Although concerns over competition in freshwater habitats have led to management decisions that adversely affected river herring in their native range (Willis 2006), there is not clear evidence of negative impacts on freshwater piscivores (Hanson and Curry 2005) and restoration of river herring runs to their native spawning and rearing habitats remains a priority given their current population status. We present an example of this management conflict from the St. Croix River in *Section 7.2.4.2*. In contrast to concerns that led to fishway closures in that case, river herring have been documented as prey for freshwater piscivores. For example, Watson et al. (2019) noted that smallmouth bass prey upon river herring in the Penobscot River, ME, and that recovery of river herring in that system may contribute to greater individual growth in that non-native piscivore. Other studies (Yako et al. 2000; Mattocks et al. 2017) have also documented the consumption of river herring prey by recreationally-valuable freshwater fish species and noted their value as forage in their freshwater rearing habitats. Overall, the trophic interactions in freshwater systems are system-specific, mediated by a number of complex interacting factors, many of which warrant further study.

## 2.3 Management

Along the Atlantic coast, river herring are managed at many levels ranging from federal management at the coastwide stock level down to municipal management[10] at the local population level, often comprising a river- or tributary-specific run of fish. The HCP focuses on

[10] Town-level management model is most common among New England states

management at the federal level; a summary of management actions and guidelines are found in *Section 3.3*.

## 2.4 Distribution and Potential Habitat

River herring were historically abundant and widespread along the Atlantic coast of the U.S. (Figure 5 and Figure 6) and eastern Canada. Ranging from Atlantic Canada to Florida, river herring were regionally important resources for Native Americans, and later, European settlers (see *Section 6.2*). Illustrating their importance and cultural relevance to colonial settlers, legislators in New Hampshire began implementing laws for protection of river herring in Cohas Brook, a tributary to the Merrimack River, as early as the 1750s (Noon 2015). River herring remain both culturally relevant and regionally important resources in modern times, although their abundance is a fraction of historical levels.

The construction of dams on Atlantic coastal rivers commenced shortly after the arrival of European settlers, blocking important migration corridors and contributing to declines in diadromous fish abundance, including river herring. By the mid-1700s, mill dams were common on smaller tributaries across New England and were soon followed by larger mill dams like the Great Works Dam,[11] Essex Dam,[12] and Turners Falls Dam[13] on major rivers. These dams (among others) were converted for hydroelectric power generation in the early 1900s, while larger dams such as Conowingo[14] and Stevenson[15] were being built specifically for hydroelectricity. These dams collectively excluded river herring from much of their historical spawning grounds. In early attempts to mitigate this loss of connectivity, rudimentary fish ladders were constructed for upstream passage on some dams; though downstream protection measures were limited. These efforts were inconsistent and largely ineffective, leading to the functional extirpation of river herring from the middle and upper reaches of many coastal rivers.

[11] Penobscot River, ME (ca. 1830s)
[12] Merrimack River, MA (ca. 1840s)
[13] Connecticut River, MA (ca. 1790s)
[14] Susquehanna River, MD (ca. 1920s)
[15] Housatonic River, CT (ca. 1910s)

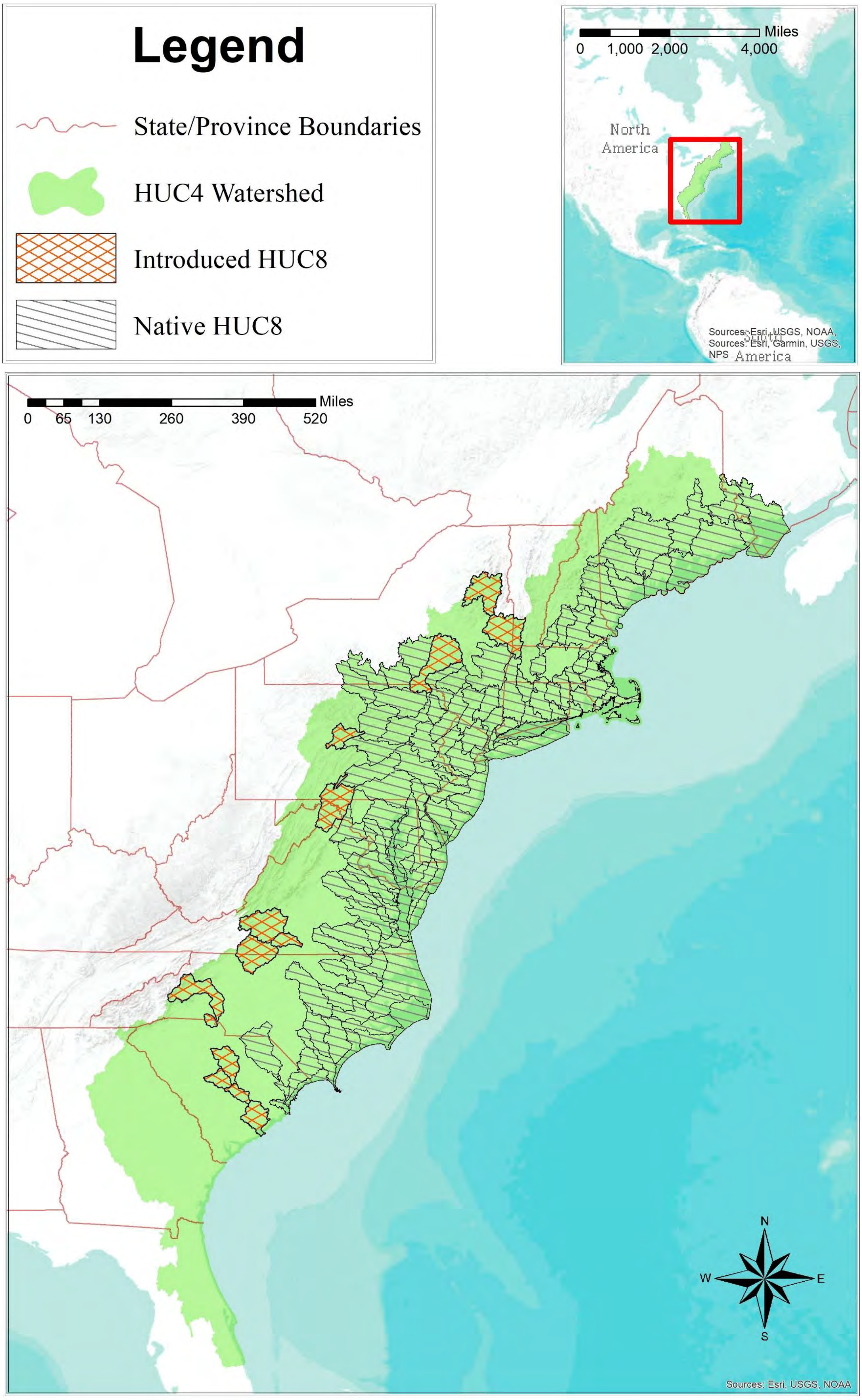


Figure 5 – U.S. Atlantic coast alewife distribution, native and introduced HUC-8 watersheds. Source: Daniel and Neilson (2020).

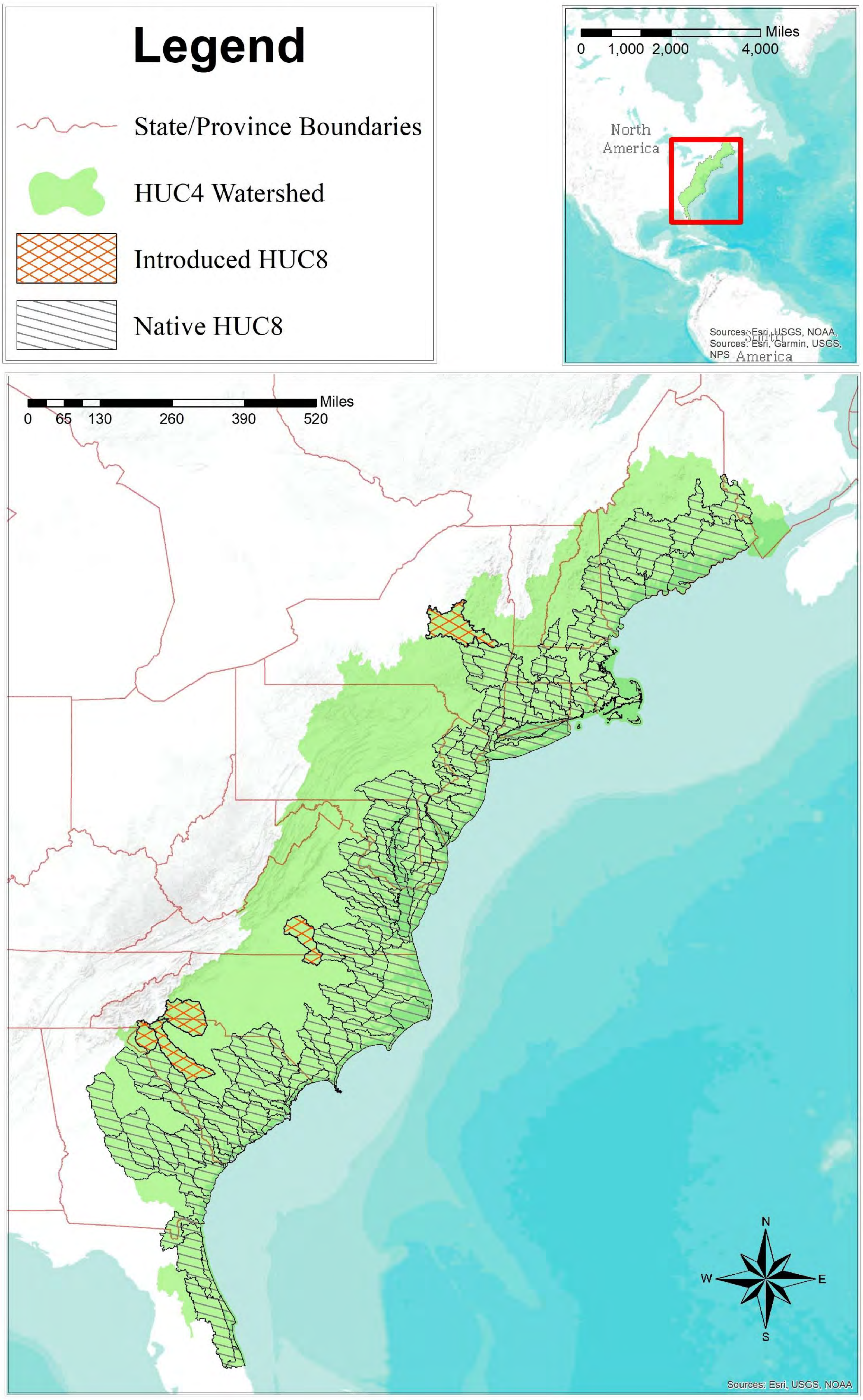


Figure 6 – U.S. Atlantic coast Blueback Herring Distribution, Native and Introduced HUC8 Watersheds. Source: Daniel and Neilson (2020).

Quantifying the currently available and potential river herring habitat presents significant challenges. First, in order to categorize habitats in an area, managers must establish which criteria determine local river herring habitat suitability. Throughout the region, fishery management and restoration practitioners use a variety of methods to demarcate suitable river herring habitat, including mean and minimum discharge, gradient, average channel width, velocity, or some combination of these metrics. Second, connectivity of habitat is a spectrum rather than a binary consideration. Dams with fish passage facilities provide a broad range of passage efficiencies and as a result, may have minor or significant impacts on upstream and downstream migrations. Therefore, labeling habitats above passable dams as "accessible" may be true in sentiment, but in practice will result in a varying amount of production and recruitment, making comparisons between systems or population estimates difficult. Furthermore, a range of habitat quality exists among remaining "suitable" habitats. Physical, chemical, biological, and spatial attributes of habitat influence successful reproduction. For river herring, substrate, annual temperature regime, flows, dissolved oxygen, presences of pollutants, predator abundance, and prey availability all play a role in the success of spawning and rearing. Inter-annual weather variability (e.g., spring precipitation) can further complicate the ability of managers to predict what areas within a particular watershed can support productive spawning or rearing habitat in a given year.

Considering these factors, potential river herring habitat falls into two general categories: habitats that lack physical access, and habitats that are accessible but are degraded such that they no longer contribute to recruitment and spawning stock. In the case of the former, dams are the primary barriers blocking fish access to historical spawning reaches on large rivers and tributaries; however, culverted road crossings are also frequently significant impediments on smaller tributaries. Barrier removal is generally the preferred solution to restore access whenever possible, while installation of technical fishways is another option where barrier removal is not feasible (Figure 7). Degraded habitats have more variable and complex causal factors, and restoration efforts must be tailored to the unique conditions of a given habitat. Restoration efforts in highly-modified or impaired watersheds should concurrently address these additional sources of habitat degradation along with measures that increase connectivity to spawning and rearing habitats.

Figure 7 – Howland Dam bypass nature-like fishway on the Piscataquis River in Howland, ME. Credit: NOAA Fisheries.

Although thought to vary regionally, the full extent of potential river herring habitat is not known; however, regional and local managers and experts have developed evaluations in many watersheds (see *Section 7.0*). Current river herring access in many rivers on the Atlantic coast is half or less of the historical extent (Rohde 2010, 2011a, 2011b; NMFS 2020) For alewife in particular, some systems are estimated to have less than ten percent of historical spawning habitat accessible (MRTC 2021).[16]

# 3.0 Stock Status, Fisheries, and Management History

## 3.1 Stock Status

The ASMFC completed the most recent benchmark stock assessment for river herring in 2012 (ASMFC 2012b). In 2017, a two-part update to the benchmark stock assessment was published based on data from the period of 2011-2015 (ASMFC 2017b, 2017b). Volume I provided a coastwide summary, while volume II focused on state-specific reports. The updated assessment used both fishery-dependent data[17] and fishery-independent data[18] and included river herring biology and life history information. The state-specific report summarized data from over 50 river systems across the U.S. range of river herring from Maine to Florida (ASMFC 2017b). The

[16] These estimates include habitats above barriers that provide fish passage, if volitional or unimpeded access is considered, numbers are even lower.
[17] Data from commercial fisheries that target or incidentally catch river herring.
[18] Data derived from scientific research or field surveys.

stock information discussed in this section is derived primarily from the coastwide summary (ASMFC 2017a). The next ASMFC peer review for river herring is currently scheduled for this year (2023).

Sharp declines in commercial landings began to occur coastwide in the early 1970s, and continue today as domestic landings are a fraction of their historical peak (Figure 8). Landings have remained at persistently low levels since the mid-1990s. In response, five states enacted harvest moratoria in the early 2000s: Massachusetts (commercial and recreational in 2005), Rhode Island (commercial and recreational in 2006), Connecticut (commercial and recreational in 2002), Virginia (for waters flowing into North Carolina in 2007), and North Carolina (commercial and recreational in 2007, with the exception of a four-day open season in the Chowan River during the week of Easter).

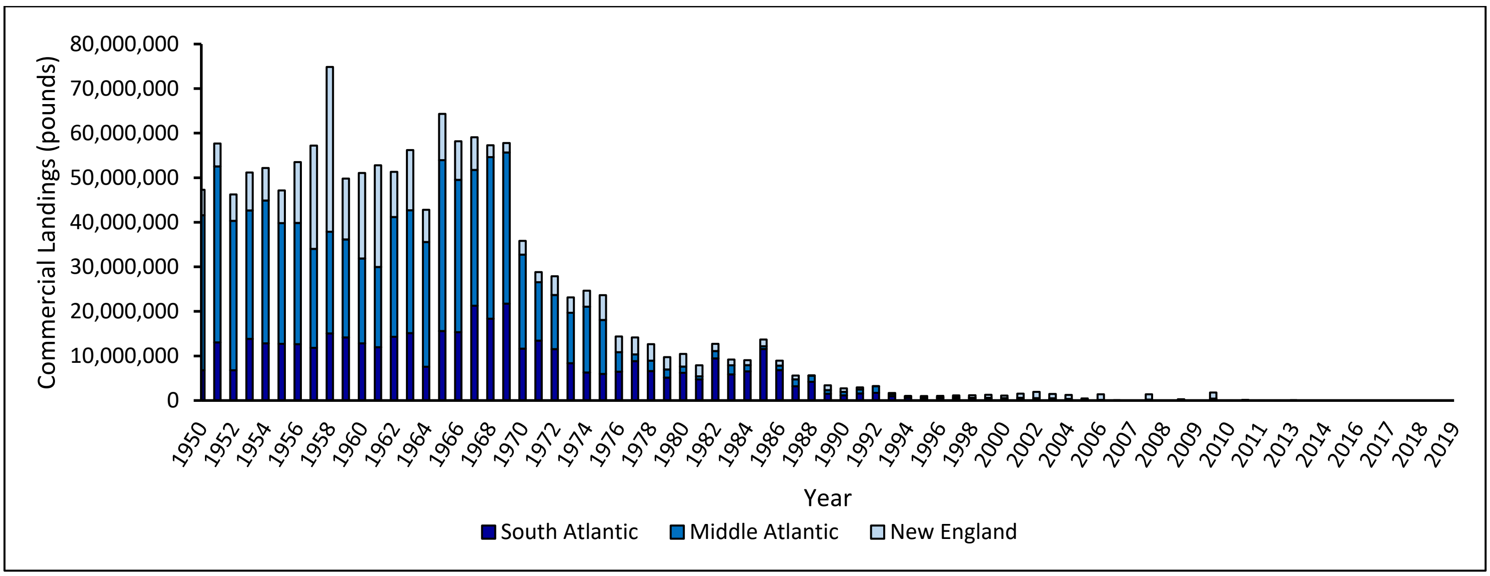


Figure 8 – Commercial alewife[19] landings by Atlantic coast region for years 1950-2019. Source: NMFS 2021.

On January 1, 2012, river herring harvest was closed for all states[20] and jurisdictions without an approved sustainable fisheries management plan (SFMP) in place, as required under ASMFC Amendment 2 to the Shad and River Herring FMP (ASMFC 2009). This action extended

[19] Historically, alewife and blueback herring were seldom distinguished in commercial catch, these values were reported as alewife, but likely represent combined total river herring landings in most instances. We note that landings from the 2000s to present are less reflective of relative abundance than in years prior due to moratoria and reduced fishing effort.
[20] Except ME, NH, and NY, where regulated harvest remained legal.

prohibitions on harvest (commercial or recreational) to New Jersey, Delaware, Pennsylvania, Maryland, D.C., Virginia (for all waters), Georgia, and Florida. As of 2021, Maine, New Hampshire, Massachusetts, New York, and South Carolina have SFMPs in place for river herring and allow regulated harvest in select systems. Georgia and Florida have alternative management plans that allow for a limited harvest of river herring; however, harvest has not been confirmed or suspected in these states outside of a small fishery that may have occurred on the Savannah River through the early 2010s.[21]

Trend analyses inform but do not determine stock status, and recent trends in abundance were updated in ASMFC (2017b) (Table 2). For this assessment, data were available for 54 in-river stocks of river herring; of these, 16 stocks showed increasing trends over the ten most recent years of the update assessment data time series (2006-2015), two stocks experienced decreasing trends, eight stocks were stable, 10 stocks experienced no discernible trend or high variability, and 18 stocks lacked sufficient data to assess recent trends, including one stock that had no returning fish. Most of the increasing trends were observed in the Northeast region where there is typically more data available. A majority of the unknown and no trend designations occurred in the Mid-Atlantic and Southeast regions.

[21] There was suspected harvest that occurred at the New Savannah Bluff Lock and Dam, but the lock area where fishing occurred was deemed unsafe, and has been off limits to the public since 2014.

Table 2 - Abundance trends of select alewife and blueback herring stocks along the Atlantic coast (Adapted from (ASMFC 2017a). *NE shelf trends are from the spring coastwide survey, [A] = Alewife only, [B] = Blueback herring only, [AB] = Alewife and blueback herring by species, [RH] = Alewife and blueback herring combined

| State | River | Benchmark Trends (2001-2010) | Updated Recent Trends (2006-2015) |
|---|---|---|---|
| | NE U.S. Continental Shelf (NMFS Bottom Trawl)* | N/A | Increasing[AB] |
| ME | Androscoggin | Unknown[A] | Increasing[A] |
| ME | Kennebec | Unknown[RH] | Increasing[RH] |
| ME | Sebasticook | Unknown[A] | Increasing[RH] |
| ME | Damariscotta | Stable[A] | Increasing[A] |
| ME | Union | Stable[A] | No Trend[A] |
| NH | Cocheco | Stable[AB] | Increasing[AB] |
| NH | Exeter | Unknown[AB] | Stable[RH] |
| NH | Lamprey | Increasing[A] | Increasing[RH] |
| NH | Oyster | Stable[B] | Decreasing[RH] |
| NH | Taylor | Decreasing[B] | No Returns[RH] |
| NH | Winnicut | Unknown[AB] | Unknown[AB] |
| MA | Mattapoisett | Unknown[A] | Increasing[A] |
| MA | Monument | Unknown[A] | Increasing[AB] |
| MA | Nemasket | Unknown[A] | Increasing[A] |
| MA | Parker | Unknown[A] | Stable[A] |
| MA | Stony Brook | Unknown[A] | Unknown[A] |
| RI | Buckeye | Unknown[A] | Increasing[A] |
| RI | Gilbert | Decreasing[A] | Stable[A] |
| RI | Nonquit | Decreasing[A] | Decrease[A] |
| CT | Bride Brook | Unknown[A] | Increasing[A] |
| CT | Connecticut | Decreasing[B] | Stable[B] |
| CT | Farmington | Unknown[AB] | Unknown[AB] |
| CT | Mianus | Unknown[AB] | No Trend[A], Increasing[B] |
| CT | Mill Brook | Unknown[A] | No Trend[A] |
| CT | Naugatuck | Unknown[AB] | Unknown[AB] |
| CT | Shetucket | Unknown[AB] | No Trend[A], Stable[B] |
| NY | Hudson | Stable[AB] | Increasing[RH] |
| NJ,DE,PA | Delaware | Unknown[AB] | No Trend[AB] |
| MD,DE | Nanticoke | Decreasing[AB] | Stable[A], No Trend[B] |
| VA,MD,DC | Potomac | Unknown[AB] | Stable[A], Unknown[B] |
| VA | James | Unknown[AB] | Unknown[AB] |
| VA | Rappahannock | Unknown[AB] | No Trend[A], Increasing[B] |
| VA | York | Unknown[AB] | Unknown[AB] |
| NC | Alligator | Unknown[AB] | Unknown[AB] |
| NC | Chowan | Stable[AB] | No Trend[A], Stable[B] |
| NC | Scuppernog | Unknown[AB] | Unknown[AB] |
| SC | Santee-Cooper | Increasing[B] | No Trend[B] |
| FL | St. Johns River | N/A | Unknown[B] |

The river herring Stock Assessment Subcommittee of the ASMFC noted that stocks included in the 2017 update were selected based on data availability and including them did not indicate they are more important than stocks that were not included in the assessment. We also note that these trends only reflect changes since the previous assessment, and do not necessarily represent overall status[22] of a stock. Whereas some positive signs were evident through the updated assessment (e.g., few declining abundance trends by data set in recent years), river herring stocks remain depleted on a coastwide basis and are near historical lows. The "depleted" determination was used in place of "overfished" and "overfishing" because of the variety of factors that have contributed to the declining abundance of river herring, including habitat loss, predation, and climate change in addition to more traditional factors such as directed and incidental harvest. In summary, historically-depressed river herring stocks are in need of continued, active management, and restoration efforts throughout their Atlantic coast ranges.

## 3.2 Overview of River Herring Management by ASMFC

The ASMFC is the regulatory authority for river herring fisheries in state waters along the Atlantic coast. The 1985 FMP for Shad and River Herring was one of the first FMPs developed by the ASMFC. Amendment 1 was implemented in October 1998, which established monitoring programs to inform future stock assessments.

Amendment 1 went into effect on January 1, 2003. It changed the conditions for marking hatchery-reared alosines, clarified the definition and intent of *de minimis* status for the American shad fishery, and modified the fishery-independent and dependent monitoring requirements.

River herring are currently managed under Amendment 2 to the Shad and River Herring FMP. The ASMFC Management Board approved Amendment 2 in May 2009 to restrict the harvest of river herring (blueback herring and alewife) due to concerns about observed declines in abundance. Amendment 2 prohibited commercial and recreational river herring harvest in state waters beginning January 1, 2012, unless a state or jurisdiction has a SFMP reviewed by the Technical Committee and approved by the Board. Amendment 2 defines a sustainable fishery as "a commercial and/or recreational fishery that will not diminish the potential future stock reproduction and recruitment." Catch-and-release only fisheries may be maintained in any river

[22] For example, an increasing trend may seem to suggest that a stock is doing well, but it may be increasing from a depressed level far below historical abundance. Similarly, some stocks may be stable, but chronically depleted.

system without an SFMP. SFMPs have been approved by the Management Board for Maine, New Hampshire, Massachusetts, New York, and South Carolina (Table 1). Amendment 2 also requires states to implement fishery-dependent and independent monitoring programs.

### 3.3 Overview of Federal River Herring Management Efforts

The protection and conservation of public trust resources, including river herring, fall under the umbrella of several federal statutes. These laws are foundational to the federal management framework and support ongoing efforts to conserve river herring and their habitats; they include but are not limited to:

- Anadromous Fish Conservation Act
- Atlantic Coastal Fisheries Cooperative Management Act
- Coastal Zone Management Act and Estuarine Areas Act
- Federal Land Management and other protective designations
- Federal Power Act
- Federal Water Pollution Control Act
- Fish and Wildlife Coordination Act
- Fisheries Act
- Magnuson-Stevens Fishery Conservation and Management Act
- Marine Protection, Research, and Sanctuaries Act of 1972; Titles I and III
- National Environmental Policy Act (NEPA)
- Rivers and Harbors Act of 1899
- Shore Protection Act of 1988

Commercial fisheries with incidental take of river herring in federal waters are managed by the regional Fishery Management Councils. On the Atlantic coast, the New England (NEFMC), Mid-Atlantic (MAFMC), and South Atlantic (SAFMC) Fishery Management are responsible for managing fisheries in their geographical jurisdictions along with NOAA Fisheries, through the Magnuson-Stevens Fishery Conservation and Management Act.

Several management measures intended to reduce commercial fisheries interactions with alosines in federal waters are currently in place or are being developed. These management measures have been developed by the NEFMC, the MAFMC, Greater Atlantic Regional Fisheries Office, and the Northeast Fisheries Science Center (NEFSC), and promulgated through federal fishery management plans for Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*), shortfin and longfin squid (*Illex illecebrosus* and *Doryteuthis pealeii*, respectively), and butterfish (*Peprilus triacanthus*). Because the seasonal and inter-annual distributions of river herring and shad are highly variable, the Councils, NOAA Fisheries, and ASMFC consider the most effective measures to address river herring and shad catch are those that increase accounting of incidental catch, limit the Atlantic herring and mackerel fisheries when appropriate, and promote cooperative efforts with the industry to minimize incidental catch. The types of management measures under consideration or in place, fall into the following general categories:

- Limitations on total river herring and shad catch
- Improvements to at-sea sampling by fisheries observers in Atlantic herring and mackerel fisheries
- Increased monitoring of Atlantic herring and mackerel fisheries
- River herring avoidance program
- Consideration of a federal management plan for river herring

### 3.3.1 Limits on Total River Herring and Shad Catch

Small mesh trawling vessels such as those fishing for Atlantic mackerel, Atlantic herring, squid, or butterfish can encounter river herring and shad (American and hickory) as bycatch. The MAFMC and NEFMC recommended river herring and shad catch caps for these fisheries and NOAA Fisheries began implementing annual catch caps for Atlantic herring and mackerel fisheries in 2014. Managers do not currently have sufficient data to determine biologically-based river herring and shad catch caps or to assess the potential effects of such catch caps on Atlantic coast alosine populations. Nevertheless, the Councils and NOAA Fisheries contend that river herring and shad catch caps are a strong incentive for the mackerel and herring fleets to continue avoiding alosine bycatch. These catch caps are intended to allow for the full harvest of the mackerel and herring annual catch limits while reducing incidental catch of river herring and shad.

In 2014, the first shad and river herring catch cap was established for the Atlantic mackerel fishery. In 2015, NOAA Fisheries proposed a two-phase river herring and shad cap for the mackerel fishery. The two-phase cap was implemented to ensure that the incentive to avoid river herring and shad remained strong independent of mackerel catch levels. The initial cap was set at 89 metric tons (mt), but was set to increase to 155 mt if mackerel catches surpassed 10,000 mt and river herring and shad catch up to that point stayed below the 89 mt threshold. Catch of river herring and shad on fishing trips landing greater than 20,000 lbs of mackerel count towards the cap. If over the course of a calendar year, NOAA Fisheries determines that 95% of the river herring and shad cap has been harvested, a 20,000-lb mackerel possession limit becomes effective for the remainder of the fishing year. Catch caps have remained in place since this initial implementation, with caps varying slightly from year to year, based on available data (Table 3). River herring and shad catch caps were reached in 2018 and 2019 resulting in mackerel fishery closures.

Table 3 – Atlantic mackerel fishery river herring and shad catch caps and landings, 2014-2021.

| Year | Catch Cap (mt) | Landings (mt) |
|---|---|---|
| 2014 | 236 | 6.42 |
| 2015 | 89 | 12.87 |
| 2016 | 82 | 12.88 |
| 2017 | 82 | 39.2 |
| 2018 | 82 | 109* |
| 2019 | 82 | 91.5* |
| 2020 | 129 | 23.1 |
| 2021 | 129 | 3.4 |
| 2022 | 129 | 6.8 |

*Landings exceeded established catch cap

In 2014, the first shad and river herring catch cap was established for the Atlantic herring fishery. The river herring and shad caps are intended to limit river herring and shad catch (landings and discards) on trips that land greater than 6,600 lbs of Atlantic herring. Framework 3 established four, area- and gear-specific catch caps: Gulf of Maine (GOM) Midwater Trawl, Cape Cod Midwater Trawl, Southern New England (SNE) Midwater Trawl, and SNE Bottom Trawl.

When 95 percent of a gear-specific cap for river herring and shad landings is projected to be reached in a catch cap area, all vessels fishing with that gear type in the respective closure area will be subject to a reduced Atlantic herring possession limit of 2,000 lb per trip, per calendar day, in or from that area for the remainder of the fishing year. Vessels using other gear types in the closure would not be subject to the 2,000 lb possession limit and could continue directed fishing for Atlantic herring in those areas with other gear types. Caps on the allowable amount of river herring bycatch have remained in place for the Atlantic herring fishery since the initial implementation, with caps varying slightly from year to year, based on available data (Table 4). Catch caps have been reached on several occasions since 2014, resulting in closures for specific gears and areas. While they can help to mitigate unnecessary mortality, catch caps are just one approach to limiting bycatch of alosines in these fisheries. Other programs (See *Section 3.4*) seeking the same type of protection have been recently implemented in certain areas. See *Section 4.4* for additional information on at-sea mortality.

Table 4 - Atlantic herring fishery area- and gear-specific river herring and American shad catch caps and landings 2014-2022.

| | GOM Mid-water Trawl | | Cape Cod Mid-water Trawl | | Southern NE Mid-Water Trawl | | **Southern NE Bottom Trawl** | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Cap (mt)** | **Landings (mt)** | **Cap (mt)** | **Landings (mt)** | **Cap (mt)** | **Landings (mt)** | **Cap (mt)** | **Landings (mt)** |
| 2014 | 86 | 0 | 13 | 0 | 124 | 15.8 | 89 | 11.3 |
| 2015 | 86 | 11.1 | 13 | 0.7 | 124 | 64 | 89* | 100.7 |
| 2016 | 77 | 0.1 | 32 | 12.1 | 130 | 42.1 | 122 | 53.3 |
| 2017 | 76.7 | 1.9 | 32.4 | 27.1 | 129.6 | 28.7 | 122.3 | 35 |
| 2018 | 76.7 | 0.5 | 32.4 | 65.1* | 129.6 | 134.5* | 122.3 | 34.4 |
| 2019 | 76.7 | 24.7 | 32.4 | 19.4 | 129.6 | 120.4† | 122.3 | 14.8 |
| 2020 | 76.7 | 30.2 | 32.4 | 3.7 | 129.6 | 5.6 | 122.3 | 2.1 |
| 2021 | 76.7 | 0.1 | 32.4 | 0 | 129.6 | 0 | 122.3 | 0.7 |
| 2022 | 76.7 | 5.2 | 32.4 | 0 | 129.6 | 0 | 122.3 | 0.5 |

*Landings exceeded established catch cap

†Fishery closed as landings approached catch cap

### 3.3.2 Improvements to At-Sea Sampling by Fisheries Observers in Atlantic Herring and Mackerel Fisheries

The NEFMC and MAFMC approve and recommend management measures to improve quality of at-sea fisheries observer data by discouraging discarding (known as slippage) before a catch has been sampled by an observer. It is important to have all catch made available to an at-sea observer because river herring and shad encounters are reported to be rare, and even a few un-sampled hauls can affect observer data on river herring and shad encounters. In 2014, NOAA Fisheries prohibited slippage on fishing trips by limited access herring and mackerel/squid vessels carrying observers, except when safety, mechanical failure, or excess catch of spiny dogfish (*Squalus acanthias*) prevented catch from being brought aboard the vessel. Additionally, midwater trawl vessels that slip catch when fishing in the groundfish closed areas (as reported voluntarily or by an at-sea observer), are required to immediately leave the closed areas and remain outside of the closed areas for the remainder of that trip. If a vessel does slip catch when an observer is aboard, the vessel is required to complete a released catch affidavit describing the slippage event. To further discourage discarding prior to sampling on observed fishing trips, the NEFMC and MAFMC also recommended slippage consequence measures. Specifically, if a herring and/or mackerel/squid vessel slips catches due to safety, mechanical failure, or excess catch of spiny dogfish, the vessel would be required to move 15 miles before resuming fishing. If a vessel slips catches for any other reason, the vessel would be required to immediately terminate its trip and return to port. These slippage consequence measures were implemented in the mackerel fishery in September 2015 and remain under review by NOAA Fisheries for the herring fishery.

### 3.3.3 Increased Monitoring of Atlantic Herring and Mackerel Fisheries

The NEFMC and MAFMC recommended increasing at-sea observer coverage in the herring and mackerel fisheries to gain a better understanding of river herring behavior and fishery encounters and to help ensure the effectiveness of management measures. Budget uncertainties prevented NOAA Fisheries from implementing the increased at-sea observer coverage recommended by the Councils. To help address the recommendations for increased monitoring, NOAA Fisheries has taken the lead on an omnibus amendment that would establish industry-funded monitoring programs for fisheries that require additional observer coverage to meet specific fishery management plan goals. This amendment would allow for industry-funded monitoring in all

New England and Mid-Atlantic fisheries and may increase coverage levels for the Atlantic herring and mackerel fisheries. In 2015, the New England and Mid-Atlantic Councils recommended that additional monitoring options, such as electronic monitoring, portside sampling, and at-sea monitors, be further developed in the industry-funded monitoring amendment.

### 3.3.4 River Herring Avoidance Program

The NEFMC and MAFMC supported a river herring avoidance program that used real-time catch data to help fishing vessels avoid areas where interactions with river herring were high. The program was a collaborative effort through the University of Massachusetts Dartmouth School for Marine Science and Technology, the Massachusetts Division of Marine Fisheries (MDMF), the Sustainable Fisheries Coalition, and members of the herring and mackerel fisheries. Results from the program (see: UMass webpage) suggested near real-time communication systems can be an effective way for fishermen to accurately avoid areas of high river herring incidental catch. This near real-time communication method offered a dynamic, fine-scale approach to river herring avoidance that reduced the likelihood of significant, negative economic impacts caused by blanket closures on river herring "hotspots". Results suggested that the program contributed to a 60% decrease in total bycatch and a 20% decrease in bycatch ratio (Bethoney et al. 2017). Twenty-six vessels responsible for at least 95% of the Atlantic herring and mackerel catches were contributors to this project. The project was funded through several groups including the National Fish and Wildlife Foundation, The Nature Conservancy (TNC), and the Atlantic Herring Research-Set Aside Program. The program ended in March 2021 due to diminished funds available in the Research-Set Aside Program associated with reductions of the Atlantic herring quota and due to the establishment of closure areas under Amendment 8 to the Atlantic Herring FMP (though, see *Section 3.4*).

### 3.3.5 Consideration of River Herring in a Federal Fishery Management Plan

Federal managers have considered the inclusion of river herring in federal fisheries management plans on several occasions. NEFMC (2015) considered whether river herring and shad stocks should be managed under a federal fisheries management plan, based on requirements in the MSA and National Standards, including definitions of a fishery, stock, as well as conservation and management requirements. The discussion document considered available river herring and shad data in the context of four questions; the questions and the conclusions were (NEFMC 2015):

1. Are river herring and shad stocks in need of additional conservation and management in federal waters? They were in need of additional management a few years ago, but there are currently multiple efforts ongoing in federal waters to address this need.
2. How would river herring and shad stocks benefit from being included as stocks in the Atlantic herring fishery? *It doesn't appear that they would benefit further, as current management measures would not likely change.*
3. Is it practicable to manage river herring and shad stocks as a unit and/or in close coordination throughout their range? No, the range is from Labrador (Canada) to Florida, and it would be very difficult to manage these different stocks as a unit.
4. Would conservation and management of river herring and shad stocks through a federal FMP be unnecessarily duplicative? Yes, it would duplicate management efforts between the New England and Mid-Atlantic Councils, the ASMFC, and NOAA Fisheries.

Like the NEFMC, the MAFMC considered initiating federal management for the species in 2013 and again in 2016. On both occasions, it was decided that managing river herring and shad through a dedicated council fisheries management plan was not warranted.

More recently, NEFMC (2018) again considered the issue of federal management of river herring and shad. In June of 2018, the NEFMC passed a motion supporting "No Action: Maintain Current Management Approach". The "current" approach at the time of the decision was as follows (NEFMC 2018):

- ASFMC and states will continue to address the management of directed fisheries for river herring and shad (state waters) through the Interstate FMP and SFMPs.
- The Councils (New England and Mid-Atlantic) will continue to manage/minimize river herring and shad catch in non-directed federal fisheries like the Atlantic herring and mackerel fisheries, as well as other fisheries in the future as necessary, through use of catch caps.

- The TEWG will continue its coordination efforts to identify threats to river herring and conservation actions in support of the HCP, as well as promote information exchange, collaboration, and outreach.
- NOAA Fisheries is in the process of reviewing the previous negative finding for ESA listing. That work is scheduled to be completed by January 2019.[23]

The NEFMC and MAFMC continue to support river herring and shad conservation through management recommendations including techniques such as catch caps in Atlantic coast fisheries likely to encounter them as bycatch. Notwithstanding, the approach outlined in NEFMC (2018) remains in practice today, and neither the NEFMC nor MAFMC have initiated management of river herring and shad through a federal fisheries management plan.

### 3.4 Timeline of Selected Notable River Herring Management Actions

2011

- National Resources Defense Council — Petition NOAA Fisheries to list river herring under the ESA.
- NOAA Fisheries — Status review initiated: ESA listing determination for each species.

2012

- ASMFC — Atlantic coast harvest moratorium (excl. ME, NH, & NY).
- ASMFC — River herring benchmark stock assessment published.

2013

- NOAA Fisheries — ESA Listing determination: Not Warranted.

2014

- NOAA Fisheries/ASMFC — TEWG is established.
- NOAA Fisheries — River herring and shad catch caps established (Atlantic mackerel fishery) as recommended by the NEFMC and MAFMC.
- NOAA Fisheries — River herring and shad catch caps established (Atlantic herring fishery) as recommended by the NEFMC and MAFMC.

[23] This listing determination was completed as planned, and found that ESA listing was not warranted. *see: NMFS, 2019.*.

2015

- NOAA Fisheries— River Herring Conservation Plan is published.
- MAFMC — Regulation on squid, Atlantic mackerel, and butterfish tightened to avoid slippage.

2017

- NOAA Fisheries — Status review initiated: ESA listing determination.

2018

- NOAA Fisheries — Mackerel closure: river herring/shad cap reached.
- NOAA Fisheries — Atlantic herring closure: river herring/shad cap reached, Cape Cod Catch Area.
- NOAA Fisheries — Atlantic herring closure: river herring/shad cap reached, Southern New England Catch Area.

2019

- NOAA Fisheries — ESA Listing determination: Not Warranted.
- NOAA Fisheries — Mackerel closure: river herring/shad cap reached.

2020

- NOAA Fisheries — Approved final rule for the New England Industry-Funded Monitoring Omnibus Amendment requiring that 50% of the Atlantic herring fishery trips be monitored (85 FR 7414).

2021

- NEFMC — Approved Amendment 8 to the Atlantic Herring FMP, which prohibits midwater trawling in inshore federal waters from the U.S.-Canadian border to the Rhode Island-Connecticut border.
    - This prohibition was subsequently overturned (see bulletin) in March 2022, and trawlers once again returned to inshore waters.

2022

- ASMFC — Began an updated benchmark stock assessment for river herring. Data workshop was held and technical committee was formed in July 2022.
- NOAA Fisheries — Announced that the industry-funded monitoring program would be suspended in April 2023 due to lack of funding (see bulletin).

## 3.5 Commercial and Recreational Fisheries

River herring harvest is closed due to the moratorium in effect since 2012 unless states and areas have submitted approved SFMPs to allow regulated harvest (commercial and/or recreationally). States with SFMPs include Maine, New Hampshire, Massachusetts, New York, and South Carolina, as well as alternative fisheries management plans for Georgia and Florida.

### 3.5.1 Commercial Fisheries

*Maine*

The state of Maine manages its river herring fisheries as a cooperative effort between the state and local municipalities that have historical runs of river herring. Harvest of river herring is allowed from the beginning of the run until June 5, unless the town is granted an extension due to a delayed run of fish. Weirs can be used to collect herring as long as an opening of at least two feet is maintained between the bank and the downstream end as well as a maximum mesh size of one inch by one inch. Additional regulations are enforced for waters with historical Atlantic salmon runs. Commercial fishing has a lift (non-harvest) period from Thursday through Sunday mornings to allow for spawning to occur naturally; weirs must have an opening of three feet by three feet during this period. Catches of herring must be submitted upon request by the Maine Department of Marine Resources (MDMR) or NOAA Fisheries.

*New Hampshire*

Although the state of New Hampshire has a SFMP, it does not allow harvest of river herring.

*Massachusetts*

The Nemasket River is currently the only watershed that is approved to allow commercial river herring harvest in Massachusetts. In 2017, the Middleborough-Lakeville Herring Fishery Commission (MLHFC) in coordination with MDMF developed a SFMP for the Nemasket River (see MDMF 2022). The ASMFC approved this plan, which permits harvest of river herring. Although harvest is permitted, the MLHFC has declined to harvest each year since the plan was approved, citing concerns with recent population fluctuations. The Wampanoag Tribe has recognized fishing rights and harvests river herring. In return, the tribe reports its harvest to the MDMF.

*New York*

New York permits a commercial fishery for river herring in the mainstem of the Hudson River. Fishermen may purchase gill net (fixed or drift) or scap (scoop-type) net permits (scap netting is not allowed in tributaries). There is a 36-hour lift period, and nets must be less than or equal to 3.5-inch stretch mesh. New York does not allow any commercial river herring harvest for Long Island, Bronx County, and Westchester County as well as the upper reaches of the Delaware River. A net ban is in place for roughly 17 miles of the upper portion of the mainstem estuary, known as the American shad spawning flats, and in any tributaries. There are also no fixed gears or night fishing allowed above the Bear Mountain Bridge in Garrison. Monthly commercial landings must be reported to the New York State Department of Environmental Conservation (NYSDEC), where catch and harvest are monitored but no limits are currently set.

*South Carolina*

The only river systems in South Carolina with a river herring fishery are the Santee-Cooper Complex and the Pee Dee River. The season runs from February 15 to May 1 in the Santee River and February 15 to April 15 in the Pee Dee River. The Rediversion Canal of the Santee River and the Tailrace Canal of the Cooper River have longer commercial seasons from March 1 to April 30. Each commercial fishing boat is allowed up to 10 U.S. bushels of river herring per day. A variety of net types and specified locations are enforced in these systems. Gill nets (fixed and drift), drop nets, lift nets, cast nets, and hook and line fishing are allowed, but certain gear types are restricted in certain areas. There is an 84-hour lift period 7 p.m. Saturday to 7 a.m. Wednesday) for the Pee Dee River. Portions of the Cooper River Tailrace and Rediversion Canal are open for varying times from sunrise to midnight with no lift period (SC Law 50-5-1507).

### 3.5.2 Recreational Fisheries

*Maine*

Beginning January 1, 2012, the state of Maine permits individuals to take up to 25 river herring per day for recreational or personal use. If a municipality or individual has obtained exclusive river herring harvesting rights to a system under 12 M.R.S. §6131, an individual may only take river herring for recreational or personal use if it is in accordance with the municipal harvest plan submitted annually to the MDMR by the municipality. Hook-and-line and dip netting are the only permissible methods for recreational river herring harvest. Maine limits the recreational harvest of river herring to 25 fish per angler, per day.

*New Hampshire*

Recreational harvest of river herring was permitted in New Hampshire until recently, primarily through state-permitted coastal harvesters engaged in fishing for personal use, such as bait. A rule change implemented a full closure in April 2021, and currently all harvest of river herring in New Hampshire remains prohibited.

*Massachusetts*

There is currently no permitted recreational fishery for river herring in Massachusetts.

*New York*

The mainstem of the Hudson River has a recreational fishery for river herring based primarily on procuring bait for the striped bass fishery. The NYSDEC collects creel data on the fishery through its cooperative angler program, in which, anglers (including charter boat captains) report their fishing trips. Anglers are allowed to keep 10 river herring (either or both species, provided the total number ≤10 individuals) per day, with a boat limit of 50 individuals. Recreational anglers are allowed to use hook-and-line as well as small scoop, seine, or cast nets in the mainstem; however, no net use is permitted in tributaries.

*South Carolina*

The only recreational fishing reported for South Carolina is bycatch of river herring from the American shad fishery.

*Georgia*

The recreational harvest of river herring in Georgia is unregulated. The Georgia Department of Natural Resources (GDNR) is not aware of any recreational fishing targeting or incidentally catching river herring based on various creel surveys by both NOAA Fisheries and the GDNR.

*Florida*

Gears that could result in incidental catch of river herring are not allowed in Florida waters including pound nets, gill nets, or haul seines. Recent creel surveys have detected no significant fishing effort for river herring. Although little effort is made to harvest river herring in Florida, hook-and-line fishing is an acceptable method of capture, and the daily bag limit is 10 alosines, and may include any combination of blueback herring, American shad, hickory shad, or Alabama shad (*Alosa alabamae*).

## 4.0 Threats to River Herring

River herring occupy a variety of habitats throughout their expansive Atlantic coast ranges including coastal plain streams of the Southeast, high-gradient rivers of New England, inland lakes and ponds, estuaries, and the open ocean. Because of their extensive geographic distributions and the diversity of the habitats in which they are found, the river herring species are subject to many threats. Several threats stand out from the long list, including lost connectivity or diminished access to spawning and nursery habitats, climate change, poor water quality, at-sea mortality (including bycatch), and predation from non-native predators such as catfish (Ictaluridae).

### 4.1 Barriers and Lost Connectivity

Migration barriers such as dams and road-stream crossings (e.g., culverts, bridges) pose one of the greatest threats to river herring. Barriers block or significantly impede the ability of river herring to access the habitats required for successful spawning and juvenile rearing. Dams are ubiquitous throughout the ranges of river herring, but impacts are most prominent from the Mid-Atlantic north into Canada where barrier density is high (Hare et al. 2021; Zydlewski et al. 2021). New dams and barriers rarely have been proposed within the ranges of river herring since the mid-twentieth century. Current design standards for potential barriers such as road-stream crossings generally consider fish passage based on state or federal regulations and guidance (such as FHWA-HIF-11-008), and a number of barriers have been removed in recent decades (see *Appendix C* for recent examples). While many projects have resulted in dramatic, positive run responses (e.g., Sebasticook River, see *Appendix C 1.3*), the compounding and chronic effects of remaining barriers necessitate targeted evaluation and passage improvements to further the recovery of these species.

Even at barriers where fish passage provisions are employed, passage efficiency and effectiveness are highly variable (Landsman and van den Heuvel 2017) and do not provide the level of connectivity offered by free-flowing, unimpeded streams and rivers (Brown et al. 2013; Alcott et al. 2021a). Some passage structures historically were designed without application of biometric data, were designed for target species other than river herring with different swimming abilities (e.g., salmonids), or were not adequately designed to accommodate the swimming abilities of river herring (Turek et al. 2016; USFWS 2019). Attraction flow to fishway entrance(s) and other site-specific hydraulics such as competing spill flows are commonly noted factors that can limit passage efficiency (Groux et al. 2015). Ineffective fishway passage can also stem from poor fishway maintenance and/or operational challenges. For example, annual inspections, repairs, and debris removal are required to maintain designed fishway passage conditions, but may be limited by the availability or ability of the fishway operator to regularly perform these activities. Furthermore, technical fishways often require adjustments (e.g., stop log removal) to accommodate different flows and water levels and/or passage requirements (e.g., opening sluiceways during the outmigration period). Additional challenges can be presented when adaptive management approaches for these structures may be insufficiently documented, or institutional knowledge is lost with staffing turnover. Finally, some fishway designs require manual operation that can be difficult to maintain or implement at a sufficiently large scale or throughout the duration of the passage season. All of these factors can lead to improperly managed or maintained fishways that present the impression of providing fish passage but may perform poorly. Similarly, a lack of proper operation and maintenance may give the impression that a potentially-effective fishway has a poor design and/or is not capable of passing target species.

If passage facilities are not performing effectively, they can lead to migratory delay and concentration of fish below barriers, in addition to low overall passage rates. Migratory delay can include individuals taking significant time to locate a fishway entrance, requiring extended periods to navigate a fishway, and/or making several failed attempts at upstream migration (Castro-Santos and Haro 2010). These failures increase energetic costs, which can, in turn, limit the ability of individual adults to reach productive spawning grounds and/or complete their post-spawn outmigration (Castro-Santos and Letcher 2010). Poor passage and related delay can lead to increased densities of juveniles, below or between barriers, that may experience negative density-dependent effects of reduced growth and fish condition, compared to upstream habitats (Mattocks et al. 2018). Cumulatively, such energetic costs have population-level implications, including a reduction in rates of iteroparity and diminished fitness (Marjadi et al. 2019).

Due to the concentrating effect of barriers (Figure 9 and Figure 10), migratory delay can also make river herring more susceptible to predators (Warner and Kynard 1986; Schmitt et al. 2017; Alcott et al. 2020; Rillahan et al. 2021). For example, double-crested cormorants (*Phalacrocorax auritus*), bald eagles (*Haliaeetus leucocephalus*), harbor seals (*Phoca vitulina*), striped bass, largemouth bass (*M. salmoides*), catfish species (e.g., *Ictalurus furcatus, Pylodictis olivaris*), snapping turtles (*Chelydra serpentina)*, and other species of mammals, fishes, and birds are all known to prey on river herring within estuarine and riverine habitats (Yako et al. 2000; Markham and Watts 2008; Dalton et al. 2009; Jones et al. 2010; Davis et al. 2012; Smith et al. 2015; Mattocks et al. 2017; Toth et al. 2018; Alcott et al. 2020; Alcott et al. 2021b). Predatory pressure and associated avoidance behavior at existing barriers also diminish passage efficiencies. Specifically, Alcott et al. (2021b) documented late-season migratory delay at a tide gate in Massachusetts and noted that poor river herring passage was likely attributable to predatory fish avoidance behavior rather than hydrological variables.

Figure 9 – Congregation of white pelicans (*Pelecanus erythrorhynchos*) and double-crested cormorants (*Phalacrocorax auritus*) in front of St. Stephen fish lock and dam located on the Rediversion Canal part of the Santee River, SC. Credit: SCDNR

Figure 10 – Temporary exclusion installed for white pelicans on the St. Stephen fish lock and dam in the Santee River, SC. Credit: USACE.

Unsuitable flow conditions (e.g., high velocities, insufficient depths) created by anthropogenic in-water structures (e.g., culverted road crossings, tide gates, submerged pipeline armoring) can also prevent or delay spawning movements by chronically presenting conditions that are either impassible or require extensive energy expenditure to pass (Alcott 2020; Alcott et al. 2021a). Some culverts are perched or elevated causing fish migration to be limited or impossible. However, even culverts with the correct passage proportions have been found to reduce the speed of passage (Alcott et al. 2021a). When accounting for the delay at each culvert, cumulative passage time for river herring doubled relative to unaltered reaches (Alcott et al. 2021a). River herring attempting to pass through tide gates experienced varying degrees of success (78 percent early season versus 16 percent late season) depending on the timing of their spawning run. This is thought to be related to tide, flow through the gates, timing of diel movements, and predator avoidance behavior later in the spawning migration (Alcott et al. 2021b). These types of barriers not only affect upstream migration but also delay emigration (Alcott et al. 2021b). Even minor, seemingly inconsequential delay at individual barriers can become cumulatively significant when the total number of such barriers encountered by river herring on the upstream migration are considered. Therefore, any source of delay regardless of magnitude has the potential to impact overall spawning success and should be avoided, minimized, or mitigated as much as possible.

Downstream passage at dams and other large structures can also be a source of mortality for adult and juvenile river herring during the outmigration without proper design considerations (Taylor and Kynard 1985; Franke et al. 1997). Mortality can be especially exacerbated at hydropower facilities where the chosen path of egress is through the turbines (Castro-Santos and Haro 2010; Holbrook et al. 2011; Stich et al. 2014). Downstream passage has not been historically considered during design to the same extent as upstream passage (Dadswell and Rulifson 1994; Brown et al. 2013). Downstream passage structures that take advantage of the natural tendency for downstream migrants to use the upper water column (e.g., log sluice) with appropriate outfall conditions (e.g., plunge pool) can be effective at minimizing the mortality of downstream migrants (USFWS 2019). However, many historical structures (e.g., mill dams) do not incorporate such designs and the results can be deleterious for river herring. This is especially true for plunge pools with inadequate depths; such configurations increase risk of injury and mortality, an issue exacerbated during summer low-flow conditions. A modeling study on the passage performance of American shad showed that an increase in downstream passage efficiency was required to maintain or increase population abundance in conjunction with increased upstream passage (Stich et al. 2019). This work suggests that downstream passage efficiency is just as important of a factor as upstream passage efficiency to the recovery of river herring populations. The importance of maintaining stock structure elements, including repeat spawning fish, has potential implications to population fitness and resilience that are also influenced by passage effectiveness.

Latitudinal connectivity between a river and its shoreline and riparian areas throughout a watershed is essential for the overall health of the riverine ecosystem, in part because it can provide critical habitat for juvenile fish to feed, grow, and avoid predation (Miller and Dunn 1980; Sheaffer and Nickum 1986; Turner et al. 1994; Ward et al. 1999; Heimbuch 2008; van der Most and Hudson 2018). Many watersheds throughout the ranges of river herring present lost or restricted connectivity to once productive spawning and rearing habitats due to modifications associated with human development. These modifications include, but are not limited to shading or filling (Able et al. 1999), tide gates, culverted road-stream crossings, unavailable former channel pathways (Phillips 2013), and restricted access to smaller tributaries and ponds.

River herring show a strong genetic isolation by distance (i.e., correlation between geographic and genetic distances) (McBride et al. 2014; Reid et al. 2018). Stock identification has shown that meta-populations of river herring return to natal rivers to spawn and could have individual populations within the same river (Palkovacs et al. 2013; McBride et al. 2014; Turner et al. 2015; Reid et al. 2018). Historically low populations and current barriers to migration routes throughout the coastwide ranges are likely contributing to a river herring genetic bottleneck and reduction of gene flow (Morita and Yamamoto 2002; McBride et al. 2014; Reid et al. 2018). Increasing habitat connectivity and available suitable habitat will help to preserve the population-level genetic integrity of both species.

The rise of the industrial era introduced new challenges for river herring and aquatic species more generally. While dams and other physical barriers are visible blockages, extreme cases of poor water quality can also impede access to spawning habitats. Rivers across the range of river herring, like the Androscoggin, Merrimack, and Mohawk, were heavily polluted from a variety of industrial discharges and other untreated wastewater sources. The historical pollution block within the Delaware River is an example of this, as discussed in *Section 4.3*.

## 4.2 Climate Change

Climate change affects river herring at all life stages and across their marine and freshwater habitats through a variety of complex and interacting pathways (Hare et al. 2016). Modeling studies have indicated that river herring will likely experience a reduction in total suitable marine habitat and that adverse effects of climate change may further inhibit population recovery (Lynch et al. 2015; McHenry et al. 2019). Climate change is expected to increase precipitation stochasticity, increase ocean acidification, decrease winter snow packs, increase heat waves, increase the severity of droughts, and shift seasonal and latitudinal temperatures (IPCC 2021). These stressors are predicted to worsen over time (IPCC 2021) and the continued risk and threats presented from climate change will likely exacerbate other current threats to river herring (Rahel and Olden 2008; Cobb 2020). The direct threats associated with climate change effects on river herring will be discussed here, and other indirect impacts will be discussed later in this section.

Temperature is considered the “master variable” in fish physiology given its influence on growth and overall fitness (Kitchell et al. 1977; Magnuson et al. 1979; Wagner et al. 2017). Unsuitable temperatures also cause stress responses in fish (Alfonso et al. 2021). Rising temperatures not only affects river herring physiology but also other aspects, like spawning, by shifting and, in some cases, compressing the suitable spawning period. In freshwater, river herring initiate spawning when water temperatures reach 50 to 60°F. In the southern portion of the range, ideal spawning temperatures may be present as early as February, whereas in the northern portion of their range, water temperatures may not be suitable until later in the spring (e.g., June). Warming water temperatures will likely result in a northward shift in the species distributions (Ellis and Vokoun 2009; Lombardo et al. 2020; Nelson et al. 2020) and spawning phenology (Ellis and Vokoun 2009; Lombardo et al. 2020). Lombardo et al. (2020) examined the change in run timing for river herring from the 1970s to the 2010s in North Carolina. They found that, for adults of both species, peak spawning time was 12-13 days earlier and outmigration was 23-27 days earlier over this time frame, representing a shifting and shortening of the average spawning period best explained by warming spring temperatures (Lombardo et al. 2020). Truncated spawning windows may have implications for successful spawning and recruitment by reducing overlap with optimal environmental or passage conditions (Lombardo et al. 2020). Shifting temperature regimes can also create a mismatch between the timing of species presence (and biological needs) and management protocols such as monitoring, passage activities at barriers, and time of year restrictions. The risk of misalignment is pronounced when operational protocols are based on calendar dates, which may not fully encompass critical environmental windows (e.g., temperature) shifted by a changing climate.

In addition to shifts in spawning phenology, recent laboratory experiments presented by Guo et al. (2021) demonstrated that high temperature (77°F) and low food rations (1 percent or 2 percent tank biomass daily) had an interacting negative effect on juvenile alewife over a 21-day rearing period. This indicates that warmer temperatures coupled with low food availability may depress juvenile alosine growth rates and energy densities during the freshwater rearing stage, which will likely negatively affect juvenile survival and recruitment. Similar responses to warming rearing temperatures have been demonstrated for American shad (Gilligan-Lunda et al. 2021). As the trend of warming temperatures across species ranges is projected to continue (Friedland et al. 2020), it will be an ongoing threat to river herring that warrants further investigation (Lombardo et al. 2020). Although rising temperature is an important factor in determining restoration potential for river herring, projecting future river herring range shifts should incorporate many variables to more accurately reflect the multi-faceted influences of climate change (McHenry et al. 2019).

In the marine environment, rising surface water temperatures have presented suboptimal conditions for foraging, adult-phase river herring over broader areas of the Northeast Atlantic shelf region (Nye et al. 2009; Friedland et al. 2013). These temperature shifts have been associated with an observed northern shift in the center of distribution for both species (Nye et al. 2009; Lynch et al. 2015) which is predicted to continue under projected climate conditions (Lynch et al. 2015; McHenry et al. 2019).[24] Climate-induced shifts in ocean conditions (e.g., sea surface temperatures, circulation patterns) are predicted to exert profound influence on marine zooplankton communities (Beaugrand and Ibanez 2004; Richardson and Schoeman 2004; Poloczanska et al. 2013; Beaugrand et al. 2015; Barton et al. 2016) which has significant trophic implications for river herring that warrant further study (Hare et al. 2021) see also *Section 5.1*.

Continued changes in the temperature of coastal environments will likely also shift the predators that feed on river herring (Coutant 1990; Portner and Peck 2010; Nack et al. 2019). Climate change is also predicted to increase the occurrences of invasive species that are introduced, potentially introducing new predators and threats to river herring (Rahel and Olden 2008). The threats associated with predation and other species interactions are discussed further in *Sections 4.6 and 6.3*, respectively.

Changing precipitation patterns as a result of climate change will likely affect river herring migrations across the coastwide ranges of both species. As they migrate into their freshwater spawning habitats, increased water level stochasticity associated with extreme weather events would increase the vulnerability to mortality and likely impede spawning and juvenile recruitment success. Shifts in river hydrology associated with diminished winter snowpack and

[24] See also the associated web tool

extreme weather events, including the frequency of low/peak flows, can also affect upstream and downstream passage success/effectiveness and spawning habitat availability (Walsh et al. 2005). Recent studies demonstrate an increasing frequency of flood events and peak flows in the northeastern United States, as well as frequency of extreme weather events throughout the United States (Collins 2009; Kunkel et al. 2013; Peterson et al. 2013; Armstrong et al. 2014; Agel 2018). The impacts of discharge on juvenile recruitment are largely system specific and dependent upon stream size and drainage area (Kosa and Mather 2001; Tommasi et al. 2015; Bi et al. 2021). However, high discharge has been demonstrated to decrease feeding efficiency of other clupeids, particularly during sensitive life phases such as the transition from larva to first-feeding fry (Crecco and Savoy 1985; Limburg 1996). Flow regimes altered by climate change could increase the frequency and/or magnitude of high river discharge events during periods critical for sensitive life phases. Over time, this can potentially diminish the adaptive environmental synchrony that developed over the evolutionary history of fish species (Fausch 2008).

This expanding body of literature describes the extent to which climate change increasingly presents many complex and interacting stressors to river herring throughout their life histories. The overall vulnerability of alewife and blueback herring and the impacts to their habitat from climate change has been synthesized in two recent efforts. In their Northeast Fish and Shellfish Climate Vulnerability Assessment, Hare et al. (2016) described the overall vulnerability rank of both species as being “very high” to climate change due to the wide variety of habitats they occupy and their sensitivity at different life stages (see Figure 11 and Figure 12). In that study climate exposure, which is the magnitude of change projected for biologically-relevant variables (e.g., temperature, salinity), was described as “very high” for both species. Biological sensitivity, which is a measure of an organism’s vulnerability to shifting climatic conditions, was described as “high” for both species. This vulnerability is especially pronounced due to diminished stocks and high exposure during spawning and early life history stages. Waldman et al. (2016) suggested that a “resilience approach” is necessary to mitigate the multifaceted impacts of stressors like climate change, including maintaining a “portfolio” of different life history strategies to hedge against unfavorable environmental conditions.

In the recent Northeast Habitat Climate Vulnerability Assessment, Farr et al. (2021) note that several habitats important to particular life stages (e.g., juvenile SAV habitats) have both high climate exposure and sensitivity. This information has been recently compiled along with the ACFHP habitat-species matrix (Kritzer et al. 2016) for use in fisheries management.[25] These studies indicate that spawning and rearing habitats are particularly vulnerable to climate change.

[25] This information is presented in the "Habitat Crosswalk" section of the Northeast Regional Habitat Assessment Data Explorer

Alewife – *Alosa pseudoharengus*

Overall Vulnerability Rank = Very High

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 79% of scores ≥ 2

| | *Alosa pseudoharengus* | Expert Scores | Data Quality |
|---|---|---|---|
| Sensitivity attributes | Stock Status | 2.5 | 1.4 |
| | Other Stressors | 3.3 | 2.2 |
| | Population Growth Rate | 2.2 | 1.4 |
| | Spawning Cycle | 3.2 | 2.9 |
| | Complexity in Reproduction | 3.2 | 3.0 |
| | Early Life History Requirements | 3.3 | 2.4 |
| | Sensitivity to Ocean Acidification | 1.5 | 1.8 |
| | Prey Specialization | 1.5 | 3.0 |
| | Habitat Specialization | 2.6 | 3.0 |
| | Sensitivity to Temperature | 2.0 | 3.0 |
| | Adult Mobility | 1.6 | 2.8 |
| | Dispersal & Early Life History | 2.8 | 2.6 |
| | Sensitivity Score | High | |
| Exposure variables | Sea Surface Temperature | 4.0 | 3.0 |
| | Variability in Sea Surface Temperature | 1.0 | 3.0 |
| | Salinity | 1.7 | 3.0 |
| | Variability Salinity | 1.2 | 3.0 |
| | Air Temperature | 4.0 | 3.0 |
| | Variability Air Temperature | 1.0 | 3.0 |
| | Precipitation | 1.3 | 3.0 |
| | Variability in Precipitation | 1.4 | 3.0 |
| | Ocean Acidification | 4.0 | 2.0 |
| | Variability in Ocean Acidification | 1.0 | 2.2 |
| | Currents | 2.0 | 1.0 |
| | Sea Level Rise | 2.8 | 1.5 |
| | Exposure Score | Very High | |
| | Overall Vulnerability Rank | Very High | |


Figure 11 – Results from the climate vulnerability ranking assessment for alewife completed by Hare et al. (2016), reprinted with permission.

Blueback Herring – *Alosa aestivalis*

Overall Vulnerability Rank = Very High

Biological Sensitivity = High
Climate Exposure = Very High
Data Quality = 88% of scores ≥ 2

| | *Alosa aestivalis* | Expert Scores | Data Quality |
|---|---|---|---|
| Sensitivity attributes | Stock Status | 2.7 | 1.2 |
| | Other Stressors | 2.7 | 2.0 |
| | Population Growth Rate | 2.3 | 2.0 |
| | Spawning Cycle | 3.5 | 2.8 |
| | Complexity in Reproduction | 3.2 | 3.0 |
| | Early Life History Requirements | 3.3 | 2.5 |
| | Sensitivity to Ocean Acidification | 1.5 | 2.2 |
| | Prey Specialization | 1.8 | 3.0 |
| | Habitat Specialization | 2.3 | 3.0 |
| | Sensitivity to Temperature | 1.8 | 3.0 |
| | Adult Mobility | 1.3 | 2.8 |
| | Dispersal & Early Life History | 3.2 | 2.6 |
| | Sensitivity Score | High | |
| Exposure variables | Sea Surface Temperature | 4.0 | 3.0 |
| | Variability in Sea Surface Temperature | 1.0 | 3.0 |
| | Salinity | 1.8 | 3.0 |
| | Variability Salinity | 1.2 | 3.0 |
| | Air Temperature | 4.0 | 3.0 |
| | Variability Air Temperature | 1.0 | 3.0 |
| | Precipitation | 1.3 | 3.0 |
| | Variability in Precipitation | 1.4 | 3.0 |
| | Ocean Acidification | 4.0 | 2.0 |
| | Variability in Ocean Acidification | 1.0 | 2.2 |
| | Currents | 2.0 | 1.0 |
| | Sea Level Rise | 2.6 | 1.5 |
| | Exposure Score | Very High | |
| | Overall Vulnerability Rank | Very High | |


Figure 12 – Results from the climate vulnerability ranking assessment for blueback herring completed by Hare et al. (2016), reprinted with permission.

## 4.3 Habitat Degradation and Water Quality

During spawning, rearing, and migration, river herring are exposed to a wide range of physiochemical conditions and are more susceptible to negative effects associated with anthropogenic degradation of surface water quality and habitat. While many of these stressors stem from historical and ongoing land cover change, several acute stressors are also associated with in-water structures/construction, stream channel alterations, water management infrastructure, and various other human-derived influences (see reviews by Greene et al. 2009; Burke and Rohde 2015; Hare et al. 2021; Waldman and Quinn 2022). Many of these physical changes have direct implications for the quality and quantity of water available for river herring and their ability to complete their complex life histories. As with most fish, early life history stages (e.g., eggs, larvae) are particularly sensitive to water and habitat quality degradation. For river herring, these early stages often coincide with areas of concentrated human activity, so the majority of these threats are distinctly focused on the overlap between human development/industry and its influence on spawning and rearing habitats. Based on modeling completed by Nelson et al. (2020), juvenile recruitment is likely a major limiting factor to population recovery, and degraded quality of rearing habitat has been identified as a major driver for poor recruitment across river systems (Hare et al. 2021).

Geomorphological changes to riverine and aquatic habitat can impede the ability of adult river herring to reach spawning grounds and diminish the quality of habitat for eggs, larvae, and juveniles (Greene et al. 2009). These waterway alterations can result from direct (e.g., dredging, filling) or indirect (e.g., land cover conversion) human activities. Channelization through ditching and dredging limits habitat availability by diminishing shallow water habitat, reducing floodplain connectivity, and altering surface water hydrology (Bryan and Rutherford 1995). For example, historical ditching to enhance drainage in many coastal areas has resulted in changes to hydrology and loss of habitat availability/complexity for alosines (Frankensteen 1976; NCDMF 2022). Because dredging and ditching alter stream/estuary morphology, they are often accompanied by changes to benthic substrates (e.g., siltation), which likely influence habitat suitability for river herring and their prey (see review by Greene et al. 2009).

Filling of shallow water habitats to stabilize shorelines or create uplands can further impact spawning and rearing habitats by diminishing habitat complexity and resiliency associated with riparian vegetation, tidal wetlands, and SAV. Extensive filling of wetlands and surface waters, which was most recently pronounced during the mid-twentieth century, was regulated under the Clean Water Act in 1972. However, shoreline alterations continue for various industrial activities, and shoreline erosion control through hardening (e.g., placement of stone) is a ubiquitous feature in densely-populated regions. While nature-based approaches[26] to shoreline stabilization are being more broadly accepted and implemented (Bilkovic et al. 2016; Hilke et al. 2020), further hardening (e.g., stone revetments, seawalls) remains a common response to future shoreline erosion (Dugan et al. 2011; Gittman et al. 2015). Historically, many natural shorelines provided nursery habitat for river herring. Shoreline hardening has been correlated with diminished estuarine habitat for fish and a reduction in SAV (Uphoff Jr et al. 2011; Patrick et al. 2014; Kornis et al. 2017). Finally, dams and other in-water structures fundamentally alter stream morphology and, aside from their role as barriers (see *Section 4.1*), can present sub-optimal lentic (e.g., shallow impoundments prone to increased temperature) and lotic (e.g., unsuitable tailwaters for spawning/rearing) habitats (Power et al. 1996; Freeman et al. 2001).

Human-induced changes to stream hydrology can also influence river herring spawning and rearing success by affecting a broad suite of factors ranging from upstream/downstream passage to the availability of suitable forage. Tommasi et al. (2015) noted that river discharge was a significant predictor of juvenile recruitment among the majority of watersheds examined, although the relationship between juvenile production and discharge differed between the systems considered. In a relatively small riverine nursery (Nanticoke River, Maryland), low discharge during the summer rearing period negatively influenced juvenile survival, whereas intermediate flows were associated with higher juvenile survival in larger riverine systems (Tommasi et al. 2015). Anthropogenic alterations of instream flow can stem from a variety of sources including hydropower/dam operations, water withdrawals, and land cover alteration. The regulation of the flow through dams can disrupt natural flow regimes (*sensu* Poff et al. 1997), causing diminished passage for upstream and downstream migrants (Yako et al. 2002; Castro-Santos and Haro 2010) and potentially poor rearing conditions (e.g., shallow water habitat stability) for juvenile fish (Power et al. 1996; Freeman et al. 2001).

---

[26] See https://ewn.erdc.dren.mil/

The intake of water for various human uses (e.g., process and cooling water, pumped storage, drinking water) can cause significant impingement/entrainment mortality and chronically-altered flows (see reviews by Greene et al. 2009; Waldman and Quinn 2022), which negatively impact passage efficiency and survival, particularly for juveniles. The magnitude of impact likely varies greatly based on life stage(s) present, project location, withdrawal rates, and intake design (see review by Gowan et al. 2002). Finally, land cover change is a large driver of shifting stream hydrology, which in turn affects floodplain connectivity, water quality, and instream habitat for fish (Allan 2004; Roy et al. 2005). Increased impervious surface cover is broadly associated with larger peak flows, which can displace early life stages of alosines to suboptimal habitats (Klauda et al. 1991). Impervious cover is also associated with diminished summer base flows (Poff et al. 1997) which can influence juvenile outmigration timing and passage success (Yako et al. 2002; Gahagan et al. 2010).

A major driver of lost habitat suitability for juvenile alosines has been associated with declining water quality in spawning/nursery habitats (Greene et al. 2009). Land cover conversion (i.e., primarily forested to human use) and associated development/industrial activity have been shown to diminish river herring returns primarily through water quality impairment and the introduction of toxic chemicals (Limburg and Schmidt 1990; Schiff and Benoit 2007; Waldman and Quinn 2022). Water quality impairment is ubiquitous throughout the range of river herring due to the concentration of human activity at the geologic fall line[27] in the U.S. Southeast, Mid-Atlantic regions, and coastal areas of New England. The effects of land cover change and associated development/industrialization impact river herring through both direct and indirect pathways. We only cover a subset here.

Non-point source pollution associated with human land cover change typically results in increased delivery of nutrients and potentially toxic chemicals to surface waters via stormwater runoff (Malmqvist and Rundle 2002) with implications for juvenile rearing habitat (Limburg and Schmidt 1990; Uphoff Jr et al. 2011; Monteiro Pierce et al. 2020; Bi et al. 2021). For example, sub-estuaries of the Chesapeake Bay with extensive urban/suburban land cover (> 10%) experienced greater chronic summer hypoxia (i.e., average summer Dissolved Oxygen [DO]

[27] The Atlantic Seaboard Fall Line is a 900-mile escarpment where the Piedmont and Atlantic coastal plain meet in the eastern United States.

below 3 mg/L), which can limit habitat suitability for anadromous fish and their prey (Uphoff Jr et al. 2011). Similarly, Kornis et al. (2017) found lower DO in Chesapeake Bay sub-estuaries with greater agricultural land cover relative to primarily forested catchments but also noted higher abundances of planktivores associated with nutrient enrichment. Typically, summer hypoxia is more severe in the U.S. Mid-Atlantic and southeast regions in association with higher summer temperatures and primary productivity. One of the more acute occurrences of hypoxia within the range of river herring was observed in the Delaware River estuary where low DO presented a chronic barrier to migration for anadromous fish in the latter half of the twentieth century (Weisberg et al. 1996; Sharp 2010). Similar anthropogenic stressors are also noted in freshwater rearing habitats. For example, Monteiro Pierce et al. (2020) noted a significant negative correlation between impervious surface cover and both condition (*see* Fulton 1904) and growth rate of juvenile alewife across a range of ponds in New England.

Land cover change and associated non-point source pollution is also associated with increases in turbidity, occurrence of toxic chemicals (e.g., insecticides, petroleum products), and road salts (Malmqvist and Rundle 2002; Kaushal et al. 2018). While each of these stressors may not be directly lethal at commonly observed concentrations, they may act synergistically (Malmqvist and Rundle 2002) and can further contribute to the degradation of nursery habitats for juvenile alosines (Limburg and Schmidt 1990; Hare et al. 2021). More broadly, loss of forested land cover and associated changes to water quality contribute to the degradation of estuarine habitats, including SAV (Kornis et al. 2017) and the forage these habitats support (see review by Greene et al. 2009). Specifically, increases in turbidity have been shown to decrease feeding efficiencies of juvenile fish, although responses can be specific to certain feeding strategies (De Robertis et al. 2003; Ljunggren and Sandström 2007).

Devine et al. (2020) reported that, other than nutrients, dissolved organic carbon (DOC) plays a significant role in the productivity of freshwater lentic nursery habitats for alewife in New England. Elevated DOC is correlated with reduced epilimnion habitat availability, which is a significant predictor for juvenile river herring recruitment. DOC limits light penetration in ponds and lakes, which contributes to a shallower thermocline, potentially increasing the volume of hypoxic water in the hypolimnion, and consequently reducing the volume of suitable epilimnetic habitat – a phenomenon most pronounced in smaller lakes (Solomon et al. 2015). The resulting “squeeze”, whereby river herring are pressed into a shallow surface layer of suitable habitat, can substantially reduce the amount of inhabitable space and potential for production and growth from what surface area calculations alone would estimate. This dynamic has also been shown to decrease predatory effectiveness and zooplankton vulnerability across many studies (e.g., Craig et al. 2017). The DOC in lentic environments has been increasing globally and is associated with changing climactic conditions and decreasing atmospheric acid deposition, among other factors (Solomon et al. 2015). While this mechanism is complex, it could represent another chronic and more subtle loss of juvenile rearing habitat for river herring (Devine et al. 2020) in New England ponds and lakes.

Discharges from industrial and wastewater treatment facilities influence nutrient and temperature dynamics in surface waters throughout the ranges of river herring (see review by Greene et al. 2009). For example, Greene et al. (2009) described several studies (Marcy Jr et al. 1972; Marcy 1976a; Barnthouse et al. 1988) that implicate the negative impacts of warm water discharges on the quality of juvenile alosine rearing habitats. Wastewater treatment systems can release nutrient-rich effluent and potentially harmful compounds (e.g., pharmaceuticals) into surface waters, although the individual and cumulative effects on river herring are poorly understood (Hare et al. 2021). Marcy (1972, 1976b); Barnthouse et al. (1988) as presented in Greene et al. (2009) also describe negative impacts of warmwater discharge on the quality of juvenile alosine rearing habitats.

Temporary impacts from in-water construction activities can also diminish the quality or quantity of habitat available for juvenile alosines. This includes activities that generate significant underwater noise (e.g., pile-driving) (Hastings and Popper 2005). Alosines are particularly sensitive to underwater noise, including ultrasonic frequencies, due to the proximity of the gas bladder to sensory organs (Mann et al. 2001). Underwater noise is ubiquitous throughout the range of habitats and, depending on the magnitude and frequency, can be sufficient to cause avoidance behavior or even injury and mortality (Hastings and Popper 2005). Another temporary stressor associated with water quality impacts is navigational dredging (Reine et al. 1998), which is also common in estuarine habitats. In one instance, channel dredging was suspected to cause diminished alosine returns although causal linkages were difficult to establish (Gibson 1987). Given that river herring are relatively intolerant of hypoxic conditions (i.e., DO concentrations below 4.0 mg/L (Klauda et al. 1991) and the potential impact of sediment-laden water on gill functioning, it is reasonable to assume that dredging can present another common stressor to river herring (Greene et al. 2009).

## 4.4 At-Sea Mortality

Marine survival is an important factor in determining river herring abundance. The importance of this factor in limiting the abundance of spawning runs may vary geographically along the Atlantic coast. There are many river systems that seem to produce large numbers of young-of-year, yet the adult returns are quite low (ASMFC 2017b). It is possible that compromised conditions in the freshwater ecosystems could lead to reduced survival in the ocean, but additional stresses in the marine ecosystem are also suspected. The mechanisms of marine survival are not well studied or understood but are suspected to fall into two categories: (a) natural and (b) fishery-related impacts. Marine mortality associated with renewable energy development (e.g., hydrokinetic power – see Dadswell and Rulifson 1994, Gibson et al. 2019) may also represent an emerging source of potential mortality.

The natural impacts could largely be accounted for by issues surrounding climate change (see *Section 4.2*). These impacts could include shifts in predator and prey communities (Coutant 1990; Portner and Peck 2010; Nack et al. 2019), changes in water temperature regimes (Lombardo et al. 2020; Alfonso et al. 2021; IPCC 2021), and changes in ocean currents (IPCC 2021), which can affect the river herring energy budgets (Hare et al. 2016; Cobb 2020). There have been some recent investigations into the decline of caloric content of some prey species in the Northwest Atlantic due to cascading effects starting with the quantity and quality of plankton (Baum and Worm 2009; Murphy et al. 2020). While the majority of studies are broadly focused on trophic shifts in marine ecosystems (Baum and Worm 2009), there is growing interest in exploring the effects of climate change on river herring in their marine phase (Hare et al. 2021).

Another important impact to river herring includes the management of striped bass and other marine piscivores. Stomach content analysis of striped bass in the coastal waters of Massachusetts were found to have roughly 5-6 percent abundance of *Alosa* spp. or unknown clupeids during summer months (Nelson et al. 2003). McDermott et al. (2015), found that alosines contributed 5-10 percent of the diet as mass for many marine piscivores[28], with consumption more frequent in near-coastal waters (McDermott et al. 2015).

River herring are an important piece of the marine food web, providing a link between trophic levels as well as linking freshwater and marine ecosystems (Dias et al. 2019; Dias et al. 2021). Dias et al. (2019) demonstrated that anadromous fish play an integral role in enhancing other fisheries through increased freshwater-ocean habitat connectivity. Recent modeling work by Dias et al. (2021) suggests that an increase in forage fish biomass would result in the increased biomass of several piscivores and species of conservation concern (e.g., species protected under the ESA). This work demonstrated that through increased habitat connectivity, at-sea predation to river herring alone would not result in tremendous population declines and may not be the greatest threat to river herring while at-sea; instead, bycatch from other fisheries could be the greater threat (Dias et al. 2019; Dias et al. 2021).

With respect to fishery impacts, there are few remaining directed fisheries for river herring although some may occur, especially in parts of the South Atlantic region, and they may have localized impact. More concerning, however, is the bycatch of river herring in other coastal fisheries such as those for Atlantic herring, Atlantic mackerel, and butterfish. There are both small mesh bottom trawl fisheries and large scale paired mid-water or bottom trawlers for Atlantic herring. Data analyses indicate that river herring and Atlantic herring habitats overlap in the marine environment for some period of time and that bycatch is common (Table 4) (Hasselman et al. 2016; ASMFC 2017b; Hare et al. 2021). Recent genetic studies (Hasselman et al. 2016; Reid et al. 2023) indicate that marine bycatch appears to more greatly impact certain river herring runs, including alewife populations that spawn in southern New England and blueback herring that spawn in the Mid-Atlantic. Generally speaking, small mesh gear used in a variety of fisheries can catch river herring, but there is not systematic sampling that would document bycatch in most fisheries, and in fisheries where bycatch is documented, the level of coverage is variable. Steps have been taken by managers to document and minimize bycatch (Bethoney et al. 2017), but the effectiveness of those efforts are unknown just as the true impact

[28] e.g., Spiny dogfish *(Squalus acanthias),* winter skate *(Leucoraja ocellata),* thorny skate *(Amblyraja radiata),* Atlantic cod *(Gadus morhua), silver hake (Merluccius bilinearis),* pollock *(Pollachius virens),* white hake (*Urophycis tenuis),* red hake *(Urophycis chuss),* longhorn sculpin *(Myoxocephalus octodicemspinosus),* sea raven *(Hemitripterus americanus)* and American anglerfish *(Lophius americanus)*.

of the bycatch on the population size remains unknown (see *Section 3.0*). Increased awareness of the importance of forage fish species to the marine ecosystem has resulted in renewed efforts to better manage forage fish species, which may help improve marine survival of river herring.

### 4.5 Hybrids and Landlocked Variants

Alewife and blueback herring remain capable of hybridization in areas of sympatry, despite divergence of the species up to one million years ago (Alexandrino et al. 2006; Faria et al. 2006). Notwithstanding co-occurrence throughout much of their historical ranges, alewife and blueback herring typically maintain reproductive isolation by differences in spawning temperatures and habitats, which often result in asynchronous spawning periods (Hasselman et al. 2014). Still, a genetic investigation by Faria et al. (2006) detected a shared mitochondrial DNA haplotype between the species, suggesting introgressive hybridization. There is some concern that migration delays such as those caused by dams and/or inefficient passage structures may increase the occurrence of hybridization. Similarly, there is evidence that, in certain systems, changes in spawning windows associated with temperature regime shifts could also increase overlap of the two species, which may present greater opportunities for increased hybridization (S. Gephardt, pers. comm.). The impact of hybridization on the success or recovery potential of a stock is poorly understood (Littrell et al. 2018).

In addition to the typical anadromous form, both species of river herring can exhibit a landlocked (permanent freshwater resident) life history strategy. Successfully reproducing landlocked populations appear to be more common for alewife than blueback herring (Loesch and Lund 1977; Loesch 1987), with the former also exhibiting a more expansive inland distribution, particularly with its introduction to the Great Lakes region (Smith 1970; Owens et al. 1998).

In lakes where these species are not native, landlocked river herring can alter the natural food web or even the trophic status of the waterbody. The reason they are presented as a threat here is because negative perceptions of this landlocked form by managers or the public can present a barrier to anadromous river herring restoration. For example, stakeholders may oppose construction of a fishway to reconnect alewife to their historical spawning habitat because of the misconception that anadromous alewife presence will cause these changes in the local aquatic system. We include information regarding the potentially undesirable effect of landlocked alewife here to clearly dispel this misconception and provide greater context to this management issue. Landlocked river herring may overgraze zooplankton leading to smaller average sizes or changes in community composition (Makarewicz 2000; Post et al. 2008). A reduction in zooplankton biomass can lead to a higher frequency or duration of algal blooms, altering the trophic balance in the lake. When landlocked alewife are introduced, shifts in the diet composition of predatory fish can also occur. In contrast, native anadromous river herring runs can facilitate a net export in nutrients from freshwater lake systems (Barber et al. 2018) and their influences on plankton assemblages in freshwater lakes are seasonal (Post et al. 2018). For more information regarding the ecosystem benefits of anadromous river herring runs, refer to *Section 6.3*.

In addition to disrupting the natural predator-prey ratio and relationship, alewife are known to contain higher concentrations of the enzyme thiaminase than other forage species (Tillitt et al. 2005). In Lake Champlain, alewife (rich in thiaminase) are thought to be the source of the thiamine deficiency observed in landlocked Atlantic salmon (Simonin et al. 2018). While the freshwater food web changes elicited by landlocked river herring in some cases can be considered undesirable, this life history variant typically occurs outside of the historical anadromous distribution and is not the focus of this plan (Daniel and Neilson 2020).

## 4.6 Predation and Trophic Interactions

Both river herring species are highly desirable prey throughout the marine, estuarine, and freshwater habitats they occupy (*Section 4.1*). When river herring stocks are robust and recruitment is sustainable, predation likely poses an insignificant threat to the species. However, when populations are low or otherwise imperiled, the impacts of predation can be severe, especially in rivers with barriers like dams that concentrate herring and enhance their vulnerability to predation. The negative impacts of predation are a prominent concern in areas south of Maine. From Southern New England to the extent of river herring distribution in the South Atlantic, striped bass are highly effective at preying on river herring in estuaries, bays, and below barriers such as dams and tide gates (Davis et al. 2009; Alcott et al. 2021b). In the Mid-Atlantic and South Atlantic regions, introduced species like flathead catfish (*Pylodictis olivaris*) and blue catfish (*Ictalurus furcatus*) are also known to prey heavily on river herring and are known to select directly for alosines (Schmitt et al. 2017; Schmitt et al. 2019). Other piscivorous fish that are known to prey on river herring within the riverine/estuarine habitats include white catfish (*Ameiurus catus*), northern pike (*Esox lucius*), white perch (*M. americana*), bowfin (*Amia calva*), black basses (*Micropterus spp*.), and possibly invasive snakehead (*Channa* spp.) (Saylor et al. 2012; Isel and Odenkirk 2019). In addition, avian predators such as osprey (*Pandion haliaetus*), great blue heron (*Ardea herodias*), double-crested cormorant, and pelicans (*Pelecanus* spp.) are known to feed on river herring, especially at natural (e.g., rapids) and anthropogenic (e.g., dams) concentration points (for example, see Figure 9).

There are also management concerns related to the collection and transportation of fish from one location to another; whether intentional or unintentional (e.g., bait escape/release) these unsanctioned relocations have the propensity to negatively alter aquatic food webs. Introduction of non-native species can present threats such as increased predation or destabilization of the biotic assemblages in habitats that support river herring. In the case of more commonly introduced species within the range of river herring (e.g., catfish), the spread of invasive species can also present competing management objectives — restoration of aquatic connectivity for native species versus controlling the spread of invasive species. Naturally, this can lead to increased scrutiny of existing fish passage operations and may erode support for barrier removal. Although invasive species are of concern, the focus of managers and decision makers should be on balancing efforts between invasive species management and restoring critical habitats for river herring.

Other, non-piscivorous invasive species, such as zebra mussels (*Dreissena polymorpha*), could have potential impacts to river herring and the ecosystem dynamics of their related habitats. Strayer et al. (1999) demonstrated that bivalves (e.g., zebra mussels) may drive changes in ecosystem structure derived from high rates of filtration of suspended edible particles and phytoplankton. These changes in ecosystem structure could shift grazing species of large-bodied zooplankton (Strayer et al. 1999), such as *Daphnia* spp.; a food source of river herring (Collette and Klien-MacPhee 2002; Simonin et al. 2007). Simonin et al. (2007) suggested that the more protracted spawning migrations of blueback herring may lead them to depend more on feeding late during their spawning run due to diminished energy reserves as well as increased energy requirements. A shift in ecosystem structure, resulting in a redistribution or decline of zooplankton communities, could add an additional stressor on, and threat to, river herring migrations.

## 5.0 Data Gaps and Research Needs

There are data gaps and research needs that can be addressed to increase our understanding of river herring populations throughout their Atlantic coast ranges. Key among these is the need for commonly-adopted approaches and methods to describe population metrics (e.g., run size, mean spawning age, etc.) that allow for a coastwide description of population dynamics over time. The ASMFC and TEWG Stock Status Subgroup previously described research recommendations with associated priority, time frame, and relative costs (Appendix Table A 2). The majority of the data gaps described in that effort remain relevant and data gaps we identified during development of the HCP were generally consistent with those reported by the TEWG.

This section, highlights some of the major data gaps and research needs for river herring. These informational gaps encompass a wide-range of topics including climate change effects (5.1), ocean (bycatch) and river fisheries (both current and historical harvesting; 5.2), life history strategies (5.3), habitat condition (5.4), trophic interactions (5.5), and historical population information (5.6).

One overarching need related to research and available data is for congruent data collection and analysis methods for fish collected throughout the ranges of river herring. Stock assessments, coastwide population surveys, fish condition assessments and comparisons, and management strategies/decisions on a coastwide scale can be greatly enhanced when data are collected and analyzed systematically. The variability in monitoring efforts and approaches to document seasonal distributions, fish counts, and other biological indicators of river herring stocks presents challenges in determining regional stock status and prioritizing restoration actions. For example, estimating current and potential distributions, based on accessible river habitats and inaccessible river reaches due to existing dams and other barriers, requires assumptions related to habitat use, and habitat quantity and condition estimates vary widely based on the assumptions applied. Without a standard set of criteria to define what is or is not (or what was or was not) suitable habitat[29], meaningful comparisons at a regional or coastwide scale are challenging.

---

[29] There are a number of physical and ecological parameters that have been used to estimate boundaries or distribution extent; these include, but are not limited to, drainage area, gradient, mean stream width, annual average discharge, historical presence, and water quality.

Pardue (1983) described one method to assess habitat quality in a habitat suitability index (HSI) model composed of two components: cover and water quality. It offered an approach to categorize habitats based on suitability for blueback herring or alewife on a scale from 0.0 (unsuitable habitats) to 1.0 (optimal habitat). More recent data available from studies conducted in subsequent years could help refine these models and may help to standardize the river herring HSIs coastwide. Such standardization for habitat and production estimation would likely enhance management of river herring and benefit restoration planning, scaling, and prioritization. Nevertheless, challenges remain to standardizing methods at this scale (e.g., differing priorities among state fishery agencies, lack of funding or perceived need for funding, differences in expert opinions relating recruitment success to both riverine habitat wetted area and habitat quality factors).

## 5.1 Climate Change

The effects of climate change are causing increased concerns related to the ecological changes that threaten the sustainability of river herring and other Atlantic coast diadromous fish populations. Uncertainty over the potential risks to each species posed by these changes — particularly increasing in-stream seasonal water temperature and variability in stream flows, makes recommending or prioritizing mitigation measures more difficult. Changes in river herring biology related to environmental conditions have been described (Walsh et al. 2005; Tommasi et al. 2015; Lombardo et al. 2020; Alfonso et al. 2021; Guo et al. 2021), but few detailed analyses are available to distinguish the impacts of climate change from climate variability. In 2016, the TEWG Climate Change Subgroup developed a ranked list of recommendations for priority research needs (Appendix Table B 1). The climate-related data gaps identified through the development of the HCP were aligned with the top five climate-related research needs identified by the TEWG,[30] these include:

- Environmental tolerances and thresholds (e.g., temperature, salinity, water flow, pH, DO) for each life stage of each species

[30] The TEWG Climate Change Subgroup emphasized that although some research needs were ranked higher than others in their list, all the identified research priorities warranted attention to promote a better understanding of the effects of climate change and variability on river herring populations.

- Behavior and physiological studies related to climate-sensitive environmental variables
- Continuous data on river flow and temperature in systems where annual numbers of adults and juveniles are monitored
- River herring run size and juvenile survival data measured with same methods along a latitudinal gradient
- Historical relationships between environmental conditions and river herring abundance and distributions

Similar short- and long-term research recommendations were identified by ASMFC (2012c) in its benchmark stock assessment, and will likely be included in the forthcoming benchmark stock assessment, anticipated for release in 2023.

The negative impacts from global climate change will become even more prominent in future years (IPCC 2021) and the resilience of river herring to this threat (see *Section 4.2*) in the face of other compounding stressors is not yet known. Effects of climate change on river herring and their habitats have been investigated in both marine and freshwater ecosystems (Crowder et al. 2006; Lynch et al. 2015; Hare et al. 2016; Farr et al. 2021; IPCC 2021). For example, a change in the quantity of preferred marine habitat and a northward shift in marine distribution of river herring and their predators/competitors are occurring as a result of climate change (McHenry et al. 2019). Anomalous or extreme environmental conditions also affect survival and recruitment of juvenile river herring in their freshwater rearing habitats (Tommasi et al. 2015; Devine et al. 2020; Guo et al. 2021). In their Atlantic coast fisheries climate vulnerability assessment Hare et al. (2016) characterized river herring as highly vulnerable to climate change-related impacts.

Predictive modeling is becoming an increasingly important tool for fisheries managers to evaluate population-level impacts under a suite of potential climate scenarios. Since climate change is shifting the distribution of river herring along the Atlantic coast, models estimating range shifts and habitat suitability under these scenarios should help managers prioritize among and within river drainages for river herring passage and habitat restoration. Models may also be used to investigate shifts in river herring forage and predator dynamics to further refine predictive outputs. While some river herring-population models are currently available (e.g., Nelson et al. (2020), there is significant potential to expand their content and application to better inform management decisions. There is also a need to update these models as additional population data and/or analytical techniques become available.

## 5.2 Fisheries and Stock Status

River herring historically supported significant commercial and recreational fisheries throughout their ranges. Fisheries traditionally occurred in rivers, estuaries, and coastal waters using weirs, traps, dip nets, and gillnets. Currently, fewer river herring runs are harvested in targeted commercial and recreational fisheries than in the past, and only in select states/watersheds (see *Section 3.5*). Fisheries- and stock-related data gaps identified through the development of the HCP include:[31]

- Improving long-term population data through standardization of sampling and analysis methodology
- Impacts of recreational harvest on river herring populations
- Extent of unintentional (e.g., misidentification) or illegal harvest
- Monitoring, reporting, and quantification of bycatch:
    - At-sea bycatch contribution by gear and fishery
    - Genetic analyses to determine population stock structure and facilitate determination of river origin of incidental catch in non-targeted ocean fisheries
    - Which stocks are most impacted by bycatch, and whether bycatch impacts are proportional among stocks
    - Severity of bycatch originating from sources other than at-sea (e.g., inland fisheries)
- Effective strategies to minimize bycatch, primarily in at-sea fisheries

[31] List order does not correspond to relative priority or importance

- Attribution of mixed-stock fisheries (including bycatch fisheries) to natal watersheds/regions

The impacts of recreational river herring harvest are poorly documented but are likely substantial, at least at the local level. ASMFC requirements stipulate that only states with an approved SFMP or an Alternative Management Plan (AMP) in place are authorized to permit recreational harvest of river herring. Additional information regarding recreational harvest in these systems would address an existing data gap which could, in turn, improve model precision and facilitate informed decision making by fisheries managers. Similarly, quantifying unintentional (e.g., misidentification) or illegal recreational harvest in states without an SFMP or AMP would more fully-describe coastwide fisheries-related mortality.

Commercial fishing bycatch, both riverine and at-sea, are known to impact river herring species (see *Section 4.4*). Although it is understood that river herring experience at-sea mortality as bycatch (see *Section 3.3.1*), more research is needed to better understand this and other sources of at-sea mortality and their impacts (e.g., population status, and predation versus fisheries mortality). For example, quantifying and attributing at-sea bycatch mortality to specific stocks has been previously identified as a research need. While several studies (Palkovacs et al. 2013; Reid et al. 2023) have shown disproportionate impacts to specific stocks, further study could help to inform targeted bycatch avoidance of sensitive stocks. Coastwide DNA collection/analysis efforts undertaken by the USGS Eastern Ecological Science Center have helped to attribute at-sea bycatch to specific river stocks which can, in turn, inform management decisions (e.g., American shad in the Delaware River).

Knowing which commercial fisheries, with regard to time-of-year (TOY) and fishing locations have the greatest contribution to river herring fishing mortality, as well as the proportional impact they have on individual river herring stocks, would help managers to focus on the most impactful fisheries[32] and determine appropriate mitigation measures. While voluntary efforts have been undertaken to describe (e.g., Amendment 8 to the Atlantic Herring FMP) and minimize bycatch of river herring (Bethoney et al. 2017), these efforts could certainly be augmented, given the spatial and temporal variation in bycatch and the potentially deleterious

[32] Based on target species, location, or method

effect that substantial at-sea mortality can have on river herring runs throughout their ranges (Palkovacs et al. 2013; Dias et al. 2021).

In recent years, monitoring efforts such as the mid-water trawl bycatch monitoring (portside) and river herring avoidance program administered by UMass Dartmouth's School for Marine Science & Technology (see *Section 3.3.4*), have provided important information related to the impacts of commercial fishing on river herring at sea (Turner et al. 2015; Bethoney et al. 2017), but these programs ended when federal grants and donations were suspended in 2021. In addition to the catch caps described in *Section 3.3.1*, NOAA Fisheries also employs at-sea observers as staff availability and resources allow, and manages the Study Fleet Program through the NEFSC's Cooperative Research Program to collect high-resolution catch, effort, and environmental data using electronic logbooks (Jones et al. 2022). While these efforts have been undertaken to document and help set limits on bycatch of river herring with some success, they are not comprehensive and rely on good faith documentation by fishermen. Consistent, systematic real-time approaches to monitoring and reporting bycatch to change fishery behavior when river herring are observed are necessary to minimize bycatch. While programs such as the Study Fleet Program (Jones et al. 2022) and the SMAST voluntary bycatch avoidance program (Bethoney et al. 2017) may be effective, they have not been widely or consistently implemented.

Other than at-sea bycatch, inland commercial fisheries, such as those employing pound and fyke nets in the tidal estuaries of the Chesapeake Bay, may overlap both spatially and temporally with river herring migration and spawning; however, their impact on river herring is largely unknown. Identifying river systems where these types of fisheries are located, as well as understanding the level and magnitude of impact from these types of fisheries on river herring is an ongoing concern (ASMFC 2012a). More committed monitoring is needed on these fisheries to define the fishing seasons and locations and quantify their catch and effort to more fully assess the impact of these fisheries on river herring.

Annual run size estimates using standardized survey designs would improve insight into how populations of river herring change over time and help to predict which environmental factors substantially influence annual returns. This type of information can help resource managers diagnose emerging issues such as poor recruitment or delayed fish run response following barrier removal. Monitoring programs further need to take into consideration that annual estimates of juvenile abundance will not be reflected in adult population status for 3–5 years when they return as adults. When improvements are made to the accessibility of suitable habitat or quality of the habitat in a river system, documenting population responses are critical to determining the relative success of implemented restoration projects or management measures. This information can then be used to advocate and guide future restoration efforts.

## 5.3 Life History Strategies and Population Dynamics

Run counts and other fundamental life history metrics such as age and length distributions over time continue to provide valuable insight into recent population trends and dynamics in various drainages. For example, (ASMFC 2012a) identified that, in many systems, the proportion of the spawning runs composed of younger and potentially less-fecund adults is increasing, while the mean length at age in most systems is decreasing. Many of these trends were consistent with the stock assessment update completed in 2017 (ASMFC 2017a), although trends were variable in certain systems (e.g., southern New England versus runs north of Cape Cod) across these two assessments. This variability coupled with the lack of consistent and/or long-term measurements of these variables continues to be a challenge associated with quantifying coastwide population trends (ASMFC 2012a, 2017b). Data gaps related to life history and described here include:

- Standardized data collection and analysis methodology to determine trends at a coastwide scale, including:
    - Abundance and spawning run counts
    - Length at age
    - Run composition by sex, age, and fecundity
    - Spawning mortality
- Variability in life history strategies among juveniles
- Relative lack of data concerning blueback herring compared to alewife, notably in New England
- Prevalence and ecological/evolutionary implications of hybridization

Juvenile river herring exhibit a highly variable range of outmigration patterns depending on the characteristics of the system and environmental conditions in a given year. The varying outmigration behaviors should be more thoroughly documented throughout the ranges of river herring, as well as between alewife and blueback herring. Typically, juvenile outmigration to the ocean takes place in the late spring through fall, depending on the location, but can vary based on stream flow and temperature. Juveniles may overwinter in estuaries (Limburg 1998; Payne Wynne et al. 2015), and overwintering in estuaries may reduce mortality for river herring (e.g., predator avoidance) but could also make them more susceptible to human disturbance (e.g., wintertime navigational channel dredging) or climate-related changes in predator distributions (e.g., greatly increasing gray seal populations in southern New England). An enhanced understanding of life history variation for young-of-year in each system can help to inform appropriate restoration and management approaches.

In the New England region, blueback herring are data poor relative to alewife, particularly in larger river systems which are more challenging to sample compared to coastal lakes and ponds. Additionally, a greater understanding of the factors that influence the spawning success of river herring and their synergistic effects is needed (e.g., water temperature, DO, pH, salinity, stream flow) to inform management priorities. This understanding will become increasingly important as climate change continues to influence these environmental parameters.

Anthropogenic factors leading to a loss of river connectivity could result in hybridization between blueback herring and alewife, and may be a common occurrence (McBride et al. 2014). Hasselman et al. (2014) suggested human disturbances such as barriers to spawning grounds may increase the frequency of hybridization. The effects of hybridization on anadromous populations of river herring have not been adequately assessed. A better understanding of the presence of, causes and frequency of hybridization and its potential effects on anadromous river herring populations, could better inform management and restoration objectives.

## 5.4 Habitat

There are various data gaps related to river herring habitat quality and habitat utilization by each species. Habitat-related data gaps identified through the development of the HCP include:

- Environmental factors driving population dynamics at a coastwide scale

- Lack of congruent monitoring and sampling methodology within and across regions
- Extent of freshwater and estuarine habitat use for spawning and rearing (habitat quantity)
- Stock benefits of restoring the quantity and/or quality of potential and available spawning habitat (e.g., production potential)
- Habitat suitability related to optimal and marginal thresholds regarding environmental conditions (e.g., flow, water quality, thermal shifts), and additional habitat attributes including:
    - Watershed land cover
    - Contaminants
    - Seasonal or inter-annual variability in habitat suitability

Sampling methodologies for environmental and habitat data lack standard approaches throughout the coastwide ranges of river herring (ASMFC 2012). These aspects present challenges when determining past population trends and projecting future conditions at the coastwide and/or regional scale. A standardized coastwide sampling protocol would enhance our ability to compare trends and make predictions at the coastwide scale.

River herring habitat utilization in the upper reaches of rivers and their tributaries is poorly defined and understood. The emergence of environmental DNA (eDNA) as a method for detecting species presence could become a more widely used and useful tool when evaluating current river herring current habitat utilization and the efficacy of fish passage and restoration techniques (Lacoursière-Roussel et al. 2016; Plough et al. 2018; Rourke et al. 2022). For example, this technique was used to evaluate the response of river herring to the Embrey Dam removal in Virginia (for more on the Embrey Dam removal see *Appendix C 1.9*). In a study completed by (Plough et al. 2018), blueback herring eDNA was collected at sites at least 64 miles upstream of the former Embrey Dam site. Unified eDNA sampling programs can help refine understanding of habitat use, and should be used to inform future management or restoration actions.

There are other research needs related to environmental thresholds during migration and emigration of river herring, particularly the minimum flows required for adult upstream migration as well as those flows for juvenile out-migration. For example, understanding the minimum flows required for river herring passage at a variety of sites would help agencies assess permit applications for water withdrawals (e.g., municipal, commercial, industrial, agricultural) as well as negotiating hydropower licensing/relicensing conditions which includes setting minimum flow requirements. Similarly, modified flow regimes can also impact habitat suitability (described in further detail below) through changes to the physical or chemical properties of the water (e.g., temperature, dissolved oxygen, etc.). Increasing stream temperatures due to localized hydrological alterations and climate change are also a concern for river herring passage and survival.[33]

Tantamount to understanding habitat use is understanding habitat quality. For areas where herring are currently present, habitat quality data can help managers identify potential threats and prioritize conservation and/or restoration actions. For potential habitat access and use (i.e., barriers currently present), restoration practitioners should evaluate the quality of habitat upstream of passage enhancement projects to help inform prioritizations. Some parameters that should be considered for habitat quality include land cover data such as percent impervious surface cover, forested land, and agriculture (row crop and pasture) since watershed land cover influences basin runoff and the quality of receiving waters serving as spawning and rearing habitats (Limburg and Waldman 2009). Furthermore, long-term monitoring of chemical and physical habitat parameters including seasonal water quality and the extent of productive juvenile rearing habitat (e.g., SAV) can help to inform conservation, enhancement, and management actions. For example, such information may allow fisheries managers to implement a "resist, accept, direct" or RAD framework (Thompson et al. 2021) to prioritize restoration initiatives in areas where they could be most effective. Additional studies are also warranted regarding the effect of persistent environmental contaminants on river herring reproduction and recruitment. Emerging and existing contaminants of concern include heavy metals, chlorides from road salt, and per- and polyfluoroalkyl substances (known as PFAS), among others. When restoring access to previously unavailable habitat, it is important to ensure that habitat is and

[33] See https://www.epa.gov/climate-indicators/climate-change-indicators for information on stream temperature and streamflow

remains capable of supporting the critical life functions of the species. In summary, data regarding habitat quality are essential for effective river herring management and restoration to help identify priority barrier removals and river reaches in need of habitat enhancement, which can be undertaken either independent of or collectively with herring passage restoration efforts.

### 5.5 Species Interactions

As mentioned in *Section 4.6*, invasive fish species management is a key issue in both restoring habitat and preventing excessive predation of river herring. Data gaps related to inter-specific interactions identified through the development of the HCP include:

- The extent of predation by invasive freshwater and estuarine species on river herring
- Interactions and potential impacts of non-predatory invasive species on river herring
- Co-benefits of sustainable river herring populations for other native species

Piscivory from invasive species represents a potentially significant source of mortality, although the extent of their impact remains poorly understood and range expansions are continuing rapidly for many species. Non-native species including black bass (*Micropterus* spp.) prey upon river herring in many freshwater settings (Yako et al. 2002; Mattocks et al. 2017; Watson et al. 2019). The invasive flathead catfish is known to selectively predate river herring during their spawning migration (Schmitt et al. 2017; Schmitt et al. 2019). Other invasive species like blue catfish, northern snakehead, round goby (*Neogobius melanostomus*), and others have largely unknown/understudied predation rates on river herring. With shifting ranges for both river herring and their predators, as well as new invasive species introductions or range expansions, predation and diet studies are needed. The more research that is available on invasive species diets and river herring predation rates, the better equipped managers and restoration practitioners will be to address and prioritize these varied threats.

There is also a need for better understanding of the potential effects non-piscivorous invasive species may have on river herring. These invasive species could cause a wide range of impacts to river herring habitat (e.g., sedimentation, hypoxia, excess nutrient loading) as well as altering food web dynamics (e.g., prey availability, competition). Examples include bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus* *carpio*), common rudd (*Scardinius erythrophthalmus*), nutria (*Myocastor coypus*), zebra mussels, quagga mussels (*Dreissena bugensis*), Asiatic clam (*Corbicula fluminea*), mitten crab (*Eriocheir sinensis*), rusty crayfish (*Orconectes rusticus*), virile crayfish (*Orconectes virilis*), spiny waterflea (*Bythotrephes longimanus*), black mat algae (*Lyngbya wollei*), didymo (*Didymosphenia geminata*), water chestnut (*Trapa natans*), and hydrilla (*Hydrilla verticillata*) (Stahlman 2016).

The active restoration of alosines can similarly have co-benefits for freshwater resident and other anadromous fish (Saunders et al. 2006), among other ecosystem functions (see *Section 6.3*). The extent of these benefits should be better explored to strengthen restoration objectives and support. For example, the alewife floater (*Utterbackiana implicata*), a species of freshwater mussel, relies primarily on parasitizing adult alewife (see *Section 6.3.4*) while in freshwater (Price 2005) to complete its life cycle. Additional research describing the co-benefits of river herring restoration for other imperiled species, including freshwater mussels, could help to strengthen support for restoration initiatives in certain settings.

## 5.6 Historical Population Information

An accurate estimate of historical abundance (through anecdotal or official records) establishes reference conditions and can help to set targets for river herring population recovery. Historical population-related data gaps identified during development of the HCP include:

- Extent of historical habitat loss for river herring at the watershed and coastwide scale
- Distribution and abundance prior to anthropogenic barrier construction
- Lost potential of river herring production throughout their range

Without reference conditions, shifting baselines can lead future generations to accept a severely depleted stock as normal, termed shifting baseline syndrome (Pauly 1995). Because river herring populations are largely influenced by the extent of available habitat, historical accounts of habitat use can also inform these targets (Hall et al. 2011; Hall et al. 2012; Mattocks et al. 2017). For example, Hall et al. (2011) estimated that approximately two percent of the collective stream and lake habitat remained accessible to anadromous fish in Maine in 1900, following over two centuries of dam building activities throughout the state. They then estimated that dammed rivers in Maine saw a biomass reduction over the period ranging from 1600–1900 of at least six orders of magnitude relative to their undammed potential (Hall et al. 2012). Mattocks et al. (2017) extended this study to estimate the biomass lost through damming of rivers throughout New England over the period extending from 1630 to 2014. Their analysis indicated a cumulative loss over this period of 7 million, 2.4 million, and 0.6 million metric tons of freshwater forage, marine forage, and returning adult spawning biomass, respectively. Similarly, Zydlewski et al. (2021) detailed the amount of riverine habitat historically available (before man-made barriers) to American shad, and compared these conditions to current conditions in major Atlantic coast drainages. They found that 41percent of previously available habitat was lost when the large-scale dams were installed. Through multiple models, they predicted that a production potential of over 20 million spawning American shad has been theoretically lost due to the current blockages. This study demonstrates the importance of spawning habitat availability for these fish, and identifies areas with the greatest restoration potential. Because these alosines do not share the exact ranges or riverine habitat types, this study is not directly applicable to river herring. A similar study and model rendering for both blueback herring and alewife would be a highly beneficial analysis helping to define the production potential for river herring.

## 6.0 Social-Ecological Benefits of River Herring Restoration

A healthy, well-functioning riverine system holds intrinsic values measured in economic, social, cultural, and ecosystem services (Wilson 2002). Performance metrics such as economic value added, community resilience, and cultural opportunity help to quantify or define the public benefit[34] derived from discrete contributions of natural systems. In instances where diadromous fish stocks are reduced or depleted, restoration provides opportunity to restore runs of fishes and the economic and cultural benefits supported by well-functioning ecosystems. Furthermore, restoration efforts targeted for river herring can present extensive ecological benefits including co-benefits for other diadromous fishes (Saunders et al. 2006; Hall et al. 2012; Mattocks et al. 2017; Ouellet et al. 2022).

Several factors can inhibit societal perceptions of natural resource benefits and, in some cases, reduce support for restoration efforts. One such factor is a shifting baseline syndrome (Pauly

[34] In this section, “public” and “social” benefit are used interchangeably.

1995), which is particularly pronounced for diadromous fishes of the Northwestern Atlantic, given their current low abundance (Limburg and Waldman 2009; Ouellet et al. 2022). This can occur when the experiences of current residents or generations vary substantially from past conditions ("generational amnesia") or through direct observers forgetting or misremembering ("personal amnesia") biological conditions as time passes (Papworth et al. 2009). Either situation can lead to lower expectations of a restored ecosystem as a result of the gradual loss of ecological integrity (Pauly 1995; McClenachan et al. 2015). Reduced expectations and diminished collective memory of significant runs of migratory fish may reduce the perceived benefit of restoration for current and future stakeholders. Moreover, shifting baseline syndrome can lead to lower perceptions of need for action. For example, if modern observers only knew a stream to have 1,000 river herring returning each year, but they all come in at once providing the perception of abundance, those observers may not see the need to 'restore' abundance, despite the fact that 100 years ago that stream may have supported annual runs of 100,000 fish. Such a scenarios is not uncommon, as anadromous fish have seen declines around an order of magnitude in the North Atlantic (Hall et al. 2012). Professional fishery managers can be influenced by this syndrome as well, affecting management decisions including on which historical population level to base restoration goals. Changing social perceptions and shifting baseline syndrome are management challenges, but they do not change the benefits that accompany natural or effectively-restored ecological systems.

McClenachan et al. (2015) identified five social benefits resulting from the restoration of ecosystem connectivity, with a focus on alewife fisheries in Maine Rivers:

(1) restored runs reconnect communities with fish and fisheries

(2) diversification and enhancement of local economies and fisheries

(3) community building in postindustrial towns

(4) broadening the community of conservationists

(5) ecosystem services and recreation

These categories highlight the diverse social and economic benefits derived from the restoration of a single diadromous species in a small geographic area. These elements are applicable to restoration efforts for river herring on a coastwide scale, although the ability of restoration efforts to fully realize each benefit will vary based on watershed context. Overall, these concepts offer a framework to showcase the importance of river herring restoration for community benefit and enhancement of ecological function.

## 6.1 Social-Ecological Systems

The concept of a Social-Ecological System (SES), as described by Ratzlaff (1969) has been refined by others (e.g., Cherkasskii 1988, Berkes and Folke 1998). Colding and Barthel (2019) noted that less than one-half of publications they analyzed defined SES, and suggested that the absence of a unifying definition is a drawback when communicating the concept to a broader audience. For the purposes of this HCP, we use the definition provided by Anderies et al. (2004)— "an ecological system intricately linked with and affected by one or more social systems, both social and ecological systems contain units that interact interdependently and each may contain interactive subsystems as well."

The current and past SES of the U.S. Atlantic coast and associated estuaries/watersheds are enormously complex. The human communities are comprised of numerous interconnected relationships of social institutions including private landowners, states, counties, municipalities, state and federal natural resource managers, tribal organizations, hydropower operators, utility providers, NGOs, and many other stakeholders and members of the public. The ecological system is an interconnected web of terrestrial, aquatic, and marine habitats and the vast diversity of organisms they support. Keystone species such as river herring are a common thread that connects many of these diverse systems and their restoration has the potential to enhance the functions and values of the broader SES.

## 6.2 Social Benefits

### 6.2.1 Economics

The regionally-significant historic runs of river herring provided a significant source of sustenance and trade to many indigenous communities that lived throughout the Atlantic coast drainages. These native fish continue to hold importance to indigenous communities. Historically, fish weirs constructed using stones in spawning rivers, or stakes, poles, and branches in rivers and coastal estuaries, were used to harvest the runs (Lutins 1992; Taylor 1992; Heath Jr 1997; Lutins and DeCondo 1999; Michelson 2021).

Later, colonial settlers in New England relied on diadromous runs of fish to provide calories when other food was scarce, such as during harsh New England winters. These early colonists adopted many of the techniques learned from indigenous people. The weirs were considered so efficient that "… European settlers in North Carolina adopted them for both local subsistence and export commercial fisheries in the eighteenth century" (Heath Jr 1997). European colonists were reliant upon the seasonal abundance of river herring and other diadromous species such that preserved fish became a form of currency used for trading and settling debts (Limburg et al. 2003).

As technology progressed, the types of food products produced, and the associated cultural and social networks for exploitation, exportation, transportation, and consumption also changed (Heath 1997). River herring were exported in the 17th and 18th centuries to be canned overseas (Michelson 2021). River herring were also traditionally salted and shipped in barrels to the West Indies and other locations, and also produced and consumed in local markets (Taylor 1992; Heath Jr 1997). During this time, regionally-significant fisheries continued and expanded. In North Carolina much of the labor was performed by people of color, many of whom were enslaved (Boyce 1917; Heath Jr 1997) and this was likely true of river herring fisheries in neighboring states (e.g., Virginia, South Carolina). Many of these coastal communities also relied on the seasonal bounty of fish for sustenance throughout the year and as fertilizer at planting time (Boyce 1917; Heath Jr 1997).

Substantial harvest continued and expanded through the 19th century in many systems, some of which supported extensive fisheries (Belding 1921; Walburg and Nichols 1967; Cecelski 2021). These fisheries represented an important source of seasonal income and sustenance for a variety of working peoples throughout the Atlantic coast (Boyce 1917). Many of these fisheries continued into the 20th century, if runs had not been diminished by overfishing, damming, and poor water quality, as occurred notably in many New England drainages (Hall et al. 2012; Mattocks et al. 2017). For example, Cecelski (2021) contextualizes historical photographs of Charles A. Farrell who captured the significant economic role that the river herring fishery represented in black communities, including employing women and children, in coastal North

Carolina. To give a coastwide scale of the fishery in the late 19th and early 20th century (1887-1928), reported annual commercial landings averaged approximately 18.5 million pounds (ASMFC 2017a). Landings were higher still in the mid-20th century, with reported U.S. commercial landings (for food and bait) peaking at 75 million pounds in 1958 (ASMFC 2017a). During this time, river herring were among the most valuable anadromous fishes harvested commercially in New England and the Mid-Atlantic. This level of harvest was not sustainable, especially when coupled with the concurrent degradation of water quality and sustained lack of access to spawning habitat in many of the major U.S. East Coast rivers (see *Section 5.2*). Through the 1980s, commercial river herring harvest was only a small fraction of historical landings; depressed populations and changing regulations both contributed to a reduction in overall harvest (Nelson et al. 2011; ASMFC 2017a; NMFS 2021). River herring populations declined to historic lows by the 1990s resulting in harvest moratoria throughout much of their range. As of 2021, many of these harvest moratoria remain in place (see *Section 3.0* for further details).

Today, limited in-river harvest of river herring supports local fisheries, mainly in New England. In addition to the economic contribution of the fishery itself, local communities benefit from eco-tourists who come to directly view the river herring spawning migration runs at fish ladders provided for herring access to spawning habitats. As McClenachan et al. (2015) report, "The restoration of fish populations has also created seasonal harvesting jobs and extended the summer tourism season in certain [Maine] towns;" They further note that "…the fishery draws in tourists before the summer tourist season begins." McClenachan et al. (2015) conclude that in addition to these economic benefits, "…the perception of a financial benefit also provides incentive to invest in restoration, thereby contributing to broader social benefits." Finally, river herring festivals represent a discrete economic benefit to towns and municipalities that host them. There have historically been many spring festivals focused on river herring and shad along the East Coast. Contemporary festivals, particularly in New England, (see Table 5) provide opportunities to view spawning fish, eat smoked alewives, and participate in community dinners and discussions. The alewife festivals held in Damariscotta and Benton, ME attracted between 1,000 and 1,500 participants, which represents 50-75 percent of the town populations (McClenachan et al. 2015). Comparable benefits are undoubtedly occurring at similar festivals.

### 6.2.2 Cultural Values

Runs of river herring, shad, and salmon were culturally significant and helped define the regional identity and sense of place among Atlantic coast communities. River herring were, and continue to be, important to indigenous communities. Native Americans began constructing stone fish weirs approximately 3,800 years ago, these structures were typically associated with the harvest of anadromous fishes (Goodby et al. 2014; Cranford 2021). The presence of fish was of utmost importance to selecting the location of settlements for both Native Americans and colonists. Sebasticook Lake[35] was found to have a prehistoric fish weir constructed and used by Native Americans. This translated quote published by Petersen et al. (1994) from a Winisk Cree elder depicts the importance of fish to many native peoples:

> "You can depend on fish more than any other. You can be certain that you will get a fish. And it has happened… ever since I can remember. And even though there were settlements around the Bay …when the families were asked to leave for their hunting ground no matter how far they may be… their first priority is to select the area where there is plenty of fish, and, where there is a good place, they will set a fish trap. And… even before the European… it is always the same. Because that is all the people can depend on is actually fish. They can catch [fish] more easily than any other kind of food stuff." (Petersen et al. 1994)

Native Americans smoked and salt-cured river herring for seasonal or future use and for trade. Heath Jr (1997) provides an extensive discussion of the cultural implications of anadromous fish exploitation and explains that the anadromous species, including river herring, because of their accessibility, availability, predictability, and storability, led to significant changes in the social structure of Native American cultures. Heath Jr (1997) notes "The demands for coordinated, organized labor for anadromous fish exploitation and long-term storage would potentially contribute to the development of a more complex, less egalitarian social structure through the organization and implementation of a large-scale community enterprise each spawning season ." Lutins and DeCondo (1999) note that "The presence of weirs has implications for the reconstruction not only of subsistence patterns, but for settlement patterns as well. Weir use implies seasonal settlement of at least a portion of the community in the vicinity of the structure in order to attend to such tasks as weir set-up, structural maintenance, and processing of the catch."

[35] Sebasticook Lake is located in the Kennebec watershed; historically supported large numbers of river herring.

Many communities have retained their appreciation, celebration, and management of river herring despite the overall population decline of these species. This comes in many forms including river herring festivals (Table 5), watershed-based group engagement, and river herring wardens. Festivals in particular help instill a sense of connection to local resources and accountability to protect and restore river herring and other anadromous species (McClenachan et al. 2015). Many festivals also celebrate the culinary traditions associated with preparing and/or preserving (e.g., smoking) river herring. The celebration of these runs and associated traditions can also provide a source of local pride, identity, and connection with the past. In many watersheds, the visibility of river herring is augmented through watershed-based groups that serve as a nexus for education and engagement by coordinating festivals and river-herring related events. Watershed-based groups can also elevate the visibility and cultural relevance of river herring through a myriad of avenues including clearing/maintaining fishways and assisting with run counts. In addition to in-person citizen science, recent technological advancements have also allowed interested members of the public to assist with run counts through virtual platforms.

Table 5 – Select river herring festivals and events, both current and historic, held throughout the range of river herring.

| EVENT | LOCATION-SPONSOR | COMMUNITY | DATE(S) | STATUS/CONTACT INFO |
|---|---|---|---|---|
| Blackman Stream Alewife Festival and Cross Country Race | Maine Forest and Logging Museum, Bradley, ME | Bradley, ME and surrounding communities, near Bangor | June 16, 2018 (3rd annual); June 16, 2019 (4th annual); May 30, 2022 | Recent news articles indicate that this event is still active. For more information contact: Maine Forest and Logging Museum |
| China Lake Alewife Celebration | Outlet Stream-Maine Rivers | Vassalboro, ME | May 19, 2022 | Active, as described in World Fish Migration Day event page; Event coordinated by Maine Rivers |
| Alewife Festival | Damariscotta Mills, ME- | Towns of Newcastle and Nobleboro, ME | Began 2007, cancelled in recent years due to Covid | For more information, see: Damariscotta Mills Alewife Festival |
| Run with the Alewives 5 K | Great Salt Bay, Damariscotta Mills, ME-Coastal Rivers Conservation | Damariscotta Mills, ME | May 28, 2022 | For more information, see: Damariscotta Mills Event: Run With the Alewives. Alternatively, call (207) 458-3389 or contact Bob Barkalow (bob.barkalow@gmail.com). |

| EVENT | LOCATION-SPONSOR | COMMUNITY | DATE(S) | STATUS/CONTACT INFO |
|---|---|---|---|---|
| | Trust, Central Lincoln County Ambulance Service et al. | | | |
| Benton Alewife Festival | Sebasticook River-Benton Select Board | Benton, ME | May 11, 2015 (4th annual); May 2019 (8th annual) | Event was cancelled in 2020, and 2021, due to the COVID-19 pandemic; For more information, see: Benton Alewife Festival |
| Maine Alewife Trail | Various – Maine Rivers | Coastal Maine | Various | This is an actively-maintained trail map curated by Maine Rivers to aid participation in river herring-themed events held throughout coastal Maine. |
| Exeter Alewife Fest | Exeter River, Founder's Park-Exeter Planning and Sustainability Department, Exeter Conservation Commission | Exeter, NH | May 14, 2022 | Newly reestablished after a decade of absence, according to news articles; For more info, see: Exeter Alewife Festival news article from Seacoast Online |
| Friends of Herring River Celebrates World Fish Migration Day | Gull Pond Landing, off Route 6-Friends of Herring River | Truro and Wellfleet, MA | May 26, 2022 | This event is coordinated by: Friends of Herring River |
| Acushnet River Herring Festival | Acushnet Sawmill- Buzzards Bay Coalition | Acushnet, MA | May 11, 2019 | For more information, see: Destination New Bedford event page, or call (508) 999-6363 x219; The event was coordinated by the Buzzards Bay Coalition |
| Mystic River Herring Run and Paddle | Somerville, MA-Mystic River Watershed Association | Somerville, MA | May 17, 2015; May 19, 2018 (22nd); May 15, 2022 (26th) | Paddling races for canoe and kayak hosted by the Mystic River Watershed Association; More information can be found at their event page |
| Herring Run Festival | Jenny Grist Mill, Town Brook-Plimouth Plantation | Plymouth, MA | April 25, 2015, 2018 | The event is coordinated by the town of Plymouth, MA. For more information ,see their event page, or contact Eric Hutchins (NOAA) at (978) 281-9313 |
| Herring Run Festival | Oliver Mill Park- | Middleborough, MA | April 9-10, 2022 (9th annual) | The event is supported by the town of Middleboro, MA see: Discover Middleborough and Middleborough on the Move |
| Art Show and Festival: A Photographic Journey with the River Herring of Plymouth Town Brook | Town of Plymouth- Marine & Environmental Affairs; CLEAR Lab at Northeastern University; and | Plymouth, MA | September 21, 2021 | This event was coordinated by the Plymouth Center for the Arts and more information can be found on their event page. |

| EVENT | LOCATION-SPONSOR | COMMUNITY | DATE(S) | STATUS/CONTACT INFO |
|---|---|---|---|---|
| | Plymouth Center for the Arts | | | |
| Plimoth Plantation Herring Run Festival | Plimoth Grist Mill, Jenny Pond, Town Brook- Jones River Watershed Association | Plymouth, MA | April 26, 2014; April 21, 2018; April 23, 2022 | The event is coordinated by the Jones River Landing Environmental Heritage Center at Plimoth Plantation. For more information, see their event page or contact (508) 746-1622, extension 8346 |
| Herring Festival | Jenny Pond Park-The Herring Ponds Watershed Assoc. and Herring Pond Wampanoag Tribe | Sagamore Beach, MA | April 23, 2022 | The event is coordinated by The Herring Ponds Watershed Association and Herring Pond Wampanoag Tribe. For more information, see the event page. Listed contact is Melissa Ferretti (melissa@herringpondtribe.org) |
| Weymouth Herring Run Tour | Jackson Square, Stephen Rennie Herring Run Park-Town of Weymouth | Weymouth, MA | May 14, 2022 | The event was coordinated by the town of Weymouth, MA as part of their 400 year anniversary. For more information, see their event page |
| Pembroke Fisheries Festival | North River-Pembroke Herring Fisheries Commission | Pembroke, MA | April, 2022, 9th annual | This event is coordinated by the Pembroke Herring Fisheries Commission. For more information, see this recent radio story from 95.9 WATD or contact the Commission superintendent Bill Boulter at billb13865@gmail.com |
| What Lives in the River (educational event) | Narrow River-Narrow River Preservation Association | Saunderstown, RI | September 17, 2022 | This event is active and coordinated by the Narrow River Preservation Association and more information can be found on the event page. |
| NC Herring Festival | Roanoke River, Town of Jamesville, NC | Jamesville, NC | Easter Weekend, 2019 was the 70th anniversary of the festival | This event has been active for decades and is coordinated by the town of Jamesville, NC. For more information, see the event website or contact director@ncherringfestival.net |

In Maine and Massachusetts, river herring wardens and municipalities work to protect, conserve, and manage river herring in their designated watersheds. Herring wardens are invested in the resource, sometimes serving in this role for a lifetime. Wardens are responsible for regulating harvest of river herring, enforcing specific town regulations, and maintaining free passage of adult and juvenile herring to and from their spawning grounds. The wardens work closely with their state and local governing agencies to help enforce regulations and develop annual reporting. While this practice may be difficult to replicate in some states, the value of creating a sense of responsibility and accountability for the river herring and the environment at the local/community level has been shown to yield tangible results (WHOI 2017).

### 6.2.3 Recreational Values

River herring are a preferred bait for recreational anglers. In certain areas/seasons, fishermen will often start their fishing trips by angling or dip netting for river herring for use as live or chunk bait. This bait fishery is driven by the popularity of, and co-occurrence with striped bass and represents a notable recreational value and cultural connection with river herring in these coastal communities. Recreational fishing for river herring only occurs legally in states where sustainable fisheries management plans have been implemented (*Section 3.5*). Because recreational creel surveys for river herring are rare, the full extent and implications of this harvest are unknown to managers.

Additional recreational value generated by river herring stems from ecotourism activities such as art and wildlife photography. These activities instill or enhance corresponding cultural values as well. Paintings and drawings have been created by many artists, including those images that are presented in several historical books on fishes. Notable examples include the color plates of both river herring species in Smith (1907), which are attributed to A. Hoen and Co.; the works of Sherman Foote Denton known for the nature drawings that he was commissioned to illustrate for the U.S. Fish Commission;[36] the black and white line drawings in Bigelow and Schroeder (1953) by H.L. Todd; and renderings by well-known and highly-regarded contemporary fish artists including J.R. Tomelleri. Similarly, the proliferation of waterproof cameras and the popularity of nature photography have produced abundant photographs of river herring in habitat, taken during their spawning runs and as they were preyed upon by various predators. This wildlife photography/videography has greatly enhanced documentaries about the restoration of runs through dam removals and/or provision of restored access.

## 6.3 Ecosystem Function Benefits

River herring are a keystone species that serve various ecological functions with potential co-benefits for aquatic systems as well as humans. Limburg and Waldman (2009) and more recently Ouellet et al. (2022) summarized several ecosystem services of diadromous fishes that we have divided into social and ecosystem benefits, noting that overlap exists. These include: provisioning of protein, linking inland and marine ecosystems by transporting nutrients,

[36] Dissolved ca. 1940 when personnel and facilities became part of the newly-created USFWS

supporting marine and freshwater food webs, and additional co-benefits for other native species. River herring support each of these ecosystem functions throughout their coastwide ranges, though their influence is largely diminished in many systems given depressed stocks (Hall et al. 2012; Mattocks et al. 2017).

### 6.3.1 Provisioning of Protein

The life history of river herring makes them especially susceptible to exploitation. The predictable seasonal availability and ease of collection during river herring spawning runs made them extremely attractive to fishermen (Bolster 2008). In addition to table fare, river herring make excellent bait for use in traps (e.g., lobster pots) and for catching larger, predatory fish (e.g., striped bass). Given their historical abundance, river herring played an important role in supporting human sustenance in many areas and were culturally-important to many societies (see *Sections 6.2.1 and 6.2.2*). The seasonal abundance of river herring also made them an attractive source of nutrients to supplement livestock feed or to use as fertilizer for crops (Morton 1637; Baird 1883; Nedeau 2003; Hall 2011).

### 6.3.2 Nutrient Transport

Semelparous anadromous fishes (or incidental/natural mortality from iteroparous stocks) can provide a significant nutritional subsidy to their associated ecological communities through direct consumption by wildlife and stream fauna or through nutrient release into the water and riparian zones during decomposition (Limburg and Waldman 2009). Although much of our knowledge regarding marine-derived nutrient transport by diadromous fish comes from studies focused on salmonids of the *Oncorhynchus* genus (Naiman et al. 2002; Schindler et al. 2003; Post and Walters 2009), the nutrient dynamics associated with river herring migrations in Atlantic coast ecosystems are conceptually comparable to effects observed in analogous salmon-influenced Pacific coast systems (Durbin et al. 1979). However, depressed populations of Atlantic coast diadromous fishes and corresponding reduced average body size have diminished this marine-derived nutrient pathway in the majority of Atlantic slope drainages (Twining et al. 2017; Barber et al. 2018).

The extent to which nutrients derived from migrating/spawning river herring are incorporated into freshwater systems are highly influenced by the complex delivery pathways (e.g., bioavailability, predator-prey relationships) and the degree of nutrient limitation in the receiving waterbody (Weaver et al. 2016; Barber et al. 2018). Garman (1992) investigated blueback herring in the non-tidal portion of the James River in Virginia, and estimated annual allochthonous biomass input from herring exceeded ~155 kg/hectare, prior to the incidence of dams. Through modeling, Barber et al. (2018) demonstrated that the relationships among the biomass of spawning adults, degree of iteroparity, and the escapement of their juvenile offspring can determine whether river herring represent a net import or export of nutrients from freshwater systems.

The influx of nutrients is exploited at multiple trophic levels. Carcasses are useful to many other animals, being consumed directly by birds, mammals, fish, invertebrates and microorganisms. Nutrient release resulting from decomposition may also increase algal and invertebrate abundance (Limburg and Waldman 2009; Walters et al. 2009). Nutrient inputs from iteroparous stocks, through excretion, may also contribute significantly to the nutrient dynamics in smaller tributaries and associated lentic waters such as those frequented by spawning alewives (Post and Walters 2009; Barber et al. 2018).

### 6.3.3 Food Web Support

River herring provide extensive food web support throughout their life history in freshwater systems, estuaries, and in the ocean. Mattocks et al. (2017) estimated the cumulative loss of alewife forage in New England from 1630 – 2014 in freshwater and marine systems at 7.0 million and 2.4 million metric tons, respectively. The extent of species that have been documented to prey upon river herring are described in *Sections 2.2 and 4.6*. The restoration of river herring offers an opportunity to restore an important source of forage across these systems (Hall et al. 2012).

In freshwater, juvenile alosines support piscivorous fishes (Mattocks et al. 2017) and, given their energy density, have been indicated to positively impact growth in those species (Yako et al. 2002, Watson et al. 2018). The outmigration of juvenile fish from their natal rivers represents an export of freshwater or estuarine-derived nutrients to the sea (Limburg and Waldman 2009; Barber et al. 2018). Nineteenth century observers documented that the abundant emigration of juvenile anadromous fish served as important forage for marine species such as Atlantic cod, closely linking inland production to coastal food webs (Stevenson 1899; Ames 2004; Limburg and Waldman 2009). By comparing targeted inshore sampling with broader groundfish surveys in the GOM, McDermott et al. (2015) inferred that alosines likely represent a significant prey source in inshore waters near productive freshwater systems. This effect was detectable despite the broad spatial distribution of alosines in the GOM and their current depressed population levels. In a retrospective study, Ames and Lichter (2013) examined early-twentieth century commercial fishing data from the Gulf of Maine and hypothesized that the movements of target species (e.g., Atlantic cod) were significantly influenced by the seasonal migrations of alewife.

For forage fish such as alewife, seemingly everything in the estuarine and marine environment consumes them, including striped bass, bluefish, tuna (*Thunnus spp.*), cod, haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*), seabirds, osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), herons, gulls, terns, cormorants, seals, whales, and turtles (McDermott et al. 2015; MDMR 2016; Toth et al. 2018). Dias et al. (2019) modeled the marine food web impacts of contemporary versus restored biomass of forage fish groups and concluded that alosines, especially alewife, demonstrate the largest increase in the keystone index among all forage fish groups. Furthermore, their findings highlighted the importance of alosines as a component of the forage fish complex, with the model indicating a potential biomass increase in more than 30 different functional groups in response to restored alosine biomass (Dias et al. 2019). Ultimately, restoring river herring habitat and population levels will benefit food webs in freshwater, estuarine, and marine systems.

#### 6.3.4 Co-Benefits for Native Species

Given their importance as forage, river herring can also serve as prey buffers for co-occurring fish, especially diadromous species (Saunders et al. 2006, Oulette et al. 2022). For example, the recovery of river herring populations in the Penobscot River, Maine, was inferred by Leach et al. (2022) to reduce the rate of salmon injury during the spring spawning run. Migratory fish also serve unique ecological roles as transport vectors for native mussel species (Freeman et al. 2003; Flecker et al. 2010). Native mussels often use fish species as hosts for their glochidia (larval stage), where they attach to host fish gills or fins primarily for dispersal purposes (Modesto et al. 2018). River herring have been documented or inferred to support a variety of native mussel species including alewife floater (Smith 1985) and Roanoke slabshell (*Elliptio roanokensis*; see Eads et al. 2015). As described in *Section 5.5*, the relationship between migratory alosines and native mussel species remains poorly understood (Smith 1985; Modesto et al. 2018). However, the potential co-benefits of improving fish passage for both mussels and alosines has been described in at least one study in the Connecticut River (Smith 1985).

## 7.0 Watershed Overview and Evaluation of River Herring Restoration Potential

Effective habitat conservation, enhancement, and restoration actions are framed by historical and current conditions that may be specific to each watershed. Each watershed (or sub-watershed) can present a distinct combination of threats or obstacles to river herring and unique challenges for restoration that should be considered during planning efforts. This section provides an overview of watersheds that currently support spawning and rearing habitats for river herring, including factors that may affect their restoration potential at both the HUC8 and HUC4 levels.

### 7.1 Evaluation of Restoration Potential for HUC8 Watersheds

To examine river herring habitat and restoration potential at a coastwide scale, 233 Atlantic coast HUC8 watersheds (Table 6) were evaluated by various tribes, state agencies, and management practitioners familiar with each watershed. Acknowledging that watersheds do not conform to anthropogenic boundaries, state agencies and other stakeholders were asked to provide input on all watersheds wholly or partially within their respective jurisdictions[37]. Reviewers were asked several questions to determine which watersheds were considered the focus of river herring restoration activities. Additionally, reviewers were asked to assess whether or not a watershed met[38] each of the following four criteria:

1. Watersheds with greatest river herring potential — this could mean production in total numbers or the importance of the contribution to region
2. Watersheds in greatest need of river herring restoration — degraded historical habitat, extirpated runs, invasive species, lost connectivity, etc.
3. Historical or cultural significance of former river herring runs — regional sense of place, includes economic impacts
4. Watersheds with ongoing river herring work — including tribal-, federal-, state-, local-, academic-, or NGO-run projects

[37] This convention resulted in some watersheds being reviewed by multiple agencies.
[38] Based solely on expert opinion

We developed a map to depict responses. Watersheds colored in green signify that HUC8 was identified as a focus area for river herring. The shading depicts how many of the four criteria were met; darker colors correspond to more criteria met. Red-colored areas signify that the HUC8 was not identified as a focus area for river herring. Many of the non-focus areas are above natural barriers or simply not in the historical range of river herring. Meeting one (or more) of the four criteria was not intrinsically linked to the focus area designation. A watershed could be designated a non-focus for river herring even if several criteria were met. For example, a watershed having great production potential and a historical river herring presence might be designated a non-focus under this framework if modern watershed use or other factors make river herring restoration currently impractical. Likewise, a watershed with a focus area designation may only meet a single criterion. These often occur where there are few hurdles to restoration, and/or improvements can be sought with relatively minimal effort or investment. Grey watersheds denote data deficient areas where available information was insufficient to make a determination.

Based on this review, several areas stand out with a high concentration of river herring focus areas. This is especially evident in New England and the Mid-Atlantic where clusters of focus watersheds that also meet all four criteria can be seen (Figure 13). These areas contain watersheds that management practitioners and reviewers viewed as having the greatest potential benefit for river herring with successful restoration.

Figure 13 is not intended to indicate "priority" projects or watersheds, as a more formal prioritization exercise might. Rather, it is included to highlight areas where river herring restoration is currently occurring and are expected to be a focus of tribes and state agencies over the next decade. This exercise also served to inform the development of the HCP providing relevance and context to our goals, objectives, and recommendations for river herring habitat conservation.

Table 6 – List of HUC8 watersheds considered in the HCP, including their identifying numbers, names, and their corresponding states or territories. Also described are the results of the focus area characterization[39] and respective number of criteria met (max = 4) as described in *Section 7.1*.[40]

| HUC8 ID | NHD HUC8 Number | NHD HUC4 Number | State(s) | NHD HUC8 Name | Focus Area | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 | Number of Criteria Met |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1100007 | 0110 | CT,RI | Pawcatuck River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 2 | 1050004 | 0105 | CN,ME | Passamaquoddy Bay-Bay of Fundy | Yes | | | ✓ | ✓ | 2 |
| 3 | 1100006 | 0110 | CT,NY | Saugatuck | ND | | ✓ | | ✓ | 2 |
| 4 | 1090002 | 0109 | MA,RI | Cape Cod | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 5 | 1100002 | 0110 | CT,MA | Shetucket River | Yes | | ✓ | | ✓ | 2 |
| 6 | 1080205 | 0108 | CT,MA | Outlet Connecticut River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 7 | 1100004 | 0110 | CT | Quinnipiac | Yes | | ✓ | | ✓ | 2 |
| 8 | 1080107 | 0108 | NH,VT | West River-Connecticut River | ND | | | | ✓ | 1 |
| 9 | 1080106 | 0108 | NH,VT | Black River-Connecticut River | No | | | | | 0 |
| 10 | 1080102 | 0108 | NH,VT | Passumpsic River | No | | | | | 0 |
| 11 | 1080203 | 0108 | MA,VT | Deerfield River | ND | | | | | 0 |
| 12 | 1080105 | 0108 | VT | White River | No | | | | | 0 |
| 13 | 1050001 | 0105 | CN,ME | Saint Croix River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 14 | 1030001 | 0103 | CN,ME | Upper Kennebec River | No | | | | | 0 |
| 15 | 1020004 | 0102 | ME | Piscataquis River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 16 | 1020003 | 0102 | ME | Mattawamkeag River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 17 | 1020002 | 0102 | ME | East Branch Penobscot River | No | | ✓ | | | 1 |
| 18 | 1080201 | 0108 | MA,NH,VT | Ashuelot River-Connecticut River | Yes | | ✓ | ✓ | ✓ | 3 |
| 19 | 1080202 | 0108 | MA,NH | Millers River | ND | | | | | 0 |
| 20 | 1080204 | 0108 | MA | Chicopee River | ND | | ✓ | | | 1 |
| 21 | 1070003 | 0107 | NH | Contoocook River | No | | | | | 0 |
| 22 | 1080206 | 0108 | CT,MA | Westfield River | Yes | | | ✓ | ✓ | 2 |
| 23 | 1080104 | 0108 | NH,VT | Waits River-Connecticut River | No | | | | | 0 |
| 24 | 1080101 | 0108 | CN,ME,NH,VT | Headwaters Connecticut River | No | | | | | 0 |
| 25 | 1100003 | 0110 | CT,RI | Thames | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 26 | 1090006 | 0109 | RI | Point Judith-Block Island | Yes | | | ✓ | ✓ | 2 |
| 27 | 1040001 | 0104 | CN,ME,NH | Upper Androscoggin River | No | | | | | 0 |
| 28 | 1090004 | 0109 | MA,RI | Narragansett | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 29 | 1100001 | 0110 | CT,MA,RI | Quinebaug River | Yes | | ✓ | | ✓ | 2 |
| 30 | 1080207 | 0108 | CT,MA | Farmington River | Yes | | ✓ | ✓ | ✓ | 3 |
| 31 | 1100005 | 0110 | CT,MA,NY | Housatonic | Yes | ✓ | ✓ | | | 2 |
| 32 | 1050002 | 0105 | ME | Maine Coastal | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 33 | 1020005 | 0102 | ME | Penobscot River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 34 | 1030003 | 0103 | ME | Lower Kennebec River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 35 | 1050003 | 0105 | ME | St. George-Sheepscot | Yes | | ✓ | ✓ | ✓ | 3 |
| 36 | 1060001 | 0106 | ME | Presumpscot | Yes | | ✓ | | ✓ | 2 |
| 37 | 1040002 | 0104 | ME,NH | Lower Androscoggin River | Yes | | ✓ | | | 1 |
| 38 | 1070006 | 0107 | MA,NH | Merrimack River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 39 | 1090001 | 0109 | MA | Charles | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 40 | 1060003 | 0106 | MA,ME,NH | Piscataqua-Salmon Falls | Yes | | | ✓ | ✓ | 2 |
| 41 | 1070002 | 0107 | NH | Winnipesaukee River | ND | ✓ | ✓ | ✓ | ✓ | 4 |
| 42 | 1080103 | 0108 | NH,VT | Ammonoosuc River-Connecticut River | No | | | | | 0 |
| 43 | 1090003 | 0109 | MA,RI | Blackstone River | Yes | | ✓ | ✓ | ✓ | 3 |
| 44 | 1070001 | 0107 | NH | Pemigewasset River | No | | | | | 0 |
| 45 | 1060002 | 0106 | ME,NH | Saco River | Yes | | ✓ | | | 1 |
| 46 | 1070005 | 0107 | MA | Concord River | Yes | | ✓ | ✓ | ✓ | 3 |
| 47 | 1070004 | 0107 | MA,NH | Nashua River | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 48 | 1030002 | 0103 | CN,ME | Dead River | No | | | | | 0 |
| 49 | 1020001 | 0102 | CN,ME | West Branch Penobscot River | No | ✓ | ✓ | | | 2 |
| 50 | 2040202 | 0204 | DE,NJ,PA | Lower Delaware | Yes | ✓ | ✓ | | ✓ | 3 |
| 51 | 2070008 | 0207 | DC,MD,VA,WV | Middle Potomac-Catoctin | ND | | ✓ | ✓ | | 2 |
| 52 | 2030101 | 0203 | CT,NJ,NY | Lower Hudson | Yes | | | ✓ | ✓ | 2 |
| 53 | 2040304 | 0204 | VA | Eastern Lower Delmarva | No | | | | | 0 |
| 54 | 2070004 | 0207 | MD,PA,VA,WV | Conococheague-Opequon | No | | | | | 0 |
| 55 | 2020007 | 0202 | NJ,NY | Rondout | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 56 | 2020008 | 0202 | NY | Hudson-Wappinger | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 57 | 2040204 | 0204 | DE,NJ | Delaware Bay | Yes | ✓ | ✓ | | ✓ | 3 |
| 58 | 2020002 | 0202 | NY | Sacandaga | No | | | | | 0 |
| 59 | 2080103 | 0208 | VA | Rapidan-Upper Rappahannock | Yes | ✓ | ✓ | | ✓ | 3 |
| 60 | 2080105 | 0208 | VA | Mattaponi | Yes | ✓ | ✓ | ✓ | ✓ | 4 |

[39] Focus area classifications: Yes = Identified as a focus area, No = Not identified as a focus area, ND= No designation, not enough information to make a determination

[40] For corresponding maps see *Appendix B*

| HUC8 ID | NHD HUC8 Number | NHD HUC4 Number | State(s) | NHD HUC8 Name | Focus Area | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 | Number of Criteria Met |
|---|---|---|---|---|---|---|---|---|---|---|
| 61 | 2070001 | 0207 | MD,VA,WV | South Branch Potomac | No | | | | | 0 |
| 62 | 2030103 | 0203 | NJ,NY | Hackensack-Passaic | Yes | | ✓ | | ✓ | 2 |
| 63 | 2020005 | 0202 | NY | Schoharie | No | | | | | 0 |
| 64 | 2020006 | 0202 | MA,NY | Middle Hudson | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 65 | 2020004 | 0202 | NY | Mohawk | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 66 | 2080206 | 0208 | VA | Lower James | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 67 | 2030102 | 0203 | CT,NY | Bronx | Yes | | ✓ | ✓ | ✓ | 3 |
| 68 | 2030104 | 0203 | NJ,NY | Sandy Hook-Staten Island | No | | | | | 0 |
| 69 | 2030202 | 0203 | NJ,NY,RI | Southern Long Island | Yes | | | | | 0 |
| 70 | 2040206 | 0204 | DE,NJ | Cohansey-Maurice | Yes | ✓ | ✓ | | ✓ | 3 |
| 71 | 2040301 | 0204 | NJ,NY | Mullica-Toms | Yes | | ✓ | | | 1 |
| 72 | 2050106 | 0205 | PA | Upper Susquehanna-Tunkhannock | No | | | | | 0 |
| 73 | 2050201 | 0205 | PA | Upper West Branch Susquehanna | No | | | | | 0 |
| 74 | 2050206 | 0205 | PA | Lower West Branch Susquehanna | No | | | | | 0 |
| 75 | 2020003 | 0202 | MA,NY,VT | Hudson-Hoosic | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 76 | 2050102 | 0205 | NY | Chenango | No | | | | | 0 |
| 77 | 2050203 | 0205 | PA | Middle West Branch Susquehanna | No | | | | | 0 |
| 78 | 2050204 | 0205 | PA | Bald Eagle | No | | | | | 0 |
| 79 | 2050205 | 0205 | PA | Pine | No | | | | | 0 |
| 80 | 2050303 | 0205 | PA | Raystown | No | | | | | 0 |
| 81 | 2050304 | 0205 | PA | Lower Juniata | Yes | ✓ | ✓ | | ✓ | 3 |
| 82 | 2050107 | 0205 | PA | Upper Susquehanna-Lackawanna | No | | | | | 0 |
| 83 | 2040106 | 0204 | PA | Lehigh | Yes | ✓ | ✓ | | ✓ | 3 |
| 84 | 2030105 | 0203 | NJ | Raritan | Yes | | ✓ | | | 1 |
| 85 | 2040104 | 0204 | NJ,NY,PA | Middle Delaware-Mongaup-Brodhead | Yes | ✓ | ✓ | ✓ | | 3 |
| 86 | 2040201 | 0204 | NJ,PA | Crosswicks-Neshaminy | Yes | ✓ | ✓ | | ✓ | 3 |
| 87 | 2040105 | 0204 | NJ,PA | Middle Delaware-Musconetcong | Yes | ✓ | ✓ | | ✓ | 3 |
| 88 | 2030201 | 0203 | NY | Northern Long Island | Yes | ✓ | | | | 1 |
| 89 | 2020001 | 0202 | NY | Upper Hudson | No | | | | | 0 |
| 90 | 2040302 | 0204 | NJ | Great Egg Harbor | Yes | | ✓ | | | 1 |
| 91 | 2040102 | 0204 | NY | East Branch Delaware | No | ✓ | | | | 1 |
| 92 | 2080111 | 0208 | DE,MD,VA | Pokomoke-Western Lower Delmarva | Yes | ✓ | ✓ | ✓ | | 3 |
| 93 | 2040303 | 0204 | DE,MD,NJ,VA | Chincoteague | No | | | | ✓ | 1 |
| 94 | 2080108 | 0208 | VA | Lynnhaven-Poquoson | Yes | | ✓ | ✓ | | 2 |
| 95 | 2070005 | 0207 | VA,WV | South Fork Shenandoah | No | | | | | 0 |
| 96 | 2080104 | 0208 | VA | Lower Rappahannock | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 97 | 2080106 | 0208 | VA | Pamunkey | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 98 | 2080107 | 0208 | VA | York | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 99 | 2080204 | 0208 | VA | Rivanna | No | | | | | 0 |
| 100 | 2080205 | 0208 | VA | Middle James-Willis | No | | ✓ | | | 1 |
| 101 | 2060001 | 0206 | MD | Upper Chesapeake Bay | Yes | ✓ | | | | 1 |
| 102 | 2060003 | 0206 | MD,PA | Gunpowder-Patapsco | Yes | | ✓ | ✓ | ✓ | 3 |
| 103 | 2060004 | 0206 | MD | Severn | No | | ✓ | | | 1 |
| 104 | 2050202 | 0205 | PA | Sinnemahoning | No | | | | | 0 |
| 105 | 2040101 | 0204 | NY,PA | Upper Delaware | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 106 | 2080109 | 0208 | DE,MD | Nanticoke | Yes | ✓ | ✓ | ✓ | | 3 |
| 107 | 2070002 | 0207 | MD,PA,WV | North Branch Potomac | No | | | | | 0 |
| 108 | 2040207 | 0204 | DE | Broadkill-Smyrna | Yes | ✓ | ✓ | | ✓ | 3 |
| 109 | 2050101 | 0205 | NY,PA | Upper Susquehanna | No | ✓ | ✓ | ✓ | ✓ | 4 |
| 110 | 2070007 | 0207 | MD,VA,WV | Shenandoah | No | | | | | 0 |
| 111 | 2080102 | 0208 | MD,VA | Great Wicomico-Piankatank | ND | | | | | 0 |
| 112 | 2070011 | 0207 | MD,VA | Lower Potomac | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 113 | 2040203 | 0204 | PA | Schuylkill | | | | | | 0 |
| 114 | 2050302 | 0205 | PA | Upper Juniata | Yes | ✓ | ✓ | | | 2 |
| 115 | 2070006 | 0207 | VA,WV | North Fork Shenandoah | No | | | | | 0 |
| 116 | 2080201 | 0208 | VA,WV | Upper James | No | | | | | 0 |
| 117 | 2080202 | 0208 | VA | Maury | No | | | | | 0 |
| 118 | 2080203 | 0208 | VA | Middle James-Buffalo | Yes | | ✓ | | | 1 |
| 119 | 2080207 | 0208 | VA | Appomattox | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 120 | 2070003 | 0207 | MD,PA,VA,WV | Cacapon-Town | No | | | | | 0 |

| HUC8 ID | NHD HUC8 Number | NHD HUC4 Number | State(s) | NHD HUC8 Name | Focus Area | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 | Number of Criteria Met |
|---|---|---|---|---|---|---|---|---|---|---|
| 121 | 2070009 | 0207 | MD,PA | Monocacy | No | | | | | 0 |
| 122 | 2040103 | 0204 | PA | Lackawaxen | No | ✓ | | | | 1 |
| 123 | 2050301 | 0205 | PA | Lower Susquehanna-Penns | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 124 | 2050104 | 0205 | NY,PA | Tioga | No | | | | | 0 |
| 125 | 2050306 | 0205 | MD,PA | Lower Susquehanna | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 126 | 2080208 | 0208 | VA | Hampton Roads | Yes | | ✓ | ✓ | | 2 |
| 127 | 2080101 | 0208 | MD,VA | Lower Chesapeake Bay | No | | | | | 0 |
| 128 | 2050305 | 0205 | PA | Lower Susquehanna-Swatara | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 129 | 2070010 | 0207 | DC,MD,VA | Middle Potomac-Anacostia-Occoquan | Yes | | ✓ | | ✓ | 2 |
| 130 | 2060005 | 0206 | DE,MD | Choptank | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 131 | 2060006 | 0206 | MD | Patuxent | Yes | | ✓ | ✓ | | 2 |
| 132 | 2080110 | 0208 | DE,MD,VA | Tangier | Yes | | ✓ | ✓ | ✓ | 3 |
| 133 | 2060002 | 0206 | DE,MD,PA | Chester-Sassafras | Yes | ✓ | ✓ | ✓ | | 3 |
| 134 | 2040205 | 0204 | DE,MD,PA | Brandywine-Christina | Yes | ✓ | ✓ | | ✓ | 3 |
| 135 | 2030203 | 0203 | CT,NY,RI | Long Island Sound | Yes | | | | ✓ | 1 |
| 136 | 2050103 | 0205 | NY,PA | Owego-Wappasening | No | | | | | 0 |
| 137 | 2050105 | 0205 | NY,PA | Chemung | No | | | | | 0 |
| 138 | 3010203 | 0301 | NC,VA | Chowan | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 139 | 3030006 | 0303 | NC | Black | Yes | | | ✓ | ✓ | 2 |
| 140 | 3030007 | 0303 | NC | Northeast Cape Fear | Yes | | | ✓ | ✓ | 2 |
| 141 | 3010107 | 0301 | NC | Lower Roanoke | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 142 | 3020202 | 0302 | NC | Middle Neuse | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 143 | 3020103 | 0302 | NC | Lower Tar | Yes | | | ✓ | ✓ | 2 |
| 144 | 3020201 | 0302 | NC | Upper Neuse | Yes | | | ✓ | ✓ | 2 |
| 145 | 3020302 | 0302 | NC | New River | No | | | | | 0 |
| 146 | 3050101 | 0305 | NC,SC | Upper Catawba | No | | | | | 0 |
| 147 | 3070201 | 0307 | GA | Satilla | No | | | | | 0 |
| 148 | 3030005 | 0303 | NC | Lower Cape Fear | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 149 | 3040208 | 0304 | NC,SC | Coastal Carolina | No | | | | | 0 |
| 150 | 3050201 | 0305 | SC | Cooper | Yes | ✓ | ✓ | | ✓ | 3 |
| 151 | 3050202 | 0305 | SC | South Carolina Coastal | Yes | | | ✓ | | 1 |
| 152 | 3050206 | 0305 | SC | Edisto River | Yes | | | ✓ | | 1 |
| 153 | 3050207 | 0305 | SC | Salkehatchie | Yes | | | ✓ | | 1 |
| 154 | 3050209 | 0305 | SC | Bulls Bay | No | | | | | 0 |
| 155 | 3050210 | 0305 | SC | St. Helena Island | No | | | | | 0 |
| 156 | 3040101 | 0304 | NC,VA | Upper Yadkin | No | | | | | 0 |
| 157 | 3040202 | 0304 | NC,SC | Lynches | Yes | ✓ | ✓ | ✓ | | 3 |
| 158 | 3050104 | 0305 | SC | Wateree | Yes | | | ✓ | | 1 |
| 159 | 3050110 | 0305 | SC | Congaree | Yes | | | ✓ | | 1 |
| 160 | 3050203 | 0305 | SC | North Fork Edisto | Yes | | | ✓ | | 1 |
| 161 | 3050205 | 0305 | SC | Four Hole Swamp | Yes | | | ✓ | | 1 |
| 162 | 3060107 | 0306 | SC | Stevens Creek | Yes | | | ✓ | | 1 |
| 163 | 3040201 | 0304 | NC,SC | Lower Pee Dee | Yes | | | ✓ | | 1 |
| 164 | 3040203 | 0304 | NC,SC | Lumber | Yes | | | ✓ | | 1 |
| 165 | 3040204 | 0304 | NC,SC | Little Pee Dee | Yes | | | ✓ | | 1 |
| 166 | 3040206 | 0304 | NC,SC | Waccamaw | Yes | | | ✓ | | 1 |
| 167 | 3050103 | 0305 | NC,SC | Lower Catawba | No | | | | | 0 |
| 168 | 3020105 | 0302 | NC | Pamlico Sound | Yes | | ✓ | ✓ | ✓ | 3 |
| 169 | 3030003 | 0303 | NC | Deep | No | | | | | 0 |
| 170 | 3030004 | 0303 | NC | Upper Cape Fear | Yes | | | ✓ | ✓ | 2 |
| 171 | 3040102 | 0304 | NC | South Yadkin | No | | | | | 0 |
| 172 | 3040103 | 0304 | NC | Lower Yadkin | No | | | | | 0 |
| 173 | 3040104 | 0304 | NC,SC | Upper Pee Dee | No | | | | | 0 |
| 174 | 3040105 | 0304 | NC,SC | Rocky | No | | | | | 0 |
| 175 | 3050102 | 0305 | NC,SC | South Fork Catawba | No | | | | | 0 |
| 176 | 3080202 | 0308 | FL | Cape Canaveral | No | | | | | 0 |
| 177 | 3080201 | 0308 | FL | Daytona-St. Augustine | No | | | | | 0 |
| 178 | 3010202 | 0301 | NC,VA | Blackwater | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 179 | 3060104 | 0306 | GA | Broad | No | | | | | 0 |
| 180 | 3060105 | 0306 | GA | Little | No | | | | | 0 |

| HUC8 ID | NHD HUC8 Number | NHD HUC4 Number | State(s) | NHD HUC8 Name | Focus Area | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 | Number of Criteria Met |
|---|---|---|---|---|---|---|---|---|---|---|
| 181 | 3010205 | 0301 | NC,VA | Albemarle | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 182 | 3040205 | 0304 | SC | Black | Yes | | | ✓ | | 1 |
| 183 | 3040207 | 0304 | SC | Carolina Coastal-Sampit | Yes | | | ✓ | | 1 |
| 184 | 3050111 | 0305 | SC | Lake Marion | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 185 | 3070104 | 0307 | GA | Lower Ocmulgee | Yes | | | ✓ | | 1 |
| 186 | 3060108 | 0306 | GA | Brier | Yes | | | ✓ | | 1 |
| 187 | 3060201 | 0306 | GA | Upper Ogeechee | No | | | | | 0 |
| 188 | 3060202 | 0306 | GA | Lower Ogeechee | Yes | | | ✓ | | 1 |
| 189 | 3060203 | 0306 | GA | Canoochee | Yes | | | ✓ | | 1 |
| 190 | 3060204 | 0306 | GA | Ogeechee Coastal | Yes | | | ✓ | | 1 |
| 191 | 3070101 | 0307 | GA | Upper Oconee | No | | | | | 0 |
| 192 | 3070102 | 0307 | GA | Lower Oconee | Yes | | | ✓ | | 1 |
| 193 | 3070103 | 0307 | GA | Upper Ocmulgee | No | | | | | 0 |
| 194 | 3020101 | 0302 | NC | Upper Tar | No | | | | | 0 |
| 195 | 3020102 | 0302 | NC | Fishing | No | | | | | 0 |
| 196 | 3020104 | 0302 | NC | Pamlico | Yes | | | ✓ | ✓ | 2 |
| 197 | 3020203 | 0302 | NC | Contentnea | Yes | | ✓ | ✓ | | 2 |
| 198 | 3020204 | 0302 | NC | Lower Neuse | Yes | | ✓ | ✓ | ✓ | 3 |
| 199 | 3030002 | 0303 | NC | Haw | No | | | | | 0 |
| 200 | 3070105 | 0307 | GA | Little Ocmulgee | No | | | | | 0 |
| 201 | 3070106 | 0307 | GA | Altamaha | Yes | | | ✓ | | 1 |
| 202 | 3070107 | 0307 | GA | Ohoopee | Yes | | | ✓ | | 1 |
| 203 | 3070202 | 0307 | GA | Little Satilla | No | | | | | 0 |
| 204 | 3050106 | 0305 | SC | Lower Broad | Yes | | | ✓ | | 1 |
| 205 | 3070204 | 0307 | FL,GA | St. Marys | Yes | | | ✓ | | 1 |
| 206 | 3020301 | 0302 | NC | White Oak River | No | | | | | 0 |
| 207 | 3010102 | 0301 | NC,VA | Middle Roanoke | No | | | | | 0 |
| 208 | 3010103 | 0301 | NC,VA | Upper Dan | No | | | | | 0 |
| 209 | 3010104 | 0301 | NC,VA | Lower Dan | No | | | | | 0 |
| 210 | 3010106 | 0301 | NC,VA | Roanoke Rapids | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 211 | 3010204 | 0301 | NC,VA | Meherrin | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 212 | 3050107 | 0305 | SC | Tyger | No | | | | | 0 |
| 213 | 3050108 | 0305 | SC | Enoree | No | | | | | 0 |
| 214 | 3050112 | 0305 | SC | Santee | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 215 | 3050204 | 0305 | SC | South Fork Edisto | Yes | | | ✓ | | 1 |
| 216 | 3050208 | 0305 | SC | Broad-St. Helena | Yes | | | ✓ | | 1 |
| 217 | 3060102 | 0306 | GA,NC,SC | Tugaloo | No | | | | | 0 |
| 218 | 3060103 | 0306 | GA,SC | Upper Savannah | Yes | | | ✓ | | 1 |
| 219 | 3060106 | 0306 | GA,SC | Middle Savannah | Yes | | | ✓ | | 1 |
| 220 | 3060110 | 0306 | SC | Calibogue Sound | Yes | | | ✓ | | 1 |
| 221 | 3050105 | 0305 | NC,SC | Upper Broad | No | | | | | 0 |
| 222 | 3050109 | 0305 | NC,SC | Saluda | No | | | | | 0 |
| 223 | 3060101 | 0306 | NC,SC | Seneca | No | | | | | 0 |
| 224 | 3010101 | 0301 | VA | Upper Roanoke | No | | | | | 0 |
| 225 | 3010105 | 0301 | VA | Banister | No | | | | | 0 |
| 226 | 3010201 | 0301 | NC,VA | Nottoway | Yes | ✓ | ✓ | ✓ | ✓ | 4 |
| 227 | 3070205 | 0307 | FL,GA | Nassau | No | | | | | 0 |
| 228 | 3080102 | 0308 | FL | Oklawaha | No | | | | | 0 |
| 229 | 3080103 | 0308 | FL | Lower St. Johns | Yes | | | ✓ | | 1 |
| 230 | 3070203 | 0307 | FL,GA | Cumberland-St. Simons | Yes | | | ✓ | | 1 |
| 231 | 3060109 | 0306 | GA,SC | Lower Savannah | Yes | | ✓ | ✓ | | 2 |
| 232 | 3080101 | 0308 | FL | Upper St. Johns | Yes | | | ✓ | | 1 |
| 233 | 3080203 | 0308 | FL | Vero Beach | No | | | | | 0 |

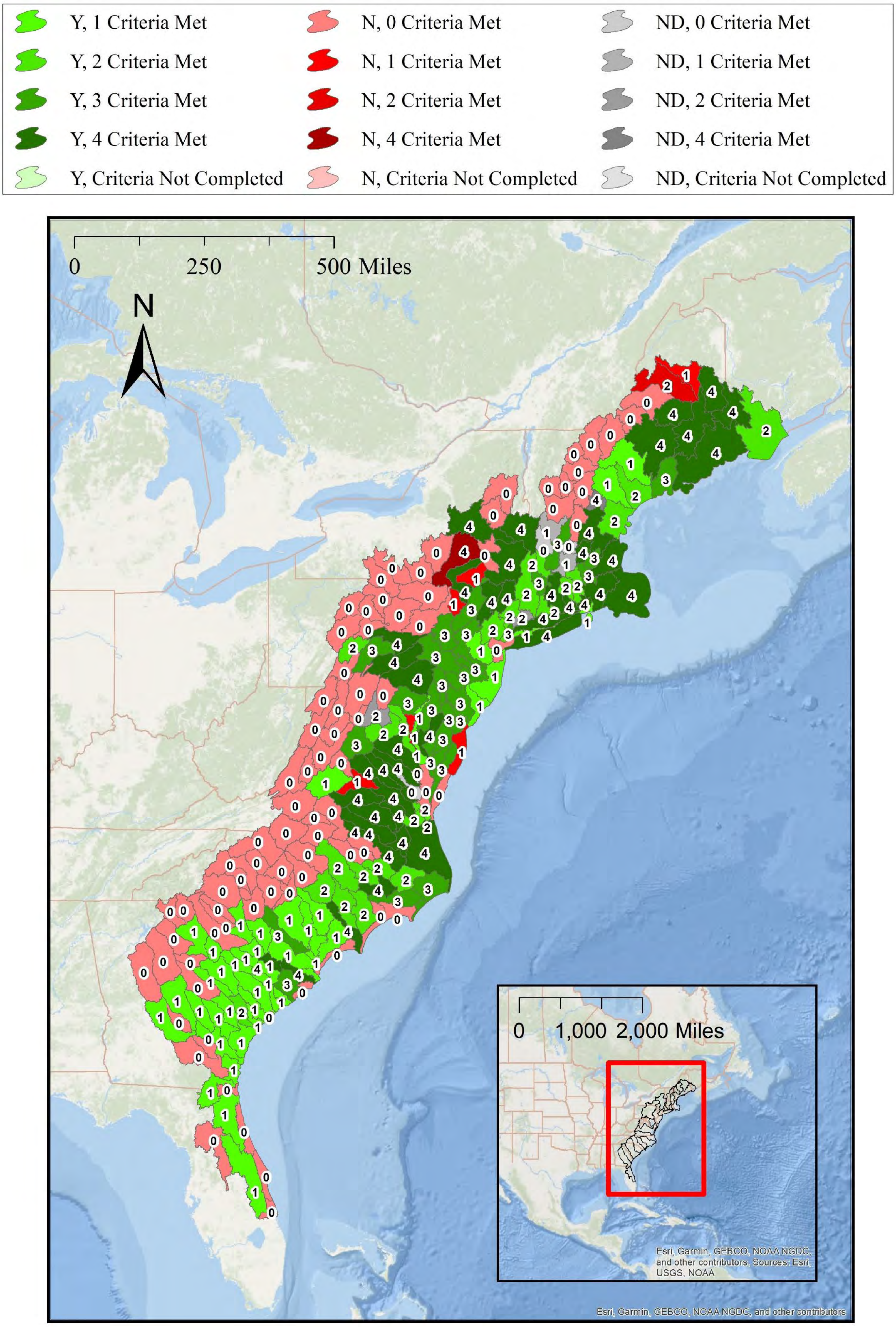


Figure 13 – HUC8 watersheds considered in the HCP. “Y” watersheds (green) designate river herring focus areas based on regional input, “N” indicates the watershed was not identified as a focus (red), and “ND” indicates there was not enough information to make a determination, and therefore no designation (gray). Level of shading indicates how many of the four criteria listed at the beginning of Section 7.1 a watershed met.

## 7.2 Overview of HUC4 Watersheds

For this section, our resolution widens to an overview of each Atlantic coast HUC4 watershed within the ranges of river herring. These descriptions are not meant to be a comprehensive description but rather designed to provide context on each watershed, and to outline certain unique habitat conditions that river herring face in each setting. *Sections 7.2.1 through 7.2.24*, provide a review of each of the 24 HUC4 watersheds considered in the HCP, including barriers, water quality, and restoration/management efforts associated with these watersheds. Existing river herring management documents (Appendix Table B 2) as well as readily available comprehensive watershed management reports, water quality reports, organizational webpages, and land use data (USGS 2016) were used when compiling the information included in this section.

### 7.2.1 Penobscot Watershed

#### 7.2.1.1 System Overview

The Penobscot River drains the second largest watershed in New England, and the largest wholly within Maine. The watershed is over 8,500 square miles and contains more than 12,000 miles of streams. The mainstem of the Penobscot River flows approximately 110 miles from the confluence of its east and west branches near Medway, ME, to Penobscot Bay, where it empties into the GOM. The tidal wedge, or mixing zone, extends roughly 12 miles from Bangor, ME to where the river joins the Penobscot Bay (Stevens et al. 2021). This watershed supports 14 hydropower facilities, the lowermost on the mainstem being the Milford Dam. There are five HUC8 watersheds within the larger HUC4 Penobscot watershed: the East Branch Penobscot, West Branch Penobscot, Mainstem Penobscot, Mattawamkeag, and Piscataquis watersheds. The watershed is heavily forested and dotted with many lentic features, just 2 percent of land area is categorized as urban or developed (Table 7).

Table 7 – Available land use data for the Penobscot watershed (USGS 2016).

| Land Use | Percent (%) |
|---|---|
| Urban/Developed | 2% |
| Impervious | < 1% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 17% |

#### 7.2.1.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Penobscot watershed there are over 1,100 recorded barriers (dams or stream crossings), including 14 hydropower facilities. Of these, 103 were classified as "severe" impediments to fish passage, and 131 stream crossings (e.g., culverted road crossings) were designated as "moderate" or "significant" barriers to fish passage (Martin and Levine 2017). Several hydropower dams within the watershed currently have no upstream or downstream passage facilities. Additional information regarding habitat accessibility for river herring can be found in Trinko Lake et al. (2012).

*Water Quality*

Two significant portions of the Penobscot received Class C water quality classifications (AA-best, C-worse) based on the Maine Department of Environmental Protection (MEDEP) in 2008 (MDMR and MDIFW 2008): the West Branch Penobscot River from Ferguson and Quakish Lakes to the confluence with the East Branch Penobscot River and the mainstem Penobscot from the confluence of the East and West Branches to the confluence of the Mattawamkeag River. Sections of four tributaries also received a Class C classification: Millinocket Stream, Camcolasse Stream, Mattanawcook Stream, and Kenduskeag Stream. A potential source for this degradation is point source discharges. As of 2008, there were 201 licensed point source discharges in the Penobscot River basin.

The watershed faces other various challenges to water quality as outlined in MDMR and MDIFW (2008). Roughly 10 acres of river bottom along the Bangor waterfront is covered with coal tar from an old gas manufacturing facility. The deposit is slowly eroding, but it has been reported that during hot days some tar bubbles to the surface (MDMR and MDIFW 2008). There are fish consumption advisories for mercury, dioxins, and polychlorinated biphenyls (PCBs) for all freshwater fish caught in Maine (MDMR and MDIFW 2008). There are also concerns over the re-suspension of wood chips from the historical lumbering industry of the region (MDMR and MDIFW 2008).

*Invasive Species*

Invasive/introduced fish species that could impact river herring include: largemouth bass, smallmouth bass, northern pike, chain pickerel (*Esox niger*), white perch, and white catfish.

*Restoration Efforts*

The Penobscot River benefits from a landmark collaborative initiative among hydropower developers, state and federal agencies, and NGOs that began in 1999 and resulted in the 2004 Lower Penobscot River Multiparty Settlement Agreement. This 2004 settlement agreement led to the Penobscot River Restoration Project (PRRP). The Penobscot River Restoration Trust (PRRT) helped to implement this agreement which maintained hydropower capacity while enhancing connectivity for migratory fishes throughout much of the Penobscot watershed. This effort led to the removal of the two lowermost dams – Great Works Dam (2012) and Veazie Dam (2013); a river-like bypass channel was constructed in 2016, which allows fish passage around the Howland Dam. In addition, a state of the art fishlift (completed 2014), and improved downstream passage facilities at the Milford Dam, which is the current lowermost mainstem dam; and a fish trap at the rebuilt Orono Dam, which is the first dam on the Stillwater Branch of the Penobscot River. Trinko Lake et al. (2012) predicted that alewife and blueback herring would be able to access 31 percent and 93 percent of their historical habitat following the completion of the PRRP. Prior to the removal of Veazie and Great Works Dams, the Milford Dam passed no river herring. After those removals and construction of the new fishlift, river herring returns increased dramatically, exceeding one million adult returns at the Milford Dam fish lift first in 2016, two million in 2018, and approximately 2.8 million in 2022 (J. Valliere, MDMR, pers. comm.). Pro-active stocking of adult river herring from neighboring areas into suitable spawning habitat in the Penobscot River watershed helped to spur this response. Other efforts to restore river herring habitat throughout the watershed have been completed and are ongoing. For more information on the restoration efforts within the Penobscot River watershed see *Appendix C 1.2* Bagaduce River Watershed Restoration Efforts. These extensive efforts were coupled with the designation of the Penobscot River Watershed as a Habitat Focus Area by NOAA's Office of Habitat Conservation (OHC) in 2014, which provided further impetus and funding to address fish habitat priorities throughout the larger watershed.

#### 7.2.1.3 Supplemental Information

For more information about the Penobscot watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see MDMR and MDIFW (2008), MDMR (2020b) and MDMR (2009).

### 7.2.2 Kennebec Watershed

#### 7.2.2.1 System Overview

The Kennebec River watershed is over 5,900 square miles and is the third largest in New England and second largest in Maine. The watershed contains more than 12,800 miles of rivers and streams. The mainstem of the Kennebec River flows 145 miles from Moosehead Lake in northern Maine, to Merrymeeting Bay where it meets the Androscoggin River, before emptying into the GOM. The Kennebec River watershed is split into three different HUC8 watersheds. These are the lower Kennebec, upper Kennebec, and the Dead River. The watershed is heavily forested, with only 4 percent of land area categorized as urban or developed (Table 8).

Table 8 - Available land use data for the Kennebec watershed (USGS 2016).

| Land Use | Percent (%) |
|---|---|
| Urban/Developed | 4% |
| Impervious | 1% |
| Storage (e.g., lakes, ponds, reservoirs, wetlands) | 14% |

#### 7.2.2.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

There are over 1,200 recorded barriers (dams or stream crossings) in the Kennebec watershed. Over 130 of the documented barriers were deemed “severe” to fish passage, and almost 200 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Levine 2017).

There are currently 22 hydropower projects within the watershed, 16 of which are within the historical range of Maine’s diadromous fishes (MDMR 2020a). There are at least 40 non-hydropower dams within the historical range of diadromous fishes (MDMR 2020a). Approximately 60 percent of historical alosine habitat above the Lockwood Hydropower Project remains inaccessible to river herring (Wippelhauser 2021).

*Water Quality*

Two portions of the Kennebec originally received Class C water quality classifications (AA-best, C-worse) in 1993, but since have been upgraded to a Class B based on MEDEP in 2008 (MDMR 2020a). These are the mainstem Kennebec River from Waterville to Augusta and a segment between the Lockwood Dam and the Abenaki Dam. Several impoundments have also remained as Class C water quality designations.

*Restoration Efforts*

The Kennebec is well-known for the Edwards Dam removal in 1999, which re-established 16 miles of accessible river to diadromous fish. The Guilford Dam on the Sebasticook River, the first major tributary to the Kennebec, was removed in 2002; the Madison Electric Works Project Dam on the Sandy River, was removed in 2006 (MDMR 2020a); and the Fort Halifax Dam on the Sebasticook River was removed later in 2008 (Wippelhauser 2021). Fish passage has also been implemented at several barriers throughout the watershed, including: a pool-and-chute fishway at Sebasticook Lake Dam, an Alaskan steep-pass fishway at Plymouth Pond Dam, and fish lifts at the Lockwood (first dam on the Kennebec River), Benton Falls and Burnham Projects (second and third dams on the Sebasticook River) (Wippelhauser 2021). Habitat restoration includes realigning and improving the river reach between the Guilford dam and the Sebasticook Lake outlet dam. River herring have responded positively the restored access, with up to 4.2 million adult alewife and 1.4 million adult blueback herring returning annually based on counts at the Benton Falls and Lockwood Project (Wippelhauser 2021). Tens or hundreds of thousands of returning river herring remain uncounted below Benton Falls and Lockwood Projects annually. For more information on the restoration efforts within the Kennebec watershed see *Appendix C 1.3* and Wippelhauser (2021).

#### 7.2.2.3 Supplemental Information

For more information about the Kennebec watershed and watershed-specific plans that are applicable to river herring and diadromous fish, see MDMR (2020b), MDMR (2020a) and Maine State Planning Office (1993).

### 7.2.3 Androscoggin Watershed

#### 7.2.3.1 System Overview

The Androscoggin River is the sixth largest watershed in New England and is Maine's third largest watershed. It drains an area of approximately 3,530 square miles; 80 percent of which lies in Maine, with the remainder in New Hampshire. The Androscoggin River runs nearly 180 miles from the Magalloway River at Umbagog Lake to meet the Kennebec River at Merrymeeting Bay, which extends another 20 miles before reaching the GOM. The Androscoggin River drops more than 1,500 ft over its course from origin to tidewater. The Brunswick Hydroelectric Project is the lowermost mainstem barrier on the Androscoggin River, located at a high-gradient river reach at the head-of-tide in Brunswick, ME. The watershed is heavily forested, with only 4 percent of land area categorized as urban or developed (Table 9).

Table 9 - Available land use data for the Androscoggin watershed (USGS 2016).

| Land Use | Percent (%) |
|---|---|
| Urban/Developed | 4% |
| Impervious | 1% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 10% |

#### 7.2.3.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Over 700 barriers (dams or stream crossings) were documented throughout the Androscoggin watershed. At least 80 barriers were deemed "severe" to fish passage, and almost 60 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017).

There are 32 licensed hydroelectric projects throughout the watershed, and 8 are within the restoration focus area outlined in (NMFS 2020). Passage at the Brunswick Project fish ladder is highly variable and is not meeting the restoration potential for the watershed (NMFS 2020). There is a lack of upstream passage at seven dams along the mainstem of the Little Androscoggin River as well as dams blocking tributaries to this stretch of river (NMFS 2020). Alewife currently occupy less than 13 percent of their potential spawning habitat, and with the exception of the mainstem of the Androscoggin River and a short reach of the Little River, historical blueback herring habitat is currently unoccupied and inaccessible (NMFS 2020).

*Water Quality*

Several portions of the Androscoggin River watershed received Class C water quality classifications (AA-best, C-worse) (Brown et al. 2017) including: portions of the mainstem of the Androscoggin River, and the mainstem of the Little Androscoggin River near the confluence with the main Androscoggin River. Tributaries to both the Little Androscoggin and Androscoggin River mainstem received predominately Class B classifications. Mill discharges, sewer overflows, dam impacts, and historical sediment contaminants continue to affect water quality throughout the watershed (ARWC 2016).

*Restoration Efforts*

In 1983, a 270 ft vertical slot fishway with 42 individual pools (1 ft drop, each) was installed at the Brunswick Hydroelectric Project. Downstream passage was also installed, in the form of a 12-in pipe located between two turbine intakes. The Pejepscot Dam (second barrier on the Androscoggin) and the Worumbo Dam (third barrier on the Androscoggin) each received an automated fish lift in 1987 and 1988, respectively, which operate annually from May 15 to November 1. Two 18-inch diameter pipes serve as downstream passage at Pejepscot, while a single 24-inch pipe serves as downstream passage at the Worumbo Dam. The upstream and downstream passage effectiveness has been evaluated for each of these dams and is summarized in McDermott et al. (2020). Fish passage improvements are also in development for several barriers on the Little Androscoggin and Sabbattus River tributaries.

#### 7.2.3.3 Supplemental Information

For more information about the Androscoggin watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see NMFS (2020b), MDMR (2020b), Brown et al. (2010) and Brown et al. (2017).

### 7.2.4 Maine Coastal Watershed

#### 7.2.4.1 System Overview

The Maine coastal watershed encompasses a total drainage area of more than 11,500 square miles and spans from the southwest portion of the Bay of Fundy in Canada, south to Brunswick, ME. This watershed contains several notable HUC8 and HUC10 watersheds as well as numerous bays and islands along the Maine coastline. It contains over 11,800 miles of rivers and streams. The major HUC8 watersheds include the Saint Croix River and the St. George-Sheepscot watersheds, as well as the Passamaquoddy-Bay of Fundy watershed. Smaller watersheds along the coastline include the Machias, Narraguagus, Pleasant, Passagassawakeag, and Union Rivers.

Notable among these for river herring is the St. Croix River, which forms a portion of the United States/Canada border. The St. Croix River flows 110 miles along the international border down to Passamaquoddy Bay, with New Brunswick to the north, and Maine to the south. The east branch originates from the Chiputneticook Lakes (North Lake, East Grand Lake, Mud Lake, and Spednic Lake) and the west branch flows through several large lakes (including Sysladobsis Lake, West Grand Lake, and Big Lake) before meeting the east branch at Grand Falls. The St. Croix River watershed has a significant potential for river herring production in the tens of millions (Clarke et al. 2022). There are five dams along the mainstem, with the first, Milltown Dam, located in Calais, ME. The next mainstem dam upriver is the Woodland Dam in Baileyville, ME, followed by the Grand Falls Dam at the outlet of Big Lake/Grand Falls Flowage. Further upstream is the Vanceboro Dam at the outlet of Spednic Lake, and finally the Forest City Dam located at the outlet of Grand Lake. Like many watersheds in Maine, the Maine Coastal watershed is heavily forested, with only a small fraction of the land designated urban/developed (Table 10)

Table 10 - Available land use data for the St. Croix and Sheepscot watersheds within the larger Maine Coastal watershed (USGS 2016).

| Land Use | St. Croix | Sheepscot |
|---|---|---|
| Urban/Developed | 1% | 5% |
| Impervious | <1% | <1% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 18% | 16% |

#### 7.2.4.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Maine coastal watershed, over 1,200 barriers (dams or stream crossings) were documented throughout the larger watershed. Almost 150 barriers were deemed “severe” to fish passage, and over 150 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Levine 2017).

The St. Croix River currently has five mainstem dams: Milltown,[41] Woodland, Grand Falls, Vanceboro, and Forest City Dams, the first four with fish passage improvements. McLean et al. (2007) stated that of the 17 dams present in the Sheepscot River watershed, nine have the potential to influence water quality and habitat (Arter 2004), and four dams potentially restrict fish passage.

*Water Quality*

The Sheepscot River watershed has nine segments that were listed as impaired for aquatic life (approximately 38 river miles). Low DO is listed as primary driver of water quality degradation, likely caused from non-point source pollution from nitrogen and phosphorous run-off (Dill et al. 2010). High turbidity (average of 3.11 Nephelometric Turbidity Units [NTU]) and total suspended solids (average of 7.3 mg/L) measurements could stem from poorly maintained road/stream crossings and inadequate riparian buffers that contribute to an increased sediment load after periods of high flow (Dill et al. 2010). Other water quality concerns in the Sheepscot include bacteria from wastewater, excessive chloride from road salts, alterations to flow and river morphology, and toxins such as metals and organohalides (Dill et al. 2010).

*Restoration Efforts*

Constructed in the 1700s, the Milltown Dam prevented fish passage until a primitive fishway was built in 1883. The Milltown Dam is now slated for complete removal starting in the summer of 2023. The Woodland Dam and Grand Falls Dam lacked fishways until a Denil ladder was constructed at each in the mid-1960s. These aged fishway are still in use today but are in disrepair and present operational challenges. Speculation based on anecdotal information about interspecies competition arose in the 1990s on the St. Croix River on the border of Maine and New Brunswick. Essentially, local anglers argued that reintroduced alewife negatively affected the food availability for the introduced smallmouth bass, which supports a recreational fishery in the watershed (Hoffman 2007; Willis 2009). In response, the State of Maine closed the fish passage facilities on several U.S.-owned dams on the St. Croix River in 1995 (Hoffman 2007). This action resulted in a collapse of the alewife population with some estimates suggesting less than 1,000 fish remained in the mainstem St. Croix River (Willis 2009). Willis et al. (2006) evaluated the connection between alewife population growth and the decline of smallmouth bass

[41] Milltown Dam is slated for removal in 2023

in several lakes in Maine. Their findings indicated that presence of alewife did not have a significant effect on smallmouth bass growth, and there was not significant overlap between the diets of the two species (Willis et al. 2006). Similar findings were reported by Hanson and Curry (2005), though they did note evidence of late-summer diet overlap between these species in an impoundment setting. In 2013, the 1995 law was repealed and the fishways were reopened. This has resulted in ongoing recovery of the river herring population of the St. Croix River, with recent population estimates over 700,000 individuals (SCIWC 2022).

As a part of the ongoing efforts to improve passage, and potentially construct new fishways, a study by Bradley et al. (2021) prepared for the International Joint Commission's International St. Croix River Watershed Board (ISCRWB) explored the upstream and downstream passage effectiveness of these dams on the St. Croix River. The ISCRWB helps to prevent and resolve disputes over the boundary waters of the St. Croix River, monitors the ecological health of these waters, and ensures that the dams comply with the Commission's Orders of Approval (ISCRWB 2022). The Vanceboro Dam fishway is on the Canadian side of the border. NOAA Fisheries has worked with the owner, Woodland Pulp, LLC, to proactively address potential issues that limit passage efficiency.

The Sheepscot Valley Conservation Association (SVCA) has worked with stakeholders to establish several nature preserves along the Sheepscot River, providing a stable forested riparian buffer to the river. These include the Bass Falls Preserve, Whitefield Salmon Preserve, and the Palermo Preserve. The SVCA also conducts native shrub plantings along the river bank, water quality monitoring, and works with the Maine Department of Marine Resources (MEDMR) to protect critical habitat (SVCA 2022).

For a more detailed list of restoration projects completed along the coast as well as in the Maine coastal watershed, see Appendix Table B 7.

#### 7.2.4.3 Supplemental Information

For more information on the Maine coastal watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see McLean et al. (2007), (Dill et al. 2010) MDMR (2020b), (Clarke et al. 2022), and (USFWS and NMFS 2018).

### 7.2.5 Saco Watershed

#### 7.2.5.1 System Overview

The Saco River watershed originates from the White Mountains in New Hampshire, and some of its northernmost tributaries stem from Mount Washington (the highest peak in the Northeast at 6,288 ft). The watershed is the fifth largest in New England with portions in both Maine and New Hampshire. The drainage area of the Saco watershed is more than 1,700 square miles and nearly 8,900 miles of rivers and streams. The mainstem of the Saco River runs 136 miles from Saco Lake in New Hampshire to where it empties into Saco Bay in the GOM. The first dam on the mainstem of the river is the Cataract Dam, at the head of tide and just six miles from the mouth of the river (Novak et al. 2017). The HUC4 Saco River watershed contains three different HUC8 watersheds. These are the Saco, Presumpscot, and Piscataqua-Salmon Falls watersheds. The Piscataqua-Salmon Falls watershed has a small portion reaching into Massachusetts. The rest of the HUC4 Saco River watershed is located in NH and ME. The Saco watershed is slightly more developed than some of the other watersheds in Maine, but urban/developed land accounts for only 6 percent of the total land use (Table 11).

Table 11 - Available land use data for the Saco watershed (USGS 2016).

| Land Use | Percent (%) |
|---|---|
| Urban/Developed | 6% |
| Impervious | 1% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 10% |

#### 7.2.5.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Saco River watershed, over 2,800 barriers (dams or stream crossings) were documented throughout the watershed, including nine hydropower facilities. Over 300 barriers were deemed “severe” to fish passage, and almost 330 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Levine 2017).

*Water Quality*

With its protected headwater streams and high groundwater recharge, the Saco River generally exhibits water quality suitable for most aquatic life and segments predominantly meet Maine water quality standards of class “B” or higher (i.e., “A” or “AA”)(SRCC 2021). Low DO and nutrient enrichment are listed as a primary drivers of water quality degradation, likely caused from non-point source pollution in areas with relatively higher levels of impervious surface cover (SRCC 2021). Other water quality concerns in the Saco include bacteria from wastewater, excessive chloride from road salts, and alterations to flow and river morphology.

*Restoration Efforts*

The Cataract Project (FERC P-2528) is the first federally-licensed hydropower project on the river. This head of tide project consists of four dams, all of which provide upstream passage: 1) Cataract East (fish lift), 2) Cataract West (Denil ladder), 3) Springs Island Dam that has a lock and a nature-like fishway (NLF) that was operational in 2019, and 4) Bradbury Dam that has a lock. The entrance to the Cataract East fish lift is slated to receive significant improvements to its entrance in 2023 and is expected to benefit fish that approach the entrance during the spring run in 2024. Due to channel complexity and based on route selection, fish have options when navigating past these projects such that they only need to make passage at two of the four dams to reach upstream habitat.

The next upstream dam is the Skelton Project (FERC P-2527; effectively barrier #3), which has a fish lift. Since the construction of the Spring Island NLF, window count data at this project indicate that greater than 85 percent of river herring that pass at Cataract also pass at Skelton. The next upstream project is the Bar Mills Project (FERC P-2194). This Project has not generated power since 2017 and is slated for removal by 2024 under the Saco River Fisheries Assessment Agreement Amendment 2. The Saco River Fisheries Assessment Agreement Amendment 2 also revised the dates for the next three projects to provide upstream anadromous passage (FERC Accession # 20190508-5127). Upstream fish passage at the West Buxton Project (FERC P-3) is set for 2027 and the Bonney Eagle Project (FERC P-2529) in 2029. Should Atlantic salmon be present at the Hiram Project (FERC P-2530) upstream passage will be required but not before 2031.

#### 7.2.5.3 Supplemental Information

For more information on the Saco watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see USFWS et al. (1987) and MDMR (2020b).

### 7.2.6 Merrimack Watershed

#### 7.2.6.1 Watershed Overview

The Merrimack River drains the fourth largest watershed in New England. Encompassing 5,008 square miles and containing over 9,500 river miles. The majority (approximately 75 percent) of the drainage is located within New Hampshire; the remainder is in Massachusetts. The Merrimack River flows approximately 116 miles from the confluence of the Pemigewasset and Winnipesaukee Rivers in Franklin, NH, to where the river meets the GOM near Plum Island in Newburyport, MA. Many of the upper tributaries are high gradient, finding their source in the White Mountains of New Hampshire with some originating at elevations above 4,000 ft. The mainstem of the Merrimack has a gentle gradient, only falling around 250 ft from its origin to tidewater. The tidal influence extends many river miles inland with the head of tide generally falling between river mile 21 and 22, just to the west of Haverhill, MA (Hartwell 1970; MRTC 2021). The Merrimack watershed presents a notable proportion (17 percent) of urban/developed land cover, with forests still predominant at 66 percent (Table 12).

Table 12 - Available land use data for the Merrimack watershed (MRTC 2021).

| Land Use | Percent (%) |
|---|---|
| Forested | 66% |
| Agricultural | 5% |
| Urban/Developed | 17% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 13% |

#### 7.2.6.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

More than 5,200 barriers (dams or stream crossings) were documented throughout the Merrimack River watershed. Over 800 barriers were deemed “severe” to fish passage, and over 600 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Levine 2017).

There are currently 49 hydropower projects within the watershed. Many of the mainstem hydropower facilities lack measures to prevent entrainment of downstream migrants, which is a significant concern for alosines. Similarly, upstream fish passage facilities are either lacking or are not properly designed for alosines (MRTC 2021).

*Water Quality*

Urban runoff, combined sewer overflows, dam impacts, heated discharge from power plants, and historical sediment contaminants were listed as the major contributors to water quality degradation (MRTC 2021). The water quality of the mainstem of the Merrimack River from its origin in Franklin, NH, to its confluence with the Atlantic Ocean has been designated as Class B (AA=best, D=worst) since the 1990s (NHWSPCC 1978; MRTC 2021). The majority of lotic waters in the historical range of diadromous fishes are considered Class B or C (USACE 2006; MRTC 2021).

*Restoration Efforts*

New Hampshire legislators began implementing laws for the protection of river herring in Cohas Brook as early as the 1750s (Noon 2015). Though impoundments were common place on smaller tributaries by the 1800s, the first anthropogenic barriers to affect river herring on the mainstem Merrimack River were the Pawtucket and Essex dams (ca. 1840s). Essex Dam, the lowermost mainstem dam, is located roughly eight miles upriver from the head of tide. This barrier halted river herring movement upstream and restricted available spawning and rearing habitats to the tidal and lowermost portions of the Merrimack mainstem.

Unfortunately, despite the size and regional importance of this watershed, historical data on river herring populations are scant. Much of our knowledge is based on anecdotal accounts. It appears that efforts to restore herring runs on the upper Merrimack began as early as 1830 with the installation of a fish ladder at Amoskeag Dam, and later at Pawtucket and Essex dams (Stolte 1981). Early efforts to provide fish passage at dams were inconsistent and largely ineffective, leading to the functional extirpation of river herring from the upper watershed.

For over 50 years, anadromous fisheries management in the Merrimack has been under the purview of a restoration cooperative comprising multiple state and federal agencies. Organized in 1969, the restoration cooperative or Anadromous Fish Restoration Program consists of two committees. The Policy Committee for Anadromous Fishery Management of the Merrimack River (Policy Committee) provides overall program direction and resolves policy issues. This committee is composed of Regional Directors of NOAA Fisheries (Greater Atlantic Region), USFWS (Region 5) and Directors of the MADMF, MassWildlife, NHFGD, and (formerly) USFS (White Mountain National Forest Supervisor). The Technical Committee for Anadromous Fishery Management of the Merrimack River or Merrimack River Technical Committee

(MRTC) provides oversight of program implementation and advises the Policy Committee on technical issues. The MRTC is composed of staff members (assigned by the Policy Committee) from each of the six agencies. The MRTC remains active producing documents, recommendations, and holding multiple meetings per year. The USFS has been inactive on the committee since the termination of the Atlantic salmon restoration program.

In the 1970s the State of Massachusetts made a concerted effort to maintain existing fishways (e.g., cleaning debris and other maintenance activities) to facilitate upstream migration of alosines, to the extent possible (MRTC 1997). In some years, river flow conditions allowed for river herring passage; however, these ladders were not reliable and the numbers of passed fish remained low and inconsistent. Modern attempts to restore herring runs accelerated in the 1980s with construction of contemporary fish passage facilities at the first three dams on the mainstem of the Merrimack River. Adult river herring were also stocked above impassable dams through intra- and inter-basin trap and transport efforts. The trap and transport effort continues today but progress is limited by capacity of collection facilities and a lack of adult fish available for transport (MRTC 2019). Despite these obstacles, the strategy has realized some success. It is likely that river herring populations would rapidly decline if the effort were to cease and fish passage facilities not improved.

#### 7.2.6.3 Supplemental Information

For more information on the Merrimack watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see MRTC (2021) and MDMR (2020b).

### 7.2.7 Connecticut Watershed

#### 7.2.7.1 System Overview

The Connecticut River watershed is the largest in New England with a drainage area of more than 11,200 square miles, and over 26,500 miles of streams and rivers. The mainstem of the Connecticut River is the second longest along the entire Atlantic coast at almost 410 miles. Fourth Connecticut Lake, near the border of the U.S. and Canada is the source water for the mainstem of the river. The river comprises the border between VT and NH and crosses through western MA and central CT. The Connecticut River empties into Long Island Sound, where it is responsible for 70 percent of the freshwater inflow to the sound (Marshall and Randhir 2008). The salt wedge can typically be found almost 17 miles from the mouth and over 60 mainstem river miles are tidally influenced (Marshall and Randhir 2008). The first five dams on the mainstem have fish passage facilities, including the Holyoke (MA), Turners Falls (MA), Vernon (VT), Bellows Falls (VT), and Wilder dams (VT). American shad and blueback herring were not able to ascend a natural falls barrier at Bellow Falls, and that is considered the mainstem upper limit of their ranges. Within the HUC4 Connecticut River watershed there are 14 HUC8 watersheds; seven include river herring habitat: the Ashuelot, Chicopee, Westfield, Farmington, West River, Millers, and lower Deerfield rivers. Overall, the watershed is primarily (77 percent) forested (USGS 2016), with moderate levels of agriculture and developed land cover (Table 13).

Table 13 - Available land use data for the Connecticut watershed (USGS 2016; USACE 2022).

| Land Use | Percent (%) |
|---|---|
| Forested | 77% |
| Agricultural | 9% |
| Urban/Developed | 9% |
| Wetlands | 7% |

#### 7.2.7.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Over 10,000 barriers (dams or stream crossings) are documented in the Connecticut River watershed. Over 1,500 barriers were deemed "severe" to fish passage, and roughly 1,700 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017). There are over 60 "major" dams throughout the Connecticut River watershed (USACE 2022), and over 100 hydropower projects.

*Water Quality*

Several reaches of the Connecticut River watershed were listed as impaired for aquatic life (MDEP 2003). Roughly three miles of the mainstem of the Connecticut River were listed as impaired due to hydropower-related flow regime alterations downstream of the Turners Falls Dam (its bypassed reach). Several tributaries to the Connecticut River including Bloody Brook, Stony Brook, and Wilton Brook were listed as impaired due to the introduction of a non-native macrophyte hydrilla (*Hydrilla verticillata*), which has been expending in the mainstem river into

Massachusetts reaches, and where prolific may cause or worsen depressed DO concentrations. Numerous lakes, ponds, and reservoirs were also listed as impaired due to the introduction of hydrilla. A fish consumption advisory is in effect for the mainstem Connecticut River between Northfield and Longmeadow, MA, due to PCB contamination (MDEP 2003).

*Invasive Species*

Hydrilla has been noted as a concern in the Connecticut River watershed due to its propensity to form dense mats, contributions to low DO, and impairment of critical river herring habitat (CCE 2020).

*Restoration Efforts*

The formation of the Cooperative Fishery Restoration Program for the Connecticut River basin in 1967, was one of the first steps towards addressing struggling anadromous fish populations, habitat restoration, and improving fish passage throughout the river basin. The basin state and federal fishery agencies (only USFWS before creation of NOAA Fisheries) while interested in working on shad and river herring, focused initial restoration and management efforts on restoring Atlantic salmon. In 1983, following state compact development, Congress recognized the formation of the Connecticut River Atlantic Salmon Commission (CRASC) that included the federal fisheries agencies with federal legislation (CRASC 2017, 2020). Since 1983, the CRASC has continued work to improve diadromous fish habitat access and support management and research on work involving river herring. There are numerous upstream fishways installed throughout the Connecticut River that are used or intended for use by river herring. However, river herring abundance dramatically declined beginning in the late 1990s. Restoration efforts by the CRASC and other stakeholders continued. Numerous small dam removals to benefit river herring, and a suite of other species, have also occurred over the past two decades, principally in lower basin tributaries in Connecticut.

Fishways on the mainstem dams had been attempted in the mid- and late-1800s with no detectable effect. A rudimentary fish lift was installed on the Holyoke Dam in 1955 and later received significant modifications in 1976 to include a second lift and measures for fish to swim through that lift system, rather than using hand carts (as was done pre-1976). In 2004, additional upstream passage improvements occurred with additional significant downstream passage measures in 2016. The second mainstem dam at Turners Falls had upstream passage provided first in 1980. The facility uses a modified Ice Harbor design at both the Cabot Power Station (base of power canal) and at the dam (approximately three miles upstream). Fish using either of these ladders must also use a third Gatehouse ladder (vertical slot design) to successfully pass the dam. The Turners Falls fishways have had passage efficiency issues since their installation due to unforeseen issues with the agency-recommended designs, sizing, and other site-specific issues. As part of the current FERC relicensing process, these upstream fishways are to be upgraded with additional downstream fish passage protections.

The third upstream dam, Vernon, has had the modified Ice Harbor and upper vertical slot fishway operating since 1981. This fishway is considered to be performing well, with modifications applied over time. This dam is also in the FERC relicensing process and additional improvements to upstream passage are expected, with substantial gains to occur on addressing downstream passage protection. The Bellows Falls Dam, the fourth mainstem dam, is the upstream historic extent of alosines and there are no plans by the agencies to expand their range upstream. Other passage facilities on tributaries to the Connecticut River that are, or may be used by, river herring include a vertical slot fishway on the Farmington River (CT), a Denil and steeppass fishway on the Mattabesset River (CT), Denil fishways on the Westfield, and Manhan rivers (MA), a steeppass fishway on the Eightmile River (CT), three steeppass fishways on Mill Brook leading to Rogers Lake (CT), and a fish lift on the Ashuelot River (NH) (CRASC 2017). Downstream fish passage measures are considered in these examples with a range of designs or operations that often have yet to be fully evaluated for effectiveness, for river herring specifically. Passage effectiveness studies to assess passage performance for river herring have not been conducted at all projects in this basin, a shortfall not unique to the Connecticut.

Numerous dam removals have also occurred within the lower Connecticut River watershed that currently do, or have the potential to, benefit river herring. The McGoldrick, Winchester, and Swanzy Mill dams were removed from the Ashuelot River in the early 2000s and are examples of “future” benefits due to the absence of river herring habitats since the population declines in the 1990s (CRASC 2017, 2020). Other dam removals have occurred in the Scantic, Salmon (three), and Eightmile (three) rivers (CT). The Connecticut River Conservancy (CRC) has worked to improve fish passage throughout the watershed, and since 2014, has restored access to 402 miles of habitat through 17 dam removals and four culvert projects (CRC 2022).

#### 7.2.7.3 Supplemental Information

For more information on the Connecticut watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see CRASC (2004), CRASC (2017), CRASC (2020), and USFWS (2020).

### 7.2.8 Massachusetts-Rhode Island Coastal Watershed

#### 7.2.8.1 System Overview

The Massachusetts-Rhode Island coastal watershed has a drainage area of over 7,100 square miles with over 8,200 miles of rivers and streams. The watershed extends from just south of the Merrimack River inlet, down through Massachusetts and Cape Cod, and terminates to the south near Point Judith abutting the Block Island watershed. The major HUC8 watersheds within this area include the Blackstone, Narragansett, Charles, and Cape Cod watersheds. These watersheds encompass most of eastern Massachusetts and almost all of Rhode Island.

The Charles watershed includes the Charles River and many smaller HUC10 watersheds that extend from north of Gloucester to the south of Boston. The Cape Cod watershed includes the Cape Cod Canal, Cape Cod Bay, Nantucket Island, Martha’s Vineyard, Paskamanset, North River, Mattapoisett, Sakonnet Point, and Buzzards Bay. The Narragansett watershed contains many HUC10 watersheds that drain into the Narragansett Bay between Rhode Island and Massachusetts.

Land cover in both the Charles River and Blackstone River watersheds is heavily modified by human activity. The urban/developed land cover comprises over 50 percent and 30 percent of the land cover in the Charles and Blackstone watersheds, respectively (Table 14).

Table 14 - Available land use data for the Charles and Blackstone watersheds within the larger Massachusetts-Rhode Island Coastal watershed (USGS 2016).

| Land Use | Charles | Blackstone |
|---|---|---|
| Forested | 39% | 56% |
| Agricultural | - | 7% |
| Urban/Developed | 52% | 30% |
| Impervious | 22% | 12% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 12% | 7% |

### 7.2.8.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Massachusetts-Rhode Island coastal watershed, over 4,300 barriers (dams or stream crossings) were documented throughout the watershed. 900 barriers were deemed "severe" to fish passage, and almost 300 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017).

*Water Quality*

According to MDEP (2006), approximately 124 miles (75 percent) of the rivers and streams in the Charles River watershed were determined to be impaired for aquatic life (4 percent not assessed). Approximately 42 percent of lakes and ponds were determined to be impaired for aquatic life (56 percent not assessed).

The State of the Waters Cape Cod 2021 web tool (APCC 2022) indicates that 87 percent of the embayment watersheds on Cape Cod were graded to have unacceptable water quality, likely as a result of coastal eutrophication from excessive nutrient inputs. Of all ponds on Cape Cod, 35 percent received an unacceptable grade due to several potential factors including cyanobacteria, total phosphorous, and turbidity (APCC 2022).

According to MDEP (2007), 62 miles (43 percent ) of the rivers and streams in the Blackstone River watershed were determined to be impaired for aquatic life (~10 percent not assessed), and 61 percent of lakes and ponds were also determined to be impaired for aquatic life (39 percent not assessed).

*Restoration Efforts*

In recent years, managers, restoration practitioners, and local organizations have successfully restored portions of historical river herring habitat within the Massachusetts-Rhode Island coastal watershed. While there is still much work left to be done, two successful restoration projects from this area are highlighted in the Restoration Showcase (*Appendix C*); These are the Coonamessett River Passage and Habitat Improvement (*Appendix C 1.4*) and the Herring River Estuary Restoration Project (*Appendix C 1.5*). The Taunton River, which is a designated Wild and Scenic River, has also been a focus for restoration since 2005 through Taunton River Restoration initiative. Thanks to targeted restoration efforts, the mainstem Taunton River no longer has any dams. Since 2012, six dam removals and three fishway installations have been completed throughout the watershed, with another dam removal scheduled for spring 2023 (Bowden 2014; Bozek 2014).

For further reading, a case study of the Mill River restoration by Bridges et al. (2021) detailed three barrier removals and a fishway installation on this Taunton River tributary. Significant restoration efforts have also been completed at Town Brook in Plymouth, MA. The NOAA Restoration Center has been supporting the Town of Plymouth for just over 20 years to remove five dams and enhance fish passage at a sixth dam to restore access for river herring and other migratory fish. The final dam removal was completed in 2019. As part of the project, NOAA provided funding to install an underwater camera that allows citizen scientists to count returning herring in order to estimate the annual run size.[42] For a more detailed list of restoration projects completed along the coast as well as in the Massachusetts-Rhode Island coastal watershed, see Appendix Table B 7.

Several organizations within the larger HUC4 coastal watershed actively pursue and engage in restoration projects. These organizations include, but are not limited to, the Charles River Watershed Association (CRWA), Mystic River Watershed Association, Blackstone River Watershed Council (BRWC), and Narragansett Bay Estuary Program (NBEP). The CRWA works to restore the watershed through dam removals, invasive species management, and naturalizing urbanized streams. The CRWA is currently advocating for the removal of the Watertown Dam, Charles River Dam at South Natick, and the Wrentham Eagle Dam. The Invasive Species Removal Volunteer Program has been established to address hydrilla expansion, as well as a five-year invasive aquatic vegetation management plan in collaboration with the Department of Conservation and Recreation. The CRWA also works with the MDMF and the USFWS, specifically in an attempt to restore American shad and other alosine populations in the Charles River (CRWA 2021). The BRWC began a stewardship program to perform river clean-ups, convert old agriculture land into a nature preserve, restore wetland areas, and improve fish passage/connectivity within the watershed. The NBEP helps to support watershed restoration projects and scientific data analysis. This program also engages with

[42] For more information, see: https://www.citizenscience.gov/catalog/506/#

stakeholders from the three different states within the Narragansett Bay watershed and produces comprehensive planning documents to facilitate restoration efforts (NBEP 2022).

#### 7.2.8.3 Supplemental Information

For more information on the Massachusetts-Rhode Island coastal watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see NBEP (2002), Erkan (2002), CRWA (2003), NHFGD (2020), and MDMF (2022).

### 7.2.9 Connecticut Coastal Watershed

#### 7.2.9.1 System Overview

The Connecticut coastal watershed consists of any watershed along the coast of the state of Connecticut, with the exception of the larger Connecticut River watershed. It has a drainage area of over 4,800 square miles, and has almost 12,500 total miles of rivers and streams. The watershed spans across four different states (CT, MA, NY, and RI). To the east of the Connecticut River inlet, there is the Thames River, Quinebaug River, Shetucket River and Pawcatuck River watersheds. To the west of the Connecticut River inlet, there is the Quinnipiac River, Saugatuck River, and Housatonic River watersheds. All watersheds along the Connecticut coastal region drain into the Long Island Sound. The Housatonic River watershed is the largest HUC8-level watershed along the Connecticut coastal region with a drainage area of almost 2,000 square miles. The mainstem of this river runs nearly 140 miles from Pittsfield, MA, to where it drains into the Long Island Sound in Stratford, CT.

Table 15 - Available land use data for the Pawcatuck, Thames, Quinnipiac, Saugatuck and Housatonic watersheds within the larger Connecticut Coastal watershed (USGS 2016).

| Land Use | Pawcatuck | Thames | Quinnipiac | Saugatuck | Housatonic |
|---|---|---|---|---|---|
| Urban/Developed | 13% | 12% | 53% | 21% | 15% |
| Impervious | 4% | 3% | 19% | 3% | 4% |
| Wetlands | 13% | 5% | 2% | 1% | 2% |

### 7.2.9.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Connecticut coastal watershed there were over 6,800 documented barriers (dams or stream crossings), including 13 hydropower projects dispersed throughout these coastal watersheds. Over 1,500 barriers were deemed "severe" to fish passage, and almost 900 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017).

*Water Quality*

Approximately 20 percent of Connecticut rivers and streams were determined to be impaired for supporting aquatic life (56 percent fully supporting and 12 percent with insufficient data) (CTDEEP 2020). Approximately 4 percent of lakes (by surface acreage) were determined to be impaired for supporting aquatic life (77 percent fully supporting and 7 percent with insufficient data) (CTDEEP 2020). Approximately 51 percent of estuaries (by square miles) were determined to be impaired for supporting aquatic life (41 percent fully supporting and <1 percent with insufficient data) (CTDEEP 2020).

*Restoration Efforts*

The Pawcatuck River has been the focus of several restoration efforts including dam removals and fish passage improvements. Refer to the Restoration Showcase (*Appendix C 1.6*) for a detailed description of these efforts.

The Thames River Basin Partnership is a collaborative effort to document various water quality and watershed-based approaches to restoration and management within the larger Thames River watershed. Information on planning documents and ongoing restoration work within the watershed can be found on their web page (see TRBP 2022). Within the Quinnipiac watershed, two dams have been removed (Clark Brothers and Carpenters dams), as has a large in-stream water pipe, to restore connectivity and allow the proper flow of nutrients and sediments (Save the Sound 2022). For a more detailed list of restoration projects completed in coastal Connecticut, see Appendix Table B 7.

### 7.2.9.3 Supplemental Information

For more information on the Connecticut coastal watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see Minta (1992), CTDEEP (2009), and Erkan (2002).

### 7.2.10 Upper Hudson Watershed

#### 7.2.10.1 System Overview

The Upper Hudson watershed is part of the larger Hudson River watershed. The Upper Hudson spans from upstate New York down to Stony Point in the Hudson Valley and reaches into parts of NJ, MA, and VT. The total drainage area of the Upper Hudson watershed is almost 13,000 square miles and is the northern most watershed in the Mid-Atlantic region. The mainstem of the Hudson River begins in Lake Tear of the Clouds (over 4,000 ft in elevation) in the Adirondack Park and continues roughly 260 miles before it is considered the Lower Hudson. The tidal portion of the river extends north to the Troy Dam, the first mainstem dam in Troy, NY. The Troy dam is a federal dam with navigation locks operated by the United States Army Corps of Engineers (USACE). The dam also supports the Green Island Hydropower Project (P-13). The salt wedge is typically located near river mile 35, near Newburgh, NY. The Upper Hudson has over 26,000 miles of rivers and streams within its watershed. The smaller HUC8 watersheds that comprise the Upper Hudson include the Sacandaga, Rondout, Mohawk, Schoharie, Upper Hudson, Hudson-Hoosic, Middle Hudson, and Hudson-Wappinger.

The State of the Hudson Report (HREP 2020) provides excellent information on land use, riparian areas, stream barriers, biologically significant lands, tidal wetlands, water quality, SAV, contaminants, as well as climate change considerations (HREP 2020).

Table 16 - Available land use data for the Upper Hudson watershed (USGS 2016).

| Land Use | Percentage |
|---|---|
| Forested | 71% |
| Urban/Developed | 9% |
| Impervious | 2% |
| Storage (e.g., lakes, ponds, reservoirs, wetlands) | 6% |

### 7.2.10.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Upper Hudson River watershed there are over 10,000 recorded barriers (dams or stream crossings). Over 1,200 of the documented barriers were deemed "severe" to fish passage, and almost 1,600 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017). The first major dam on the mainstem of the Hudson River impeding migratory fish species is the Troy Dam.

*Water Quality*

HREP (2020) reported on trends in DO, nutrients (nitrates and total phosphorous), salinity, pH, and bacteria levels. Water quality data are routinely collected at established monitoring stations from the mainstem Hudson River. Dissolved oxygen was consistently above the Environmental Protection Agency (EPA) standard of 4.8 mg/L. There was an improving long-term trend observed with nitrogen concentrations, although levels were still deemed moderately high when compared to other river systems (Lampman et al. 1999). There was no long-term trend in phosphorous concentrations and concentrations were moderately high when compared to other river systems (Lampman et al. 1999). There was a positive long-term trend in pH and levels remained within the 6.5-8.5 range, while values gradually trended higher (more basic).

*Invasive Species*

Zebra mussels, introduced in 1991 (Strayer et al. 1999), have been found to influence the growth rates of alewife and blueback herring in the Hudson River. More research is needed to describe the long-term impacts (Strayer et al. 2004; Strayer et al. 2014; Eakin et al. 2016). Channel catfish (*Ictalurus punctatus*), native to the St. Lawrence-Great Lakes and Missouri-Mississippi River basins, appeared in the Hudson River in the 1970s. Round goby have also been recently documented in the Hudson River. There is little research on how these introductions could potentially impact river herring.

*Restoration Efforts*

A dam on the Wynants Kill was removed in 2016. The confluence of Wynants Kill with the mainstem Hudson River is located just below the large Troy Dam. Just days after the dam removal was complete, river herring were documented moving past the former barrier. Later sampling efforts have found river herring eggs above the former dam, providing evidence that they are actively spawning in the newly accessible habitat (Eakin et al. 2016). Access to the non-tidal portion of the Hudson River above the Troy Dam is only available through the Champlain lock system and the Erie Canal. Fish passage was required by a 2009 Federal Energy Regulatory Commission (FERC) relicensing agreement but remains in the design phase (Eakin et al. 2016).

The Hudson River Estuary Habitat Restoration Plan (Miller 2013) identified priority habitats for restoration (i.e., intertidal habitats, shallow habitats, shorelines, tributary habitats), as well as the needed restoration actions required to restore those priority habitats. For more information on these recommended restoration actions please see Miller (2013).

The SFMP for NY river herring (Eakin et al. 2016) listed side channel restoration as an important effort to improve habitat for river herring. The side channels provide an area isolated from the high-energy demand of the main channel. Many of these habitats have been destroyed or degraded within the Hudson River estuary. Eakin et al. (2016) also identified potential locations for side channel restoration.

#### 7.2.10.3 Supplemental Information

For more information on the Upper Hudson River watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see Miller (2013), Eakin et al. (2016), HREP (2020), and Eakin (2023).

### 7.2.11 Lower Hudson-Long Island Watershed

#### 7.2.11.1 System Overview

The Lower Hudson-Long Island watershed covers the mainstem of the Hudson River from Haverstraw Bay out to where it empties into New York Bay, as well as all of Long Island. The watershed has a drainage area of over 7,000 square miles and is in parts of NY, NJ, CT, and RI. The Lower Hudson-Long Island watershed contains several smaller HUC8 watersheds. These include the Hackensack-Passaic, Lower Hudson, Bronx, Raritan, Sandy Hook-Staten Island, Long Island Sound, Northern Long Island, and Southern Long Island watersheds. The watershed is heavily developed (Table 17).

Table 17 - Available land use data for the Long Island watershed (USGS 2017).

| Land Use | Percentage |
|---|---|
| Forested | 18% |
| Agricultural | 7% |
| Urban/Developed | 63% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 9% |

#### 7.2.11.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Lower Hudson-Long Island watershed there were over 5,600 barriers (dams or stream crossings) documented throughout the watershed. Over 700 barriers were deemed "severe" for fish passage, and over 500 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017).

*Water Quality*

Stony Brook University has reported water quality impairments in Long Island waters, including the Long Island Sound. The reported impairments include hypoxia; brown, rust, and mahogany tides; dinophysis; toxic blue-green algal blooms; and fish kills in several lakes and ponds. The cause of these impairments is listed as excessive nutrient loading as a result of runoff and increased precipitation rates from climate change (SBU 2021).

*Restoration Efforts*

The Hudson River Foundation has developed an interactive web tool to display all restoration activities within the estuary of the Lower Hudson and Raritan watersheds (HRF 2022). This tool displays completed restoration projects, in-progress projects, and potential opportunities for restoration. The Long Island Diadromous Fish Restoration Strategy (Dunn 2020) lists priority restoration projects across Long Island. Along with the priority projects, this effort also details both the currently available habitat to river herring within each watershed, as well as the potential habitat behind impassable barriers. The Seatuck Environmental Association has produced an interactive web tool, called the River Revival Map, to view restoration projects, available habitat to diadromous fish and current dams across Long Island (SEA 2022; also see accompanying story map).

#### 7.2.11.3 Supplemental Information

For more information on the Lower Hudson-Long Island watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see Miller (2013), Eakin et al. (2016), Dunn (2020), and HREP (2020).

### 7.2.12 Delaware-Mid Atlantic Coastal Watershed

#### 7.2.12.1 System Overview

The Delaware-Mid Atlantic coastal watershed encompasses a large geographic area and is located throughout six different states (DE, MD, NJ, NY, PA, and VA). The total drainage area of the watershed is roughly 7,300 square miles. The watershed can be divided into three HUC6 watersheds. These are the Upper and Lower Delaware River watersheds, and the Mid-Atlantic coastal watershed.

The mainstem of the Delaware River begins in Hancock, NY at the confluence of the East and West Branches. The river runs over 330 miles until it passes through Philadelphia, PA and empties into Delaware Bay. The river comprises the border between NY and PA, as well as the border between PA and NJ. The salt wedge is typically located between river miles 65–75 near Wilmington, DE. The Delaware River Basin Commission (DRBC) provides excellent information on land use, water quality monitoring, and other management efforts within the watershed (DRBC 2022b). The watershed is predominantly forested, with a significant proportion (26 percent) of agricultural land cover (Table 18).

The Mid-Atlantic coastal HUC6 runs from near Raritan Bay and Sandy Hook, NJ, in the north, to the mouth of the Chesapeake Bay in the south and covers the coastline of NJ, DE, MD, and part of VA. The Mid-Atlantic coastal watershed can be broken into four smaller watersheds. From north to south these include the Mullica-Toms, Great Egg Harbor, Chincoteague, and Eastern Lower Delmarva.

Table 18 - Available land use data for the Delaware River watershed within the larger Delaware-Mid Atlantic Coastal watershed (USGS 2016).

| Land Use | Percentage |
|---|---|
| Forested | 60% |
| Agricultural | 24% |
| Urban/Developed | 9% |
| Storage (e.g. lakes, ponds, reservoirs, wetlands) | 7% |

### 7.2.12.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Delaware-Mid Atlantic coastal watershed there are over 16,000 recorded barriers (dams or stream crossings). Over 1,600 of the documented barriers were deemed "severe" to fish passage, and over 2,000 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Levine 2017). The Delaware watershed is one of the only HUC4 systems on the Atlantic coast without a dam on the mainstem of the river. However, many major tributaries are dammed near in proximity to their confluence with the mainstem Delaware, including the Schuylkill (Fairmount Dam) and Lehigh (Easton Dam) rivers. In the northern extent of the watershed, the East and West Branches of the Delaware River, as well as the Neversink River, are dammed forming the Pepacton, Cannonsville, and Neversink reservoirs, respectively. There are ten additional reservoirs throughout the Delaware River Basin mainly used for water supply, hydroelectric power, flood control, and recreational purposes (DRBC 2022a). In the relatively smaller Atlantic coastal watersheds (e.g., Mullica), many barriers exist, including several designated as "severe." These generally exist in association with water supply impoundments and historical mills(Able et al. 2020).

*Water Quality*

In the latter half of the twentieth century, pollution led to low DO concentrations in the Delaware estuary, contributing to a chronic chemical barrier to river herring migration (Weisberg et al. 1996; Sharp 2010). As of a 2018 water quality assessment of the Delaware River basin, all zones that were observed met the DO criteria to support aquatic life (DRBC 2018). In the relatively smaller Atlantic coastal watersheds, water quality varies largely dependent upon upland uses, with those that are more urbanized (e.g., Indian River) likely provisioning diminished rearing habitat and others (e.g., Mullica) presenting suitable conditions due to their largely undeveloped landscape.

*Invasive Species*

In recent years, northern snakehead have been found in the upper Delaware River (NYSDEC 2020) within the known spawning area of river herring and American shad. The extent of the snakehead population and its potential effect on river herring are not sufficiently understood at this time (Saylor et al. 2012; Isel and Odenkirk 2019).

*Restoration Efforts*

While there is still much restoration work to be done within this watershed, managers, restoration practitioners, and local organizations have successfully restored portions of habitat for river herring throughout the Delaware-Mid Atlantic coastal watershed. The removal of the Columbia Dam on the Paulin's Kill, a tributary to the Delaware River, is one of these successful restoration efforts highlighted in the Restoration Showcase (see *Appendix C 1.7*). For a more detailed list of restoration projects completed along the coast as well as in the Delaware-Mid Atlantic coastal watershed, see Appendix Table B 8.

The DRBC was created in 1961 as the first regional body overseeing a watershed without regard to the political boundaries. The Commission is composed of representatives of the four states (NY, NJ, PA, and DE), a commissioner, as well representative(s) from the USACE. The DRBC administers watershed planning programs involving water quality protection, water supply allocation, regulatory review, water conservation, drought management, flood loss reduction, and recreation (DRBC 2022b).

The Delaware River Basin Restoration Program is a non-regulatory program administered by the USFWS designed to conserve and restore the network of lands and waters that support wildlife. The program focuses on four distinct areas: reducing flooding/runoff, restoring fish and wildlife habitats, improving water quality, and enhancing safe recreational access for the public (USFWS 2022). The program also runs the Delaware Watershed Conservation Fund (DWCF), which has awarded over $26 million to more than 120 projects that support their mission (USFWS 2022). A recent project funded by the DWCF was the Delaware River Basin Restoration Roadmap for American shad, alewife, and blueback herring (DeSalvo et al. 2022). This plan seeks to increase the spawning runs of alosines within the watershed by improving aquatic connectivity and the quality of their habitat in priority areas (DeSalvo et al. 2022).

Finally, in the Atlantic coastal watersheds, river herring runs are generally modest due to the small watershed size, so restoration efforts may not be nationally visible. However, several barrier removals have occurred, including the Bishopville Dam in Maryland. Additional information regarding these efforts is generally available from local watershed groups.

#### 7.2.12.3 Supplemental Information

For more information on the Delaware-Mid Atlantic coastal watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see DRBFWMC (2011), PAFBC (2011), and DeSalvo et al. (2022).

### 7.2.13 Susquehanna Watershed

#### 7.2.13.1 System Overview

The Susquehanna is the largest of the 24 HUC4 watersheds considered in this HCP, spanning three states (MD, NY, and PA), with a total drainage area of 27,500 square miles. The Susquehanna River originates in upstate NY at Otsego Lake and runs almost 480 river miles to where it empties into the northern end of the Chesapeake Bay. The Susquehanna contributes almost half of the freshwater flow to the Chesapeake Bay estuary (Simpson 2007). Similar to the Delaware River watershed (7.2.12), the Susquehanna River watershed is predominantly forested with significant agriculture land cover (Table 19).

Table 19 - Available land use data for the Susquehanna watershed (USGS 2016).

| Land Use | Percentage |
| --- | --- |
| Forested | 62% |
| Agriculture | 24% |
| Urban/Developed | 9% |

#### 7.2.13.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

There are over 28,000 recorded barriers (dams or stream crossings) within the Susquehanna watershed. Over 1,100 of the documented barriers were characterized as a “severe” impediment to fish passage, and over 5,600 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Apse 2013). The lower Susquehanna has four large hydropower dams (Conowingo, Holtwood, Safe Harbor, and York Haven), the first being the Conowingo Dam, located 10 miles from the mouth of the river (Kocovsky et al. 2009; Zhang et al. 2016). There are currently two fish lifts on the Conowingo Dam; however, SRAFRC (2010) notes that river herring are typically excluded from capture by the two fish lifts. A vertical slot fishway was constructed at York Haven Dam and began operating in the spring of 2000, and fish lifts were installed at the Holtwood and Safe Harbor Dams in 1997. While these hydroelectric dams have passage measures in place, the passage performance on the Susquehanna River has not met the expectations of the Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC 2010). The Migratory Fish Management and Restoration Plan for the Susquehanna River Basin (SRAFRC 2010) discusses in detail the upstream and downstream passage measures in place.

*Water Quality*

Approximately 15 percent of streams and rivers (7,500 miles) in the Susquehanna watershed were determined to be impaired for aquatic life. The sources responsible for impairment were primarily agriculture, acid mine drainage, urban runoff, habitat modification, and atmospheric deposition (SRBC 2021). The Susquehanna River Basin Commission (SRBC) has developed several web tools to map out current point source pollution sources including abandoned mine drainage sites (SRBC 2022).

*Invasive Species*

In recent years, northern snakehead have been documented in the Susquehanna River, including at the fishlift at Conowingo Dam, in Lake Redmond, and within the known spawning area of river herring and American shad (SRBC 2022). The extent of the snakehead population and its potential effect on river herring are not well understood at this time (Saylor et al. 2012; Isel and Odenkirk 2019), although their relative abundance appears to be increasing in recent years. Invasive blue catfish are present below Conowingo Dam and have not been detected upstream. In contrast, invasive flathead catfish are considered widespread throughout the lower mainstem

Susquehanna River. Currently, all three of these invasive species are manually culled from the fishlifts at Conowingo Dam. The impact of this sorting practice on alosines (e.g., additional handling) and the attainment of passage standards has not been evaluated.

*Restoration Efforts*

A substantial focus of the river herring restoration effort in the Susquehanna River watershed has been on operations at the Conowingo Dam, the lowermost barrier on the mainstem. Trap and transport efforts were attempted during the 1990s for both species of river herring. Almost 90,000 river herring (mostly blueback herring) were transported to portions of the upper Susquehanna from Conowingo Dam; however, later monitoring detected very few juvenile river herring resulting from the effort (SRAFRC 2010). The causes for this low-recruitment were not investigated. Detections of river herring in the Conowingo Dam fish lifts have been minimal (i.e., less than 1,000) in recent years (SRBC 2022). Elevated water velocities near the entrance of the fishway are likely a contributing factor (S. Eyler, pers. comm.). However, fish passage improvements at the Conowingo Dam, including potential upgrades to the zone of passage, are underway in accordance with recent FERC relicensing.

#### 7.2.13.3 Supplemental Information

For more information on the Susquehanna watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see SRAFRC (2010) and SRBC (2021).

### 7.2.14 Upper Chesapeake Watershed

#### 7.2.14.1 System Overview

The Upper Chesapeake watershed covers portions of three states (DE, MD, and PA) and has a total drainage area of over 5,800 square miles. Along the west side of the Chesapeake Bay, the watershed spans south to the outlet of the Potomac River, and along the east side it reaches to South Marsh Island and the Nanticoke River outlet. Within the Upper Chesapeake Bay watershed there are six HUC8 watersheds. These are the Gunpowder-Patapsco, Chester-Sassafras, Upper Chesapeake Bay, Patuxent, Severn, and Choptank watersheds.

Land cover in the Patuxent River watershed is emblematic of much of the western shore of the Bay with a significant proportion of developed lands. In contrast, the Choptank River watershed on the Delmarva Peninsula is dominated by agricultural land cover (Table 20).

Table 20 – Available land use data for two Upper Chesapeake HUC-8 watersheds (CBF 2022b).

| Land Use | Patuxent | Choptank |
|---|---|---|
| Forested, Wetlands or other use | 55% | 42% |
| Agricultural | 13% | 48% |
| Urban/Developed | 32% | 10% |

#### 7.2.14.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Upper Chesapeake watershed there are over 4,200 recorded barriers (dams or stream crossings). Over 200 of the documented barriers were characterized as a "severe" impediment to fish passage, additionally, nearly 800 stream crossings were deemed "moderate" or "significant" barriers to fish passage (Martin and Apse 2013).

*Water Quality*

The University of Maryland Center for Environmental Science (UMCES 2018) reported on the water quality trends throughout the Chesapeake Bay and larger watershed. Although most scores declined in 2018, the Bay is experiencing positive long-term trends in water quality. An observed increase of precipitation as a result of climate change likely contributed to enhanced delivery of nutrients and sediment which are the primary source of chronically degraded water quality in the Chesapeake Bay and its sub-estuaries (UMCES 2018). Several river systems that flow into the Chesapeake Bay are assigned grades (A through F, with A being the highest and F being the lowest) on their overall health and long-term water quality trends. Measurements of dissolved oxygen, chlorophyll α, total phosphorous, total nitrogen, water clarity, aquatic grasses, and benthic communities were used to determine the scores. The Patapsco and Back Rivers received a score of F but are on an increasing long-term trend. The Patuxent River, Choptank River, Lower Western (MD) Shore, and the Upper Eastern Shore all received scores of D, with either increasing long-term trends or no trends.

*Invasive species*

In recent years, several invasive species have exhibited range/population expansions, which has been the focus of management actions. This includes northern snakehead, blue catfish, and flathead catfish. The State of Maryland and USFWS have undertaken various management actions including incentivizing recreational/commercial harvest of these species. The State of Maryland has also closed several fishways to restrict passage for northern snakehead.

*Restoration Efforts*

There have been several dam removals throughout the Upper Chesapeake watershed. The Maryland Department of Natural Resources (MDNR) lists the Whitehall Dam in the Gunpowder watershed, and the Simkins, and Union dams on the Patapsco River as completed dam removals (MDNR 2022). These removals opened up approximately 30 miles of stream habitat for spawning/migrating river herring. Other notable restoration efforts within the Upper Chesapeake watershed include the Bloede Dam removal and associated Patapsco River restoration efforts which are described in detail in the Restoration Showcase (see *Appendix C 1.8*).

Many organizations and municipalities are actively pursuing efforts to address water quality and habitat impairments in the Chesapeake Bay watershed. The 2014 Chesapeake Bay Watershed Agreement, to which each of the watershed states are party, stipulates habitat and water quality goals and outcomes for the entire watershed. In addition, non-governmental organizations, such as the Chesapeake Bay Foundation, pursue complimentary restoration programs throughout the watershed. Restoration efforts include restoring oyster habitat, stream and shoreline restoration, stormwater management, underwater grass plantings, and tree plantings (CBF 2022a).

Finally, NOAA designated the Choptank River as a Habitat Focus Area in 2014 as part of the Habitat Blueprint effort.[43] The Choptank River complex is located on Maryland's Eastern Shore (i.e., Maryland portion of the Delmarva Peninsula) and includes the Choptank River and its major tributaries. This part of the Chesapeake Bay ecosystem represents critical habitat for spawning striped bass and river herring, as well as historically abundant oyster reefs. The ultimate objective of the Habitat Focus Area is a healthy Choptank River ecosystem. NOAA's efforts leverage partnerships with other agencies, public and private organizations, research and science institutions, and local communities. Accomplishments of this effort includes:

[43] https://www.habitatblueprint.noaa.gov

- Restored more than 670 acres of oyster reef in the Little Choptank River, Tred Avon River, and Harris Creek
- Developed a climate vulnerability assessment that combines social, structural, and natural resource vulnerability with anticipated effects from a changing climate to determine places in the Choptank watershed that most need climate adaptation
- Established a partnership initiative, Envision the Choptank, and developed the Choptank Common Agenda to guide its work

#### 7.2.14.3 Supplemental Information

For more information on the larger Chesapeake watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see EPA (1989), Ogburn et al. (2015), and MDNR (2021).

### 7.2.15 Potomac Watershed

#### 7.2.15.1 System Overview

The Potomac watershed is the fourth largest in the Mid-Atlantic, covering the District of Columbia (DC) and four states (MD, PA, VA, and WV) with a total drainage area of almost 15,000 square miles. The mainstem of the Potomac begins on the eastern side of the Allegheny Mountains and runs almost 400 miles, passing by the District of Columbia, before emptying into the western shore of the Chesapeake Bay. The Potomac watershed contains over 34,000 total river miles. The smaller HUC8 watersheds that are a part of the larger Potomac watershed include the Monocacy, Shenandoah, South Fork Shenandoah, North Fork Shenandoah, Cacapon-Town, Conocoheague-Opequon, South Branch Potomac, Lower Potomac, Middle Potomac-Catoctin, Middle Potomac-Anacostia-Occoquan, and the North Branch Potomac. The overall Potomac River watershed has significant agricultural and developed land cover (Table 21).

Table 21 – Available land use data of the Potomac watershed (CBF 2022b).

| Land Use | Percent (%) |
|---|---|
| Forested, Wetlands or other use | 48% |
| Agricultural | 26% |
| Urban/Developed | 26% |

### 7.2.15.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Potomac watershed there are over 14,000 recorded barriers (dams or stream crossings). Over 3,000 of the documented barriers were deemed “severe” to fish passage, and over 300 stream crossings were deemed “moderate” or “significant” barriers to fish passage (Martin and Apse 2013). The Great Falls of the Potomac River, located approximately 14 miles upstream from DC, presents a natural barrier to anadromous fish migration, rendering much of the watershed inaccessible.

*Water Quality*

UMCES (2018) reported on the water quality trends throughout the Chesapeake Bay, including the Potomac River watershed. Several river systems to the Chesapeake Bay were graded (A through F, with A being the highest and F being the lowest) on their overall health and long-term water quality trends. Levels of DO, chlorophyll α, total phosphorous, total nitrogen, water clarity, aquatic grasses, and benthic communities were used in determining the scores. The Potomac River received a score of D, and has not exhibited a positive or negative long-term trend.

*Restoration Efforts*

Although spawning habitat is restricted to areas of the Potomac River and its tributaries below Great Falls, several fish passage restoration efforts have been completed. In 2000, a fishway was constructed at the Little Falls Dam to facilitate passage up to Great Falls. Also, in 2007 a fishway was constructed at Pierce Mill Dam on Rock Creek in DC to facilitate upstream movement of river herring. In addition to fish passage projects, many efforts are underway to improve habitat and water quality for the entire Chesapeake Bay Watershed. These are described in greater detail in *Section 7.2.14.2*.

#### 7.2.15.3 Supplemental Information

For more information on the Potomac watershed, and watershed-specific plans applicable to river herring and diadromous fish please refer to the documents listed for the larger Chesapeake watershed (CBP 1989; Ogburn et al. 2015; MDNR 2021).

### 7.2.16 Lower Chesapeake Watershed

#### 7.2.16.1 System Overview

The Lower Chesapeake watershed is considered to have the second largest drainage area of any watershed in the Mid-Atlantic region at over 20,000 square miles and contains over 50,000 total miles of rivers and streams. The watershed begins in the west near the George Washington National Forest and spans across several states (DE, MD, VA, and WV). The watershed contains two larger river systems, the James River and the Rappahannock River, with approximately 350 and 200 mainstem river miles, respectively. Other notable HUC8 watersheds within the Lower Chesapeake include the Mattaponi, Tangier, Pokomoke-Western Lower Delmarva, Pamunkey, York, Rivanna, Nanticoke, Great Wicomico-Piankatank, Maury, Appomattox, Hampton Roads, and Lynnhaven-Poquoson watersheds. Both the James and Rappahannock river watersheds present primarily forested land cover with notable agriculture and developed constituents (Table 22).

Table 22 - Available land use data for the James and Rappahannock watersheds within the Lower Chesapeake watershed (USGS 2016).

| Land Use | James | Rappahannock |
|---|---|---|
| Forested | 69% | 52% |
| Agricultural | 14% | 28% |
| Urban/Developed | 10% | 8% |
| Impervious | 2% | 1% |
| Wetlands | 3% | 5% |

#### 7.2.16.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

Within the Lower Chesapeake watershed there are over 13,000 recorded barriers (dams or stream crossings). Over 600 of the documented barriers were characterized as a "severe" impediment to fish passage, with an additional 2,000 stream crossings characterized as “moderate” or “significant” barriers (Martin and Apse 2013).

*Water Quality*

UMCES (2018) reported on the water quality trends throughout the Chesapeake Bay and larger watershed. Although most scores declined in 2018, the Bay is exhibiting positive long-term trends in water quality. UMCES (2018) stated that an observed increase of precipitation as a result of climate change likely contributed to the observed decline in water quality in 2018 due to increased delivery of sediment and nutrients from upland sources. Several river systems that flow into the Chesapeake Bay were graded (A through F, with A being the highest and F being the lowest) on their overall health and long-term water quality trends. Levels of DO, chlorophyll α, total phosphorous, total nitrogen, water clarity, aquatic grasses, and benthic communities were used in determining the scores. The York River, Elizabeth River, and the middle portion of the Chesapeake Bay all received scores of D, with long-term trends indicating modest water quality improvement (e.g., decreased nutrients, improving water clarity) or no change. Other portions of the Lower Chesapeake watershed all received scores between B and C.

*Invasive Species*

Non-native catfishes (e.g., blue catfish and flathead catfish) are of concern for their potential impact on river herring populations in several rivers in this watershed. In Virginia, for example, there is a recreational catfish fishery with liberal harvest regulations. There is also a traditional commercial fishery (nets, etc.) administered by Virginia Marine Resources Commission and a limited entry low-frequency boat electrofishing fishery (one permit each for the James, Rappahannock and Pamunkey rivers). Initial equipment acquisition for this electrofishing effort was government subsidized with the general goal being to attempt to curb non-native catfish impacts on native species. The Virginia Department of Wildlife Resources (VDWR) is currently developing a catfish management plan. Several rivers within this watershed also have northern snakehead populations (e.g., Rappahannock) that are under surveillance by state and federal monitoring programs.

*Restoration Efforts*

There have been several dam removals and technical fishway installations throughout the Lower Chesapeake watershed. The Maryland Department of Natural Resources (MDNR) lists the

Puckem Branch Dam in the Nanticoke watershed as a completed dam removal (MDNR 2022). This removal opened up approximately five miles of habitat for river herring. In the James watershed, the VDWR removed the Harvell Dam from the Appomattox River in 2014, providing access to 127 miles of confirmed and potential river herring habitat on the mainstem alone. On the Chickahominy River, a double Denil fishway on Walkers Dam is successfully passing river herring into 30 miles of suitable mainstem habitat above the dam (Owen and Weaver 2020). The Embrey Dam removal on the Rappahannock River is described in detail in the Restoration Showcase (see *Appendix C 1.9*).

In addition to broader Chesapeake Bay watershed restoration efforts mentioned previously, the James River Association and the Friends of the Rappahannock, both non-governmental organizations, perform similar restoration work throughout their respective watersheds including living shorelines, tree plantings, river cleanups, and educational programs (JRA 2022; Friends of the Rappahannock 2022). In 2022, the Middle Peninsula, which contains much of the spawning habitat available in the York River, was designated as a Habitat Focus Area by NOAA in 2022 as part of the Habitat Blueprint effort. NOAA will coordinate efforts across the agency to support habitat restoration, improve coastal resiliency, and provide science and tools to regional decision makers.

#### 7.2.16.3 Supplemental Information

For more information on the larger Chesapeake watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see CBP (1989, 2015), Martin and Apse (2013), Ogburn et al. (2015), and MDNR (2021).

### 7.2.17 Chowan-Roanoke Watershed

#### 7.2.17.1 System Overview

The Chowan-Roanoke watershed consists of two main rivers: the Chowan and Roanoke rivers. The watershed as a whole has the third largest drainage area in the Southeast region at over 19,000 square miles and spans across parts of Virginia and North Carolina. The north and south forks of the Roanoke River join together in Lafayette, VA, forming the mainstem, which continues over 375 miles to the Albemarle Sound. The Nottoway and Blackwater Rivers join together at the border of Virginia and North Carolina to form the mainstem of the Chowan River, a smaller drainage (compared to the Roanoke) that flows around 50 miles to where it empties into the Albemarle Sound. The Chowan-Roanoke watershed contains almost 45,000 total miles of streams and rivers. Other notable HUC8 watersheds within the Chowan-Roanoke include the Albemarle, Blackwater, Nottoway, Banister, Meherrin, Upper Dan, and Lower Dan watersheds. The majority of land use in the Chowan-Roanoke watershed is attributed to either forested or agricultural land, with each respective drainage having less than 10 percent of land cover characterized as urban/developed (Table 23)

Table 23 - Available land use data for the Chowan and Roanoke watersheds (USGS 2016).

| Land Use | Chowan | Roanoke |
|---|---|---|
| Forested | 42% | 55% |
| Agricultural | 22% | 21% |
| Urban/Developed | 6% | 8% |
| Impervious | <1% | 1% |
| Wetlands | 14% | 5% |

7.2.17.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Chowan-Roanoke watershed contains over 10,000 documented dams and over 23,000 potential road-stream crossings. Over 30 of the road-stream crossings have been assessed and 4 were determined likely to impact aquatic organisms (SARP 2022). Notable hydroelectric projects on the Roanoke River include the John H. Kerr Dam, Lake Gaston Dam, and the Roanoke Rapids Dam (SARP 2005a).

*Water Quality*

The North Carolina Wildlife Resources Commission states that of the nearly 800 freshwater river miles in the Chowan River, approximately 60 miles are considered impaired by the NC Division of Water Resources but over 500 miles lack data or are not rated (NCWRC 2015). The Roanoke River watershed also has approximately 60 miles of impaired fresh water out of over 2,200 miles but about 1,200 miles lack data or are not rated. The Chowan River is known to have seasonally low DO levels, mostly associated with elevated summer water temperatures and large rainfall events. Other water quality concerns in the Chowan-Roanoke River watershed include mercury bioaccumulation, dioxin contamination, soil erosion, and nutrient-rich runoff from agricultural and urban areas (NCWRC 2015). The NCWRC (2015) and NCDENR (2005) provide a robust water quality evaluation of both the Roanoke and Chowan watersheds.

*Invasive Species*

Hydrilla is established within the Chowan-Roanoke River watershed and is listed as a threat to aquatic life (NCWRC 2015). Non-native blue catfish are of concern, but are regularly harvested by commercial fishers.

*Restoration Efforts*

While there is still much restoration work to be done within these watersheds, managers, restoration practitioners, and local organizations have successfully restored portions of habitat for river herring throughout the Chowan-Roanoke basin. The Lower Roanoke River Floodplain Restoration Project is one of these successful restoration efforts highlighted in the Restoration Showcase (see *Appendix C 1.10*).

The Chowan-Roanoke watershed has several documents focused on restoration goals and priorities. USDOI and USDOC (2016) provides an overview of the present and historical status of river herring, threats, and status of the remaining habitat; this plan also offers recommendations for restoring diadromous fish to the Roanoke watershed. SARP (2005a) and NCDMS and NCDEQ (2018) provide in-depth descriptions of smaller watersheds, as well as restoration goals and priorities. APNEP (2012) provides detailed goals and management objectives for the greater Albemarle and Pamlico Sound.

#### 7.2.17.3 Supplemental Information

For more information on the Chowan-Roanoke watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see NCDENR (2005), SARP (2005a), NCWRC (2015), USDOI and USDOC (2016), and NCDMS and NCDEQ (2018).

### 7.2.18 Neuse-Pamlico Watershed

#### 7.2.18.1 System Overview

The Neuse-Pamlico watershed is over 5,600 square miles and consists of two main rivers: the Neuse River and the Tar/Pamlico River. The Neuse River is formed by the confluence of the Flat and Eno Rivers prior to entering the Falls Reservoir near Raleigh, NC, and flows over 250 miles before it empties into Pamlico Sound. The mainstem of the Pamlico River, which is the lower tidal portion of the Tar River, runs almost 40 miles from Washington, NC, to Pamlico Sound. The HUC8 watersheds within the larger Neuse-Pamlico basin include the Upper, Middle, and Lower Neuse, Upper and Lower Tar, Pamlico River, New River, Contentnea, White Oak River, Fishing, and Pamlico Sound watersheds. The Neuse-Pamlico watershed supports a variety of land uses, with agricultural and forested land most abundant (Table 24)

Table 24 - Available land use data for the Neuse and Pamlico watersheds (USGS 2016).

| Land Use | Neuse | Pamlico |
|---|---|---|
| Forested | 25% | 28% |
| Agricultural | 28% | 29% |
| Urban/Developed | 13% | 7% |
| Impervious | 1% | 1% |
| Waterbodies and Wetlands | 19% | 19% |

#### 7.2.18.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Neuse-Pamlico watershed contains over 7,000 documented dams and almost 14,000 potential road-stream crossings. Over 150 of the road-stream crossings have been assessed and 9 were determined likely to impact aquatic organisms (SARP 2022). There are at least 650 impoundments documented in the Neuse River watershed (NCWRC 2015). Some of the major dams and reservoirs within the Neuse River watershed include the Falls of the Neuse Reservoir Dam, Little River Reservoir Dam, and dams creating the following lakes and reservoirs: Lake Michie, Lake Orange, Corporation Lake, Lake Ben Johnson, Lake Butner, Lake Rodgers, Lake Wheeler, Lake Benson, and Buckhorn Reservoir (NCWRC 2015).

*Water Quality*

NCWRC (2015) states that out of over 3,400 freshwater river miles in the Neuse River, approximately 450 miles are classified as "impaired", with approximately 1,800 river miles lacking data or not rated. The Tar/Pamlico River watershed has approximately 100 miles of impaired freshwater out of over 2,500 miles (with more than 1,300 miles lacking data or not rated). The Neuse and Pamlico Rivers have been designated as some of the most affected rivers in the U.S. from eutrophication as a result of high nutrient input from the forestry and agriculture industries within the watershed (NCWRC 2015). Other water quality concerns include bioaccumulation of mercury and PCBs, dioxins, low DO, soil erosion, and modification of flow regimes from impoundments (NCWRC 2015). NCWRC (2015) provides a more detailed water quality evaluation of both the Neuse and Pamlico River watersheds.

*Invasive Species*

Hydrilla has been established within the Neuse River watershed and is listed as a threat to aquatic life (NCWRC (2015) Due to the lower flows in this river system, Hydrilla was able to become well established, primarily in the Eno River, and continues to spread annually (NCWRC 2015). Also, non-native catfish (e.g., blue and flathead catfish) are of concern, but they are sought after by recreational and commercial fishermen. Management of both native and non-native catfish are described by NCWRC (2019).

*Restoration Efforts*

While there is still much restoration work to be done within this watershed, managers, restoration practitioners, and local organizations have successfully removed multiple dams and restored portions of habitat for river herring throughout the Neuse-Pamlico watershed. Recent successful restoration efforts from the Neuse River watershed are highlighted in the Restoration Showcase (see *Appendix C 1.11*).

There are several documents focused on restoration goals and priorities for the Neuse-Pamlico watershed. EEP (2010) and NCDMS and NCDEQ (2010) provide in-depth descriptions of smaller watersheds within the Neuse-Pamlico watershed, as well as restoration goals and priorities. APNEP (2012) provides detailed goals and management objectives for the greater Albemarle and Pamlico Sound.

#### 7.2.18.3 Supplemental Information

For more information on the Neuse-Pamlico watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see EEP (2010), NCDMS and NCDEQ (2010), APNEP (2012) and NCWRC (2015).

### 7.2.19 Cape Fear Watershed

#### 7.2.19.1 System Overview

The Cape Fear watershed has the smallest drainage area of any HUC4 watershed in the Southeast region at just over 9,000 square miles. The mainstem of the Cape Fear River is formed at the confluence of the Haw and Deep Rivers and flows almost 200 miles to where it empties into the Atlantic Ocean. The watershed supports over 22,000 miles of rivers and streams and contains several smaller HUC8 watersheds which include the Black River, Haw River, Deep River, and the Northeast, Upper, and Lower Cape Fear watersheds. The Cape Fear watershed supports a variety of land uses, with forested and agricultural lands accounting for around half of all land use (Table 25).

Table 25 - Available land use data for the Cape Fear watershed (USGS 2016).

| Land Use | Percentage |
|---|---|
| Forested | 33% |
| Agricultural | 22% |
| Urban/Developed | 11% |
| Impervious | 3% |
| Waterbodies and Wetlands | 18% |

#### 7.2.19.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Cape Fear watershed contains over 8,000 documented dams and over 11,000 potential road-stream crossings. Over 200 of the road-stream crossings have been assessed and 32 were determined likely to impact aquatic organisms (SARP 2022). There have been almost 1,300 impoundments documented in the Cape Fear watershed (NCWRC 2015). Some of the major dams and reservoirs within the Cape Fear watershed include three USACE locks and dams on the mainstem Cape Fear River, Buckhorn Dam, and Jordan Dam, as well as numerous dams on the tributaries to the Cape Fear River (NCWRC 2015). CFRP (2013) stated the Cape Fear watershed currently contains approximately 400 river miles of unobstructed habitat for migratory fishes.

*Water Quality*

NCWRC (2015) states that out of over 6,500 freshwater river miles evaluated in the Cape Fear watershed, approximately 450 miles are considered impaired (there are over 4,200 miles with no data or not rated). The Cape Fear watershed has many Confined Animal Feeding Operations that contribute to overall fecal coliform contamination, habitat degradation, chlorophyll α, low DO, turbidity, and eutrophication from high nutrient inputs (NCWRC 2015). Other water quality concerns in the Cape Fear watershed include point-source pollution (e.g., PFAS), high-density human population areas with associated nonpoint-source pollutants, and changes in flow regimes from impoundments throughout the watershed (NCWRC 2015). NCWRC (2015) provides a more detailed water quality evaluation of the Cape Fear watershed.

*Invasive Species*

Invasive species within the Cape Fear watershed that are a known threat to river herring species are the flathead and blue catfish (NCWRC 2015). These catfish are known to prey heavily on river herring in certain settings and to select directly for alosines (Schmitt et al. 2017; Schmitt et al. 2019). Blue catfish is harvested commercially and large flathead catfish are sought after by recreational fishermen.

*Restoration Efforts*

While there is still much restoration work to be done within this watershed, managers, restoration practitioners, and local organizations have successfully removed dams and installed a NLF in the Cape Fear watershed. Examples from some of the successful restoration efforts from the Cape Fear watershed are highlighted in the Restoration Showcase (see *Appendix C*).

The Cape Fear watershed has several documents focused on restoration goals and priorities. CFRP (2013) outlines the necessary actions required to restore migratory fish populations within the Cape Fear watershed. EEP (2009) and NCWRC (2015) provide in-depth descriptions of smaller watersheds within the Cape Fear watershed, as well as general restoration goals and priorities.

#### 7.2.19.3 Supplemental Information

For more information on the Cape Fear watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see EEP (2009), CFRP (2013), and NCWRC (2015).

### 7.2.20 Pee Dee Watershed

#### 7.2.20.1 System Overview

The Pee Dee River watershed originates from the Appalachian Mountains and has a drainage area of over 18,800 square miles. The mainstem of the Pee Dee River is formed at the confluence of the Yadkin and Uwharrie rivers in North Carolina and flows over 230 miles to where it empties into Winyah Bay, near Georgetown, SC. The watershed spans across a small portion of Virginia, as well as primarily in North and South Carolina, and has over 47,000 miles of rivers and streams. There are several HUC8 watersheds that comprise the larger Pee Dee River watershed which include the Upper, South, and Lower Yadkin River, Upper, Lower, and Little Pee Dee River, Lynches, Lumber, Waccamaw, Rocky, Black, Carolina Coastal, and Carolina Coastal-Sampit watersheds. The Pee Dee watershed is primarily forested, with agricultural and developed lands interspersed (Table 26)

Table 26 - Available land use data for the Pee Dee watershed (NCWRC 2015; USGS 2016).

| Land Use | Percentage |
|---|---|
| Forested | 37% |
| Urban/Developed | 10% |
| Wetlands/Waterways | 22% |
| Impervious | 2% |

#### 7.2.20.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Pee-Dee watershed contains almost 10,000 documented dams along with nearly 23,000 potential road-stream crossings. Approximately 90 of the road-stream crossings have been assessed and 21 were determined likely to impact aquatic organisms (SARP 2022). The Pee Dee watershed is impounded by eight mainstem dams and numerous other dams throughout the tributary systems to the Pee Dee River (NCWRC 2015).

*Water Quality*

NCWRC (2015) states that out of almost 6,000 freshwater river miles in the Pee Dee watershed within North Carolina, approximately 750 miles are considered impaired (3,500 miles lack data or were not rated). The Pee Dee watershed has many Confined Animal Feeding Operations contributing to fecal coliform contamination, habitat degradation, chlorophyll α, low DO, turbidity, and eutrophication from high nutrient inputs (NCWRC 2015). Other water quality concerns in the Pee Dee watershed include excessive sedimentation from urban areas, agriculture, and mining, eutrophication caused by runoff from agricultural areas, as well as changes in flow regimes from impoundments throughout the watershed (NCWRC 2015). NCWRC (2015) provides a more detailed water quality evaluation of the North Carolina portion of the Pee Dee watershed. Similarly, SCDHEC (2016) provides information regarding the portion of the watershed in South Carolina.

*Invasive Species*

Invasive species within the Pee Dee watershed that are a known threat to river herring species are the flathead and blue catfish (NCWRC 2015). These catfish may prey heavily on river herring in certain settings and are known to exhibit prey-selectivity for alosines (Schmitt et al. 2017; Schmitt et al. 2019). The North Carolina Wildlife Resources Commission recently imposed a five-fish creel limit as well as a minimum size limit for the non-native Blue and Flathead catfish in the Pee Dee River. The purpose of this creel limit was to enhance the trophy fishery for these species.

*Restoration Efforts*

The Pee Dee watershed has several documents focused on restoration goals and priorities. USFWS (2006) outlines the necessary actions required to restore migratory fish populations within the Pee Dee watershed. NCWRC (2015) and USFWS (2008) provide descriptions of the condition of aquatic resources, threats affecting aquatic species, as well as general restoration goals and priorities.

#### 7.2.20.3 Supplemental Information

For more information on the Pee Dee watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see USFWS (2006), USFWS (2008), and NCWRC (2015).

### 7.2.21 Edisto-Santee Watershed

#### 7.2.21.1 System Overview

The drainage area of the Edisto-Santee watershed is the largest in the Southeast region at almost 24,000 square miles. The watershed originates from the Appalachian Mountains and spans across North Carolina and South Carolina. The watershed is comprised of two distinct rivers, the Edisto

River and the Santee River System. The mainstem of the relatively smaller Edisto River originates near Branchville, SC at the confluence of the North and South forks and continues over 120 miles to where it empties into the Atlantic Ocean. The mainstem of the much larger Santee River originates from the confluence of the Congaree and Wateree Rivers in upper Lake Marion and continues almost 150 miles before reaching the coast. Several complex water diversion actions occurred in this watershed in the twentieth century, including the diversion of much of the Santee River into the Cooper River through Lake Moultrie and the Pinopolis Dam followed by the re-diversion of much of that water back into the Santee River through St. Stephens Dam (NMFS et al. 2017). The larger HUC4 watershed contains over 62,000 miles of rivers and streams and contains several HUC8 watersheds including Edisto River, North and South Fork Edisto, Santee, Cooper, Upper, Lower, and South Fork Catawba, Upper and Lower Broad, Broad-St. Helena, St. Helena Island, Enoree, Tyger, Lake Marion, Four Hole Swamp, Congaree, Wateree, Bulls Bay, Salkehatchie, Saluda, and South Carolina Coastal watersheds. The land use distribution in the Edisto and Santee drainages is somewhat different, the Santee has a higher proportion of forested land, while the Edisto contains around three time the Santee's surface area of waterbodies and wetlands (Table 27).

Table 27 - Available land use data for the Edisto and Santee watersheds (USGS 2016).

| Land Use | Edisto | Santee |
|---|---|---|
| Forested | 32% | 54% |
| Urban/Developed | 7% | 15% |
| Impervious | 1% | 4% |
| Waterbodies and Wetlands | 27% | 9% |

#### 7.2.21.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Edisto-Santee watershed contains almost 15,000 documented dams and over 23,000 potential road-stream crossings. Nearly 900 of the road-stream crossings have been assessed and 161 were determined likely to impact aquatic organisms (SARP 2022). The Edisto River is the longest undammed blackwater river in the US (American Rivers 2022). The Santee watershed contains several notable hydrologic modifications affecting diadromous fish. These include the

Santee Cooper Power and Navigation Project, the Cooper River Rediversion Project, and other hydropower projects in the Catawba-Wateree, Broad River, and Saluda River watersheds (NMFS et al. 2017). The Santee watershed had 66 dams identified as barriers to fish migration. Of the existing dams, 47 support current, former, or pending FERC Projects, and the other 19 dams are either old non-hydropower dams or dams created for municipal drinking water (NMFS et al. 2017).

*Water Quality*

Water quality issues within the Edisto-Santee watershed are primarily from wastewater treatment plants, industrial discharges, and nonpoint source pollution contributing to high nutrient inputs and sedimentation leading to high turbidity (SCDHEC 2012, 2016; SCDNR 2020a). Other water quality concerns in the Edisto-Santee watershed include soil and streambank erosion from mismanaged pasture lands and lack of adequate riparian vegetation, eutrophication caused by runoff from agricultural areas, as well as changes in flow regimes from impoundments throughout the watershed (NCWRC 2015). NCWRC (2015) provides a more detailed water quality evaluation of the Broad and Catawba watersheds within the greater Edisto-Santee watershed.

*Invasive Species*

Invasive species within the Edisto-Santee watershed that are a known threat to river herring species are the flathead and blue catfish (SCDNR 2008; NMFS et al. 2017). These catfish may prey heavily on river herring in certain settings and are known to exhibit prey-selectivity for alosines (Schmitt et al. 2017; Schmitt et al. 2019). Hydrilla has been established within the Santee River watershed and is listed as a threat to aquatic life; SCDNR has released thousands of triploid grass carp (*Ctenophryngodon idealla*) into Lakes Marion and Moultrie to combat the spread of Hydrilla.

*Restoration Efforts*

The Edisto-Santee watershed has several documents focused on restoration goals and priorities. NMFS et al. (2017) describes individual watersheds within the greater Santee watershed, the current status of diadromous fish, and provides a detailed account of previous efforts to restore habitat and water quality for diadromous fish. Recent restoration efforts included fish passage improvements at the Wateree Dam (ca. 2018) and the Columbia Diversion Dam (ca. 2006). It also outlines the necessary actions required to restore diadromous fish populations within the Santee watershed. NCWRC (2015) provides descriptions of the condition of aquatic resources, threats affecting aquatic species, as well as general restoration goals and priorities for the smaller Broad and Catawba watersheds specifically.

#### 7.2.21.3 Supplemental Information

For more information on the Edisto-Santee watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see SCDNR (1996), NCWRC (2015), and NMFS et al. (2017).

### 7.2.22 Ogeechee-Savannah Watershed

#### 7.2.22.1 System Overview

The Ogeechee-Savannah watershed spans across three states (GA, NC, and SC), has a drainage area of almost 17,000 square miles, and contains almost 36,000 miles of rivers and streams. This watershed is comprised of two major rivers, the Ogeechee River and the Savannah River. The mainstem of the Ogeechee River is formed near Crawfordville, GA at the confluence of the North and South Fork Ogeechee Rivers and travels almost 280 miles before reaching the coast. The mainstem of the Savannah River forms the border between South Carolina and Georgia and originates from the confluence of the Tugaloo and Seneca Rivers in Lake Hartwell, running almost 300 miles to Savannah, GA on the coast. The larger HUC4 watershed contains several HUC8 watersheds including the Upper and Lower Ogeechee, Upper, Middle, and Lower Savannah, Stevens, Broad, Little, Brier, Canoochee, Tugaloo, Seneca, Ogeechee Coastal and the Calibogue Sound-Wright River watersheds. SCDHEC (2010) and GDNR (2001) provide a detailed breakdown of land use and water quality by sub-basin within the Ogeechee-Savannah watershed, Table 28 provides a summary from USGS (2016).

Table 28 - Available land use data for the Ogeechee and Savannah watersheds (USGS 2016).

| Land Use | Ogeechee | Savannah |
|---|---|---|
| Forested | 37% | 53% |
| Agricultural | 21% | 14% |
| Urban/Developed | 7% | 13% |
| Impervious | 1% | 2% |

#### 7.2.22.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Ogeechee-Savannah watershed contains over 10,000 documented dams and almost 16,000 potential road-stream crossings. Over 730 of the road-stream crossings have been assessed and 184 were determined to likely to impact aquatic organisms (SARP 2022). Some of the major dams on the Savannah River include the New Savannah Bluff Lock and Dam, Augusta Diversion Dam, Stevens Creek Dam, J. Strom Thurmond Dam, Prices Mill, and Parks Mill Dam (USFWS and NMFS 2005). USFWS and NMFS (2005) provide a barrier inventory, description of upstream and downstream passage facilities, and barrier prioritization for removal within the Savannah River watershed.

*Water Quality*

The Ogeechee River watershed contains over 40 different river segments and tributaries that have been listed as impaired or not supporting their designated uses (GRN 2018). The Savannah River watershed is known to have low DO in areas with inadequate instream flows as a result of changes in flow regimes from impoundments (USFWS and NMFS 2005). SCDHEC (2010) and GDNR (2001) include water quality grades and classifications, National Pollutant Discharge Elimination System (NPDES) facilities, non-point source facilities and watershed protection and water quality restoration strategies for each drainage within the Ogeechee-Savannah watershed.

*Invasive Species*

Invasive species within the Ogeechee-Savannah watershed that are a known threat to river herring species are the flathead and blue catfish (SCDNR 2008). These catfish may prey heavily on river herring in certain settings and are known to exhibit prey-selectivity for alosines (Schmitt et al. 2017; Schmitt et al. 2019).

*Restoration Efforts*

USFWS (1994) and USFWS and NMFS (2005) provide goals, objectives, and strategies aimed to restore habitat quality and access for diadromous fishes within the Savannah River watershed. The USACE and the Savannah and Jacksonville Districts have begun a saltmarsh restoration project as of 2022, which will improve nursery habitats for juvenile fish (Orr 2022). Projects such as saltmarsh restoration, improvements to flow regimes and restoring connectivity are just some of the efforts benefiting river herring within the Ogeechee-Savannah watershed.

#### 7.2.22.3 Supplemental Information

For more information on the Ogeechee-Savannah watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see USFWS (1994), GDNR (2001), USFWS and NMFS (2005), NCWRC (2015), Crist et al. (2019), GADNR and SCDNR (2020), and SCDNR (2020b) .

### 7.2.23 Altamaha-St. Mary's Watershed

#### 7.2.23.1 System Overview

The Altamaha-St. Mary's watershed has the second largest drainage area in the Southeast region at almost 21,000 square miles and contains over 39,000 miles of rivers and streams. The watershed contains two notable river systems: the Altamaha River and the smaller St. Mary's River. The mainstem of the Altamaha River is formed at the confluence of the Oconee and Ocmulgee Rivers and flows over 130 miles to the Altamaha Sound. The mainstem of the St. Mary's River comprises the border between Florida and Georgia and runs almost 130 miles to where it empties into the Cumberland Sound. Wetlands account for over 40 percent of the land use within the St. Mary's River watershed (SMRMC 2022). SMRMC (2003) provides a detailed description of land use within the St. Mary's watershed. The larger HUC4 watershed contains several smaller HUC8 watersheds including the Altamaha and St. Mary's, Upper, Lower and Little Ocmulgee, Upper and Lower Oconee, Satilla and Little Satilla, Ohoopee, Nassau, and the Cumberland-St. Simmons watersheds. A brief summary of land use is provided in Table 29.

Table 29 - Available land use data for the Altamaha watershed (USGS 2016).

| Land Use | Altamaha |
|---|---|
| Forested | 48% |
| Agricultural | 16% |
| Urban/Developed | 13% |
| Impervious | 2% |

#### 7.2.23.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The Altamaha-St. Mary's watershed contains over 15,000 documented dams and almost 18,000 potential road-stream crossings. Almost 160 of the road-stream crossings have been assessed and 47 were determined to be likely to impact aquatic organism movement (SARP 2022). USFWS (2013) provides a detailed list of anthropogenic and natural barriers to diadromous fish passage, as well quantifying the total habitat that would become available if specific barrier(s) were removed. There are no dams on the mainstem portion of the Altamaha, but there are several dams on the Ohoopee, Oconee, and Ocmulgee tributary rivers (USFWS 2013).

*Water Quality*

The Altamaha River watershed has several water quality related priorities that were ranked as "High" by SARP (2005b) according to their conservation targets (which include consideration of diadromous fishes). These threats primarily pertain to wastewater and stormwater management, invasive species, dams, and ground water and surface water withdrawals (GWP 2017). The St. Mary's watershed is considered to have overall good water quality; however, there are several portions where wastewater treatment plants and runoff from urban areas have degraded the water quality. SMRMC (2003) provides water quality classifications for the St. Mary's watershed, and also lists NPDES wastewater discharges impaired streams and river segments, as well as strategies to improve water quality within the watershed.

*Invasive Species*

Invasive species within the Altamaha River-St. Mary's watershed that are a known threat to river herring species are the flathead and blue catfishes (GDNR 2022). These catfish may prey heavily on river herring in certain settings and are known to exhibit prey-selectivity for alosines (Schmitt et al. 2017; Schmitt et al. 2019). GDNR has an active program to remove flathead catfish and blue catfish from the Satilla River (GDNR 2022).

*Restoration Efforts*

The Altamaha-St. Mary's watershed has several documents focused on restoration goals and priorities. USFWS (2013) describes the current status of American shad within the Altamaha River and outlines the goals, restoration strategies, and monitoring and research needs required to restore American shad and other diadromous fish populations within the Altamaha River watershed. While the plan is focused on American shad, the goals and restoration strategies would also likely benefit river herring habitat. SARP (2005b) provides descriptions of the condition of aquatic resources, threats affecting aquatic species, as well as general restoration objectives and strategic actions for the Altamaha River watershed.

#### 7.2.23.3 Supplemental Information

For more information on the Altamaha-St. Mary's watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see SARP (2005b), USFWS (2013), and GDNR (2020).

### 7.2.24 St. Johns Watershed

#### 7.2.24.1 System Overview

The St. Johns watershed is one of the smaller watersheds in the Southeast region and has a drainage area of approximately 12,000 square miles. The mainstem of the St. Johns River originates in central Florida and flows northward almost 280 miles to where it empties into the Atlantic Ocean near Jacksonville, FL. The larger HUC4 watershed is comprised of several smaller HUC8 watersheds including the Upper and Lower St. Johns, Oklawaha, Daytona-St. Augustine, Vero Beach, and the Cape Canaveral watersheds. The St. Johns watershed has a significant amount of wetland habitat interspersed with developed areas; land use is summarized in Table 30.

Table 30 - Available land use data for the lower St. Johns watershed (UNF 2021).

| Land Use | Percentage |
|---|---|
| Forested | 35% |
| Urban/Developed | 18% |
| Wetlands | 24% |

#### 7.2.24.2 Current Status of Watershed

*Barriers and Loss of Connectivity*

The St. Johns watershed contains over 150 documented dams and over 11,000 potential road-stream crossings. Almost 150 of the road-stream crossings have been assessed and 10 were determined likely to impact aquatic organisms (SARP 2022).

*Water Quality*

The overall water quality of the St. Johns River watershed is considered suitable for recreation, however, there are several water quality concerns that could affect aquatic life. These include runoff from agriculture and urban areas, contamination from metals, pesticides and PCBs, habitat degradation of wetlands and swamps, and increased salinity from sea level rise and dredging practices (UNF 2021). UNF (2021) provides an in-depth description of water quality parameters including DO, nutrient input, algal blooms, turbidity and bacteria levels, as well as a brief description of the water quality of the major tributaries to the St. Johns River.

#### 7.2.24.3 Supplemental Information

For more information on the St. Johns watershed, and watershed-specific plans that are applicable to river herring and diadromous fish see FFWCC (2020) and UNF (2021).

## 8.0 River Herring Habitat Conservation Goals, Objectives, and Recommendations

The ultimate goal is to restore healthy, sustainable Atlantic coast river herring populations that support a broad array of social and ecological services and functions, with stocks that are no longer designated depleted by ASMFC. This section outlines the focused goals, objectives, and recommended actions to support this goal. The recommendations, reinforced by the record of information within this document, creates a framework to restore, maintain, and enhance river herring habitats and the populations they support. It should be noted that the goals and objectives in this section are not presented in order of importance, likewise, numbering of objectives and goals is for organization only, and does not correlate with a ranking or priority level. The recommendations herein should not be interpreted as directives and are not regulatory in nature; rather, they are meant to provide guidance and context for actions that we consider beneficial to river herring. The following recommendations reflect our current[44] understanding of the issues facing Atlantic coast river herring populations and may be refined with new information gained or goals modified through an adaptive management approach. Therefore, we recommend these goals be revisited as circumstances evolve, and staffing/funding allow.

### 8.1 **Goal 1: Improve connectivity of river herring habitats throughout the species ranges.**

The ASMFC identified barriers to spawning habitat as a major threat (see Section 4.1) and contributing factor to the observed decline of river herring (ASMFC 2010). Where barriers have been removed, river herring populations can increase rapidly. However, barrier removal is often challenging and can require years of significant planning efforts with various stakeholders. In such cases where barrier removal cannot be accomplished, other techniques such as fishways may be used to mitigate barrier impacts and improve passage to the extent practicable. The following objectives and recommendations were developed in support of this goal.

#### 8.1.1 *Objective 1: Develop watershed-based planning and prioritization for barrier removals, fish passage, and habitat connectivity.*

Watershed plans help support management actions, focus restoration activities, and can support funding opportunities. We recommend the following actions to support this objective:

[44] These recommendations were designed around what we expect conditions to be like over the next decade.

a. Pursue and distribute funding opportunities for barrier removals and fish passage opportunistically, employing a watershed-based approach to habitat connectivity improvements.[45]
b. Identify high-quality habitat areas with high production potential for river herring with restored connectivity (see Goal 2).
c. Develop watershed-based restoration plans where plans do not currently exist or would benefit from updates, to identify and prioritize barriers for removal or fishway installation or modifications (see Appendix Table B 2).
d. Identify and/or categorize existing barriers at a watershed level to facilitate prioritization, and ultimately, incentivize key removals.
e. Plan to implement passage improvements on an opportunistic rather than sequential basis. Consider status of upstream and downstream barriers, as well as quality and quantity of potential habitats benefitting from a proposed project.
f. The plan should account for unexpected opportunities that may arise. These may come from unexpected infrastructure failure, a change in perspective of a dam owner, a significant infusion of funds, and other factors.

### 8.1.2 *Objective 2: Remove passage barriers throughout the species ranges.*

Restoring access to suitable spawning and rearing habitats is central to the recovery of river herring populations and is one of the best ways to build population resilience, and mitigate climate change-related habitat effects. We recommend the following actions to support this objective:

a. Pursue dam, weir, and tide gate[46] removals and replace impassible or restrictive culverts with properly designed and installed structures where and whenever possible to allow river herring access to suitable and productive habitats.
   - Leverage existing federal/state regulatory programs and guidance (e.g., USACE Regulatory Guidance Letter 18-01) to incentivize the removal of barriers for the benefit of river herring.
   - Leverage and expand existing funding sources to identify, assess, and ultimately remove barriers that maximize benefits to river herring.
   - Priority should be given to areas that support high-quality habitat and high production potential for river herring.

### 8.1.3 *Objective 3: Where barrier removal is not practical or feasible,[47] install and/or improve upstream and downstream passage measures at barriers blocking or inhibiting migration for all life history stages of river herring.*

[45] Projects located above currently impassable dams may still be prioritized to allow for future connectivity.
[46] Where tide gates are essential, fish passage should be implemented.
[47] Barrier removal is preferred over fishway construction, but where removal is not feasible, installation of fish passage facilities is recommended.

Ensuring fish passage routes or facilities provide safe, timely, and effective passage in upstream and downstream directions is imperative for such measures to support restoration. We recommend the following actions to support this objective:

a. Advocate for, and ensure compliance with, passage-related FERC license articles and fish passage performance criteria, exercising prescriptive authorities where appropriate.
b. Seek to implement downstream protective measures and optimize existing downstream passage facilities to minimize mortality and outmigration delay.
c. At a watershed level, encourage the establishment of a dedicated team or division to address fish passage restoration and design. This team should comprise a broad coalition of local, state, federal, tribal, and NGO partners, as appropriate, to maximize alignment of strategies and effectiveness of restoration actions.
d. Seek to identify and/or improve other potential barriers to river herring migration.[48]
    - Ensure that passage facilities support safe and effective river herring passage by identifying and providing a sufficient zone of passage in both upstream and downstream directions for adults and juveniles.[49]
    - Ensure that in-stream flow regime is adequate to support native aquatic ecosystem function, including river herring spawning and rearing habitats.

#### 8.1.4 *Objective 4: When new barriers are proposed, and properly justified, ensure that adequate upstream and downstream passage are installed and monitored.*

It is important to consider and accommodate the requirements of each river herring life history stage during review, permitting, design, and construction or modification of barriers. With proper implementation, mitigation measures can help to facilitate recovery and maintenance of river herring populations to the extent conditions allow (e.g., barrier density, fishway capacity and efficiency, carrying capacity of available habitat). We recommend several actions accompany the construction of any new potential barriers, including:

a. Use the public review process for permitting and licensing to ensure that fish passage and habitat conservation needs are thoroughly considered in the design, permitting, and licensing requirements.
b. Work with partners and stakeholders to ensure that river herring life history requirements are included in any development or infrastructure planning process.

---

[48] Such barriers may include less apparent blockages such as culverted road crossings or condition-related barriers such as velocity barriers, low flows resulting in a dry channel (can be seasonal or intermittent barriers), or degraded water quality resulting in a chemical barrier

[49] e.g., avoid excessive velocities and drops, determine appropriate wetted width, and provide minimum water depth for passage.

## 8.2 Goal 2: Assess and enhance spawning and rearing habitats for river herring throughout their coastwide ranges.

In support of restoration, management, and overall planning purposes, assessing and enhancing spawning and rearing habitat for river herring will help to drive conservation and restoration throughout their coastwide ranges (See *Section 5.4*). Defining the productivity of currently- and potentially-accessible (i.e., through barrier removal or provision of effective fish passage) spawning and rearing habitats will help to inform future management actions and priorities. Habitat degradation is another major factor contributing to the decline of these species (see *Section 4.3*).Efforts to restore these habitats and their associated functions are critical to the restoration of river herring populations. The following objectives and recommendations were developed in support of this goal.

### 8.2.1 *Objective 5: Pursue (non-barrier-related) habitat restoration opportunities.*

Barrier removal is critical to the success of river herring restoration (see *Section 4.1*). The habitat above existing or removed barriers needs to be of suitable condition to fulfill restoration goals. We recommend the following actions, where applicable, to support this objective:

a. Address water quality issues related to physical or chemical imbalances (see *Section 4.3*) such as those stemming from chemical or thermal pollution, excess sediment or nutrient inputs, or water withdrawal and competing water uses (e.g., irrigation, municipal water supply).
b. Establish or enhance flood plain (lateral) connectivity
c. Restore or improve vegetated riparian buffers
d. Remove historical fill impacting spawning and rearing habitat
e. Restore or improve function of fluvial wetlands and areas of submerged aquatic vegetation
f. Restore spawning areas impacted by erosion or sedimentation.

### 8.2.2 *Objective 6: Assess the quantity and quality of current and potential river herring spawning and rearing habitats at the watershed level.*

Assessing the quantity and quality of habitat for spawning and rearing, including potential habitats, will help guide restoration and management goals, and set expectations for the future (see *Section 5.4*). We recommend the following action to support this objective:

a. Quantify currently available river herring spawning and rearing habitats. Evaluate habitat use across a range of environmental conditions using consistent and comparable survey and assessment methods to allow for a description of common habitat suitability factors.

- Consider/evaluate applicability of reconnaissance methods like eDNA and/or other approaches that would be cost effective to regularly assess and describe habitat use across the range of spawning and rearing habitats.

b. Quantify potential river herring spawning and rearing habitats based on restored passage.
c. Determine the quality and relative ecological value of both current and potential spawning and rearing habitats[50] to inform/direct restoration efforts.
d. Model the potential population benefits associated with restored spawning and rearing habitats.

### 8.2.3 *Objective 7: Identify and mitigate effects of water intake facilities.*

Water intakes for agricultural, municipal, and industrial uses can have significant impacts on fish resources, including river herring (see *Section 4.3*). At a coastwide level, we recommend the following actions and criteria for water intake screens:

a. Avoiding known river herring spawning and rearing habitats should be a priority when siting proposed intake structures and requiring/enforcing water intake standards.
b. Where intakes are proposed, require justification and alternatives analysis, including the evaluation of alternatives that fully avoid the installation of intake structures in priority spawning and rearing habitats.
c. Monitor effectiveness of intake screen fish exclusion wherever possible.
d. Catalog unpermitted and legacy intake structures and quantify the potential impacts to river herring.
e. State and federal resource agencies should engage with the necessary entities[51] designated to implement the NPDES to ensure that the necessary standards are applied to new permits and existing permit holders as they are renewed.
f. In support of these actions, we recommend the following intake screen standards to avoid impingement/entrainment of river herring during early life stages:[52]

- Intakes should be fitted with a screen that has openings no larger than 1 millimeter (mm)
- Intake velocity should not exceed 0.25 ft. per second (fps)
- Orient screens parallel to river flow to take advantage of sweeping velocity
- Intakes should not withdraw more than 10% of instantaneous flow (90% flowby)[53]

---

[50] The criteria used to determine the suitability and relative ecological value of spawning and rearing habitats will vary based on the watershed.
[51] For Atlantic coast states within the range of river herring, EPA administers the NPDES program in New Hampshire, Massachusetts and the District of Columbia, this authority has been delegated to the states in all others.
[52] These standards are consistent with the standards described in Gowan et al. 2002 and VADWR 2021.
[53] This is to ensure continued access to necessary instream habitats by resident aquatic species.

### 8.2.4 *Objective 8: Identify and mitigate effects of coastal development projects.*

Coastal development projects such as dredging, filling, shoreline hardening, and similar activities have substantial consequences for short- and long-term habitat availability and quality (see *Section 4.3*). Some projects such as dredging and pile-driving may interrupt the seasonal migration or physically harm fish. Other projects, such as shoreline hardening, may result in long-term or permanent habitat loss. We recommend the following action to support this objective:

a. Require or recommend time-of-year restrictions[54] for in-water work such as dredging and pile-driving when warranted.
b. Encourage best management practices for construction projects with potential adverse effects to aquatic habitat and documented spawning/rearing habitats (e.g., environmental bucket dredge, turbidity curtain, cushion block, and bubble curtain, among others).
c. Use the state and federal permitting processes to support project designs that consider habitat requirements for river herring.

## 8.3 **Goal 3: Establish and strengthen partnerships among state and federal agencies, NGOs, tribes, and other river herring stakeholders.**

Single parties rarely complete successful restoration that meets broad-based goals. Successful projects often require a suite of components to align including: funding, planning, willing landowners, permits, engineering designs, and more (see *Appendix C*). Each phase of the habitat restoration process can benefit from, or require collaboration. Partnerships among state and federal agencies, NGOs, tribes, and other river herring stakeholders is often key to successful restoration. This goal is designed to bring the people, information, and skills together to promote successful, meaningful restoration. The following objectives were developed in support of this goal.

### 8.3.1 *Objective 9: Support, provide access to, and distribute existing planning documents produced by partners, including efforts administered by the ASMFC Shad and River Herring Technical Committee and Management Board.*

### 8.3.2 *Objective 10: Where possible, connect stakeholders with appropriate funding opportunities for restoration, partnerships, and public education and outreach.*

---

[54]TOY restrictions will vary based on the stressor under consideration, geographic location and river herring life stage in that particular locality.

#### 8.3.3 *Objective 11: Continue to develop and promote stakeholder engagement groups such as the Atlantic Coast River Herring Collaborative Forum to allow for communication, collaboration, and exchange of ideas.*

#### 8.3.4 *Objective 12: Support and maintain shared data resources and web tools (see Appendix Table A ).*

### 8.4 Goal 4: Address information gaps and research needs where applied research is needed to expand knowledge of river herring related topics.

Despite the significant monitoring and research surrounding river herring, data gaps remain regarding fish passage, life history, species interactions, and other factors. The focus of this goal is to support applied research to expand our knowledge of river herring and fill those information gaps (see *Section 5.0* for further detail). The following objectives and recommendations were developed in support of this goal.

#### 8.4.1 *Objective 13: Advocate for and distribute funding for applied research.*

Adequate, multi-year funding is necessary to support complex research projects that address questions relevant to river herring restoration and management. Due to the inter-annual variability that these species exhibit, several years of data collection may be necessary to answer critical questions regarding life history variation or population variability. We recommend the following actions to support this objective:

a. Identify funding opportunities that support river herring research and monitoring.
b. Work with partners and stakeholders to proactively develop grant proposals to address priority research projects or restoration efforts.
c. Expand funding opportunities in support of river herring research and habitat restoration.

#### 8.4.2 *Objective 14: Develop new models and/or improve existing modeling frameworks to predict the effects of climate change on river herring and their habitat.*

Climate change presents challenges (e.g. droughts, storm events, increasing water temperatures, and diminishing dissolved oxygen) for predicting population responses to management and restoration actions (see *Section 4.2*). Developing new models or improving existing models that incorporate the most current data (including climate projections) will assist with restoration planning and management. We recommend the following actions in support of this objective:

a. Incorporate the best available climate change projections with existing information about river herring habitat requirements (e.g., river hydrology, habitat suitability indices) to predict conditions suitable to sustain future river herring runs. Use these predictions to inform management.

b. Model the shifting predatory/prey distributions with climate change and its impact on river herring stocks.

### 8.4.3 *Objective 15: Monitor river herring populations, fisheries (including bycatch and stock origin), and stock status.*

Monitoring and evaluating populations over time with standardized techniques is essential to provide the data necessary to support effective management. Both seasonal and long-term datasets provide information on stock status, trends over time, and can help identify potential impacts or emerging issues. We recommend the following actions to support this objective:

a. Establish reliable run count and recruitment estimation approaches across the coastwide ranges to allow for direct comparisons between and among watersheds.
b. Establish restoration goals by maintaining a historical perspective on river herring populations and abundance by cataloging/archiving commercial catches, run counts, and historical reference conditions. Make these data widely available.

### 8.4.4 *Objective 16: Support research related to alternate life history strategies (i.e., juvenile overwintering in estuaries, hybridization, and semelparity) and population dynamics of river herring (see Section 2.0).*

### 8.4.5 *Objective 18: Support research into species interactions (see Sections 2.2, 4.6, and 6.3) with river herring (i.e., other fish species, invasive species, mammal and bird predation, zooplankton, mussels etc.).*

### 8.4.6 *Objective 19: Support research focused on the effectiveness of upstream and downstream passage, including alternative approaches to provide passage for both juvenile and adult life stages.*

### 8.4.7 *Objective 20: Support and encourage research on impingement and entrainment rates of various intake screen designs (e.g., angle of screen, sweeping velocities versus intake velocities).*

### 8.4.8 *Objective 21: Support research on the potential effects of construction activities on river herring (e.g., pile-driving, hydraulic and mechanical dredging, overboard material placement).*

## 9.0 Implementation of the HCP

This HCP will inform river herring habitat conservation and restoration activities of NOAA Fisheries, in collaboration with our many valuable partners and stakeholders, over the next decade and potentially longer. The actions and objectives detailed in Section 8.0 were developed collaboratively with our partners, and are designed to support the higher-level goals outlined herein. Through the HCP, we endeavor to increase public awareness, promote restoration and cooperative applied research, and inform efforts to address sources of mortality and improve both the quantity and quality of available spawning and rearing habitats for river herring.

Ultimately, by pursuing these goals, objectives, and actions, we seek to restore river herring throughout their native ranges to healthy, viable populations that support a broad array of social and ecological functions, with stocks that are no longer designated depleted by ASMFC. The realization of this overall goal would include enhancing the productivity of spawning and rearing habitats such that it is not a significant factor limiting recovery. Successful restoration of sustainable river herring populations will require a high degree of collaboration among state and federal resource agencies, NGOs, tribes, hydropower operators, commercial and recreational fishermen, municipalities, and an array of other stakeholders. Our intent is that this HCP constitutes a milestone towards realizing the ultimate goal of restoring river herring stocks coastwide, which will benefit the social-ecological system of the US Atlantic coast at large.

10.0 References


Able, K. W., and M. P. Fahay. 2010. Ecology of estuarine fishes: temperate waters of the western North Atlantic. The Johns Hopkins University Press, Baltimore, MD.

Able, K. W., J. P. Manderson, and A. L. Studholme. 1999. Habitat quality for shallow water fishes in an urban estuary: the effects of man-made structures on growth. Marine Ecology Progress Series 187: 227–235.

Able, K. W., T. M. Grothues, M. J. Shaw, S. M. VanMorter, M. C. Sullivan, and D. D. Ambrose. 2020. Alewife (*Alosa pseudoharengus*) spawning and nursery areas in a sentinel estuary: spatial and temporal patterns. Environmental Biology of Fishes 103: 1419–1436.

Agel, L. 2018. Dynamical analysis of extreme precipitation in the Northeast US. Ph.D. diss., 198 p. University of Massachusetts, Lowell.

Alcott, D., M. Long, and T. Castro-Santos. 2020. Wait and snap: eastern snapping turtles (*Chelydra serpentina*) prey on migratory fish at road-stream crossing culverts. Biology letters 16: 20200218.

Alcott, D., E. Goerig, and T. Castro-Santos. 2021a. Culverts delay upstream and downstream migrations of river herring (*Alosa* spp.). River Research and Applications 37: 1400–1412.

Alcott, D., E. Goerig, C. Rillahan, P. He, and T. Castro-Santos. 2021b. Tide gates form physical and ecological obstacles to river herring (*Alosa* spp.) spawning migrations. Canadian Journal of Fisheries and Aquatic Sciences 78: 869–880.

Alcott, D.J. 2020. Don't delay: the effects of tide gates and road-stream crossing culverts on river herring (*Alosa* spp.) spawning migrations. Ph.D. diss., 169 p. University of Massachusetts, Amherst.

Alexandrino, P., R. Faria, D. Linhares, F. Castro, M. Le Corre, R. Sabatié, J. Baglinière, and S. Weiss. 2006. Interspecific differentiation and intraspecific substructure in two closely related clupeids with extensive hybridization, *Alosa alosa* and *Alosa fallax*. Journal of Fish Biology 69: 242–259.

Alfonso, S., M. Gesto, and B. Sadoul. 2021. Temperature increase and its effects on fish stress physiology in the context of global warming. Journal of Fish Biology 98: 1496–1508.

Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics. 35: 257–284.

American Rivers. 2022. Edisto River: South Carolina's black beauty. [Available at https://www.americanrivers.org/river/edisto-river/, accessed October 2022.]

Ames, E. P. 2004. Atlantic cod stock structure in the Gulf of Maine. Fisheries 29: 10–28.

Ames, E. P., and J. Lichter. 2013. Gadids and alewives: structure within complexity in the Gulf of Maine. Fisheries Research 141: 70-78.

Anderies, J. M., M. A. Janssen, and E. Ostrom. 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society 9(1): 18 [Available at http://www.jstor.org/stable/26267655, accessed June 2022.]

APCC. 2022. State of the waters Cape Cod 2021 webmap. [Available at https://capecodwaters.org/, accessed May 2022].

APNEP. 2012. Comprehensive conservation and management plan 2012–2022. Albemarle-Pamlico National Estuary Partnership. [Available at https://apnep.nc.gov/resources/publications-and-reports/ccmp, accessed May 2022.]

Armstrong, W. H., M. J. Collins, and N. P. Snyder. 2014. Hydroclimatic flood trends in the northeastern United States and linkages with large-scale atmospheric circulation patterns. Hydrological Sciences Journal 59: 1636–1655.

Arter, B. 2004. Sheepscot River water quality monitoring strategic plan: a guide for coordinated water quality monitoring efforts in an Atlantic salmon watershed in Maine. Prepared for the Project SHARE: Research and Management Committee. 78 p.

ARWC. 2016. Volunteer river monitoring program: 2016 data report. Androscoggin River Watershed Council, Maine Department of Environmental Protection. 31p.

ASMFC. 1985. Fishery management plan for american shad and river herrings. Atlantic States Marine Fisheries Commission, Washington D.C.

ASMFC. 1999. Amendment I to the Interstate Fishery Management Plan for shad and river herring. Atlantic States Marine Fisheries Commission.

ASMFC. 2009. Amendment II to the Interstate Fishery Management Plan For shad and river herring. Atlantic States Marine Fisheries Commission.

ASMFC. 2010. Amendment III to the Interstate Fishery Management Plan for shad and river herring (american shad management). Atlantic States Marine Fisheries Commission.

ASMFC. 2012a. River herring benchmark stock assessment volume I. Stock Assessment Report No. 12–02, 392 p.

ASMFC. 2012b. River herring benchmark stock assessment volume II: Atlantic States Marine Fisheries Commission. Stock Assessment Report No. 12–02, 706 p

ASMFC. 2017a. River herring stock assessment update volume I: coastwide summary. Atlantic States Marine Fisheries Commission. 172p.

ASMFC. 2017b. River herring stock assessment update volume II: state-specific reports. Atlantic States Marine Fisheries Commission. 680p.

Baird, S. 1883. Bulletin of the United States Fish Commission – 1883. 84p.

Barber, B. L., A. J. Gibson, A.J. O'Malley, and J. Zydlewski. 2018. Does what goes up also come down? Using a recruitment model to balance alewife nutrient import and export. Marine and Coastal Fisheries 10: 236–254.

Barnthouse, L. W., R. Klauda, D. Vaughan, and R. Kendall. 1988. Science, law, and Hudson River power plants: a case study in environmental impact assessment.

Barton, A. D., A. J. Irwin, Z. V. Finkel, and C. A. Stock. 2016. Anthropogenic climate change drives shift and shuffle in North Atlantic phytoplankton communities. Proceedings of the National Academy of Sciences 113: 2964–2969.

Baum, J. K., and B. Worm. 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology 78: 699–714.

Beasley, C. A., and J. E. Hightower. 2000. Effects of a low-head dam on the distribution and characteristics of spawning habitat used by striped bass and American shad. Transactions of the American Fisheries society 129: 1316–1330.

Beaugrand, G., and F. Ibanez. 2004. Monitoring marine plankton ecosystems. II: long-term changes in North Sea calanoid copepods in relation to hydro-climatic variability. Marine Ecology Progress Series 284: 35–47.

Beaugrand, G., M. Edwards, V. Raybaud, E. Goberville, and R. R. Kirby. 2015. Future vulnerability of marine biodiversity compared with contemporary and past changes. Nature Climate Change 5: 695–701.

Belding, D. L. 1921. A report upon the alewife fisheries of Massachusetts. Wright & Potter Printing Co., Boston, MA. 56 p.

Berkes, F., and C. Folke. 1998. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, New York, NY.

Berry, F. H. 1964. Review and emendation of: family Clupeidae. Copeia. 1964(4): 720–730.
Bethoney, N. D., B. P. Schondelmeier, J. Kneebone, and W. S. Hoffman. 2017. Bridges to best management: effects of a voluntary bycatch avoidance program in a mid-water trawl fishery. Marine Policy 83: 172–178.
Beverley, R., and W. M. Elkins. 1705. The history and present state of virginia in four parts. R. Parker, ed. London.
Bi, R., Y. Jiao, L. A. Weaver, B. Greenlee, G. McClair, J. Kipp, K. Wilke, C. Haas, and E. Smith. 2021. Environmental and anthropogenic influences on spatiotemporal dynamics of *Alosa* in Chesapeake Bay tributaries. Ecosphere 12(6): e03544.
Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. No. 592. US Government Printing Office, Washington, D.C.
Bilkovic, D. M., M. Mitchell, P. Mason, K. and Duhring. 2016. The role of living shorelines as estuarine habitat conservation strategies. Coastal Management 44: 161–174.
Boger, R. A. 2002. Development of a watershed and stream-reach spawning habitat model for river herring *Alosa pseudoharengus* and *Alosa aestivalis*. The College of William and Mary. 214p.
Bolster, W. J. 2008. Putting the ocean in Atlantic history: maritime communities and marine ecology in the Northwest Atlantic, 1500–1800. The American Historical Review 113(1): 19–47.
Bourdon, R. 2021. American shad habitat plan for Maryland. American shad habitat plan for Maryland. Maryland Department of Natural Resources, Annapolis, MD. 31 p.
Bowden, A. A. 2014. Towards a comprehensive strategy to recover river herring on the Atlantic seaboard: lessons from Pacific salmon. ICES Journal of Marine Science 71: 666–671.
Boyce, W. S. 1917. Economic and social history of Chowan County, North Carolina, 1880–1915. No. 179–180. Columbia University Press, New York.
Bozek, C. 2014. Removing dams: benefits for people and nature. Solutions 5(6): 79–84.
Bradley, D., J. M. Nestler, and G. Allen. 2021. Exploring upstream and downstream fish passage improvements on the lower Saint Croix River. Prepared for the International St. Croix River Watershed Board and Workgroup. 131p.
Bridges, T. S., E. M. Bourne, B. C. Suedel, E. B. Moynihan, and J. K. King. 2021. Engineering with nature: an atlas, Volume 2. U.S. Army Engineer Research and Development Center, Vicksburg, MS. 321 p.
Brown, J. J., K. E. Limburg, J. R. Waldman, K. Stephenson, E. P. Glenn, F. Juanes, and A. Jordaan. 2013. Fish and hydropower on the US Atlantic coast: failed fisheries policies from half-way technologies. Conservation Letters 6: 280–286.
Brown, M. E., J. Maclaine, and L. Flagg. 2010. Androscoggin River anadromous fish restoration program. Final report. Department of Marine Resources Stock Enhancement Division. Augusta, ME. 94 p.
Brown, M. E., P. Christman, G. Wippelhauser, F. Brautigam, and J. Pellerin. 2017. Draft fisheries management plan for the Lower Androscoggin River, Little Androscoggin River and Sabattus River. Marine Resources Documents 42.
Bryan, C. F., and D. A. Rutherford. 1995. Impacts on warmwater streams: guidelines for evaluation. Southern Division of the American Fisheries Society, Warmwater Streams Committee. 295 p.

Burdick, S. M. 2005. Distribution of spawning activity by migratory fishes in the Neuse River, North Carolina, after removal of a low-head dam.. M.S. thesis.178p. North Carolina State University, Raleigh, NC.
Burke, J. S., and F. C. Rohde. 2015. Diadromous fish stocks of America's southeastern Atlantic coast. NOAA Technical Memorandum NOS NCCOS 198. Silver Spring, MD. 50 p.
Cashman, M. J., A. C. Gellis, E. Boyd, M. J. Collins, S. W. Anderson, B. D. McFarland, and A. M. Ryan. 2021. Channel response to a dam-removal sediment pulse captured at high-temporal resolution using routine gage data. Earth Surface Processes and Landforms 46: 1145–1159.
Castro-Santos, T. 2006. Modeling the effect of varying swim speeds on fish passage through velocity barriers. Transactions of the American Fisheries Society 135: 1230–1237.
Castro-Santos, T., and B. H. Letcher. 2010. Modeling migratory energetics of Connecticut River American shad (*Alosa sapidissima*): implications for the conservation of an iteroparous anadromous fish. Canadian Journal of Fisheries and Aquatic Sciences 67: 806–830.
Castro-Santos, T. and A. Haro. 2010. Fish guidance and passage at barriers. *In* Fish locomotion: and etho-ecological perspective (P. Domenici and B.G. Kapoor, eds.), p. 62–89. Science Publishers, Enfield, NH.
CBF. 2022a. Through restoration. [Available at https://www.cbf.org/how-we-save-the-bay/through-restoration/, accessed June 2022].
CBF. 2022b. Land use and pollution across the bay watershed. [Available at https://www.cbf.org/about-the-bay/land-use-and-pollution-across-the-bay-watershed.html#:~:text=Across%20the%20Chesapeake%20Bay%20watershed,the%20remaining%20land%20is%20forested, accessed June 2022].
CBP. 1989. Chesapeake Bay Alosid management plan. Chesapeake Bay Program, Annapolis, MD. 37 p.
CBP. 2015. Fish passage outcome management strategy 2015–2025, ver. 2. Chesapeake Bay Program, Annapolis, MD. 11p
CBP. 2022. Bay Program History. [Available at https://www.chesapeakebay.net/who/bay_program_history, accessed March 2022].
CCE. 2020. Hydrilla FAQ. [Available at http://ccetompkins.org/environment/aquatic-invasives/hydrilla/about-hydrilla/hydrilla-faq#:~:text=populations%20as%20well.-,Large%20infestations%20can%20cause%20oxygen%20depletion%20zones%20which%20can%20lead,toxic%20to%20animals%20and%20people, accessed May 2022].
Cecelski, D. 2021. The herring workers. [Available at https://davidcecelski.com/2021/02/24/the-herring-workers/, accessed July 2022.]
CFRP. 2013. Cape Fear River basin action plan for migratory fish. Cape Fear River Partnership. 80 p.
Cherkasskii, B. 1988. The system of the epidemic process. Journal of Hygiene, Epidemiology, Microbiology, and Immunology 32(3): 321–328.
Chesapeake Executive Council. 1987. Chesapeake Bay Agreement. Chesapeake Bay Program, Annapolis, MD. 7 p.
City of Fredericksburg. 1997. Historic resources along the Rappahannock and Rapidan rivers. [Available at https://www.fredericksburgva.gov/766/Historic-River-Resources, accessed March 2022.]

Clarke, G. A., T. Willis, A. Hoar, E. Bassett, and M. Abbott. 2022. Skutik watershed strategic sea-run fish and river restoration plan. Peskotomuhkati Nation at Skutik, St. Stephen, New Brunswick, Canada. 78p.

Cobb, C. K. 2020. The impact of climate change on the migration phenology of New England's anadromous river herring and American shad. Honors thesis, 42 p. Colby College, Waterville, ME.

Colding, J., and S. Barthel. 2019. Exploring the social-ecological systems discourse 20 years later. Ecology and Society 24(1).

Collette, B. B., and G. Klien-MacPhee. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine. Third ed. Smithsonian Institution Press, Washington, D.C.

Collins, M. J. 2009. Evidence for changing flood risk in New England since the late 20th century. Journal of the American Water Resources Association 45: 279–290.

Collins, M. J., N. P. Snyder, G. Boardman, W. S. Banks, M. Andrews, M. E. Baker, M. Conlon, A. Gellis, S. McClain, and A. Miller. 2017. Channel response to sediment release: insights from a paired analysis of dam removal. Earth Surface Processes and Landforms 42: 1636–1651.

Coutant, C. C. 1990. Temperature-oxygen habitat for freshwater and coastal striped bass in a changing climate. Transactions of the American Fisheries Society 119: 240–253.

Craig, N., S. E. Jones, B. C. Weidel, and C. T. Solomon. 2017. Life history constraints explain negative relationship between fish productivity and dissolved organic carbon in lakes. Ecology and Evolution 7: 6201–6209.

Crane, J. 2009. Setting the river free: The removal of the Edwards Dam and the restoration of the Kennebec River. Water History 1: 131–148.

Cranford, D. 2021. Where the water is shallow and the current is strong stone fish weirs of the eastern woodlands. NOAA Office of National Marine Sanctuaries. [Available at https://sanctuaries.noaa.gov/education/teachers/stone-fish-weirs-of-eastern-woodlands.html, accessed June 2022.]

CRASC. 2004. Management plan for river herring in the Connecticut River basin. Connecticut River Atlantic Salmon Commission. Sunderland, MA. 13 p.

CRASC. 2017. Connecticut River American shad management plan. Connecticut River Atlantic Salmon Commission. Sunderland, MA.

CRASC. 2020. Connecticut River American shad management plan: addendum on fish passage performance. Connecticut River Atlantic Salmon Commission. Sunderland, MA. 38 p.

CRC. 2022. Reconnecting habitat for fish. [Available at https://www.ctriver.org/our-work/reconnecting-habitat-for-fish/, accessed May 2022.]

Creaser, E. P., and H. C. Perkins. 1994. The distribution, food, and age of juvenile bluefish, *Pomatomus saltatrix*, in Maine. Fishery Bulletin 92: 494–508.

Crecco, V. A., and T. F. Savoy. 1985. Effects of biotic and abiotic factors on growth and relative survival of young American shad, *Alosa sapidissima*, in the Connecticut River. Canadian Journal of Fisheries and Aquatic Sciences 42: 1640–1648.

Crist, P. J., R. White, M. Chesnutt, C. Scott, R. Sutter, E. Linden, P. Cutter, and G. Dobson, 2019. Coastal resilience assessment of the Savannah River watershed. 157 p.

Crowder, L. B., G. Osherenko, O. R. Young, S. Airamé, E. A. Norse, N. Baron, J. C. Day, F. Douvere, C. N. Ehler, B. S. Halpern, S. J. Langdon, K. L. McLeod, J. C. Ogden, R. E. Peach, A. A. Rosenberg, and J. A. Wilson. 2006. Resolving mismatches in U.S. ocean governance. Science 313(5787): 617–618.

CRWA. 2003. Assessment of fish communities and habitat in the Charles River Watershed. Charles River Watershed Association, Waltham, MA. 30 p.
CRWA. 2021. The nature valley storage Area. [Available at https://www.crwa.org/restore.html , accessed May 2022.]
CTDEEP. 2009. The plan to restore diadromous fishes to the Shetucket River watershed. Department of Environmental Protection, Inland Fisheries Division. Hartford, CT. 47 p.
CTDEEP. 2020. 2020 Connecticut integrated water quality report (IWQR) factsheet. Connecticut Department of Energy and Environmental Protection. Hartford, CT. 4 p.
Dadswell, M. J., and R. A. Rulifson. 1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biological Journal of the Linnean Society 51(1–2): 93–113.
Dalton, C. M., D. Ellis, and D. M. Post. 2009. The impact of double-crested cormorant (*Phalacrocorax auritus*) predation on anadromous alewife (*Alosa pseudoharengus*) in south-central Connecticut, USA. Canadian Journal of Fisheries and Aquatic Sciences 66: 177–186.
Daniel, W. M., and M. E. Neilson. 2020. Native ranges of freshwater fishes of North America: U.S. Geological Survey data release. [Available at https://www.usgs.gov/data/native-ranges-freshwater-fishes-north-america, accessed June 2022]
Davis, J. P., E. T. Schultz, and J. Vokoun. 2009. Assessment of river herring and striped bass in the Connecticut River: abundance, population structure, and predator/prey interactions. University of Connecticut, EEB Articles. 26.
Davis, J. P., E. T. Schultz, and J. C. Vokoun. 2012. Striped bass consumption of blueback herring during vernal riverine migrations: does relaxing harvest restrictions on a predator help conserve a prey species of concern? Marine and Coastal Fisheries 4: 239–251.
De Robertis, A., R. Schabetsberger, C. Morgan, R. Emmet, and R. Brodeur. 2003. Do fish feed at fronts? Feeding ecology of juvenile salmon in frontal regions of the Columbia River plume.
Dennen, R. 2004a. A fighting chance. Free Lance Star. [Available at https://fredericksburg.com/local/a-fighting-chance/article_4deaed67-6fc1-5050-9f14-3991f370168b.html, March 2022.]
Dennen, R. 2004b. Inside Embrey. Free Lance Star. [Available at https://fredericksburg.com/local/inside-embrey/article_12455bd6-1028-548a-ad93-df460ca93115.html, accessed March 2022].
Dennen, R. 2014. River has run free for 10 years. Free Lance Star. [Available at https://fredericksburg.com/sports/outdoors/river-has-run-free-for-10-years/article_b7054cc4-7d37-54f4-90d3-2d21ef7756af.html, accessed March 2022].
DeSalvo, L., M. DeLucia, E. H. Martin, and D. H. Keller. 2022. Delaware River basin restoration roadmap for American shad, alewife, and blueback herring. The Nature Conservancy, Harrisbug, PA. 94 p.
Devine, S. M., A. T. O'Geen, H. Liu, Y. Jin, H. E. Dahlke, R. E. Larsen, and R. A. Dahlgren. 2020. Terrain attributes and forage productivity predict catchment-scale soil organic carbon stocks. Geoderma 368: 114286.
Dias, B. S., M. G. Frisk, and A. Jordaan. 2019. Opening the tap: increased riverine connectivity strengthens marine food web pathways. PloS one 14(5): 27.

Dias, B. S., M. G. Frisk, and A. Jordaan. 2021. Contrasting fishing effort reduction and habitat connectivity as management strategies to promote alewife (*Alosa pseudoharengus*) recovery using an ecosystem model. Limnology and Oceanography 67 (S1): S5 – S22.

Dill, R., J. Trial, E. Atkinson, J. Gibson, R. Jordan, S. Lary, R. Saunders, and P. Seymour. 2010. An adaptive plan for managing alewife in the St. Croix River watershed, Maine and New Brunswick.

DRBC. 2018. Delaware River and Bay water quality assessment. West Trenton, NJ. 80 p.

DRBC. 2022a. Reservoirs in the DRB. [Available at https://www.nj.gov/drbc/programs/flow/reservoirs.html , accessed June 2022.]

DRBC. 2022b. About DRBC. [Available at https://www.nj.gov/drbc/about/, accessed June 2022.]

DRBFWMC. 2011. Delaware River sustainable fishing plan for American shad. The Delaware River Basin Fish and Wildlife Management Cooperative. 67 p.

Dugan, J., L. Airoldi, M. Chapman, S. Walker, T. Schlacher, E. Wolanski, and D. McLusky. 2011. Estuarine and coastal structures: environmental effects, a focus on shore and nearshore structures. *In* Treatise on estuarine and coastal science. E. Wolanski and D. McLusky, eds. p. 17–41. Academic Press, Waltham, MA.

Dunn, M., E. Nardone, J. Turner, and B. Young. 2020. Long Island diadromous fish restoration strategy. Seatuck Environmental Association, Islip, NY. 18 p.

Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effects of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. Ecology 60(1): 8–17.

Eads, C. B., J. E. Price, and J. F. Levine. 2015. Fish hosts of four freshwater mussel species in the Broad River, South Carolina. Southeastern Naturalist 14(1):85–97.

Eakin, W. W., R. D. Adams, G. H. Kenney, and C. Hoffman. 2016. Sustainable fishery management plan for New York river herring stocks. 72 p.

Eakin, W. W., G. Kenny, and E. Streifeneder. 2023. Recovery plan for Hudson River American shad. New York State Department of Environmental Conservation, Division of Marine Resources. 47 p.

Edsall, T. A. 1964. Feeding by three species of fishes on the eggs of spawning alewives. Copeia 1964(1): 226–227.

EEP. 2009. Cape Fear River basin restoration priorities. Ecosystem Enhancement Program. 79 p.

EEP. 2010. Neuse River basin restoration priorities. Ecosystem Enhancement Program. 99 p.

Ellis, D., and J. C. Vokoun. 2009. Earlier spring warming of coastal streams and implications for alewife migration timing. North American Journal of Fisheries Management 29: 1584–1589.

Erkan, D. E. 2002. Strategic plan for the restoration of anadromous fishes to Rhode Island coastal streams. Rhode Island Department of Environmental Management, Division of Fish and Wildlife, Wakefield, RI. 81 p.

Faria, R., S. Weiss, and P. Alexandrino. 2006. A molecular phylogenetic perspective on the evolutionary history of *Alosa* spp. (Clupeidae). Molecular Phylogenetics and Evolution 40: 298–304.

Farr, E. R., M. R. Johnson, M. W. Nelson, J. A. Hare, W. E. Morrison, M. D. Lettrich, B. Vogt, C. Meaney, U. A. Howson, P. J. Auster, F. A. Borsuk, D. C. Brady, M. J. Cashman, P. Colarusso, J. H. Grabowski, J. P. Hawkes, R. Mercaldo-Allen, D. B. Packer, and D. K. Stevenson,. 2021. An assessment of marine, estuarine, and riverine habitat vulnerability to climate change in the Northeast U.S. PLoS One 16(12): e0260654.

Fausch, K. D. 2008. A paradox of trout invasions in North America. Biological Invasions 10: 685–701.

Fay, C. W., R. J. Neves, and G. B. Pardue. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic): Alewife/blueback/herring. USFWS Tech. Rep. 82–11.9. 25 p.

FFWCC. 2020. ASMFC alternative management plan for shad and river herring in Florida. Florida Fish and Wildlife Conservation Commission.

Flagg, L. N. 2007. Historical and current distribution and abundance of the anadromous alewife (*Alosa pseudoharengus*) in the St Croix River. State of Maine Atlantic Salmon Commission. Augusta, ME. 53 p.

Flecker, A. S., P. B. McIntyre, J. W. Moore, J. T. Anderson, B. W. Taylor, and R. O. Hall, Jr. 2010. Migratory fishes as material and process subsidies in riverine ecosystems. *In* Community ecology of stream fishes: concepts, approaches, and techniques, symposium 73 (K. B. Gido and D. A. Jackson, eds.) p. 559–592. American Fisheries Society, Bethesda, MD.

Franke, G. F., D. R. Webb, R. K. Fisher, Jr., D. Mathur, P. N. Hopping, P. A. March, M. R. Headrick, I. T. Laczo, Y. Ventikos, and F. Sotiropoulos. 1997. Development of environmentally advanced hydropower turbine system design concepts. Lockheed Martin Idaho Technologies Co., Rep. No. 2677–0141 Idaho Falls, ID. 456 p.

Frankensteen, E. D. 1976. Genus *Alosa* in a channelized and an unchannelized creek of the Tar River basin, North Carolina. M.A. Thesis. 123 p. East Carolina University, Greenville, NC.

Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11(2): 631–631.

Freeman, M. C., C. M. Pringle, E. A. Greathouse, and B. J. Freeman. 2003. Ecosystem-level consequences of migratory faunal depletion caused by dams. *In* Biodiversity, status, and conservation of the world's shads, symposium 35 (K. E. Lumburg and J. R. Waldman, eds.), p. 255–266. American Fisheries Society, Bethesda, MD..

Friedland, K. D., J. Kane, J. A. Hare, R. G. Lough, P. S. Fratantoni, M. J. Fogarty, and J. A. Nye. 2013. Thermal habitat constraints on zooplankton species associated with Atlantic cod (*Gadus morhua*) on the U.S. northeast continental shelf. Progress in Oceanography 116: 1–13.

Friedland, K. D., R. E. Morse, J. P. Manning, D. C. Melrose, T. Miles, A. G. Goode, D. C. Brady, J. T. Kohut, and E. N. Powell. 2020. Trends and change points in surface and bottom thermal environments of the U.S. northeast continental shelf ecosystem. Fisheries Oceanography 29: 396–414.

Friends of the Rappahannock. 2022. Restoration. [Available at https://riverfriends.org/restoration/, accessed June 2022.]

Fulton, T. W. 1904. The rate of growth of fishes. *In* 22nd Annual Report of the Fisheries Board of Scotland. p. 141–241.

Gahagan, B. I., K. E. Gherard, and E. T. Schultz. 2010. Environmental and endogenous factors influencing emigration in juvenile anadromous alewives. Transactions of the American Fisheries Society 139: 1069–1082.

Gahagan, B. I., J. C. Vokoun, G. W. Whitledge, and E. T. Schultz. 2012. Evaluation of otolith microchemistry for identifying natal origin of anadromous river herring in Connecticut. Marine and Coastal Fisheries 4: 358–372.
Garman, G., S. McIninch, and D. Hopler. 2014. Rocky Pen Run Reservoir fisheries entrainment monitoring plan, year 1 (2014) findings. Report submitted to ARCADIS U.S., Inc. VWP Permit No. 99–2064.
Garman, G., S. McIninch, and D. Hopler. 2015. Rocky Pen Run fisheries entrainment monitoring plan, year 2 (2015) findings. Report submitted to ARCADIS U.S., Inc. VWP Permit No. 99–2064.
Garman, G., S. McIninch, and D. Hopler. 2016. Rocky Pen Run Reservoir fisheries entrainment monitoring plan, Year 3 (2016) findings. Report submitted to ARCADIS U.S., Inc. VWP Permit No. 99–2064.
Garman, G. C. 1992. Fate and potential significance of postspawning anadromous fish carcasses in an Atlantic coastal river. Transactions of the American Fisheries Society 121(3): 390–394.
GDNR. 2001. Ogeechee River basin management plan. Georgia Department of Natural Resources, Environmental Protection Division. 218 p.
GDNR. 2020. ASMFC alternative management plan for river herring for Georgia. Georgia Department of Natural Resources, Wildlife Resources Division. 6 p.
GDNR. 2022. Aquatic nuisance species in Georgia. [Available at https://georgiawildlife.com/ans, accessed July 2022.]
GDNR and SCDNR. 2020. American shad habitat plan for the Savannah River. GA Department of Natural Resources and SC Department of Natural Resources. 13 p.
Gibson, A. J. F., S. J. Fulton, and D. Harper. 2019. Fish mortality and its population-level impacts at the Annapolis Tidal Hydroelectric Generating Station, Annapolis Royal, Nova Scotia: a review of existing scientific literature. DFO Canada Science Advisory Report 2019/055, 26 p.
Gibson, M. R. 1987. Disparities between observed and expected stock dynamics in American shad exposed to dredge operations. Rhode Island Division of Fish and Wildlife, Research reference document 87/6. West Kingston, RI.
Gilligan-Lunda, E. K., D. S. Stich, K. E. Mills, M. M. Bailey, and J. D. Zydlewski. 2021. Climate change may cause shifts in growth and instantaneous natural mortality of American shad throughout their native range. Transactions of the American Fisheries Society 150: 407–421.
Gittman, R. K., F. J. Fodrie, A. M. Popowich, D. A. Keller, J. F. Bruno, C. A. Currin, C. H. Peterson, and M. F. Piehler. 2015. Engineering away our natural defenses: an analysis of shoreline hardening in the US. Frontiers in Ecology and the Environment 13: 301–307.
Goodby, R. G., S. Tremblay, and E. Bouras. 2014. The Swanzey Fish Dam: A large, precontact Native American stone structure in southwestern New Hampshire. Northeast Anthropology 81/82: 1–22.
Gowan, C., G. Garman, and V. Richmond. Design criteria for fish screens in Virginia: recommendations based on a review of the literature. 2002. *In* Proceedings of the Virginia water research symposium: drinking water supplies assessment and management strategies for the 21st century; Richmond, 6–7, November ( ed.), p 127–134. Virginia Water Resource Research Center,  Richmond, VA.

Greene, K. E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9. 464 p.

GRN. 2018. Ogeechee River. [Available at https://garivers.org/ogeechee-river/, accessed June 2022.]

Groux, F., J. Therrien, M. Chanseau, D. Courret, and S. Tetard. 2015. Knowledge update on shad upstream migration fishway design and efficiency. Conservation and Restoration of the Allis Shad in the Gironde and Rhine watersheds – Action A1. Report from WSP to ONEMA. Ref. LIFE09 NAT/DE/000008. 81 p.

Guo, L. W., S. D. McCormick, E. T. Schultz, and A. Jordaan. 2021. Direct and size-mediated effects of temperature and ration-dependent growth rates on energy reserves in juvenile anadromous alewives (*Alosa pseudoharengus*). Journal of Fish Biology 99: 1236–1246.

GWP. 2017. Altamaha regional water plan. [Available at https://waterplanning.georgia.gov/altamaha-regional-water-plan, accessed June 2022.]

Hall, C. 2011. Damming of Maine watersheds and the consequences for coastal ecosystems with a focus on the anadromous river herring (*Alosa pseudoharengus* and *Alosa aestivalis*): a four century analysis. M.S. Thesis, 159 p. Stony Brook University, Stony Brook, NY.

Hall, C. J., A. Jordaan, and M. G. Frisk. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology 26: 95–107.

Hall, C. J., A. Jordaan, and M. G. Frisk. 2012. Centuries of anadromous forage fish loss: consequences for ecosystem connectivity and productivity. BioScience 62: 723–731.

Hanson, S. D., and R. A. Curry. 2005. Effects of size structure on trophic interactions between age-0 smallmouth bass and juvenile anadromous alewives. Transactions of the American Fisheries Society 134: 356–368.

Harbold, W. A., K. Hodgson, M. Genovese, and J. Sivalia. 2021. Initial effects of Bloede Dam removal on anadromous fish, benthic macroinvertebrate assemblages, and American eels in the Patapsco River Maryland. Maryland Department of Natural Resources, Annapolis, MD. 53 p.

Hare, J. A., W. E. Morrison, M. W. Nelson, M. M. Stachura, E. J. Teeters, R. B. Griffis, M. A. Alexander, J. D. Scott, L. Alade, R. J. Bell, A. S. Chute, K. L. Curti, T. H. Curtis, D. Kircheis, J. F. Kocik, S. M. Lucey, C. T. McCandless, L. M. Milke, D. E. Richardson, E. Robillard, H. J. Walsh, M. C. McManus, K. E. Marancik, and C. A. Griswold. 2016. A vulnerability assessment of fish and invertebrates to climate change on the Northeast US Continental Shelf. PloS one 11(2): e0146756.

Hare, J. A., D. L. Borggaard, M. A. Alexander, M. M. Bailey, A. A. Bowden, K. Damon-Randall, J. T. Didden, D. J. Hasselman, T. Kerns, R. McCrary, S. McDermott, J. A. Nye, J. Pierce, E. T. Schultz, J. D. Scott, C. Starks, K. Sullivan, and M. Beth Tooley. 2021. A review of river herring science in support of species conservation and ecosystem restoration. Marine and Coastal Fisheries 13: 627–664.

Haro, A. 2020. Passage performance of alewife and American shad in the Pawcatuck River, Rhode Island. Memorandum prepared for the U.S. Fish and Wildlife Service, Coastal and Partners Program, Charlestown, Rhode Island. 31 p.

Hartwell, A. D. 1970. Hydrography and holocene sedimantation of the Merrimack River estuary, Massachusetts. University of Massachusetts Contribution No. 5–CRG. 166 p.

Hasselman, D. J., E. E. Argo, M. C. McBride, P. Bentzen, T. F. Schultz, A. A. Perez-Umphrey, and E. P. Palkovacs. 2014. Human disturbance causes the formation of a hybrid swarm between two naturally sympatric fish species. Molecular Ecology 23: 1137–1152.

Hasselman, D. J., E. C. Anderson, E. E. Argo, N. D. Bethoney, S. R. Gephard, D. M. Post, B. P. Schondelmeier, T. F. Schultz, T. V. Willis, and E. P. Palkovacs. 2016. Genetic stock composition of marine bycatch reveals disproportional impacts on depleted river herring genetic stocks. Canadian Journal of Fisheries and Aquatic Sciences 73: 951–963.

Hastings, M. C., and A. N. Popper. 2005. Effects of sound on fish. California Department of Transportation, Sacramento, CA. 82 p.

Havey, K. A. 1973. Production of juvenile alewives, *Alosa pseudoharengus*, at Love Lake, Washington County, Maine. Transactions of the American Fisheries Society **102**(2): 434–437.

Heath Jr, C. L. 1997. A cultural history of river herring and shad fisheries in eastern North Carolina: the prehistoric period through the twentieth century. M.A. thesis, 252 p. Eastern Carolina University, Greenville, NC.

Heimbuch, D. G. 2008. Potential effects of striped bass predation on juvenile fish in the Hudson River. Transactions of the American Fisheries Society 137: 1591–1605.

Hildebrand, S. F., and W. C. Schroeder. 1928. Fishes of Chesapeake Bay. Bulletin of the U.S. Bureau of Fisheries 43(1): 1–366.

Hilke, C., J. Ritter, J. Ryan-Henry, E. Powell, A. Fuller, B. Stein, and B. Watson. 2020. Softening our shorelines: policy and practice for living shorelines along the Gulf and Atlantic coasts. National Wildlife Federation, Washington, DC. 67 p.

Hitt, N. P., S. Eyler, and J. E. Wofford. 2012. Dam removal increases American eel abundance in distant headwater streams. Transactions of the American Fisheries Society 141: 1171–1179.

Hoffman, K. 2007. The Maine legislature's bill: an act to stop the alewives restoration program in the St. Croix River - have the canadians and the biologists gone berserk. Ocean and Coastal Law Journal 13: 309–337.

Holbrook, C. M., M. T. Kinnison, and J. Zydlewski. 2011. Survival of migrating Atlantic salmon smolts through the Penobscot River, Maine: a prerestoration assessment. Transactions of the American Fisheries Society 140: 1255–1268.

HREP. 2020. The State of the Hudson 2020: Environmental heath and trends of the hudson river estuary. New York. 97 p.

HRF. 2022. Hudson-Raritan Estuary restoration activity map. [Available at https://www.hudsonriver.org/article/restoration-activity-map, accessed May 2022.]

IPCC. 2021. Climate change 2021: The physical science basis. Contribution of Working Group I to the sixth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, England.

ISCRWB. 2022. International St. Croix River Watershed Board. [Available at https://www.ijc.org/en/scrwb, accessed April 2022.]

Isel, M., and J. Odenkirk. Evaluation of northern snakehead diets in Virginia's tidal rivers and lakes. 2019. *In* Proceedings of the first international snakehead symposium, symposium 89 (J. S. Odenkirk and D. C. Chapman, eds) p. 83–93. American Fisheries Society, Bethesda, MD.

Jenkins, R. E., and N. M. Burkhead. 1993. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, MD.

Jones, A. W., C. M. Dalton, E. S. Stowe, and D. M. Post. 2010. Contribution of declining anadromous fishes to the reproductive investment of a common piscivorous seabird, the double-crested cormorant (*Phalacrocorax auritus*). The Auk 127: 696–703.

Jones, A. W., K. A. Burchard, A. M. Mercer, J. J. Hoey, M. D. Morin, G. L. Gianesin, J. A. Wilson, C. R. Alexander, B. A. Lowman, and D. G. Duarte. 2022. Learning from the study fleet: maintenance of a large-scale reference fleet for Northeast U.S. fisheries. Frontiers in Marine Science 9:869560.

Jones, P., F. Martin, and J. Hardy, Jr. 1978. Development of fish of the Mid-Atlantic Bight. an atlas of egg, larval and juvenile stages, vol. I. Acipenseridae through Ictaluridae. U.S. Fish and Wildlife Service, FWS/OBS-78/12. Washington, DC. 366 p.

JRA. 2022. Watershed restoration. [Available at https://thejamesriver.org/programs/watershed-restoration/, accessed June 2022.]

Juanes, F., R. E. Marks, K. A. McKown, and D. O. Conover. 1993. Predation by age-0 bluefish on age-0 anadromous fishes in the Hudson River estuary. Transactions of the American Fisheries Society 122(3): 348–356.

Kaushal, S. S., G. E. Likens, M. L. Pace, R. M. Utz, S. Haq, J. Gorman, and M. Grese. 2018. Freshwater salinization syndrome on a continental scale. Proceedings of the National Academy of Sciences 115(4): E574–E583.

Kircheis, F. W., J. G. Trial, D. P. Boucher, B. Mower, T. Squiers, N. Gray, M. O'Donnell, and J. S. Stahlnecker. 2004. Analysis of impacts related to the introduction of anadromous alewife into a small freshwater lake in central Maine, USA. State of Maine Interagency Report Series 02–1. Augusta, ME. 53 p.

Kissil, G. W. 1974. Spawning of the anadromous alewife, *Alosa pseudoharengus*, in Bride Lake, Connecticut. Transactions of the American Fisheries Society 103(2): 312–317.

Kitchell, J. F., D. J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum vitreum*). Journal of the Fisheries Board of Canada **34**(10): 1922–1935.

Klauda, R., S. Fischer, L. Hall, Jr., and J. Sullivan. 1991. American shad and hickory shad. *In* Habitat requirements for Chesapeake Bay living resources, 2nd edition. (S. L. Funderburk, J. A. Mihursky, S. J. Jordan, and D. Riley, eds.), p. 9.1–9.27. Chesapeake Bay Program, Annapolis, MD.

Kocovsky, P. M., R. M. Ross, and D. S. Dropkin. 2009. Prioritizing removal of dams for passage of diadromous fishes on a major river system. River Research and Applications **25**(2): 107–117.

Kornis, M. S., D. Breitburg, R. Balouskus, D. M. Bilkovic, L. A. Davias, S. Giordano, K. Heggie, A. H. Hines, J. M. Jacobs, and T. E. Jordan. 2017. Linking the abundance of estuarine fish and crustaceans in nearshore waters to shoreline hardening and land cover. Estuaries and Coasts 40(5): 1464–1486.

Kosa, J. T., and M. E. Mather. 2001. Processes contributing to variability in regional patterns of juvenile river herring abundance across small coastal systems. Transactions of the American Fisheries Society 130(4): 600–619.

Kritzer, J. P., C. J. Hall, B. Hoppe, C. Ogden, and J. M. Cournane. 2022. Managing small fish at large scales: the emergence of regional policies for river herring in the Eastern United States. Fisheries 47(10): 435–445.

Kritzer, J. P., M. DeLucia, E. Greene, C. Shumway, M. F. Topolski, J. Thomas-Blate, L. A. Chiarella, K. B. Davy, and K. Smith. 2016. The importance of benthic habitats for coastal fisheries. BioScience 66(4): 274–284.

Kunkel, K. E., T. R. Karl, H. Brooks, J. Kossin, J. H. Lawrimore, D. Arndt, L. Bosart, D. Changnon, S. L. Cutter, and N. Doesken. 2013. Monitoring and understanding trends in extreme storms: state of knowledge. Bulletin of the American Meteorological Society 94(4): 499–514.

Lacoursière-Roussel, A., G. Côté, V. Leclerc, and L. Bernatchez. 2016. Quantifying relative fish abundance with eDNA: a promising tool for fisheries management. Journal of Applied Ecology 53: 1148–1157.

Lampman, G., N. Caraco, and J. Cole. 1999. Spatial and temporal patterns of nutrient concentration and export in the tidal Hudson River. Estuaries 22(2): 285–296.

Landsman, S., and M. van den Heuvel. 2017. Fish passage requirements for rainbow smelt (*Osmerus mordax*) and gaspereau (alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis*) at fishways and culverts: current knowledge, research gaps, and recommendations. Canadian Technical Report of Fisheries and Aquatic Sciences 3210. 29 p.

Leach, L., M. Simpson, J. R. Stevens, and K. Cammen. 2022. Examining the impacts of pinnipeds on Atlantic salmon: The effects of river restoration on predator–prey interactions. Aquatic Conservation: Marine and Freshwater Ecosystems 32: 645–657.

Leim, A. H., and W. Scott. 1966. Fishes of the Atlantic coast of Canada. Bulletin of the Fisheries Research Board of Canada 155: 1–485.

Limburg, K. E. 1996. Modelling the ecological constraints on growth and movement of juvenile American shad (*Alosa sapidissima*) in the Hudson River estuary. Estuaries 19: 794–813.

Limburg, K. E. 1998. Anomalous migrations of anadromous herrings revealed with natural chemical tracers. Canadian Journal of Fisheries and Aquatic Sciences 55: 431–437.

Limburg, K. E., and R. E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban gradient? Ecology 71: 1238–1245.

Limburg, K. E., and Waldman, J. R. 2009. Dramatic declines in North Atlantic diadromous fishes. BioScience 59: 955–965.

Limburg, K. E., K. A. Hattala, and A. Kahnle. American shad in its native range. *In* Biodiversity, status, and conservation of the world's shads, symposium 35 (K. E. Lumburg and J. R. Waldman, eds.), p. 125–140. American Fisheries Society, Bethesda, MD..

Littrell, K. A., D. Ellis, S. R. Gephard, A. D. MacDonald, E. P. Palkovacs, K. Scranton, and D. M. Post. 2018. Evaluating the potential for prezygotic isolation and hybridization between landlocked and anadromous alewife (*Alosa pseudoharengus*) following secondary contact. Evolutionary Applications 11: 1554–1566.

Ljunggren, L., A. and Sandström. 2007. Influence of visual conditions on foraging and growth of juvenile fishes with dissimilar sensory physiology. Journal of Fish Biology 70: 1319–1334.

Loesch, J. 1969. A study of the blueback herring, *Alosa aestivalis* (Mitchill), in Connecticut waters. Ph.D. diss. 78 p. University of Connecticut, Storrs, CT.

Loesch, J. G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. *In* Common strategies of anadromous and catadromous fishes, Symposium 1. (M. J. Dadswell, R. J. Klauda, C. M. Moffitt, and R. L. Saunders, eds.) p. 89–103. American Fisheries Society, Bethesda, MD.

Loesch, J. G., and W. A. Lund. 1977. A contribution to the life history of the blueback herring, *Alosa aestivalis*. Transactions of the American Fisheries Society 106(6): 583–589.

Lombardo, S.M., J. A. Buckel, E. F. Hain, E. H. Griffith, and H. White. 2020. Evidence for temperature-dependent shifts in spawning times of anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). Canadian Journal of Fisheries and Aquatic Sciences **77**: 741–751.

Lutins, A. 1992. Prehistoric fishweirs in Eastern North America. M.A. Thesis. 36 p. State University of New York, Binghamton, NY.

Lutins, A., and A. P. DeCondo. 1999. The Fair Lawn-Paterson fish weir. Bulletin of the Archaeological Society of New Jersey 54. [Available at https://www.lutins.org/weir/index.html, accessed October 2022].

Lynch, P. D., J. A. Nye, J. A. Hare, C. A. Stock, M. A. Alexander, J. D. Scott, K. L. Curti, and K. Drew. 2015. Projected ocean warming creates a conservation challenge for river herring populations. ICES Journal of Marine Science 72: 374–387.

Maine State Planning Office. 1993. Kennebec River resource management plan. State Planning Office, Augusta, ME. 78 p.

Magnuson, J. J., L .B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19(1): 331–343.

Makarewicz, J. C. 2000. Trophic interactions: changes in phytoplankton community structure coinciding with alewife introduction (*Alosa pseudoharengus*). Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen 27(4): 1780–1783.

Malmqvist, B., and S. Rundle. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29(2): 134–153.

Mann, D. A., D. M. Higgs, W. N. Tavolga, M. J. Souza, and A. N. Popper. 2001. Ultrasound detection by clupeiform fishes. The Journal of the Acoustical Society of America 109(6): 3048–3054.

Mansueti, R. J. 1956. Alewife herring eggs and larvae reared successfully in lab. Maryland Tidewater News **13**(1): 2–3.

Mansueti, R. J., and J. D. Hardy. 1967. Development of fishes of the Chesapeake Bay region: an atlas of egg, larval, and juvenile stages, part I. Natural Resources Institute, University of Maryland, Baltimore, MD.

Marcy, B.C., Jr. 1972. Spawning of the American shad, *Alosa sapidissima* in the lower Connecticut River. Chesapeake Science 13(2): 116–119.

Marcy, B. C. Jr. 1976a. Planktonic fish eggs and larvae of the lower Connecticut River and the effects of the Connecticut Yankee plant including entrainment. *In* The Connecticut River ecological study: the impact of a nuclear power plant, Monograph No. 1 (D. Merriman, and L. M. Thorper, eds), p. 115–139. American Fisheries Society, Bethesda, MD.

Marcy, B.C., Jr. 1976b. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. *In* The Connecticut River ecological study: the impact of a nuclear power plant, Monograph No. 1 (D. Merriman, and L. M. Thorper, eds), p. 141–168. American Fisheries Society, Bethesda, MD.

Marcy Jr, B. C., P. M. Jacobson, and R. L. Nankee. 1972. Observations on the reactions of young American shad to a heated effluent. Transactions of the American Fisheries Society 101(4): 740–743.

Marcy Jr., B. C. 1969. Age determinations from scales of *Alosa pseudoharengus* (Wilson) and *Alosa aestivalis* (Mitchill) in Connecticut Waters. Transactions of the American Fisheries Society 98(4): 622–630.

Marjadi, M. N., A. H. Roy, A. Jordaan, B. I. Gahagan, M. P. Armstrong, and A. R. Whiteley. 2019. Larger body size and earlier run timing increase alewife reproductive success in a whole lake experiment. Canadian Journal of Fisheries and Aquatic Sciences 76: 1134–1146.

Markham, A. C., and B. D. Watts. 2008. The influence of salinity on the diet of nesting bald eagles. Journal of Raptor Research **42**(2): 99–109.

Marshall, E., and T. Randhir. 2008. Effect of climate change on watershed system: a regional analysis. Climatic Change 89(3): 263–280.

Martin, E. H. and C. D. Apse. 2013. Chesapeake fish passage prioritization: an assessment of dams in the Chesapeake Bay watershed. The Nature Conservancy. 114p

Martin, E.H., and J. Levine. 2017. Northeast Aquatic Connectivity Assessment Project - Version 2.0: Assessing the ecological impact of barriers on Northeastern rivers. The Nature Conservancy, Brunswick, ME. 121 p.

Mattocks, S., C. J. Hall, and A. Jordaan. 2017. Damming, lost connectivity, and the historical role of anadromous fish in freshwater ecosystem dynamics. BioScience 67(8): 713–728.

Mattocks, S., B. Keleher, and K. Sprankle. 2018. Juvenile American shad assessment in the Connecticut River from Holyoke Dam to Bellows Falls Dam, 2017–2018. U.S. Fish and Wildlife Service, Sunderland, MA.

McBride, M. C., T. V. Willis, R. G. Bradford, and P. Bentzen. 2014. Genetic diversity and structure of two hybridizing anadromous fishes (*Alosa pseudoharengus*, *Alosa aestivalis*) across the northern portion of their ranges. Conservation Genetics 15(6): 1281–1298.

McClenachan, L., S. Lovell, and C. Keaveney. 2015. Social benefits of restoring historical ecosystems and fisheries: alewives in Maine. Ecology and Society 20(2): 31.

McDermott, S., N. C. Bransome, S. E. Sutton, B. E. Smith, J. S. Link, and T. J. Miller. 2015. Quantifying alosine prey in the diets of marine piscivores in the Gulf of Maine. Journal of Fisheris Biology 86: 1811–1829.

McHenry, J., H. Welch, S. E. Lester, and V. Saba. 2019. Projecting marine species range shifts from only temperature can mask climate vulnerability. Global Change Biology 25: 4208–4221.

McIninch, S., and G. Garman. 1999. The anadromous clupeid fishes of the Chesapeake Bay: an evaluation of essential habitat and barriers to migration in the Rappahannock River basin. Final Project Report to Virginia Department of Game & Inland Fisheries, Richmond, VA.

McLean, J., L. Sewall, and L. Pugh. 2007. Sheepscot River watershed management plan. Time and Tide Resource Conservation and Development Area, Augusta, ME. 98 p [Available at http://www.kcswcd.org/Projects/Sheepscot/WHOLE%20PLAN%20Jan26.07.pdf, accessed July 2022]

MDEP. 2003. Connecticut River watershed 2003 water quality assessment report. Massachusetts Department of Environmental Protection, Division of Watershed Managment. Rep. No. 34-AC-2. 136 p.

MDEP. 2006. Charles River watershed 2002–2006 water quality assesmment report. Massachusetts Department of Environmental Protection, Division of Watershed Management. Rep. No. 72-AC-4. 210p.

MDEP. 2007. Blackstone River watershed 2003–2007 water quality assesmment report. Massachusetts Department of Environmental Protection, Division of Watershed Managment. Rep. No. 51-AC-3.
MDMF. 2022. Massachusetts river herring sustainable fishery management plan. Massachusetts Division of Marine Fisheries. Boston, MA. 33 p.
MDMR. 2000. Kennebec River diadromous fish restoration annual progress report – 1999. Maine Department of Marine Resources, Augusta, ME.
MDMR. 2015. Kennebec River anadromous fish restoration annual progress report – 2013. Maine Department of Marine Resources, Augusta, ME.
MDMR. 2016. Maine river herring fact sheet. [Available at https://www.maine.gov/dmr/science-research/searun/alewife.html, accessed August 2020.]
MDMR. 2020a. Kennebec River management plan, diadromous resources amendment. Maine Deaprtment of Marine Resources, Augusta, ME. 62 p.
MDMR. 2020b. Maine herring sustainable fishing plan update. Maine Department of Marine Resources, Augusta, ME. 16 p.
MDMR and MDIFW. 2008. Strategic plan for the restoration of diadromous fishes to the Penobscot River. 354 p.
MDNR. 2021. American shad habitat plan for Maryland. Maryland Department of Natural Resources, Annapolis, MD. 31 p.
MDNR. 2022. Fish Passage Projects. [Available at https://dnr.maryland.gov/fisheries/pages/fishpassage/projects.aspx, accessed June 2022.]
Messieh, S. N. 1977. Population structure and biology of alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) in the Saint John River, New Brunswick. Environmental Biology of Fishes 2(3): 195–210.
Michelson, R. 2021. Recognition of migratory fish's value predates colonization. [Available at https://coastalreview.org/2021/11/recognition-of-migratory-fishs-value-predates-colonization/, accessed November 2022].
Micks, W. 2016. Life along the rappahannock: an oral history project. Friends of the Rappahannock, Fredericksburg, VA. 17 p.
Miller, D. E. 2013. The Hudson River estuary habitat restoration plan. New York State Department of Environmental Conservation, Hudson River Estuary Program, New Paltz, NY. 63 p.
Miller, J. M., and M. L. Dunn,. 1980. Feeding strategies and patterns of movement in juvenile estuarine fishes. *In* Estuarine perspectives (V. S. Kennedy, ed.), p. 437–448. Academic Press, New York, NY.
Milstein, C. B. 1981. Abundance and distribution of juvenile *Alosa* species off southern New Jersey. Transactions of the American Fisheries Society 110: 306–309.
Minta, P. 1992. A preliminary plan for the restoration of anadromous fish to the Thames River Basin. Connecticut Department of Environmental Protection, Harford, CT.
Modesto, V., M. Ilarri, A. T. Souza, M. Lopes-Lima, K. Douda, M. Clavero, and R. Sousa. 2018. Fish and mussels: importance of fish for freshwater mussel conservation. Fish and Fisheries 19: 244–259.
Monteiro Pierce, R., K. E. Limburg, D. Hanacek, and I. Valiela. 2020. Effects of urbanization of coastal watersheds on growth and condition of juvenile alewives in New England. Canadian Journal of Fisheries and Aquatic Sciences **77**: 594–601.

Morita, K., and S. Yamamoto. 2002. Effects of habitat fragmentation by damming on the persistence of stream-dwelling charr populations. Conservation Biology 16: 1318–1323.
Morton, T. 1637. The new English canaan of Thomas Morton with introductory matter and notes. Prince society, Boston, MA. [Available at https://library.si.edu/digital-library/book/newenglishcanaa00mort, accessed November 2022]
MRTC. 1997. Strategic plan & status review: anadromous fish restoration program, Merrimack River. Technical Committee For Anadromous Fishery Management Of The Merrimack River Basin (Merrimack River Technical Committee). 133 p.
MRTC. 2019. Draft river herring management plan for the Merrimack River watershed. Technical Committee For Anadromous Fishery Management Of The Merrimack River Basin (Merrimack River Technical Committee).
MRTC. 2021. Merrimack River Watershed Comprehensive Plan for Diadromous Fishes. Technical Committee For Anadromous Fishery Management Of The Merrimack River Basin (Merrimack River Technical Committee).
Mullen, D. M., C. W. Fay, and J. R. Moring. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic): alewife/blueback herring. U.S. Fish and Wildlife Service Biol. Rep. 82 (11.56). 21 p.
Murdy, E. O., R. S. Birdsong, and J. A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press. Washington, D.C.
Murphy, G. E., T. N. Romanuk, and B. Worm. 2020. Cascading effects of climate change on plankton community structure. Ecology and evolution 10: 2170–2181.
Nack, C. C., D. P. Swaney, and K. E. Limburg. 2019. Historical and projected changes in spawning phenologies of American shad and striped bass in the Hudson River Estuary. Marine and Coastal Fisheries 11(3): 271–284.
Naiman, R. J., R. E. Bilby, D. E. Schindler, and J. M. Helfield. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. Ecosystems 5(4): 399–417.
NBEP. 2002. Blackstone River fisheries restoration plan. The Narragansett Bay Estuary Program Rep. No. 02-120. 26 p.
NBEP. 2022. Narragansett Bay Estuary Program: Our Work. [Available at https://www.nbep.org/our-work, accessed May 2022].
NCDENR. 2005. Basinwide assessment report Roanoke River basin. NC Department of Environmental and Natural Resources, Raleigh, NC. 166 p.
NCDMF. 2022. Fishery management plan update river herring August 2022. *In* 2021 Fishery management plan review, p. 173–197. NC Department of Marine Fisheries. 702 p.
NCDMS and NCDEQ. 2010. Tar-Pamlico River basin restoration priorities. NC Division of Mitigation Services and Department of Environmental Quality. 84 p.
NCDMS and NCDEQ. 2018. Roanoke River basin restoration priorities. NC Division of Mitigation Services and the Department of Environmental Quality. 49 p.
NCWRC. 2015. North Carolina wildlife action plan. North Carolina Wildlife Resources Commission, Raleigh, NC. 1298 p.
NCWRC. 2019. Catfish Management Plan. NC Wildlife Resources Commission, Raleigh, NC. 71p.
NCWRC. 2020. Status of river herring in core creek and village creek, Neuse River basin, 2020. North Carolina Wildlife Resources Commission: Inland Fisheries Division. 6 p.

Nedeau, E. 2003. The amazing alewife. Gulf of Maine Times 7(2). [Available at http://www.gulfofmaine.org/times/summer2003/science_insights.html, accessed July 2022.]
NEFMC. 2015. Adding river herring and shad as stocks in the Atlantic Herring fishery: updated information and discussion of management and legal considerations. New England Fishery Management Council Discussion Document. 35 p. [Available at https://www.nefmc.org/library/herring-january-2015, accessed July 2022.]
NEFMC. 2018. Updated Consideration of Federal Management for River Herring and Shad Stocks. New England Fishery Management Council Discussion Document. [Available at https://www.nefmc.org/library/april-2018-herring-committee, accessed July 2022.]
Nelson, G. A., P. Brady, J. Sheppard, and M. Armstrong. 2011. An assessment of river herring stocks in Massachusetts. Massachusetts Division of Marine Fisheries Technical Report TR-46. 82 p.
Nelson, G. A., B. C. Chase, and J. Stockwell. 2003. Food habits of striped bass (*Morone saxatilis*) in coastal waters of Massachusetts. Journal of Northwest Atlantic Fishery Science 32: 1–25.
Nelson, G. A., B. I. Gahagan, M. P. Armstrong, A. Jordaan, and A. Bowden. 2020. A life cycle simulation model for exploring causes of population change in alewife (*Alosa pseudoharengu*s). Ecological Modelling 422: 109004.
Ng, C. L., K. W. Able, and T. M. Grothues. 2007. Habitat use, site fidelity, and movement of adult striped bass in a southern New Jersey estuary based on mobile acoustic telemetry. Transactions of the American Fisheries Society 136(5): 1344–1355.
NHFGD. 2020. New Hampshire ASMFC river herring sustainable fishing plan. New Hampshire Fish and Game Department, Concord, NH. 44 p.
NHWSPCC. 1978. Merrimack River basin water quality management plan. New Hampshire Water Supply and Pollution Control Commission, Concord, NH.
Nigro, A. A., and J. J. Ney. 1982. Reproduction and early-life accommodations of landlocked alewives to a southern range extension. Transactions of the American Fisheries Society 111(5): 559–569.
NMFS. 2019. Endangered and threatened wildlife and plants; Endangered Species Act listing determination for alewife and blueback herring. 84 FR 28630.
NMFS. 2020. Androscoggin River watershed comprehensive plan for diadromous fishes. Greater Atlantic Region Policy Series 20(1).
NMFS. 2021. NMFS Annual Commercial Landings Statistics. [Available at https://www.fisheries.noaa.gov/foss/f?p=215:200:0, accessed July 2021.]
NMFS, NCWRC, SCDNR, and USFWS. 2017. Santee basin diadromous fish restoration plan. 104p.
NMFS. 2018. Recovery plan for the Gulf of Maine distinct population segment of Atlantic salmon (*Salmo salar*). 74 p.
Noon, J. 2015. 150 years conserving New Hampshire's fish and wildlife. *In* New Hampshire Wildlife Journal. NH Fish and Game Department. p. 4–10.
Norden, C. R. 1968. Morphology and food habits of the larval alewife, *Alosa pseudoharengus* (Wilson) in Lake Michigan. *In* Proceedings: Eleventh Conference on Great Lakes Research. p. 103–110. International Association for Great Lakes Research.
Novak, A. J., A. E. Carlson, C. R. Wheeler, G. S. Wippelhauser, and J. A. Sulikowski. 2017. Critical foraging habitat of Atlantic sturgeon based on feeding habits, prey distribution,

and movement patterns in the Saco River estuary, Maine. Transactions of the American Fisheries Society 146(2): 308–317.
Nye, J. A., J. S. Link, J. A. Hare, and W. J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Progress Series 393: 111–129
NYSDEC. 2020. DEC Encourages Delaware River anglers to report invasive snakehead sightings. [Available at https://www.dec.ny.gov/press/121203.html, accessed June 2022.]
O'Connell, A. M. U., and P. L. Angermeier. 1997. Spawning location and distribution of early life stages of alewife and blueback herring in a Virginia stream. Estuaries 20(4): 779–791.
Ogburn, M. B. and A. H. Hines. 2015. Chesapeake Bay river herring monitoring plan, ver. 2. Smithsonian Environmental Research Center, Edgewater, MD. 12 p.
Ogburn, M. B., J. Spires, R. Aguilar, M. R. Goodison, K. Heggie, E. Kinnebrew, W. McBurney, K. D. Richie, P. M. Roberts, and A. H. Hines. 2017. Assessment of river herring spawning runs in a Chesapeake Bay coastal plain stream using imaging sonar. Transactions of the American Fisheries Society 146(1): 22–35.
Orr, M. 2022. Joint project begins process to restore saltmarsh habitat. [Available from https://www.sas.usace.army.mil/Media/News-Stories/Article/2963734/joint-project-begins-process-to-restore-savannah-saltmarsh-habitat/, accessed June 2022.]
Ouellet, V., M. J. Collins, J. F. Kocik, R. Saunders, T. F. Sheehan, M. B. Ogburn, and T. Trinko Lake. 2022. The diadromous watersheds-ocean continuum: managing diadromous fish as a community for ecosystem resilience. Frontiers in Ecology and Evolution. doi:10.3389/fevo.2022.1007599.
Owen, T., and A. Weaver. 2020. Walker's Dam double denil fishway evaluation: a 2018-2019 progress report to the City of Newport News. Virginia Department of Game and Inland Fisheries, Richmond, VA.
Owens, R. W., R. O'Gorman, E. L. Mills, L. G. Rudstam, J. J. Hasse, B. H. Kulik, and D. B. MacNeill. 1998. Blueback herring (*Alosa aestivalis*) in Lake Ontario: first record, entry route, and colonization potential. Journal of Great Lakes Research 24(3): 723–730.
PAFBC. 2011. Delaware River Management Plan. Pennsylvania Fish and Boat Commission, Harrisburg, PA.
Palkovacs, E. P., D. J. Hasselman, E. E. Argo, S. R. Gephard, K. E. Limburg, D. M. Post, T. F. Schultz, and T. V. Willis. 2013. Combining genetic and demographic information to prioritize conservation efforts for anadromous alewife and blueback herring. Evolutionary Applications 7(2): 212–226.
Papworth, S. K., J. Rist, L. Coad, and E. J. Milner-Gulland. 2009. Evidence for shifting baseline syndrome in conservation. Conservation Letters 2(2): 93–100.
Pardue, G. B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Fish and Wildlife Service. Rep. No. FWS/OBS-82/10.58. 22 p.
Patrick, C. J., D. E. Weller, X. Li, and M. Ryder. 2014. Effects of shoreline alteration and other stressors on submerged aquatic vegetation in subestuaries of Chesapeake Bay and the mid-Atlantic coastal bays. Estuaries and Coasts 37(6): 1516–1531.
Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology & Evolution 10(10): 430.

Payne Wynne, M. L., K. A. Wilson, and K. E. Limburg. 2015. Retrospective examination of habitat use by blueback herring (*Alosa aestivalis*) using otolith microchemical methods. Canadian Journal of Fisheries and Aquatic Sciences 72(7): 1073–1086.

Petersen, J. B., B. S. Robinson, D. F. Belknap, J. Stark, and L. K. Kaplan. 1994. An archaic and woodland period fish weir complex in central maine. Archaeology of Eastern North America 22: 197–222.

Peterson, T. C., R. R. Heim Jr., R. Hirsch, D. P. Kaiser, H. Brooks, N. S. Diffenbaugh, N. S., R. M. Dole, J. P. Giovannettone, K. Guirguis, T. R. Karl, R. W. Katz, K. Kunkel, D. Lettenmaier, G. J. McCabe, C. J. Paciorek, K. R. Ryberg, S. Schubert, V. B. S. Silva, B. C. Stewart, A. V. Vecchia, G. Villarini, R. S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C. A. Woodhouse, and D. Wuebbles. 2013. Monitoring and understanding changes in heat waves, cold waves, floods, and droughts in the United States: state of knowledge. Bulletin of the American Meteorological Society, 94(6), 821–834.

Phillips, J. D. 2013. Hydrological connectivity of abandoned channel water bodies on a coastal plain river. River Research and Applications 29(2): 149–160.

Plough, L.V., M. B. Ogburn, C. L. Fitzgerald, R. Geranio, G. A. Marafino, and K. D. Richie. 2018. Environmental DNA analysis of river herring in Chesapeake Bay: A powerful tool for monitoring threatened keystone species. PLoS One 13(11): e0205578.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. BioScience 47(11): 769–784.

Poloczanska, E. S., C. J. Brown, W. J. Sydeman, W. Kiessling, D. S. Schoeman, P. J. Moore, K. Brander, J. F. Bruno, L. B. Buckley, and M. T. Burrows. 2013. Global imprint of climate change on marine life. Nature Climate Change 3(10): 919–925.

Portner, H. O., and M. A. Peck. 2010. Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. Journal of Fish Biology 77(8): 1745–1779.

Post, D. M., and A. W. Walters. 2009. Nutrient excretion rates of anadromous alewives during their spawning migration. Transactions of the American Fisheries Society 138(2): 264–268.

Post, D. M., E. P. Palkovacs, E. G. Schielke, and S. I. Dodson. 2008. Intraspecific variation in a predator affects community structure and cascading trophic interactions. Ecology 89(7): 2019–2032.

Power, M. E., W. E. Dietrich, and J. C. Finlay. 1996. Dams and downstream aquatic biodiversity: potential food web consequences of hydrologic and geomorphic change. Environmental management 20(6): 887–895.

Raabe, J. H. and J. E. Joseph. 2014. Assessing distribution of migratory fishes and connectivity following complete and partial dam removals in a North Carolina River. North American Journal of Fisheries Management 34: 955–969.

Raabe, J. K., J. E. Hightower, T. A. Ellis, and J. J. Facendola. 2019. Evaluation of fish passage at a nature-like rock ramp fishway on a large coastal river. Transactions of the American Fisheries Society 148(4): 798–816.

Rahel, F. J., and J. D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation biology 22(3): 521–533.

Ratzlaff, E. D. 1969. Applications of engineering systems analysis to the human social-ecological system. Thesis. University of California, Davis, Davis, California.

Reid, K., E. P. Palkovacs, D. J. Hasselman, D. Baetscher, J. Kibele, B. Gahagan, P. Bentzen, M. C. McBride, and J. C. Garza. 2018. Comprehensive evaluation of genetic population

structure for anadromous river herring with single nucleotide polymorphism data. Fisheries Research 206: 247–258.
Reid, K., J. A. Hoey, B. I. Gahagan, B. P. Schondelmeier, D. J. Hasselman, A. A. Bowden, M. P. Armstrong, J. C. Garza, and Palkovacs, E.P. 2023. Spatial and temporal genetic stock composition of river herring bycatch in southern New England Atlantic herring and mackerel fisheries. Canadian Journal of Fisheries and Aquatic Sciences 80: 360–374.
Reine, K.J., D. D. Dickerson, and D. G. Clarke. 1998. Environmental windows associated with dredging operations. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Tech. Note DOER-E2. 14 p.
Richardson, A. J., and D. S. Schoeman. 2004. Climate impact on plankton ecosystems in the Northeast Atlantic. Science 305(5690): 1609–1612.
Richkus, W. A. 1974. Factors influencing the seasonal and daily patterns of alewife (*Alosa pseudoharengus*) migration in a Rhode Island river. Journal of the Fisheries Board of Canada 31(9): 1485–1497.
Ricks, B. R., J. E. Hightower, and A. M. Wicker. 2004. Preliminary assessment of an Alaska steeppass fishway on a North Carolina blackwater creek. *In* Proceedings of the Annual Conference, Southeastern Association of Fish and Wildlife Agencies. p. 92–99.
Riggsbee, J. A. 2006. Short-term nutrient and sediment fluxes following dam removal. Ph.D. diss., The University of North Carolina at Chapel Hill, NC.
Rillahan, C. B., D. Alcott, T. Castro-Santos, and P. He. 2021. Activity patterns of anadromous fish below a tide gate: bbservations from high-resolution imaging sonar. Marine and Coastal Fisheries 13(3): 200–212.
Rohde, F. 2010. A reference guide to the distribution of anadromous fishes in North Carolina rivers. NMFS SERO, Beaufort, NC.
Rohde, F. 2011a. A reference guide to the distribution of anadromous fishes in South Carolina rivers. NMFS SERO, Beaufort, NC.
Rohde, F. 2011b. A reference guide to the distribution of anadromous fishes in Georgia Rivers. NMFS SERO, Beaufort, NC.
Rourke, M. L., A. M. Fowler, J. M. Hughes, M. K. Broadhurst, J. D. DiBattista, S. Fielder, J. Wilkes Walburn, and E. M. Furlan. 2022. Environmental DNA (eDNA) as a tool for assessing fish biomass: A review of approaches and future considerations for resource surveys. Environmental DNA 4(1): 9–33.
Roy, A. H., M.C. Freeman, B. J. Freeman, S. J. Wenger, W. E. Ensign, and J. L. Meyer. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society 24(3): 656–678.
Rulifson, R., M. Huish, and R. Thoesen. 1994. Status of anadromous Alosa along the east coast of North America. *In* Proceedings of the anadromous *Alosa* symposium; Virginia Beach, 14–15 January (J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, eds.) p. 134–158. American Fisheries Society, Bethesda, MD.
Rulifson, R. A., M. T. Huish, and R. Thoesen. 1982. Anadromous fish in the southeastern United States and recommendations for development of a management plan. U.S. Fish and Wildlife Service Research Region 4, Atlanta, Georgia.
Sanford, D. W. 1997. An assessment of the Embrey Dam area: The Embrey Dam hydroelectric project and adjacent archeological resources. Report submitted to Virginia Department of Game and Inland Fisheries.

SARP. 2005a. Conserving the Roanoke River: conservation action plan. Southeast Aquatic Resources Partnership and The Nature Conservancy. 61 p.
SARP. 2005b. Conserving the Altamaha River watershed: conservation action plan. Southeast Aquatic Resources Partnership and The Nature Conservancy. 56 p.
SARP. 2022. Comprehensive Southeast aquatic barrier inventory. [Available at https://southeastaquatics.net/, accessed June 2022.]
Saunders, R., M. A. Hachey, and C. W. Fay. 2006. Maine's diadromous fish community: past, present, and implications for Atlantic salmon recovery. Fisheries 31(11): 537–547.
Save the Sound. 2022. Restoring the Quinnipiac River. [Available at https://www.savethesound.org/what-we-do/ecological-restoration/restoration-project-gallery/restoring-the-quinnipiac-river/, accessed September 2022.]
Savoy, T. F., and V. A. Crecco. 2004. Factors affecting the recent decline of blueback herring and American shad in the Connecticut River. American Fisheries Society Monograph 9: 361–377.
Saylor, R. K., Lapointe, N. W., and P. L. Angermeier. 2012. Diet of non-native northern snakehead (*Channa argus*) compared to three co-occurring predators in the lower Potomac River, USA. Ecology of Freshwater Fish 21(3): 443–452.
SBU. 2021. Long Island water-quality assessment shows cause for concern. [Available at https://news.stonybrook.edu/featuredpost/long-island-water-quality-assessment-shows-cause-for-concern/, accessed May 2022.]
SCDHEC. 2010. Watershed water quality assessment: Savannah River basin. SC Department of Health and Environemntal Control, Columbia, SC. 330 p.
SCDHEC. 2012. Watershed water quality assessment: Edisto River basin. SC Department of Health and Environemntal Control, Columbia, SC. 181 p.
SCDHEC. 2016. State of South Carolina integrated report for 2016, Part I: Section 303(d) list of impaired waters. SC Department of Health and Environemntal Control, Columbia, SC. 112 p.
SCDNR. 1996. Managing resources for a sustainable future: the Edisto River basin project report. SC Department of Natural Resources, Columbia, SC. 226 p. [Available at https://www.dnr.sc.gov/water/river/edisto.html, accessed June 2022.]
SCDNR. 2008. South Carolina aquatic invasive species management plan. SC Department of Natural Resources, Columbia, SC. 95 p.
SCDNR. 2020a. Characterization of the Ashepoo-Combahee-Edisto (ACE) Basin, South Carolina. [Available at https://www.dnr.sc.gov/marine/mrri/acechar/environment/waterquality.html, accessed October 2022.]
SCDNR. 2020b. Blueback herring sustainable fishing plan update for South Caorlina. South Carolina Department of Natural Resources, Columbia, SC. 24 p.
Schiff, R., and G. Benoit. 2007. Effects of impervious cover at multiple spatial scales on coastal watershed streams. Journal of the American Water Resources Association 43(3): 712–730.
Schindler, D. E., M. D. Scheuerell, J. W. Moore, S. M. Gende, T. B. Francis, and W. J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. Frontiers in Ecology and the Environment 1: 31–37.
Schmidt, R. E., B. M. Jessop, and J. E. Hightower. 2003. Status of river herring stocks in large rivers. *In* Biodiversity, status, and conservation of the world's shads, symposium 35.

(K.E. Limburg and J. Waldman, eds.), p. 171–182. American Fisheries Society, Bethesda, MD.
Schmitt, J. D., J. A. Emmel, A. J. Bunch, C. D. Hilling, and D. J. Orth. 2019. Feeding ecology and distribution of an invasive apex predator: flathead catfish in subestuaries of the Chesapeake Bay, Virginia. North American Journal of Fisheries Management 39(2): 390–402.
Schmitt, J. D., E. M. Hallerman, A. Bunch, Z. Moran, J. A. Emmel, and D. J. Orth. 2017. Predation and prey selectivity by nonnative catfish on migrating alosines in an Atlantic slope estuary. Marine and Coastal Fisheries 9(1): 108–125.
SCIWC. 2022. 2022 Anadromous fish counts at Milltown Dam. St. Croix International Waterway Commission, Calais, ME.
SEA. 2022. River revival map. [Available at https://seatuck.org/river-revival/, accessed May 2022.]
Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1987. Hydrologic unit maps. United States Government Printing Office, Denver, CO. 23 p.
Sharp, J. H. 2010. Estuarine oxygen dynamics: what can we learn about hypoxia from long-time records in the Delaware estuary? Limnology and Oceanography 55(2): 535–548.
Sheaffer, W. A., and J. G. Nickum. 1986. Backwater areas as nursery habitats for fishes in pool 13 of the upper Mississippi River. Hydrobiologia 136(1): 131–139.
Simonin, P. W., K. E. Limburg, and L. S. Machut. 2007. Bridging the energy gap: anadromous blueback herring feeding in the Hudson and Mohawk Rivers, New York. Transactions of the American Fisheries Society 136(6): 1614–1621.
Simonin, P. W., L. G. Rudstam, D. L. Parrish, B. Pientka, and P. J. Sullivan. 2018. Piscivore diet shifts and trophic level change after alewife establishment in Lake Champlain. Transactions of the American Fisheries Society 147(5): 939–947.
Simpson, T. 2007. The Susquehanna watershed influence on the Chesapeake Bay: science, management and policy. *In* Proceedings of the symposium: The ASA-CSSA-SSSA International Annual Meetings; New Orleans, 4–8 November. [Available at https://a-c-s.confex.com/a-c-s/2007am/techprogram/P32792.HTM, accessed August 2022]
Smith, B. 1971. The fishes of four low-salinity tidal tributaries of the Delaware Bay estuary. M.S. thesis. Cornell University, Ithaca, New York.
Smith, D. G. 1985. Recent range expansion of the freshwater mussel *Anodonta implicata* and its relationship to clupeid fish restoration in the Connecticut River system. Freshwater Invertebrate Biology 4(2): 105–108.
Smith, H. M. 1907. The fishes of north carolina. North Carolina Geological and Economic Survey, Raleigh, NC.
Smith, L., R. Gamble, S. Gaichas, and J. Link. 2015. Simulations to evaluate management trade-offs among marine mammal consumption needs, commercial fishing fleets and finfish biomass. Marine Ecology Progress Series 523: 215–232.
Smith, S. H. 1970. Species interactions of the alewife in the Great Lakes. Transactions of the American Fisheries Society 99(4): 754–765.
SMRMC. 2003. St. Marys River management plan. St. Marys River Management Committee.
SMRMC. 2022. St. Marys River basin. [Available at https://www.sjrwmd.com/waterways/st-marys-river/, accessed June 2022.]
Solomon, C. T., S. E. Jones, B. C. Weidel, I. Buffam, M. L. Fork, J. Karlsson, S. Larsen, J. T. Lennon, J. S. Read, and S. Sadro. 2015. Ecosystem consequences of changing inputs of

terrestrial dissolved organic matter to lakes: current knowledge and future challenges. Ecosystems 18(3): 376–389.
SRAFRC. 2010. Migratory fish management and restoration plan for the Susquehanna River Basin. 124 p.
SRBC. 2021. Comprehensive plan for the water resources of the Susquehanna River basin: 2021-2041. Susquehanna River Basin Commission, Harrisburg, PA. 36 p.
SRBC. 2022. Mine drainage portal. [Available at https://www.srbc.net/minedrainageportal/Map, accessed June 2022.]
SRCC. 2021. Saco River corridor commission 2020 water quality analysis. Saco River Corridor Commission, Cornish, ME. 48 p.
Star, F. L. 2004. River runs free: breaching the Rappahannock's Embrey Dam. The Free Lance-Star Publishing Company, Fredericksburg, VA.
Stevens, J. R., R. Saunders, and W. Duffy. 2021. Evidence of life cycle diversity of river herring in the Penobscot River estuary, Maine. Marine and Coastal Fisheries 13(3): 263–276.
Stevenson, C. H. 1899. The shad fisheries of the Atlantic coast of the United States. US Commission of Fish and Fisheries, Washington, D.C.
Stich, D., M. Bailey, and J. D. Zydlewski. 2014. Survival of Atlantic salmon *Salmo salar* smolts through a hydropower complex. Journal of Fish Biology 85(4): 1074–1096.
Stich, D. S., T. F. Sheehan, and J. D. Zydlewski. 2019. A dam passage performance standard model for American shad. Canadian Journal of Fisheries and Aquatic Sciences 76(5): 762–779.
Stolte, L. 1981. The forgotten salmon of the Merrimack. U.S. Department of the Interior. Stock No. 024-010-00589-1
Strayer, D. L., K. A. Hattala, and A. W. Kahnle. 2004. Effects of an invasive bivalve (*Dreissena polymorpha*) on fish in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences 61(6): 924–941.
Strayer, D. L., K. A. Hattala, A. W. Kahnle, and R. D. Adams. 2014. Has the Hudson River fish community recovered from the zebra mussel invasion along with its forage base? Canadian Journal of Fisheries and Aquatic Sciences 71(8): 1146–1157.
Strayer, D. L., N. F. Caraco, J. J. Cole, S. Findlay, and M. L. Pace. 1999. Transformation of freshwater ecosystems by bivalves: a case study of zebra mussels in the Hudson River. BioScience 49(1): 19–27.
SVCA. 2022. Sheepscot River. [Available at https://mainerivers.org/watershed-profiles/sheepscot-river/, accessed April 2022.]
Tayac, G., E. Schupman, and M. Hirsch. 2006. We have a story to tell: The Native peoples of the Chesapeake region. National Museum of the American Indian, Washington, D.C.
Taylor, M. T. 1992. Seiners and tongers: North Carolina fisheries in the old and new south. The North Carolina Historical Review 69(1): 1–36.
Taylor, R. E., and B. Kynard. 1985. Mortality of juvenile American shad and blueback herring passed through a low-head Kaplan hydroelectric turbine. Transactions of the American Fisheries Society 114(3): 430–435.
Thompson, L. M., A. J. Lynch, E. A. Beever, A. C. Engman, J. A. Falke, S. T. Jackson, T. J. Krabbenhoft, D. J. Lawrence, D. Limpinsel, and R. T. Magill. 2021. Responding to ecosystem transformation: Resist, accept, or direct? Fisheries 46(1): 8–21.

Tillitt, D. E., J. L. Zajicek, S. B. Brown, L. R. Brown, J. D. Fitzsimons, D. C. Honeyfield, M. E. Holey, and G. M. Wright. 2005. Thiamine and thiaminase status in forage fish of salmonines from Lake Michigan. Journal of Aquatic Animal Health 17(1): 13–25.

Timmons. 1997. Technical alternatives analysis to provide Fish Passage at Embrey Dam. Commonwealth of Virginia, Virginia Department of Game and Inland Fisheries.

Tommasi, D., J. Nye, C. Stock, J. A. Hare, M. Alexander, K. Drew, and K. Tierney. 2015. Effect of environmental conditions on juvenile recruitment of alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) in fresh water: a coastwide perspective. Canadian Journal of Fisheries and Aquatic Sciences 72(7): 1037–1047.

Toth, J., S. Evert, E. Zimmermann, M. Sullivan, L. Dotts, K. W. Able, R. Hagan, and C. Slocum. 2018. Annual residency patterns and diet of *Phoca vitulina concolor* (western Atlantic harbor seal) in a southern New Jersey estuary. Northeastern naturalist 25(4): 611–626.

Tracy, B. H., F. R. Rohde, and G. M. Hogue. 2020. An annotated atlas of the freshwater fishes of North Carolina. Southeastern Fishes Council Proceedings 60(1).

TRBP. 2022. Thames River basin partnership. [Available at https://thamesriverbasinpartnership.org/, accessed May 2022.]

Trinko Lake, T. R., K. R. Ravana, and R. Saunders. 2012. Evaluating changes in diadromous species distributions and habitat accessibility following the Penobscot River Restoration Project. Marine and Coastal Fisheries 4(1): 284–293.

Turek, J., A. Haro, and B. Towler. 2016. Federal interagency nature-like fishway passage design guidelines for Atlantic coast diadromous fishes. Interagency Technical Memorandum. 47 p.

Turner, S.M., and K. E. Limburg. 2016. Juvenile river herring habitat use and marine emigration trends: comparing populations. Oecologia 180(1): 77–89.

Turner, S. M., K. E. Limburg, and E. P. Palkovacs. 2015. Can different combinations of natural tags identify river herring natal origin at different levels of stock structure? Canadian Journal of Fisheries and Aquatic Sciences 72(6): 845–854.

Turner, T. F., J. C. Trexler, G. L. Miller, and K. E. Toyer. 1994. Temporal and spatial dynamics of larval and juvenile fish abundance in a temperate floodplain river. Copeia 1: 174–183.

Twining, C. W., E. P. Palkovacs, M. A. Friedman, D. J. Hasselman, and D. M. Post. 2017. Nutrient loading by anadromous fishes: species-specific contributions and the effects of diversity. Canadian Journal of Fisheries and Aquatic Sciences 74(4): 609–619.

UMCES. 2018. 2018 Chesapeake Bay & watershed report card. University of Maryland Center for Environmental Science, Cambridge, MD. 6 p.

UNF. 2021. State of the river report for the lower St. Johns River basin. [Available at https://sjrr.domains.unf.edu/a-guide-for-the-general-public/, accessed June 2022.]

Uphoff Jr, J. H., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2011. Impervious surface, summer dissolved oxygen, and fish distribution in Chesapeake Bay subestuaries: linking watershed development, habitat conditions, and fisheries management. North American Journal of Fisheries Management 31(3): 554–566.

USACE. 2002. Final decision document: Embrey Dam removal project, Rappahannock River, Virginia. U.S. Army Corps of Engineers, Norfolk District. 16 p.

USACE. 2006. Merrimack River watershed assessment study, final phase I report. U.S. Army Corps of Engineers, New England District. 136 p.

USACE. 2022. Connecticut River, Connecticut, Massachusetts, New Hampshire, & Vermont. [Available at https://www.iwr.usace.army.mil/sustainablerivers/sites/connecticut/, accessed June 2022.]

USFWS and NMFS. 2016. Roanoke River diadromous fishes restoration plan. U.S.Fish and Wildlife Service and National Marine Fisheries Service. 72 p.

USFWS. 1994. Elements of consensus on American shad management in the stretch of Savannah River between Strom Thurmond (Clarks Hill) Dam and Augusta. U.S. Fish and Wildlife Service.

USFWS. 2006. Restoration plan for the diadromous fishes of the Yadkin-Pee Dee River basin. U.S. Fish and Wildlife Service.

USFWS. 2008. Comprehensive conservation plan Pee Dee National Wildlife Refuge. U.S. Fish and Wildlife Service.

USFWS. 2013. Priority restoration and management actions for the American shad in the Altamaha River Basin. US Fish and Wildlife Service.

USFWS. 2019. Fish passage engineering design criteria. U.S. Fish and Wildlife Service, Northeast Region 5, Hadley, Massachusetts. 248 p.

USFWS. 2020. Connecticut River basin anadromous fish restoration: coordination and technical assistance. U.S. Fish and Wildlife Service, Connecticut River Fish and Wildlife Conservation Office. Rep. no. F-100-R-37.

USFWS. 2022. Delaware River basin restoration. [Available at https://fws.gov/program/delaware-river-basin-restoration, accessed June 2022.]

USWFS and NMFS. 2005. Diadromous fish restoration plan for the middle Savannah River: strategy and implementation schedule. 27 p.

USFWS, MDIFW, MEASRSC, and MDMR. 1987. Saco River strategic plan for fisheries management. U.S. Fish and Wildlife Service, Maine Department of Inland Fisheries and Wildlife, Maine Atlantic Sea Run Salmon Commission and Maine Department of Marine Resources.

USGS. 2016. The StreamStats program. [Available at http://streamstats.usgs.gov, accessed May 2022.]

USGS. 2017. Long Island land use and land cover. [Available at https://www.usgs.gov/centers/new-york-water-science-center/science/long-island-land-use-and-land-cover, accessed May 2022.]

VADWR. 2021. Surface water withdrawal intake design and operation standards. VA Departmnet of Wildlife Resources, Surface Water Intake Working Group. [Available at https://dwr.virginia.gov/wp-content/uploads/media/Surface-Water-Intake-Design-Operation-Standards.pdf, accessed November 2022.]

van der Most, M., and P. F. Hudson. 2018. The influence of floodplain geomorphology and hydrologic connectivity on alligator gar (*Atractosteus spatula*) habitat along the embanked floodplain of the lower Mississippi River. Geomorphology 302: 62–75.

Wagner, T., S. R. Midway, J. B. Whittier, J. T. DeWeber, and C. P. Paukert. 2017. Annual changes in seasonal river water temperatures in the Eastern and Western United States. Water 9(2): 90.

Walburg, C. H., and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U.S. Fish and Wildlife Service. Rep. no. 550. 116 p.

Waldman, J. R., K. A. Wilson, M. Mather, and N. P. Snyder. 2016. A resilience approach can improve anadromous fish restoration. Fisheries 41(3): 116–126.
Waldman, J. R., and T. P. Quinn. 2022. North American diadromous fishes: drivers of decline and potential for recovery in the anthropocene. Science Advances 8(4): eabl5486.
Walsh, H. J., L. R. Settle, and D. S. Peters. 2005. Early life history of blueback herring and alewife in the lower Roanoke River, North Carolina. Transactions of the American Fisheries Society 134(4): 910–926.
Walter , J., A. Overton, K. H. Ferry, and M. E. Mather. 2003. Atlantic coast feeding habits of striped bass: a synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology 10(5): 349–360.

Walters, A. W., R. T. Barnes, and D. M. Post. 2009. Anadromous alewives (*Alosa pseudoharengus*) contribute marine-derived nutrients to coastal stream food webs. Canadian Journal of Fisheries and Aquatic Sciences 66(3): 439–448.
Ward, J., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. River Research and Applications 15(1-3): 125–139.
Warner, J., and B. Kynard. 1986. Scavenger feeding by subadult striped bass, *Morone saxatilis*, below a low-head hydroelectric dam. Fishery Bulletin 84(1): 220–221.
Warriner, J., J. Miller, and J. Davis. Distribution of juvenile river herring in the Potomac River. 1969 *In* Proceedings Of The Twenty-Third Annual Conference Southeastern Association Of Game And Fish Commissioners; Mobile, 19–22 October (J. W. Webb, ed.), p. 384–388. Southeastern Association Of Game And Fish Commissioners, Columbia, SC.
Watson, J. F. 1970. Distribution and population dynamics of American shad, *Alosa sapidissima* (Wilson), in the Connecticut River above Holyoke Dam, Massachusetts. Ph.D. diss. University of Massachusetts, Amherst, MA.
Watson, J. M., S. M. Coghlan Jr, J. D. Zydlewski, D. B. Hayes, and D. S. Stich. 2019. Role of recovering river herring population on smallmouth bass diet and growth. *In* Managing Centrarchid fisheries in rivers and streams, symposium 87; Kansas City. (M.J. Siepker and J.W. Quinn, eds.), p. 75–92. American Fisheries Society, Bethesda, MD.
Weaver, D. M., S. M. Coghlan Jr, and J. D. Zydlewski. 2016. Sea lamprey carcasses exert local and variable food web effects in a nutrient-limited Atlantic coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 73(11): 1616–1625.
Weisberg, S. B., P. Himchak, T. Baum, H. T. Wilson, and R. Allen. 1996. Temporal trends in abundance of fish in the tidal Delaware River. Estuaries 19(3): 723–729.
Werner, R. G. 2004. Freshwater fishes of the northeastern United States: a field guide. Syracuse University Press, Syracuse, New York.
WHOI. 2017. Update on river herring network. [Available at https://seagrant.whoi.edu/news-and-events/coastal-impacts-newsletter/update-on-river-herring-network/, accessed May 2022].
Wiggins, H. 2007. A tale of two dams: from Salem Church Dam to the Embrey Dam. Lulu Enterprises Inc. Research Triangle, NC.
Willis, T. V., P. Bentzen, and I. Paterson. 2006. Two reports on alewives in the St. Croix River.
Willis, T. V. 2009. How policy, politics, and science shaped a 25-year conflict over alewife in the St. Croix River, New Brunswick-Maine. *In* Challenges for diadromous fishes in a dynamic global environment, symposium 69. (A. J. Haro, K. L. Smith, R. A. Rulifson,

C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjack, J. E. Cooper, K. L. Beal and T. S. Avery, eds), p. 793–811. American Fisheries Society, Bethesda, MD.

Wilson, E. O. 2002. The future of life. Random House, Inc. New York, NY.

Winters, G., J. Moores, and R. Chaulk. 1973. Northern range extension and probable spawning of gaspereau (*Alosa pseudoharengus*) in the Newfoundland area. Journal of the Fisheries Board of Canada 30(6): 860–861.

Wippelhauser, G. 2021. Recovery of diadromous fishes: a Kennebec River case study. Transactions of the American Fisheries Society 150(3): 277–290.

Yako, L. A., Mather, M. E., and F. Juanes. 2000. Assessing the contribution of anadromous herring to largemouth bass growth. Transactions of the American Fisheries Society 129(1): 77–88.

Yako, L. A., M. E. Mather, and F. Juanes. 2002. Mechanisms for migration of anadromous herring: an ecological basis for effective conservation. Ecological Applications 12(2): 521–534.

Zhang, Q., R. M. Hirsch, and W. P. Ball. 2016. Long-term changes in sediment and nutrient delivery from Conowingo Dam to Chesapeake Bay: effects of reservoir sedimentation. Environmental science & technology 50(4): 1877–1886.

Zydlewski, J., D. S. Stich, S. Roy, M. Bailey, T. Sheehan, and K. Sprankle. 2021. What have we lost? modeling dam impacts on American shad populations through their native range. Frontiers in Marine Science 8: 734213.

Table A – Useful links to river herring-related geospatial data, habitat mapping tools, hydropower information, and commercial fishing information.

| Title | Use | Hyperlink |
|---|---|---|
| Freshwater Network Northeast Region Tool | Geospatial Data and Habitat Mapping Tools | Freshwater Network Northeast |
| Freshwater Network (Chesapeake) Tool | Geospatial Data and Habitat Mapping Tools | Freshwater Network (Chesapeake) |
| Southeast Aquatic Barrier Prioritization Tool | Geospatial Data and Habitat Mapping Tools | Southeast Barrier Prioritization |
| Marine Range Shift Projections | Geospatial Data and Habitat Mapping Tools | Marine Range Shift Projections |
| StreamStats | Geospatial Data and Habitat Mapping Tools | StreamStats |
| USDA Web Soil Survey | Geospatial Data and Habitat Mapping Tools | USDA Web Soil Survey |
| USGS National Hydrography Dataset | Geospatial Data and Habitat Mapping Tools | USGS National Hydrography Dataset |
| USACE Dam Inventory | Geospatial Data and Habitat Mapping Tools | USACE Dam Inventory |
| NALCC Land Use | Geospatial Data and Habitat Mapping Tools | NALCC Land Use |
| List of FERC Comprehensive Plans | Hydropower | List FERC Comprehensive Plans |
| Low Impact Hydro | Hydropower | Low Impact Hydro |
| River Herring Bycatch Avoidance Programs | Commercial Fishing and Bycatch | River Herring Bycatch Avoidance Information |
| Catch Cap Information | Commercial Fishing and Bycatch | Catch Cap Information |
| Commercial Landings Data | Commercial Fishing and Bycatch | Commercial Landings Information |

Table A 1 – Table modified from ASMFC 2012 River Herring Stock Assessment Report, Table 3, which includes a summary of the Peer Review Panel's evaluation, comments, and added research recommendations (preceded by an asterisk).

| Research recommendation | Stage | Time period | Priority | Review Panel Comments |
|---|---|---|---|---|
| *Undertake an analysis of the consequences of interaction between the offshore bycatch fishery and those in the rivers | Assessment | Short Term | High | This would allow informed decisions on future mitigation measures. |
| Improve methods to develop biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for river herring stocks. | Assessment | Short Term | Moderate | Panel agrees that there is a need but other recommendations will have a greater impact. |
| Explore use of peer-reviewed stock assessment models for use in additional river systems in the future as more data become available. | Assessment | Long Term | Moderate | In addition, further develop existing models to understand coast-wide differences in dynamics, etc. 1 |
| Development of better fish culture techniques and supplemental stocking strategies for river herring. | Implementation | Long Term | Low | Success rate in other stocking programs (e.g. Atlantic salmon, shad, etc.) has been low |
| Encourage studies to quantify and improve fish passage efficiency and support the implementation of standard practices. | Implementation | Long Term | High | Dams and other impediments will continue to impact river herring; improving passage efficiency is critical to sustaining/restoring runs |
| Investigate contribution of landlocked versus anadromous produced fish. | Population dynamics | Long Term | Low | Peripheral to management of coastal population |
| Continue genetic analyses to determine population stock structure along the coast and enable determination of river origin of incidental catch in non-targeted ocean fisheries. | Population dynamics | Short Term | High | Research underway in combination with otolith chemistry |
| Determine and quantify which stocks are impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxytetracycline otolith marking, genetic analysis, and/or tagging. | Population dynamics | Long Term | High | Combined with above. |
| Develop models to predict the potential impacts of climate change on river herring distribution and stock persistence. | Population dynamics | Short Term | Low | Premature given state of data and model developments; need to link to population dynamics 2 |
| Validate [better estimate] the different values of M for river herring stocks and improve methods for calculating M. | Population dynamics | Long Term | High | Important to understand sources of high M (e.g. predation, habitat, etc.) |
| Continue to assess current aging techniques for river herring, using known-age fish, scales, otoliths and spawning marks. | Population dynamics | Short Term | High | Review panel fully supports this recommendation |
| Conduct biannual aging workshops to maintain consistency and accuracy in aging fish sampled in state programs. | Population dynamics | Long Term | High | Important for aging program quality assurance |

| Research recommendation | Stage | Time period | Priority | Review Panel Comments |
|---|---|---|---|---|
| Summarize existing information on predation by striped bass and other species and quantify consumption through modeling (e.g., MSVPA), diet, and bioenergetics studies. | Population dynamics | Long Term | Moderate | Important but sort out M issue (above) first |
| Investigate the relation between juvenile river herring production and subsequent year class strength, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, and life history requirements. | Population dynamics | Long Term | High | Has potential to indicate relative role of production (catch plus growth) and environment in recruitment strength, however, not easily achievable |
| Evaluate the performance of hatchery fish in river herring restoration. | Population dynamics | Long Term | Low | Due to low current hatchery production |
| Improve reporting of harvest by water body and gear. | Monitoring | Short Term | High | The Panel agrees this should be a priority at all levels. |
| Investigate additional sources of historical catch data of the U.S. small pelagic fisheries to better represent or construct earlier harvest of river herring. | Monitoring | Short Term | Moderate | Would assist current model formulation but would not facilitate interpretation of current status |
| Develop and implement monitoring protocols and analyses to determine river herring population responses and targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.). | Monitoring | Short Term | High | Also should be assessing success of moratoria |
| Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring. | Monitoring | Long Term | Low | It is a higher priority to address issues in larger fisheries |
| Expand observer and port sampling coverage to quantify additional sources of mortality for alosine species, including bait fisheries, as well as rates of incidental catch in other fisheries. | Monitoring | Long Term | High | However, first undertake statistical study of observer allocation and coverage (see Hanke et al., 2011 for example) |
| Evaluate and ultimately validate large-scale hydro acoustic methods to quantify river herring escapement (spawning run numbers) in major river systems. | Monitoring | Long Term | Moderate | Considered an adjunct to current monitoring systems and would have to be implemented in tandem with these |
| * Explore the sources of and provide better estimates of incidental catch in order to reduce uncertainty in incidental catch estimates. | Monitoring | Short Term | High | Explore existing data but also observer coverage analysis as indicated above 4 |
| *Develop bottom and mid-water trawl CPUE indices of offshore biomass. | Monitoring | Short Term | Moderate | This is exploratory, data are available and may or may not provide useful indices |
| *Consider the use of GLM to provide better trend estimates and to better characterize uncertainty in trends. | Monitoring | Short Term | Moderate | GLM provides a general statistical structure to the description of uncertainty in stock indices |

Table A 2 – The TEWG Stock Status Subgroup identified data and gaps and research suggestions by drawing from a recent ASMFC stock assessment, Council documents, the ESA status review process, the input of the full TEWG, and the input and advice of Stock Status Subgroup members. All subgroup members were asked to provide their individual opinion on ranking for each of the suggestions, including the relative cost (1-9K, 10-99K, 100-199K, >200K), time frame (Exists Already, Short-term, and Long-term), and comments. Below is a summary from the 8 subgroup members who provided their expert opinions.

| Identified Research Recommendation | Stock Status Subgroup Comments | Time Frame<br>"E" = Exists already<br>"S" = Short-term (1-3 yrs)<br>"L" = Long-term (3+ yrs) | Rank<br>1 = High<br>23 = Low | Relative Cost<br>$ = 1-9K<br>$$ = 10-99K<br>$$$ = 100-199K<br>$$$$ = >200K |
|---|---|---|---|---|
| Creation of a Standardized Sampling Guidance Document for the species population range. | Many of the identified research needs discussed had benefit from formation of this type of product. | S | 1 | $/$$ |
| Continue to assess current aging techniques for river herring, using known-age fish for age validation, scales, otoliths and spawning marks. Conduct biannual aging workshops to maintain consistency and accuracy in aging fish sampled in state programs. | Already occurring and ASMFC released final report; No "Known-age Library Collection"; Age and growth staff need something more definitive to demine aging protocol for herring. When do we move from assessing to implementing improved techniques? | S | 2 | $$ |
| Improve methods to develop biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for river herring stocks. | Data quality is the limiting factor in previous assessments; Standardization of Sampling (i.e., weight more important than length?, timing of age samples?, scale or otolith?, etc.); Coast-wide workshop | S | 3 | $$ |
| Validate [better estimate] the different values of M for river herring stocks and improve methods for calculating M. Summarize existing information on predation by striped bass and other species and quantify consumption through modeling (e.g., MSVPA), diet, and bioenergetics studies. | Should be some guidance (Standardized Sampling Guidance Document?) on what to collect to help understand; As fisheries close, does it end up: Z=M+ bycatch; Predation factor; Long term and high priority limited by available data and methods used; | L | 4 | $$$$ |
| Investigate the relation between juvenile river herring production and subsequent year class strength, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, and life history requirements. | Gary Nelson (MDMF) has been working on this and presented results at ASF (August 2014); Convincing trends; Could be affecting M and productivity; The model had very little explanatory power and low predictive capabilities | L | 5 | $$$ |
| Continue genetic analyses to determine population stock structure along the coast and enable determination of river origin of incidental catch in non-targeted ocean fisheries. | Fisheries and Genetics subgroups working on it already; Include in Standardized Sampling Guidance Document; Increase genetic samples | S | 6 | $$$ |
| Undertake an analysis of the consequences of interaction between the offshore bycatch fishery and those in the rivers | Need to ID source stock; Stock level or River Level?; Difficult to link to past catches, but could be used moving forward; This is once source needed to move to more detailed population models (away from data poor) | L | 7 | $$$/$$$$ |
| Determine and quantify which stocks are impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxytetracycline otolith marking, genetic analysis, and/or tagging. | Emphasis on alternative tagging methods other than genetic; Stocking reduces the strength of genetic as only tool; | S | 8 | $$$/$$$$ |
| Improve reporting of harvest by water body and gear. | Lot of room for improvement in terms of detail; Standardize across states; | L | 9 | $$ |

| Identified Research Recommendation | Stock Status Subgroup Comments | Time Frame<br>"E" = Exists already<br>"S" = Short-term (1-3 yrs)<br>"L" = Long-term (3+ yrs) | Rank<br>1 = High<br>23 = Low | Relative Cost<br>$ = 1-9K<br>$$ = 10-99K<br>$$$ = 100-199K<br>$$$$ = >200K |
|---|---|---|---|---|
| Evaluate the use of large-scale hydro acoustic methods as a way to quantify river herring escapement (spawning run numbers) in major river systems | Promising work by Ogburn lab using DIDSON; Acknowledging that DIDSON is expensive equipment, additional work with DIDSON could potentially be expanded to increase the spatial area of DIDSON use. Very expensive, very time intensive work | L | 10 | $$$$ |
| Create a Sample Processing Repository/Fund Processing | Samples have been collected, but no money for process/analysis; It can be a bottleneck for projects; Developing an inventory of what is being collected by who is an important component; Not everybody is planning to do any post-processing of collected samples, but may be happy to provide samples to someone else for that purpose; Samples sent out or picked up for further analysis; Communication on how to store samples (can differ per analysis). | S | 11 | $$/$$$/$$$$ |
| Explore use of peer-reviewed stock assessment models for use in additional river systems in the future as more data become available. | Possible after more data collection begins; | L | 12 | $ |
| Develop models to predict the potential impacts of climate change on river herring distribution and stock persistence. | Overlaps Climate Change and Stock Status; Could be incorporated into Ecosystem-Based model; NEFSC examining how to include into MARSS modeling. | L | 13 | $$ |
| Inclusion of Canadian data | Less of an issue if future focus is on river system level; Having Canadian fish data at the stock levels would be important; DFO personal communication indicated possible poor species identification; Climate change modeling might be misleading (shift rather than contraction); Would benefit the assessment | S | 14 | $/$$ |
| Ecosystem Modeling | Has been discussed briefly at both subgroup meetings; What data sources are needed?; Would be a good direction to go into and no other subgroup is addressing it; Some efforts are underway but not ready for management at this point; Need to understand biomass and stock status before ecosystem models; With a species so apparently impacted by the environment, ecosystem modeling is not something to be kept on hold until we figure out biomass and stock status; Ecosystem modeling is meant to improve estimates of biomass and stock status by including environmental effects on biomass and stock status | L | 15 | $$$$ |
| Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring. | NOAA's MRIP is primarily focused on catch in marine waters and is not designed for anadromous fish that migrate up river where recreational fisheries occur. | L | 16 | $$ |

| Identified Research Recommendation | Stock Status Subgroup Comments | Time Frame<br>"E" = Exists already<br>"S" = Short-term (1-3 yrs)<br>"L" = Long-term (3+ yrs) | Rank<br>1 = High<br>23 = Low | Relative Cost<br>$ = 1-9K<br>$$ = 10-99K<br>$$$ = 100-199K<br>$$$$ = >200K |
|---|---|---|---|---|
| Consider the use of GLM to provide better trend estimates and to better characterize uncertainty in trends. | Easy to do and should be done in next assessment: Won't "make or break" understanding of stock dynamic; Data is already available, but not a good use of time; GLM removes some of the environmental variability in indices. | S | 17 | $ |
| Evaluate the performance of hatchery fish in river herring restoration. | USFWS in conjunction with MDNR are conducting a 6-yr project that does exactly this on the Patapsco River in Maryland; Do other efforts exist? Are methods comparable?; Don't think populations levels are at a point where hatchery production should be advocated for. | L | 18 | $$$ |
| Develop bottom and mid-water trawl CPUE indices of offshore biomass. | Very Low Priority; Strongly go against using fishery-dependent for CPUE; | L | 19 | $/$$$ |
| Development of better fish culture techniques and supplemental stocking strategies for river herring. | Stocking strategy that should take into consideration current scientific recommendations: use caution when stocking and use for only extirpated runs with geographically close source population; (See Palkovacs et al. 2013. Combining genetic and demographic information to prioritize conservation efforts for anadromous alewife and blueback herring. Evolutionary Applications. 7:212-226); See very little benefit from culture/hatchery enhancement; not incredibly supportive of trap and transport either. | S | 20 | $$$ |
| MARSS model | Investigate using just the offshore strata in order to extend the time series further back in time. Also, assume separate underlying states/stocks in the coastwide model and estimate how they interact with each other. Neither of these models are really that good now; As such put these as low priorities with higher priority of collecting improved data to facilitate the use of better models. | L | 21 | $$ |
| DBSRA model | Obtain a time-varying element for the carrying capacity (K) (versus an estimate for the parameters for the entire series). Explore use of index to tune model (X-DBSRA) | L | 22 | $$ |
| Investigate contribution of landlocked versus anadromous produced fish. | Important issues for this: 1) Collection of before and after data, 2) Setup viable impact evaluation study design before restoration project is implemented, 3) Continuation of monitoring of e.g. fishways after implementation; Don't think this should be on the research list for stock status | L | 23 | $$ |

Table B 1 – Summary of individual rankings of research needs from the TEWG Climate Change Subgroup, including average cost, time frame and comments. Cost is reflected as: $ =1-9K; $$ =10-99K; $$$ =100-199K, and $$$$ =>200K. Time frame is reflected as: "E" =Exists already, "S" =Short-term (1-3 yrs); and "L"=Long-term (3+yrs)

| Rank | Research Need | Average cost | Time frame | Comments |
|---|---|---|---|---|
| 1 | Environmental tolerances and thresholds (e.g., temperature, salinity, water flow, pH, DO) for all life stages | $$$ | E-S | Some information exists, but critical thresholds are not available for most life stages |
| 2 | Behavior and physiological studies related to climate sensitive environmental variables | $$$ | S-L | |
| 3 | Need continuous data on river flow and temperature in same systems where adults and juveniles are monitored | $$ | S-L | This means adding river flow and temp measurements to rivers that are monitored for river herring; coupling USGS with state monitoring efforts |
| 4 | Need river run and juvenile survival data measured with same methods along a latitudinal gradient | $$$ | S-L | |
| 5 | Historical relationships between river herring abundance and distribution with environmental variables | $$$ | E-S | Some studies exist, but need comparison and wide geographic range |
| 6 | A population model that would allow exploration of the relative influence of climate change vs. other factors such as habitat alteration, fishing, bycatch etc. | $$$ | S-L | Build upon MARSS model by K. Curti |
| 7 | Link historical river runs to water temperatures and flow | $$ | E-S | |
| 8 | Environmental cues that lead to spawning migration and juvenile egress | $$ | E-L | |

| Rank | Research Need | Average cost | Time frame | Comments |
|---|---|---|---|---|
| 9 | Impacts of stream flow on passage and interaction with barriers | $$$ | S-L | Need this before we can apply climate scenarios |
| 10 | Quantify optimal habitat for all life stages historically and in the future | $$$ | S-L | |
| 11 | Continuous climatologies for marine estuarine and freshwater habitat | $$$ | E-L | Challenging because of different data types |
| 12 | Development of models and methods to project effects of climate change into the future | $$$ | S-L | |
| 13 | More information on river herring at the extremes of the range to see the most acute climate change effect (e.g., on blueback herring in the St. Johns River, Florida; alewife in North Carolina) | $$$ | S-L | Time series analysis will be long term because it will take time to collect enough annual data |
| 14 | Baseline habitat information to provide foundation for temporal and spatial comparisons | $$ | S-L | Need to know more about tidal freshwater and estuarine habitat use especially for blueback herring. Should be done by habitat group |
| 15 | Downscaled temperature, snow pack, and stream flow climate projections seasonal in both marine and freshwater systems at a high spatial resolution | $$$ | S-L | Exists for land variables by NARCCAP, IS NARCCAP being updated with AR5 models? |
| 16 | Linking river herring to dynamical and statistical downscaling products | $ | E-L | |

| Rank | Research Need | Average cost | Time frame | Comments |
|---|---|---|---|---|
| 17 | Homing rates to determine how quickly fish may be able to adapt to change | $$$ | E-L | |
| 18 | How flood types and timing affect recruitment, migration timing (of adults and juveniles), juvenile growth and juvenile survival | $$$ | S-L | |
| 19 | Statistical downscaling of temperature and river flow | $$ | E-L | |
| 20 | How flood magnitudes and frequencies in watersheds changes in systems impacted by human development and those that are not | $$$ | E-L | Not useful until we know more about fish passage under different flow regimes |
| 21 | Dynamical downscaling of the nearshore environment to assess prey field for juveniles entering the marine habitat | $$$ | S-L | |
| 22 | Ocean acidification impacts | $$$ | S-L | |
| 23 | High resolution elevation models to project inundation due to sea level rise to project river herring inshore habitat | $$$ | S-L | Not useful until we know more about inshore habitat use |
| 24 | Historical change or future projections in flood timing for the Northeast | $$-$$$ | S-L | USGS model applied nationwide |
| 25 | How climate change and environmental factors influences hybridization rates | $$$ | S-L | Need to know success of hybrids first, seems premature until we know more about hybrids in general |

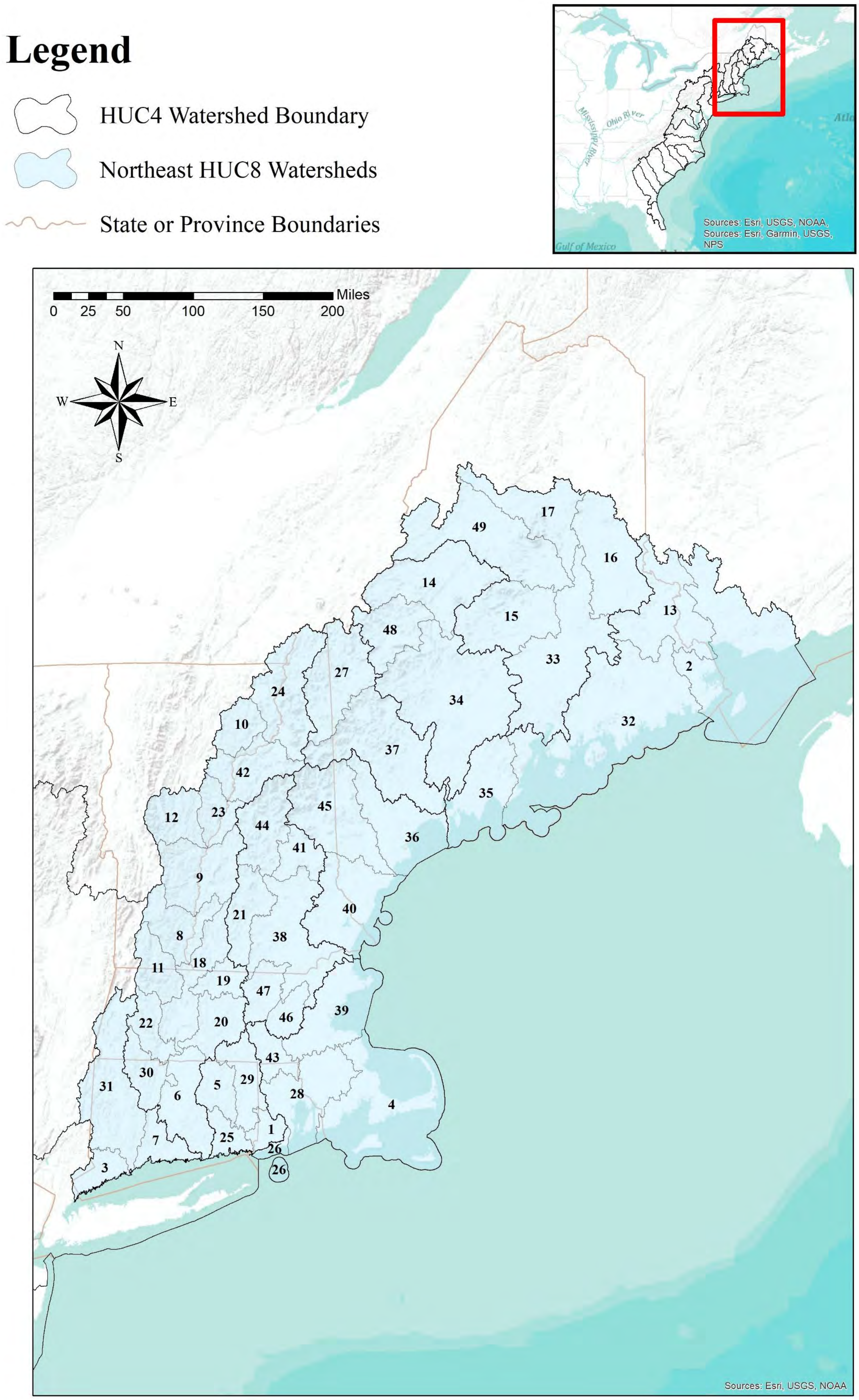


Figure B 1 – HUC8 watersheds considered in the HCP, New England region. (For reference, watershed numbers correspond HUC8 ID column in Table 6)

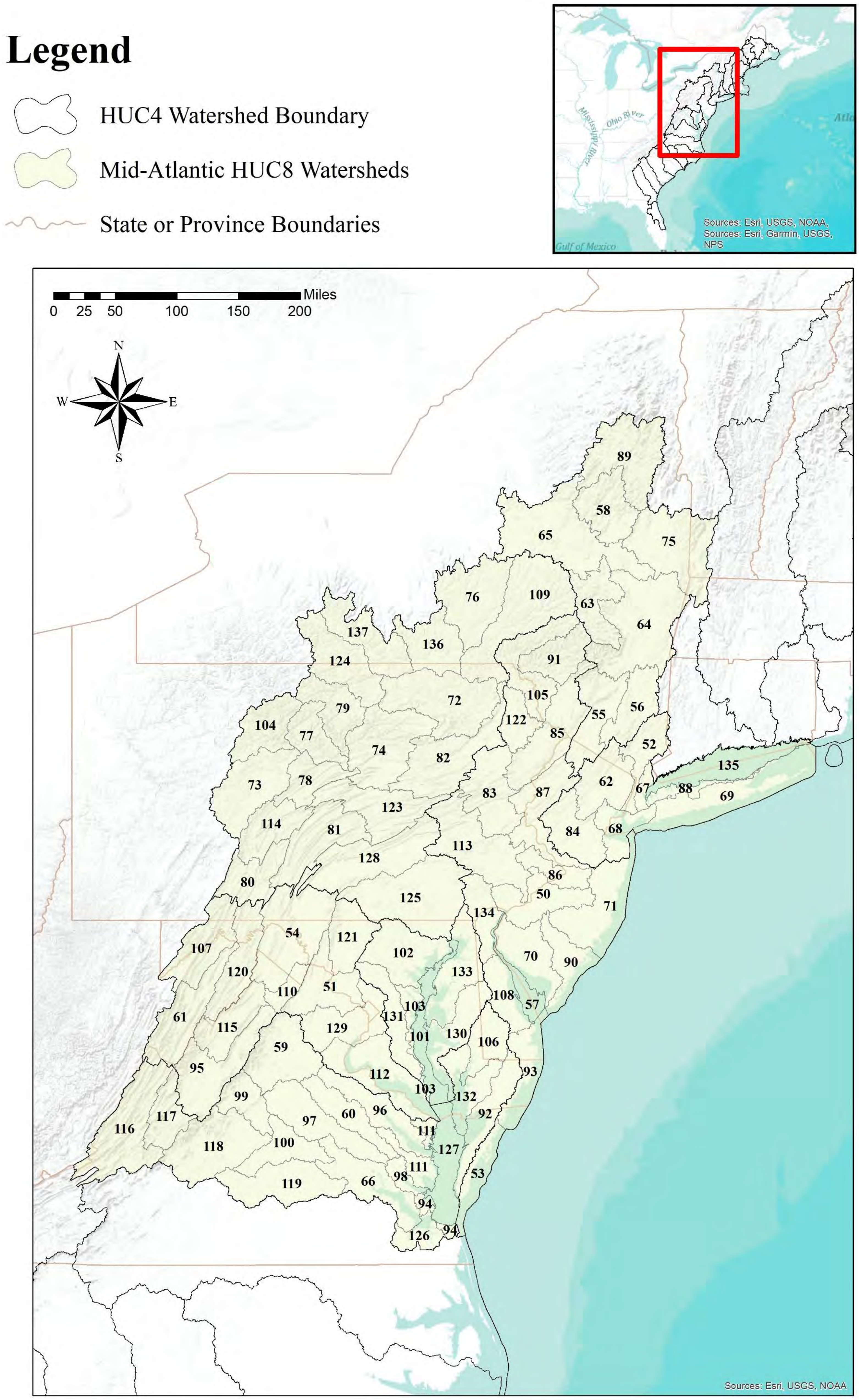


Figure B 2 – HUC8 watersheds considered in the HCP, Mid-Atlantic region. (For reference, watershed numbers correspond HUC8 ID column in Table 6)

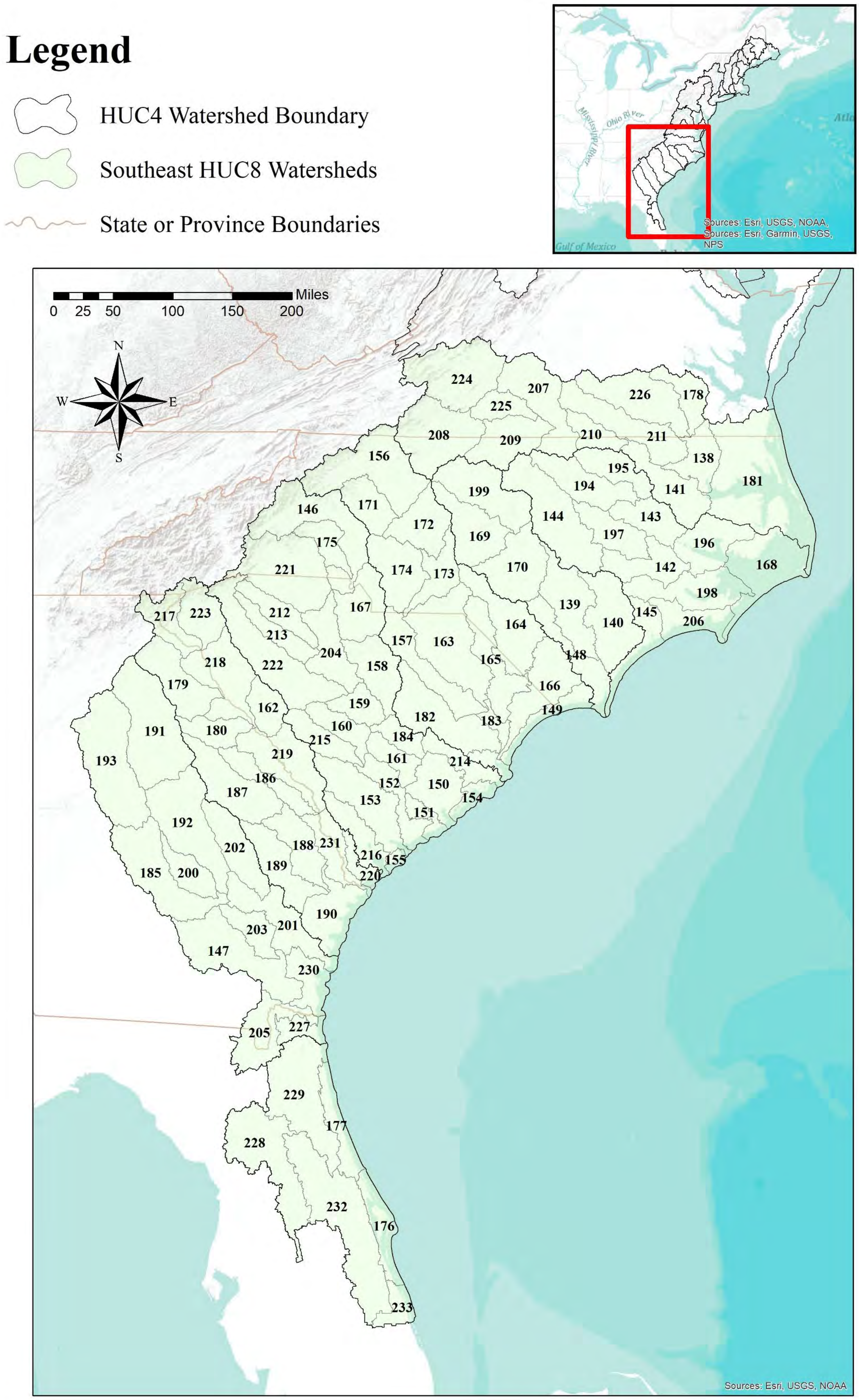


Figure B 3 – HUC8 watersheds considered in the HCP, Southeast region. (For reference, watershed numbers correspond HUC8 ID column in Table 6)

Table B 2–HUC4 watersheds considered in this HCP and the current FERC approved comprehensive management plans as well as other plans focused on the management of either river herring species, or diadromous fish in general

| HUC Number | Watershed | FERC Approved RH Plan? | Title of FERC Plan | Title of Other RH Plans |
|---|---|---|---|---|
| 0102 | Penobscot | Yes | **MDMR (2008)** *Strategic Plan for the Restoration of Diadromous Fishes to the Penobscot River*<br>**MDMR (2009)** *Operational Plan for the Restoration of Diadromous Fishes to the Penobscot River* | |
| 0103 | Kennebec | No | | **MDMR (2020)** *Kennebec River Management Plan Diadromous Resources Amendment*<br>**Maine State Planning Office (1993)** *Kennebec River Resource Management Plan* |
| 0104 | Androscoggin | Yes | **NMFS (2020)** *Androscoggin River Watershed Comprehensive Plan for Diadromous Fish* | **MDMR (2006)** *Androscoggin River Anadromous Fish Restoration Program* |
| 0105 | ME Coastal | No | | ***USFWS and NMFS (2018)** *Recovery plan for the Gulf of Maine Distinct Population Segment of Atlantic salmon (Salmo salar)*<br>**Dill et al. (2010)** *An Adaptive Plan for Managing Alewife in the St. Croix River Watershed, Maine and New Brunswick*<br>**McLean et al. (2007)** *Sheepscot River Watershed Management Plan*<br>**MDMR (2020)** *Maine Herring Sustainable Fishing Plan Update (with revisions for recreational fishery)* |
| 0106 | Saco | Yes | **USFWS (1987)** *Saco River strategic plan for fisheries management* | |
| 0107 | Merrimack | Yes | **TCAFMMRB (2021)** *Merrimack River Watershed Comprehensive Plan for Diadromous Fishes* | ***PCAFMMRB (1985)** *A strategic plan for the restoration of Atlantic salmon to the Merrimack River Basin, 1985 through 1999*<br>***MRTC (1990)** *Strategic plan for the restoration of Atlantic salmon to the Merrimack River, 1990 through 2004* |
| 0108 | Connecticut | Yes | **CRASC (2020)** *Connecticut River American Shad Management Plan*<br>**TCFMCR (1981)** *Connecticut River Basin fish passage, flow, and habitat alteration considerations in relation to anadromous fish restoration* | **USFWS (2020)** *Connecticut River Basin Anadromous Fish Restoration: Coordination and Technical Assistance*<br>**CRASC (2003)** *Management Plan for River Herring in the Connecticut River Basin* |

| HUC Number | Watershed | FERC Approved RH Plan? | Title of FERC Plan | Title of Other RH Plans |
|---|---|---|---|---|
| 0109 | MA-RI Coastal | Yes? | **RIDEM & NBEP (2002)** *Blackstone River Fisheries Restoration Plan* | **RIDEM (2002)** *Strategic Plan for the Restoration of Anadromous fishes to Rhode Island Coastal Streams*<br>**MDMF (2022)** *Massachusetts River Herring Sustainable Fishery Management Plan*<br>**NHFGD (2020)** *New Hampshire ASMFC River Herring Sustainable Fishing Plan* |
| 0110 | CT Coastal | Yes? | **CDEP (2009)** *The plan to restore diadromous fishes to the Shetucket River watershed*<br>***RIDFW & USFWS (1981)** *A strategic plan for the restoration of Atlantic salmon to the Pawcatuck River* | |
| 0202 | Upper Hudson | No | | **NYSDEC (2016)** *Sustainable Fishery Management Plan for NY River Herring Stocks*<br>**NYSDEC (2022)** *Recovery Plan for Hudson River American Shad (Draft)* |
| 0203 | Lower Hudson-Long Island | No | | **SEA (2020)** *Long Island Diadromous Fish Restoration Strategy* |
| 0204 | DE-Mid Atlantic Coastal | No | | **DRBFWMC (2011)** *Delaware River Sustainable Fishing Plan for American Shad*<br>**PAFBC (2011)** *Delaware River Management Plan*<br>**TNC (2022)** *Delaware River Basin Restoration Roadmap for American Shad, Alewife and Blueback Herring* |
| 0205 | Susquehanna | Yes | **USFWS (2010)** *Migratory fish management and restoration plan for the Susquehanna River Basin*<br>**SRBC (2021)** *Comprehensive plan for the water resources of the Susquehanna River Basin* | |
| 0206 & 0208 | Upper and Lower Chesapeake | Yes | **USFWS (1989)** *Chesapeake Bay Alosid (shad and river herring) management plan* | **SERC (2015)** *Chesapeake Bay River Herring Monitoring Plan*<br>***MDNR (2021)** *American Shad Habitat Plan for Maryland* |
| 0207 | Potomac | No | | |

| HUC Number | Watershed | FERC Approved RH Plan? | Title of FERC Plan | Title of Other RH Plans |
|---|---|---|---|---|
| 0301 | Chowan-Roanoke | Yes | **NCDENR (2000)** *Basinwide assessment report: Roanoke River Basin*<br>**NMFS (2016)** *Roanoke River Diadromous Fishes Restoration Plan* | **SARP & TNC (2005)** *Conserving the Roanoke River: Conservation Action Plan*<br>**NCDMS & NCDEQ (2018)** *Roanoke River Basin Restoration Priorities* |
| 0302 | Neuse-Pamlico | Yes | **NCDEHNR (2012)** *Comprehensive conservation and management plan: Albemarle-Pamlico estuarine study* | **NCDMS & NCDEQ (2010)** *Neuse River Basin Restoration Priorities*<br>**NCDMS & NCDEQ (2009)** *Tar-Pamlico River Basin Restoration Priorities* |
| 0303 | Cape Fear | Yes | **CFRBP (2013)** *Cape Fear River Basin Action Plan for Migratory Fish* | **NCDMS & NCDEQ (2009)** *Cape Fear River Basin Restoration Priorities* |
| 0304 | Pee Dee | Yes | **USFWS (2008)** *Restoration plan for the diadromous fishes of the Yadkin-Pee Dee River Basin* | |
| 0305 | Edisto-Santee | Yes | **NMFS (2017)** *Santee Basin Diadromous Fish Passage Restoration Plan* | |
| 0306 | Ogeechee-Savannah | Yes | **USFWS (1994)** *Elements of consensus on American shad management in the stretch of Savannah River between Strom Thurmond (Clarks Hill) Dam and Augusta*<br>**USFWS & NMFS (2005)** *Diadromous fish restoration plan for the Middle Savannah River: strategy and implementation schedule* | **GADNR & SCDNR (2020)** *American Shad Habitat Plan for the Savannah River*<br>**SCDNR (2020)** *Blueback Herring Sustainable Fishing Plan Update for South Carolina*<br>**SCDNR (2020)** *River Herring Alternative Management Plan for South Carolina* |
| 0307 | Altamaha-St. Marys | Yes* | ***USFWS (2013)** *Priority restoration and management actions for the American shad in the Altamaha River Basin* | **GDNR (2014)** *American Shad Habitat Plan*<br>**GDNR (2020)** *ASMFC Alternative Management Plan for River Herring for Georgia*<br>**SARP & TNC (2005)** *Conserving the Altamaha River Watershed* |
| 0308 | St. Johns | No | | **FFWCC (2020)** *Alternative Management Plan for Shad and River Herring in Florida* |

Table B 3 – Requirements for a watershed plan to meet the FERC Comprehensive plan (CP) standards.

| FERC CP should contain the following: | Description of the significant resources in the area should contain: |
|---|---|
| Description of the waterway or waterways that are the subject of the plan, including pertinent maps detailing the geographic area of the plan | Navigation |
| Description of the various existing and planned uses for these resources | Power Development |
| Discussion of goals, objectives, and recommendations for improving, developing, or conserving the waterway or waterways in relation to these resources | Energy Conservation |
| Description of the significant resources of the waterway or waterways | Fish and Wildlife |
| An examination of how the different uses will promote the overall public interest | Recreational Opportunities |
| | Irrigation |
| | Flood Control |
| | Water Supply |
| | Other Aspects of Environmental Quality |

Table B 4 – The three major components to an ASMFC approved Shad Habitat Plan (Habitat and Threats Assessment, and Habitat Restoration Program) and the detailed suggested to satisfy those components.

| Habitat Assessment | Threats Assessment | Habitat Restoration Program |
|---|---|---|
| Assess the habitat (historic and currently available) and impediments to full utilization of the habitat | Barriers to migration inventory and assessment | Barrier removal and fish passage program |
| i. Amount of historical in-river and estuarine spawning and rearing habitat | Water withdrawals inventory and assessment | Hatchery product supplementation program |
| ii. Amount of currently accessible in-river and estuarine spawning and rearing habitat | Toxic and thermal discharge inventory and assessment | Water quality improvement program |
| | Channelization and dredging inventory and assessment | Habitat improvement program |
| | Land use inventory and assessment | Project permit/licensing review program for water withdrawals, toxic and thermal discharge, channelization and dredging, and land use and development, that includes development of recommendations and conditions to avoid, minimize, or mitigate associated impacts to American shad migration and utilization of historic habitat |
| | Atmospheric deposition assessment | Programs to avoid, minimize, or mitigate associated impacts to American shad migration and utilization of historic habitat from atmospheric deposition and climate change |
| | Climate change assessment | |
| | Competition and predation by invasive and managed species assessment | |

Table B 5 – The components to an ASMFC Shad Sustainable Fisheries Plan Document.

| ASMFC Shad SFP Components |
|---|
| Request for fisheries |
| Definition of sustainability |
| Summary of current stock status |
| Benchmark goals and objectives or restoration goals/targets |
| Proposed time frame for achievement |
| Discussion of management measures to be taken if sustainable target is not achieved within indicated timeframe |

Table B 6 – EPA Guidance regarding the Nine Minimum Elements of a Watershed-Based Plan.

| EPA Nine Elements to a Watershed-Based Plan |
|---|
| Identify causes and sources of pollution that need to be controlled |
| Determine load reductions needed |
| Develop management measures to achieve goals |
| Develop implementation schedule |
| Develop interim milestones to track implementation of management measures |
| Develop criteria to measure progress towards meeting watershed goals |
| Develop monitoring component |
| Identify technical and financial assistance needed to implement plan |

Table B 7 – Select restoration projects from the New England Region, including the HUC4 system, agencies involved, techniques used and timeline. Restoration Techniques: B =”Barrier Removal(s), P =”Passage or Fishway”, R =”Riparian/Stabilization Work”, S =”Stocking/Trucking”.

| Region | HUC4 System | Project Name | River/Location | State | Select Entities Involved | Timeline | Restoration Techniques |
|---|---|---|---|---|---|---|---|
| NE | 102 | Wight and Pierce Ponds Alewife Project | Bagaduce River | ME | Many | 2017-2018 | B, P |
| NE | 102 | Penobscot River Restoration Project | Penobscot River | ME | Many | 1999-2013 | B, P, S |
| NE | 103 | River Herring Restoration at Nequasset Brook | Nequasset Brook | ME | Many | 2012-2015 | P |
| NE | 103 | Kennebec River Restoration | Kennebec River | ME | Many | 1997 | B, P, S |
| NE | 103 | Outlet Stream Fish Passage and Dam Removal | Outlet Stream | ME | Many | Ongoing | B, P |
| NE | 105 | West Branch Brook Culvert Replacement | Narraguagus River | ME | Many | 2018-2021 | B |
| NE | 105 | Tidmarsh Farm-Beaver Dam Brook Removal | Maine Coastal | ME | Many | 2014-2017 | B, P, R |
| NE | 105 | Patten Stream Fish Passage | Patten Stream | ME | Many | 2013-2016 | P |
| NE | 105 | Sheepscott River Barrier Removal | Sheepscott River | ME | Many | 2015-2018 | B |
| NE | 105 | Restoring Fish Passage to Shorey's Brook | Shorey's Brook | ME | Many | 2011-2012 | B |
| NE | 105 | Exeter Dam Removal | Exeter, NH | NH | Town of Exeter, NHFGD, UNH | 2016 | B, R |
| NE | 105 | Sawyer Mill Dam Removals | Bellamy River | NH | USFWS, NHCP, NHDFG | 2018-2021 | B |
| NE | 108 | Ed Bill Dam Removal | Eight Mile River | CT | NOAA RC, TNC, AR | 2010-2016 | B |
| NE | 108 | Mill Brook Restoration Projects | Mill Brook | CT | Many | 2000-2021 | P, S |
| NE | 109 | Saugatucket River Fish Passage | Saugatucket River | RI | Many | 2014-2016 | P |
| NE | 109 | Pawcatuck River Restoration | Pawcatuck River | CT/RI | Many | 2006-2023 | B, P |
| NE | 109 | Jones River Restoration Work | Jones River | MA | MDMF, JRWA, Town of Kingston | 2017-2020 | B |
| NE | 109 | Coonamessett Passage and Habitat Improvement | Coonamessett River | MA | Many | 2017-2020 | B, R |
| NE | 109 | Shawsheen River Dam Removals | Shawsheen River | MA | Many | 2013-2017 | B |
| NE | 109 | Mill River Dam Removal and Fishway | Mill River | MA | Many | 2008-2018 | B, P |
| NE | 109 | Horseshoe Mill Dam Removal | Weweantic River | MA | BBC, NOAA RC | 2020 | B |
| NE | 109 | Armstrong Dam Removal | Braintree, MA | MA | Town of Braintree | 2021 | B, P |
| NE | 109 | Fish Passage on the Satucket River | Satucket River | MA | Many | 2015-2019 | B, P |
| NE | 109 | Town Brook Stream Restoration | Town Brook | MA | Many | 2002 | P |
| NE | 109 | Saugatucket River Fishways | Saugatucket River | RI | NOAA, RIDEM, USFWS | 2014-2016 | P, R |
| NE | 109 | Hunters Pond and Bound Brook Restoration | Town of Scituate, MA | MA | Many | 2017-2017 | B, R |
| NE | 109 | Satucket River Restoration Project | Tauton and Satucket River | MA | Many | 2017-2018 | B |
| NE | 109 | Herring River Restoration Project | Welfleet, MA | MA | Many | Currently in planning | B, P, R |
| | 110 | Hyde Pond Dam Removal | Whitford Brook | CT | CT Fund for the Environment, Save the Sound | 2019 | B |
| | 110 | Pequonnock River Fishways | Pequonnock River | CT | CTDEEP, Save the Sound | 2002-2009 | P |
| | 110 | Bride Brook Pipe Replacements | Bride Brook | CT | Many | 2009 | B |

Table B 8 – Select restoration projects from the Mid-Atlantic Region, including the HUC4 system, agencies involved, techniques used and timeline. Restoration Techniques: B =”Barrier Removal(s), P =”Passage or Fishway”, R =”Riparian/Stabilization Work”, S =”Stocking/Trucking”.

| Region | HUC4 System | Project Name | River/Location | State | Select Entities Involved | Timeline | Restoration Techniques |
|---|---|---|---|---|---|---|---|
| Mid-A | 202 | Wynants Kill Barrier Removal | Hudson River | NY | Many | 2017 | B |
| Mid-A | 203 | Scoy and Staudinger's Pond Access | East Hampton | NY | Peconic Estuary Program, others | 2010 | B |
| Mid-A | 204 | Burnt Mill Dam Removal | Lamington River | NJ | USDA NRCS, USFWS, RHA | 2019-2020 | B, R |
| Mid-A | 204 | Brandywine River Dam Removals | Brandywine River | DE | NFWF, NOAA, DNREC | 2017-2019 | B |
| Mid-A | 204 | Columbia Dam Removal | Paulins Kill | NJ | TNC, NJDEP, USFWS, AR | 2014-2019 | B, P, R |
| Mid-A | 204 | Weston Mill Dam Removal | Millstone River | NJ | NJDEP, NOAA, USFWS | 2013-2017 | B |
| Mid-A | 204 | Hughesville Dam Removal | Musconetcong River | NJ | MWA, USFWS, NJDEP, NOAA, Conservation Resources Inc., Watershed Institute | 2012-2016 | B, P, R |
| Mid-A | 204 | White Clay Creek Dam Removals | White Clay Creek | DE | NOAA, AR, DNREC | 2011-2014 | B |
| Mid-A | 204 | Finesville Dam Removal | Musconetcong River | NJ | MWA, USFWS, NJDEP, NRCS, AR TU, NOAA | 2007-2011 | B, P |
| Mid-A | 204 | Army Creek Marsh Restoration | Pickering Beach | DE | USFWS, DNREC | 2021 | B, R |
| Mid-A | 206 | Bloede Dam Removal | Patapsco River | MD | MDNR, NOAA RC, AR | 2000-2018 | B, S |
| Mid-A | 208 | Embrey Dam Removal | Rappahannock River | VA | VADWR, USACE, AR, Friends of the Rappahannock | 1994-2005 | B |
| Mid-A | 208 | Walkers Dam | Chickahominy River | VA | Newport News, VADWR, USFWS | 2010-2015 | P |
| Mid-A | 208 | Harvell Dam Removal | Appomattox River | VA | VADWR, USFWS, NOAA, EPA CBP, AR | 2014 | B, P |
| Mid-A | 208 | White Oak Run Pool and Weir | Rappohannock Drainage | VA | VADWR, USFWS, VCU, TNC, VDOT, USACE | 2003-2005 | P |

Table B 9 – Select restoration projects from the Southeast Region, including the HUC4 system, agencies involved, techniques used, and timeline. Restoration Techniques: B =”Barrier Removal(s), P =”Passage or Fishway”, R =”Riparian/Stabilization Work”, S =”Stocking/Trucking”.

| Region | HUC4 System | Project Name | River/Location | State | Select Entities Involved | Timeline | Restoration Techniques |
|---|---|---|---|---|---|---|---|
| SE | 301 | Merchants Mill Pond Fish Ladder | Chowan River | NC | USFWS, NCWRC, NC Parks, NCDMF, NCDOT | 2005 | P |
| SE | 301 | Dillards Mill Pond Fish Ladder | Chowan River | NC | USFWS, NCDMF | 2006 | P |
| SE | 301 | Phelps Lake Cypress Log Ladder | Scuppernong River | NC | USFWS, NCWRC | 2006 | P |
| SE | 301 | Hoggards Mill Pond | Cashie River | NC | USFWS | 2012 | P |
| SE | 301 | Big Swash Culvert Replacements | Roanoke River | NC | NCWRC, TNC, USFWS | 2019-2021 | B, P |
| SE | 302 | Water Control Structure Improvements | Mattamuskeet | NC | USFWS | 2014-2016 | P |
| SE | 302 | Quaker Neck Dam Removal | Neuse River | NC | NCDWR, NCWRC, EPA | 1998 | B |
| SE | 302 | Milburnie Dam Removal | Neuse River | NC | Restoration Systems Inc. | 2017 | B |
| SE | 302 | Cherry Hospital Dam Removal | Little River | NC | USFWS | 1998 | B |
| SE | 302 | Rain Mills Dam Removal | Little River | NC | USFWS | 1999 | B |
| SE | 302 | Lowell Mill Dam Removal | Little River | NC | USFWS | 2005 | B |
| SE | 303 | Cape Fear River LD-1 | Cape Fear River | NC | USACE | 2012 | B, P |
| SE | 305 | Long Branch Creek Culvert Replacements | Long Branch Creek | SC | City of Charleston, SCDNR | 2013 | B, P |

Table B 10 – Summary of ASMFC Shad and River Herring TC state-by-state responses when asked for their research and restoration priorities over the next 5 to 10 years (As of June 2022). Table will be updated as more responses become available.

| State | Research and Monitoring Priorities | Restoration Priorities |
|---|---|---|
| Maine | No Response | No Response |
| New Hampshire | Measure of juvenile emigration or productivity *(i.e. How many fish are produced in each herring run? Can fish easily migrate out of river systems and impoundments? Is there enough flow over dams for them to go out?)*<br>Identify quality and quantity of spawning habitat to assist in making future decisions on dam removal and other river restoration projects<br>Identify and inventory other river herring runs in NH coastal rivers that are not currently monitored | Construct a fishway at the Oyster River Reservoir Dam in Durham. *This currently the second dam on the Oyster River (the first dam is to be removed in 2023)*<br>Provide fish passage at the Wadleigh Falls Dam on the Lamprey River in Lee<br>Provide fish passage at the second, third, and fourth dams on the Salmon Falls River *(These dams are currently all up for FERC relicensing)* |
| Massachusetts | No Response | No Response |
| Rhode Island | No Response | No Response |
| Connecticut | No Response | No Response |
| New York | No Response | The SFMP for NY river herring (Eakin et al. 2016) listed side channel restoration as an important effort to improve habitat for river herring. Many of these habitats have been destroyed or degraded within the Hudson River estuary. Eakin et al. (2016) also provided potential locations for side channel restoration. |
| New Jersey | No Response | No Response |
| Delaware | eDNA survey to understand herring distribution better within the Delaware river basin | The Delaware River Basin Fish Passage Prioritization Tool ranks restoration projects by highest to lowest priority. A link to this web tool can be found in Table X. |

| State | Research and Monitoring Priorities | Restoration Priorities |
|---|---|---|
| Maryland | Continue and expand a fishery-independent experimental gill net survey to further clarify whether current trends are a result of true changes in population abundance or just sampling variability<br>Continue to assess alosine habitat use across a gradient of development to explore the effects of urbanization on spawning habitat<br>Investigate the impact invasive predators have on river herring populations. Particularly, blue catfish, flathead catfish, and northern snakehead<br>Continued monitoring of how climate change impacts river herring species, particularly, rising water temperatures and increases in freshwater flows | MDNR Fish Passage Program (FPP) will continue to work to remove stream blockages such as dams, and provide fish passage when removal is not an option.<br>The FPP currently has plans for the removal of three more dams, as well as improvements to a natural bypass at another site. |
| DC | No Response | No Response |
| Virginia | VDWR Fish Passage Project will continue to monitor the river herring runs on several Virginia Chesapeake Bay tributaries to assess run strength using fishery independent sampling methods (electrofishing and fishway monitoring such as Walkers Dam fishway electronic fish counter and exit trapping).<br>Multiple partners (state, federal, academic, NGO) are working together to assess road-stream crossings to identify and prioritize barriers to herring migration. | VDWR Fish Passage Project will continue to work to remove stream blockages such as dams and provide fish passage when removal is not an option. Various partnerships are currently working on plans for two large dam removals on significant Chesapeake Bay tributaries. Herring passage (full AOP) at road-stream crossings is a priority of VDWR and its partners. |
| North Carolina | No Response | No Response |
| South Carolina | No Response | No Response |
| Georgia | Continue ongoing creel survey of anglers targeting river herring to identify potential angling effort in the Altamaha River.<br>Run a similar creel survey on the Savannah River in conjunction with the SCDNR<br>Continue to monitor population through fishery-independent sampling of American shad | |
| Florida | No Response | No Response |

## Appendix C: Restoration Project Showcase: Techniques, Successes, and Lessons Learned

### C 1.1 Introduction

This section contains a collection of restoration projects implemented along the Atlantic coast (Figure C 1) that demonstrate various techniques for restoring river herring habitat and re-establishing connectivity. The projects were selected to represent the diversity of techniques, site conditions, and issues addressed in restoration efforts.[55] This section is designed to provide the reader with successful project examples to highlight techniques used, common challenges, funding sources, and "lessons learned" that can be applied to future restoration efforts. Due to the unique nature of these projects, the included section headings, background information, and project details differs among showcase projects.

Several authors, reviewers, and contributors from various agencies helped develop this Restoration Project Showcase. Below is a list detailing the contributions made to each showcase project:

Bagaduce River Watershed Restoration Efforts

- Jonathan Watson, NOAA Fisheries GAR HESD
- Ciona Ulbrich, Maine Coastal Heritage Trust (MCHT)
- Mike Thalhauser, Maine Center for Coastal Fisheries (MCCF)
- Michael Brown, MDMR
- Matt Bernier, NOAA Fisheries RC

Sebasticook River Restoration

- Sean McDermont, NOAA Fisheries

Coonamessett River Passage and Habitat Improvement

- James Turek, NOAA Fisheries RC

[55] For a larger list of restoration projects coastwide, see Appendix Table B 7–Table B 9.

Herring River Estuary Restoration Project

Steve Block, NOAA Fisheries RC

Pawcatuck River Restoration

James Turek, NOAA Fisheries RC

Columbia Dam Removal on the Paulins Kill

Beth Styler Barry, TNC

Patapsco River Dam Removals

Jonathan Watson, NOAA Fisheries GAR HESD

Mary Andrews, NOAA Fisheries RC

William Harbold, MDNR

Embrey Dam Removal: Upper Rappahannock Diadromous Fish Restoration

Alan Weaver, VADWR

Lower Roanoke River Floodplain Restoration: Passage Improvements on Big Swash

Jeremy McCargo, NCWRC

Neuse River Basin Restoration

Mike Wicker, USFWS

Wilson Laney, NCSU

Cape Fear River, Nature-Like Fishway

Fritz Rohde, NOAA Fisheries SER HCD

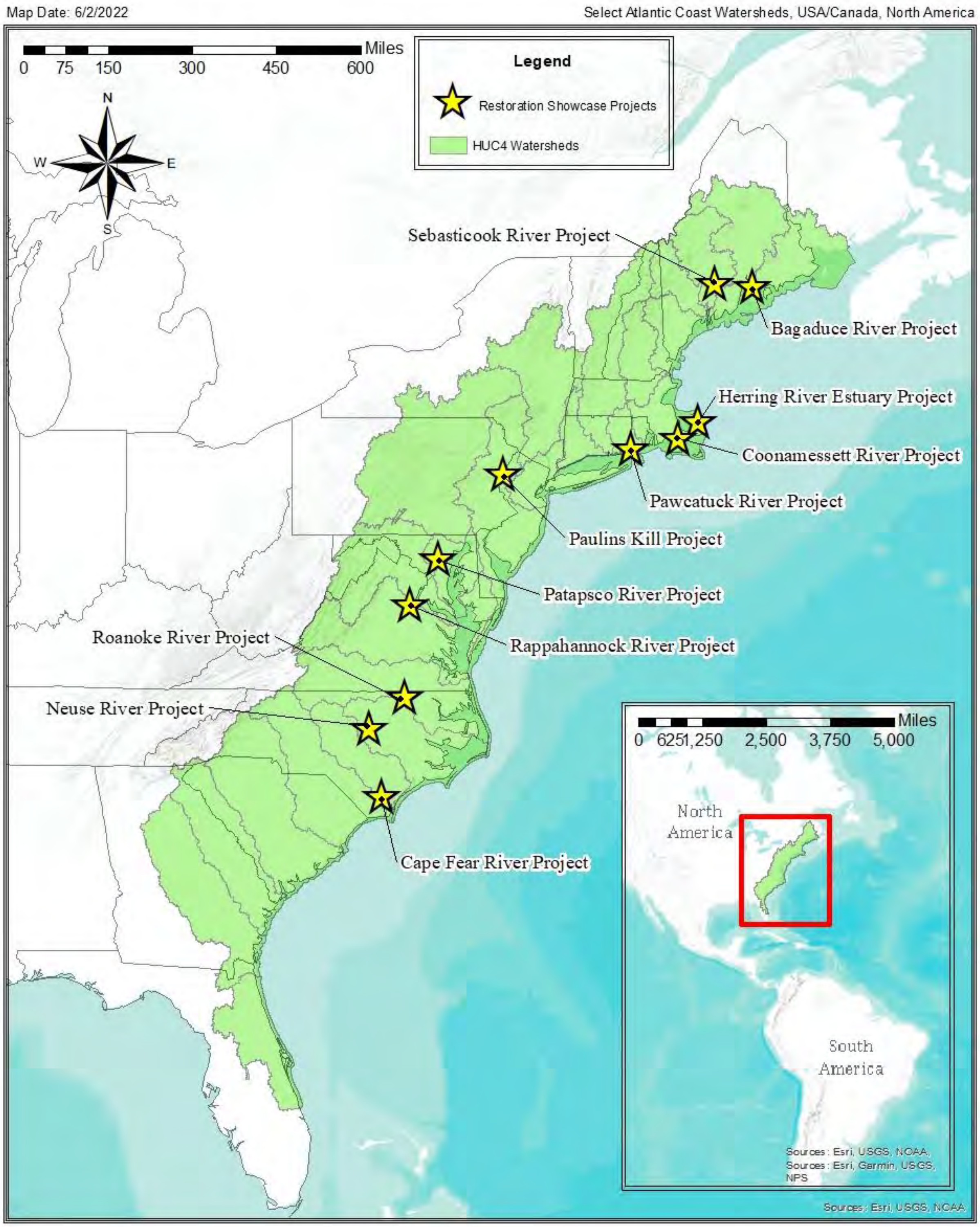


Figure C 1 – Locations of the 11 showcased restoration projects (stars) within the 24 HUC4 watersheds (green).

## C 1.2 Bagaduce River Watershed Restoration Efforts

### C 1.2.1 Background

*Historical Context*

At 8,570 square miles, the Penobscot River watershed is the largest in Maine and the second largest in New England. Historically, it supported vast populations of diadromous fishes, which provided sustenance to native peoples from several tribes that compose the Wabanaki Confederacy. Following European colonization and the subsequent expansion of the timber industry in the 19th century, many dams were constructed throughout the watershed to facilitate log drive activities and support mill operations. These included several timber dams on the mainstem Penobscot River near Bangor, Maine. Several of these sites were later converted to modern hydroelectric facilities in the early twentieth century. The construction of the various dams on the mainstem Penobscot River and its tributaries was a major factor leading to the decline of anadromous fish runs throughout the watershed (Saunders et al. 2006; Hall et al. 2012). Additional information regarding the Penobscot River watershed is presented in Section 7.2.1.

Figure C 2 – Alewife congregate at the entrance to Walker Pond. Credit: Tate Yoder/MCCF.

*Bagaduce River Fish Passage Enhancement Projects*

In an effort to enhance migratory connectivity for alewife and other diadromous species, fish passage enhancement projects were recently completed at existing dams and a road crossing in the Bagaduce River watershed in the Maine towns of Penobscot, Sedgwick, and Brooksville. The Bagaduce River is located in the lower Penobscot River basin. The Bagaduce River fish passage enhancement projects included installation of a nature-like fishway (NLF), existing fishway improvements, and culvert replacement at five different locations with the primary goal to restore or enhance access for the benefit of diadromous species. Alewife, in particular, benefitted from enhanced access to over 1,268 acres of ponds historically used for spawning and rearing. Access was also restored to more than 30 stream miles upon completion of the projects. Several public benefits were incorporated into the overall project plan and included improvements for public access and recreation, such as walking trails, safe boating access, and interpretive signage.

Several of these projects involved addressing passage issues associated with historical dams, which had fallen into disrepair. At the Walker Pond Mill Pond site (Figure C 2) for example, the construction of a dam in the late eighteenth century nearly extirpated the returning alewife run. For approximately a decade following dam construction, local residents carried alewife above the dam using baskets until a fishway was later dug around the dam. The mill building burnt down in the 1960s, and the dam and associated fishway were in need of repair, which was completed as part of this larger effort. Collectively, these efforts demonstrate a multifaceted approach to enhancing connectivity in a relatively small, but extremely productive coastal system.

### C 1.2.2 Restoration Goals

Goals included:

- Improved alewife passage (upstream/downstream) throughout watershed and enhanced passage for other diadromous species. Goals related to passage include:
    - Water level maintenance of upstream ponds for wading bird and waterfowl habitat and for recreation.

    - Improved upstream passage through the replacement of existing structures and stream blockages
    - Improved downstream passage for juvenile alewife through the installation of plunge pool structures
- Enhanced infrastructure/community resiliency
    - Dam safety improvements at existing/historical structures
    - Replacement of a perched and undersized culverts
    - Public safety improvements through the installation of an off road, dry hydrant for firefighting water supply in one pond (Walker Pond Mill Pond)
    - Use of local stone and materials as possible, including some donated by landowners to help lower costs and match local aesthetics
- Historical preservation of existing structures and public awareness-building through the installation of interpretive signage
- Enhanced public access through land acquisition, trail construction, and hand-carry boat launching facilities
- Building of community awareness through outreach efforts to schools, annual celebrations of the runs, creation of a local multi-town committee focused on alewife restoration and management in the watershed
- Low maintenance needs and costs for towns and landowners over time through engineering and material choices focused on keeping maintenance needs low

#### C 1.2.3 Restoration techniques

*Pierce Pond, Penobscot* - At the 118-acre Pierce Pond, the decrepit remains of an earthen dam and mill debris at the pond outlet were stabilized around a newly installed a NLF consisting of a series of pools separated by boulder weirs (Figure C 3). The fishway is next to a small public boat ramp and a small parking area, where interpretive signage, a short walking pathway, and a stone picnic table were installed as part of the project. This project was completed in 2018.

*Meadow Brook below Parker Pond, Brooksville* - The Meadow Brook project was upstream of a mill dam dating back to around 1767. Following the mill closure around 1900, the water control structure upstream fell into disrepair and was eventually washed out by a storm event in the 1950s. This rendered the ponds upstream (Parker, Snake) inaccessible to migrating alewife. In 2021, a NLF was constructed (Figure C 4), which re-established access to this spawning habitat. This project was located on private and land trust-owned land and was completed with the permission and support of the landowners. It's worth noting that costs for this project were nearly cut in half as a result of public input and local knowledge. During project planning, engineers identified a second "impassable" structure associated with a second historic dam structure along the stream. Public testimony indicated that this area was always passable by fish. A pit tag study confirmed this local knowledge and allowed the project to move forward with significant cost savings.

*Wight Pond, Penobscot* - A decrepit dam at the outlet of Wight Pond, with a meager but extant fish run kept alive through bucketing over a dam and a temporary Alaska steeppass fish ladder, which was illegally removed for scrap metal, was improved. The site of the steeppass was replaced with a NLF consisting of pools separated by boulder weirs. This project required direct Town government involvement as well as multiple landowners and was completed in 2017. The fishway design maintained water levels in the pond, which supports waterfowl and wading bird habitat, while improving passage for diadromous fishes. Target species were alewife and American eel, which access the 135-acre pond from coastal Winslow Stream.

*Walker Pond Mill Pond, Brooksville* - The historical dam and associated fish bypass structure at the Walker Pond Mill Pond outlet required repairs to maintain dam safety and enhance fish passage. The existing fishway was enhanced with several pools installed for upstream passage. A plunge pool was constructed at the dam outfall sluice to facilitate downstream migration of juvenile alewife. This site also included a fire safety water draw system important for multiple towns, so a safer and better off-road, dry hydrant was installed. In addition, land was acquired from two owners to make this site a small public park, with interpretive signage and an accessible walking trail. The land was placed under a permanent conservation easement and turned over to two towns to own and manage jointly. This work was completed in 2020.

*Snows Brook below Frost Pond, Sedgwick* - In 2021, a perched culvert conveying Snows Brook under State Route 15 in the town of Sedgwick, Maine was replaced with a much larger box culvert and a nature-like stream bottom (Figure C 5, Figure C 6). This project took five years to complete, required direct Town government involvement, and cost approximately $1.2 million. Upon completion, this project opened up 5.1 stream miles and 155 acres of pond habitat (Frost Pond) to access for spawning alewife and other diadromous species. This project was considered to be the final effort of this broader habitat connectivity initiative in the Bagaduce watershed, restoring access to all of the historical alewife ponds in the watershed.

Figure C 3 – Pool and weir NLF at Pierce Pond in Penobscot. Credit: Ken Woisard Photography/ MCHT.


Figure C 4 – Meadow Brook rock ramp style NLF, equipped with public walking path and interpretive signage. Credit: Ken Woisard Photography/ MCHT.

Figure C 5 – Aerial view (perpendicular to road) of the construction site for the installation of a large box culvert on Snow's Brook. Credit: Ken Woisard Photography/ MCHT.

Figure C 6 – Aerial view of fully installed box culvert on Snow's Brook. Credit: Ken Woisard Photography/ MCHT.

### C 1.2.4 Partners and Stakeholders

*Select Parties Involved and Contributions*

- MCHT- Secured/administered grants and funding for projects from various sources, conducted stakeholder outreach, obtained landowner permissions, purchased land, coordinated with federal/state/local entities for permitting of projects, facilitated community input into design process, community outreach, and served as project manager for restoration projects.
- MCCF - Community engagement, policy guidance, technical advising on project designs, coordination of monitoring efforts, coordination of multiple years of stocking of alewife from local sources by and with the MDMR at two sites before the projects to ensure a fish run ready to return upon project completion, alewife fisheries management facilitation, and technical support.
- The Three Town Alewife Committee – Members of alewife committees of Brooksville, Penobscot, and Sedgwick attended meetings and advocated for town involvement in projects, facilitated community engagement, developed locally-relevant restoration goals

and objectives (Figure C 7). This restoration work was directly tied to the Three Town Alewife Committee's 10-year vision and without these participants, success would not have been possible. In addition, these community leaders agreed to conduct monitoring and fishway maintenance moving forward to prevent natural obstructions and to ensure fish passage into the future.

- The Nature Conservancy of Maine - Developed Penobscot Watershed fish passage prioritization framework, provided funding and support for project execution including technical oversight, and monitoring for the Snows Brook project.
- Natural Resource Damage Assessment (NRDA) Settlement Partners (MEDEP; MDMR; Maine Department of Agriculture, Conservation and Forestry; Maine Department of Inland Fisheries and Wildlife (MDIFW); USFWS, NOAA) - Funding
- National Fish and Wildlife Foundation (NFWF) - Provided funding for project planning and for the Snows Brook project, and provided administration and execution across several grants.
- Maine Sea Grant - provided technical and design expertise and contributed to interpretive signage at multiple sites, and included publicly accessible sites on statewide tourism map of fish run sites to visit.
- NOAA - Funding for completion of design and permitting stages through the Habitat Blueprint program from the OHC; also provided technical/engineering and permitting assistance.
- Private foundations and donors, multiple engineering/design firms, and multiple earthwork, tree work, and construction firms - funding, design, implementation.
- MDMR – provided permits and assistance in stocking fish from Walker Pond into Frost and Parker Ponds to complete restoration.

Figure C 7 – Dana Black, a Brooksville resident and Three Town Alewife Committee member, helps alewife get to their spawning grounds by netting the fish up and into the old perched culvert under Route 15 along Snows Brook, just weeks before the culvert was replaced. Credit: Tate Yoder/MCCF.

*Select Funding Sources*

- 2016 Chevron Marine Oil Terminal Facility NRDA Settlement trustees directed funding towards the completion of several phases of these projects as compensation for environmental impacts elsewhere in the Penobscot River watershed.
- The NFWF administered several grants to support fishway improvements (Walker Pond Mill Pond, Parker Pond/Meadow Brook and Frost Pond/Snows Brook) and monitoring.
- The NFWF National Coastal Resilience Fund 2019 awarded significant funding to the Snows Brook/Frost Pond project.
- Funding for design and permitting of the projects at Wight and Pierce ponds came from the NOAA Habitat Blueprint through a partnership with TNC.
- The MEDEP provided funding to the project at Meadow Brook/Parker Pond.

- The USFWS provided funding to the project at Meadow Brook/Parker Pond as well as technical expertise and survey work at the Snows Brook/Frost Pond site.
- Members of the various non-profit organizations and other private donors contributed towards the purchase of the land on which the Walker Pond Mill Pond fishway and historic mill are located, as well as to components of each of the other projects.
- For the culvert replacement at Snows Brook, the town of Sedgwick was awarded funding from the Maine Department of Transportation (DOT) Municipal Partnership Initiative. The remaining costs were funded through multiple sources including federal and state National Resource Trustees, TNC, and the NFWF.

### C 1.2.5 Status and Outcomes

*Project monitoring and documented success*

The local community is heavily engaged in monitoring and maintaining fish passage structures in the watershed. In recent years, community members have logged over 1,000 hours of volunteer time monitoring passage, collecting biological samples (Figure C 8), and removing non-dam related obstructions that also may prohibit fish passage. In 2021, they estimated that approximately 400,000 alewife passed through the improved facility annually at Walker Pond Mill Pond. Community monitoring over the last decade has demonstrated a locally-healthy population of alewife, which has allowed for the re-establishment of a community-regulated non-commercial fishery. As a result of restoration efforts at Wight's Pond, alongside local/state/federal policy work, the town of Penobscot resumed its commercial fishery for the first time in recent memory, ensuring continued incentive for the town to keep this run alive into the future. Equipment necessary to understand the needs at one site was generously loaned to MCCF by the Natural Resources Department of the Passamaquoddy Nation at Sipayik in 2019, making a difference in the engineering and outcome at the Meadow Brook/Parker Pond site. Several additional successes have been documented for the community, including enhanced public access (i.e., land purchases) and improved dry fire hydrant facilities, which enhance public safety. Overall, this multi-faceted approach to fish passage restoration has enhanced stakeholder/community support of the project.

Figure C 8 – Collaborative beach seining efforts conducted by the town of Penobscot and MCCF as part of an effort to answer important questions for local management and planning efforts. Credit: Tate Yoder/MCCF.

*Factors contributing to project success*

Strong community support was crucial for the success of this project. The prioritization and focus of the Three Town Alewife Committee were important in obtaining the vital town engagement and direct roles needed, as well as building community support. Alewife runs in the project area are monitored and managed by the municipalities of Penobscot, Sedgwick, and Brooksville. The prospect of increasing runs with the potential for the introduction of a commercial fishery provided community incentive. The local non-profit organizations involved were essential for project facilitation at several different levels, including: building community awareness and support, developing projects with multiple co-benefits, securing funding from various sources, meeting grant reporting requirements, ensuring community engagement, land acquisition, and other vital functions. This level of local engagement and the formulation of a restoration plan that provided additional co-benefits allowed for greater community support and a diverse array of funding sources. The outlet modification projects did not alter water levels in any of the ponds, which was an important consideration to minimize the risk of user conflict.

*Obstacles and resolution*

As with all restoration projects, eligible funding sources were not always clear and several different sources were necessary to support these overall efforts. Through the identification of a diversity of project partners and overlapping goals, the local organizations were able to successfully fund the entirety of this effort.

Water levels and seasonal variations were determined with local input and were monitored in each of the ponds before and after construction to ensure that lake levels remained constant following project completion, thus avoiding common issues with upstream landowners.

Many stakeholders did not have any understanding of diadromous fishes and their needs, how water levels can remain steady, the dangers of coastal flooding to aging dam sites or culverts, or the importance of alewife and other fishes to ecosystems as forage fish. Fortunately, many members of the communities involved possess a keen sense of the life history requirements of these fishes and the benefits of their restoration. These community members were successful in communicating these principles to those that were not fully aware of these issues. This local understanding was an appreciable factor contributing to public support and overall project success.

There were multiple landowners and water rights holders who needed to give permissions or sell land for acquisition at each site, greatly complicating each effort. This was addressed through extensive coordination with these stakeholders.

The Sedgwick town Select Board expressed citizen concern about extended road closures associated with culvert replacement at Snow Brook. In their request for proposals, MCHT specifically stipulated that this could not occur over Labor Day weekend to avoid traffic issues. The project was constructed using a 30-day road closure and detour around the work site, which saved substantial construction cost.

A paper published by the MDMR in the early 1980s made an assertion that the alewife in Walker Pond were abnormally small and exhibited longer juvenile freshwater residence times. Additional information was collected by alewife committee members and MCCF to determine what effects passage restoration may have on this local run.

The challenges of the Covid-19 pandemic are worthy of mention because it resulted in freezing community input sessions at a key point and halting one project in its tracks. Related supply chain issues and rising material costs during construction impacted the cost and duration of multiple projects.

A last obstacle worth mention is weather. Unfortunately-timed significant coastal flooding events and record rainfall events presented great challenges for two projects, both from a feasibility and cost standpoint for the engineers and construction companies.

*Testimonials and contacts*

Senior Project Manager Ciona Ulbrich of MCHT stated "It is thrilling to have completed this set of projects in under five years, and it has been a big learning experience… Thanks to a key community member showing us the need and the possibilities, a lot of individuals and organizations were able to come together to make it happen."

Mike Thalhauser, Collaborative Management Specialist with MCCF said, "This really was an incredible project to watch unfold. MCHT and multiple agencies and partners brought incredible resources to the table, while ensuring that local knowledge and values dictated the goals of the work and how it got done. This is truly how this important work should be done, and I was happy to play a role in that."

Ben Astbury, chair of the Sedgwick Select Board, said about the Snows Brook project: "It's amazing when a town can see the benefit of granting monies to pay for an over a million-dollar project to alleviate safety issues with the roadway, but also to help with fishway passage and nature itself. It's really a phenomenal project."

### C 1.2.6 Lessons Learned

- Taking time early to build awareness is key: Doing the time-consuming groundwork of holding uncomfortable but important public meetings and putting time into outreach to media and to speaking publicly about the species, needs, and projects is key to building community awareness and support necessary to get projects done.
- Build on momentum and build trust: In this set of projects, visible and attractive success at the first projects, and the enthusiasm of the town government involved, was vital for other towns to be willing to put the trust and time into projects in their towns.

- Respect heritage and make it not just about fish: take the time to learn about the industries, towns, and people that created the barriers for the fishes, and mention them as part of the heritage in interpretive signage and other community outreach. These mills supported, fed, and housed towns for multiple family generations.
- Paying attention to and taking opportunities around project timing and materials costs or other seemingly minor details. This can make all the difference in total cost savings.
- Increased public awareness will help ensure longevity of the projects: Build in opportunities for public education and experience of a fish run where possible, including through making some sites accessible with interpretive signage to learn from, and through outreach such as celebrations, bumper stickers, and school activities to teach young people. Those young people who understand the importance of fish runs will help the investment in construction be maintained and better withstand the test of time.

### C 1.2.7 Supplemental Information

For additional information on efforts in the broader Penobscot River watershed, see:

NOAA: Habitat Blueprint of the Penobscot River, Maine

NRCM: Penobscot River Restoration Project Web Page

TNC: The Comeback: Restoring Free-Flowing Rivers in Maine

For additional information on the Bagaduce Project, see:

MCHT: Video of the Bagaduce Fishway Project: Walker Pond

MCHT: Video on the Bagaduce Fishways Project

MCHT: Brooksville has a new spot to learn about watersheds and fish passage

The Ellsworth American: Bagaduce River watershed fishways project hits new milestone

MEDEP: Fish Passage Restoration in the Penobscot

The Weekly Packet: Culvert project will restore fish passage in watershed

Fisherman's Voice: Organized & Funded Effort Begins Alewife Restoration, Part I

[Fisherman's Voice: Alewife Restoration Project, Part II]

[Fisherman's Voice: Alewife Restoration, Part III]

### C 1.3 Sebasticook River Restoration

#### C 1.3.1 Background

*Historical Context*

The Kennebec River watershed is the second largest in Maine. Located in west central portion of the state, the watershed drains 5,893 square miles; an area that spans approximately 149 miles north to south and 72 miles wide. A portion of the northwestern edge of the basin forms part of the boundary between the United States (Maine) and Canada (Quebec). Historically, the Kennebec River and its tributaries (Carrabassett River, Sandy River, Sebasticook River, Messalonskee Stream; Seven Mile Stream; and Cobbosseecontee Stream) supported 11 native diadromous species: alewife, blueback herring, American shad, striped bass, Atlantic salmon, shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*Acipenser oxyrhynchus*), rainbow smelt (*Osmerus mordax*), Atlantic tomcod (*Microgadus tomcod*), sea lamprey (*Petromyzon marinus*), and American eel. Annual returns and associated fisheries began to decline across their range of these species in the 19th century (Atkins 1887; ASMFC 2017). Impassable dams, overfishing, pollution, and now climate change, are implicated in the decline of these anadromous species. The Edwards Dam was constructed in 1837 below the head of tide. The dam included a fish ladder that was destroyed in an 1838 spring flood and not rebuilt. The Edwards Dam ended migration of all these sea-run fish.

Harvests of river herring in Maine were historically substantial (Hall et al. 2011). River herring provided food in the early colonies, were used in trade, and continue to support local economies as bait in the lobster industry. With continued harvest pressure and the rise of the industrial revolution (e.g., pollution and dams), river herring populations could not be sustained. In spite of public interest and legislative efforts (see Hall et al. 2011), the pressure of industry and harvest could not be overcome. Suitable habitat was limited and the number of returning adults were greatly reduced or exhausted.

*Main Restoration Projects*

Efforts to restore anadromous fish began in the 1980s with the first settlement agreement between the state of Maine and Kennebec Hydropower Developers Group (KHDG). This agreement provided date certain for fish passage on seven hydropower projects on the Kennebec River and Sebasticook River (the first major tributary to the Kennebec). In return for delaying passage to specified dates, the KHDG provided funding for stocking fish above the Edwards Dam. Improvements to the environmental conditions of the river (e.g., water quality) and to federal regulations were instrumental in making this agreement possible (Wippelhauser 2021). The 1986 agreement provided the agencies and hydropower developer's certainty for future actions in terms of restoration and capital investment. However, the Edwards Dam, the first dam on the Kennebec River, remained a focal point for restoration efforts. The federal license for the Edwards Project was due to expire in 1993. Federal and state resource agencies, in collaboration with the NGO community, sought to decommission and remove the Edwards Project. In 1997, the FERC issued an order to decommission and remove the Project based on the conclusion that the public benefit of the power generated did not outweigh the environmental impacts on fisheries. This order by FERC spurred settlement discussions among the resource agencies, Kennebec Coalition, and KHDG. With mitigation funds from KHDG and outside parties, an agreement was signed in 1998 establishing a fund for active management and triggers to implement fish passage at the seven Kennebec and Sebasticook River hydropower projects. A year later, in 1999, the Edwards Project decommissioned and the dam was removed. This sparked a cascade of events across the watershed that lead to a highly successful river herring restoration in the Kennebec River watershed.

The focus of anadromous fish restoration in the Kennebec River watershed has largely been the lower basin, below the confluence with the Sandy River (MDMR 2000, 2015, 2020a; Wippelhauser 2021). While restoration efforts have taken place across the watershed (Table C 1), the Sebasticook River has been the shining star of restoration success. The Sebasticook drainage has benefited from four dam removals (Ft. Halifax, Gilford, Masse, and Lombard dams), two fish lifts at mainstem dams (Benton Falls and Burnham), a river reach realignment, and multiple lake outlet fishways, as well as active stocking and counting. The return of river herring, primarily alewife, to the Sebasticook River has been staggering; from 1999 when zero adult river herring were migrating above the head of tide to the year 2000 when just over 137,000 were trapped at Fort Halifax, and in 2008 when 1.3 million were counted at Benton

Falls. In 2018, MDMR counted nearly 5.6 million river herring at the Benton Falls fish lift (MDMR 2020a); the returns for 2016-2019 were more consistently around 3.2 million. Each year since the fish lifts at Benton Falls and Burnham started operating, many thousands more river herring remain in the river below the dams due to fish lift and perceived habitat capacity limitations. This growth in the number of returning river herring (largely alewife), the largest on the east coast, has been staggering.

Table C 1 – Chronology of actions leading to the current status of restoration in the Kennebec River Watershed This list is adapted from MDMR 2020 and the Natural Resource Council of Maine (NRCM).

| Year | Restoration Action |
|---|---|
| 1837 | Edwards Dam constructed with fishway despite public opposition |
| 1838 | Fishway destroyed in a spring flood |
| 1974 | A large portion of the dam washes out in winter flood. |
| 1975 | The dam is repaired over the objections of fisheries biologists seeking a free flowing river. |
| 1987 | First Kennebec Hydro Developers Group (KHDG) Settlement Agreement (date certain for fish passage on mainstem Kennebec River |
| 1988 | Experimental fish pump at Edwards Dam |
| 1987-1997 | MDMR stocks American shad into historic spawning habitat above Edwards Dam |
| 1987-2006 | MDMR stocks river herring into historic habitat above Edwards Dam |
| 1988-2006 | Interim, downstream passage operational at Benton Falls, Fort Halifax, Burnham, Lockwood, Shawmut, and Hydro Kennebec projects |
| 1991 | The owner of the Edwards Dam applies for new federal license to expand the generation capacity. Governor McKernan supports dam removal.<br>Maine Legislature adopts a resolution calling for dam removal. |
| 1992 | Interim upstream passage (fish pump) installed at Edward Dam; |
| 1996 | FERC issues preliminary recommendations to relicense the dam with fish passage. The USFWS specifies that a $9 million<br>fish passage design is necessary. The Kennebec Coalition files makes the case that the benefits of removing the dam exceed the benefits of<br>continued operations. |
| 1997 | FERC's Final Environmental Impact Statement recommends dam removal. |
| 1998 | The 1998 Agreement Between Members of the Kennebec Hydro Developers Group, the Kennebec Coalition, the National Marine Fisheries<br>Service, the State of Maine, and the U.S. Fish and Wildlife Service (1998 Agreement) |
| 1999 | 1999 Removal of Edwards Dam |
| 1999 | MDMR completes upstream fish passage at Stetson Pond (Sebasticook River) |
| 1999-2011 | Installation of upstream eel passage at seven KHDG dams |
| 2002 | MDMR removes Guilford Dam and completes upstream passage at Plymouth Pond (Sebasticook River) |
| 2003 | MDMR completes upstream passage at Sebasticook Lake (Sebasticook River) |
| 2003 | MDMR initiates salmon stocking in Sandy River |

| Year | Restoration Action |
|---|---|
| 2004 | River realignment upstream of the Guilford Dam removal site. |
| 2006 | Fish lifts operational at Benton Falls and Burnham Projects (Sebasticook River) |
| 2006 | Fish lift and trap operational at Lockwood Project (Kennebec River) |
| 2006 | Removal of Madison Electric Works Dam (Sandy River) |
| 2008 | Removal of Fort Halifax Dam (Sebasticook River) |
| 2009 | MDMR completes upstream passage at Webber Pond Dam (Seven Mile Stream) |
| 2009 | Expanded listing of the GOM DPS of Atlantic salmon including Kennebec River |
| 2012-2013 | Interim Species Protection Plans for Atlantic salmon for Kennebec River and Androscoggin River |
| 2014 | Burnham Bypass constructed to move fish out of the isolated bypass channel |
| 2017 | MDMR and partners remove Masse Dam in Outlet Stream (Sebasticook River) |
| 2018 | MDMR and partners remove Lombard Dam in Outlet Stream (Sebasticook River) |
| 2018 | 5.6 million river herring return to the Sebasticook River, the largest self-sustaining run on the east coast |
| 2018 | Fishlift at Hydro-Kennebec |
| 2019 | MDMR and partners install fish passage at Ladd Dam in Outlet Stream (Sebasticook River) |
| 2019 | MDMR and partners complete upstream fish passage at Togus Pond |
| 2020 | MDMR and partners install fish passage at Box Mills Dam in Outlet Stream (Sebasticook River) |

### C 1.3.2 Restoration Goals and Techniques Employed

*Goals*

NOAA Fisheries' restoration goals for river herring are to promote sustainable runs of returning adults and healthy habitat throughout the historical range of these species. Our goals support the broader agency mission of sustainable commercial and recreational fisheries and coastal communities. We collaborate with federal, state, local, and NGOs, as well as working with the ASMFC, to reach these goals. The MDMR has developed several restoration and operational plans for the Kennebec watershed, including the Sebasticook River, since 1986. Each plan included specific goals and methods for managing the restoration of river herring. Updated in 2020, the current Kennebec River Management Plan identifies the following river herring goals (MDMR 2020a):

*The goals for blueback herring:*

- Achieve and sustain a minimum population of 6,000,000 adults entering the mouth of the Kennebec River annually based on 5,015 hectares of spawning and nursery habitat in the mainstem and identified tributaries

- Achieve and maintain an adult return of a minimum of 1,196 adults/hectare (484/acre)
- Achieve and sustain a minimum population of 3,000,000 adults above Augusta
- Pass at least 1,788,000 adults at the Lockwood and Hydro Kennebec Project dams (Kennebec River)
- Pass at least 1,535,000 adults at the Shawmut Project dam (Kennebec River)
- Pass at least 922,400 adults at the Weston Project dam (Kennebec River)
- Pass at least 585,000 adults at the Benton Falls Project dam (Sebasticook River)

*The goals for alewife:*

- Achieve and maintain an adult return that exceeds a minimum of 581.5 adults/hectare (235/acre) and is consistent with the Maine state average of 988.4/ha (400/acre)
- Achieve and sustain a minimum population of 5,785,000 adults above Augusta
- Pass at least 608,200, adults at the Lockwood, Hydro Kennebec, and Shawmut project dams (Kennebec River)
- Pass at least 473,500 adults at the Weston Project dam (Kennebec River)
- Pass at least 4,540,200 adults at the Benton Falls Project dam (Sebasticook River)

*Restoration techniques*

The scale of fisheries and habitat restoration seen in the Kennebec watershed is an ecosystem of its own. No one action or effort alone could be as effective as the whole. The river herring restoration techniques used for the Kennebec River watershed fall into two broad categories that support each other. First are the actual restoration activities (Table C 1). These observable, tangible actions directly benefit the fishes and habitat. Stocking of fishes to seed the watershed ahead of implementing restorative measures has proven vital to the rapid rate of recovery seen in the Sebasticook River. Removal or physical alteration of migratory impediments provides access to upstream spawning habitat. Dam removal is generally the preferred option; however, dam removal is not always feasible. Fishways are used where dams and other impediments cannot be removed. Where dam removal is an option; other ecological functions are restored with the return to a free-flowing river reach. Restoration of riparian habitat within a river reach provides ecological functions such as storm flow management, cold-water refugia, resting pools, and suitable migratory zone of passage. Table C 1 chronicles the most significant restoration activities since the restorations began in earnest in 1986. The on-the-ground restoration activities provide a final picture, perhaps the last steps required to support successful restoration.

The on-the-ground restoration efforts in the Kennebec watershed have relied on a backdrop of actions that created the foundation or built momentum. The restoration program grew from a combination of (a) focused regulatory influence, (b) strong collaboration among partners, (c) political will, (d) proactive public investment, and (e) adaptive management.

*Public Regulatory Process*

The Edwards Dam removal (see *Appendix C 1.3.1*) created the momentum for further restoration of anadromous fish and habitat in the Kennebec River watershed. This one action would not have happened if not for the public regulatory process and the federal agencies' authority under the FPA, as well as the equal consideration requirement under the NEPA. These federal statutes provide the venue for the public to express their interests for public trust resources, the public resources the dam owners used for their development interests. Likewise, those federal statutes are the mechanism for state and federal resource agencies to provide their expertise for the equal consideration requirement. The FPA provides under Section 18 that the Secretary of Commerce (NOAA Fisheries) and Secretary of the Interior (USFWS) shall prescribe mandatory fishway terms and conditions for the benefit of migratory fishes. This regulatory authority was the impetus for the 1987 agreement between the state of Maine and KHDG that delayed the fishway requirements and provided management funds to jumpstart the restoration. During the 1990s relicensing process for the Edwards Dam, the USFWS prescribed new fishways. The design was estimated to cost $9 million. The hydropower developer would have been responsible for that requirement. The Kennebec Coalition provided extensive information during the public review supporting the equal consideration requirement, arguing that the public benefit of the dam did not outweigh the public benefit of the natural resources without the dam. As a result of this influence and serendipitous external actions, the state and federal resource agencies, the Kennebec Coalition, the owners of the Edwards dam, and the KHDG came together to address issue of fish passage and power development for the lower Kennebec River basin. The result was a process to fund the dam removal, continue support for active management, and establish triggers for passage at upstream hydropower projects as described in the 1998 Agreement[56].

With the building momentum and the 1998 Agreement, the public regulatory process was used at the hydropower projects upstream of the Edwards Dam. Most notably was the requirement for fish passage at Ft. Halifax. The 1998 Agreement indicated passage would be through a permanent fishway (fish lift), full removal or partial breach. The hydropower developer was seeking alternatives to the permanent facility (fish pump). A potential new owner was considered. In the end, the public review of the options, within the bounds of the agreement, assured the requirements were fulfilled. If not for a combination of the 1998 Agreement, regulatory review, and public comment, the resulting dam removal could have ended up a very different project.

*Collaborative Partnerships*

The Kennebec River restoration effort benefited from a strong collaboration of non-governmental organizations (the Kennebec Coalition), state resource agencies (primarily MDMR), and federal agencies (NOAA Fisheries and USFWS). These groups worked from their individual strengths to bolster the value each brought to the regulatory process and proactive restoration platform. In the regulatory process, the Kennebec Coalition provided expertise that the agencies did not possess, and a voice that public agencies do not typically use. Likewise, the state and federal agencies' expertise is generally given deference in the review of effects, and the federal agencies have authorities not duplicated by the state of NGO community. In tandem, the argument for the public trust resources was strong.

*Political Will*

The momentum for restoration did not originate in a vacuum. After decades of pollution, the state of Maine invested $100 million in clean-up efforts (Crane 2009). Between that investment and changes in industrial use (e.g., no more log drives, fewer industrial discharges), improved habitat quality created potential for future anadromous fish restoration. With that improvement

[56] 1998 Lower Kennebec River Comprehensive Hydropower Settlement Accord and the Agreement Between Members of the Kennebec Hydro Developers Group, the Kennebec Coalition, the National Marine Fisheries Service, the State of Maine, and the U.S. Fish and Wildlife Service.

came a public perception that the river was not lost. Governor McKernan called for the Edwards Dam removal. The state legislature adopted a resolution to remove the Edwards Dam. The legislature would end up passing 161 legislative actions in support of removal. As mentioned previously, the USFWS filed a fishway prescription requiring fish passage with a design estimated to cost $9 million. This collective political will to seek dam removal of a federally licensed hydropower facility was unique for its time. It provided a foundation for a successful restoration effort.

(a) Proactive Public Investment

- Outlet dam fishways (Sebasticook Lake, Plymouth Pond)
- Small Dam Removal (Guilford Dam, Masse Dam)
- Habitat Restoration (stream realignment)

(b) Adaptive Management

- Learn from the science
- Adapt to new information
- Adapt to new management focus

C 1.3.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- NOAA Fisheries – regulatory review and conditions, post license compliance, science and monitoring, management prioritization and planning, proactive restoration funding
- USFWS – regulatory review and conditions, post license compliance, science and monitoring, management prioritization and planning, proactive restoration funding
- MDMR – regulatory review and conditions, post license compliance, science and monitoring, management prioritization and planning, implement active management, proactive restoration
- Kennebec Coalition (American Rivers, Atlantic Salmon Federation, NRCM, Trout Unlimited (TU), and Trout Unlimited–Maine Chapter), Conservation Law Foundation,

local communities – support the regulatory process; outreach and advocacy for restoration of fisheries; funding, planning, and implementing proactive restoration; building a constituency; supporting management goals.

- KHDG (licensees of the Lockwood, Hydro- Kennebec, Shawmut, Weston, Fort Halifax, Benton Falls, and Burnham hydropower projects) – funding and implanting mitigation measures.

*Select Funding Sources*

- NFWF
- GOM Council
- NOAA RC
- Restore America's Estuaries
- Fish America Foundation
- TU

### C 1.3.4 Status and Outcomes

*Project monitoring and documented success*

The Sebasticook River has been the highlight of restoration efforts in the Kennebec watershed. A convergence of proactive management, targeted restoration, and quality and quantity of habitat supported the overall success. The resource agencies and NGO community remain heavily involved in the restoration of river herring and diadromous species in the Kennebec watershed. Industry has a significant role through their federal licenses for operation that includes monitoring. Monitoring is focused on fishway counts at the Benton Falls and Lockwood Dams, and at outlet pond fishways. The MDMR has a significant role in monitoring, and works in collaboration with the hydropower developers at those hydropower facilities. With the vast number of returning adult alewife, monitoring for passage efficiency was not implemented. However, some video monitoring of alewife and tagging studies for American shad and Atlantic salmon were instrumental to identifying needed downstream passage improvements. Community support remains critical for restoration actions that affect more public facing resources, such as impoundments behind small dams.

*Factors contributing to project success*

The scope of restoration activities in the Kennebec watershed covered a wide variety of regulatory and non-regulatory actions; mitigation requirements and proactive restoration; management priorities and community initiatives. Making these diverse pieces come together for an amazing river herring success was the long-term dedication and vision of resource agencies and NGOs, and the willingness of industry to collaborate and find mutually agreeable solutions to the various interests. The diversity and longevity of actions demanded an adaptive approach to address new information, insights, obstacles, and opportunities. MDMR and NGO community were instrumental in identifying priority actions and building community support for local projects. MDMR and collaborating NGOs brought in volunteers for hands-on activities such as netting fish over dams.

*Obstacles and resolution*

Differing management goals and paradigms slowed some of the restoration growth. There was fear among some in the public and state resource agencies that too many alewife would impact their fishery resources, specifically the concern over alewife and black bass interactions. Field studies, outreach, and diligence were important to overcoming this obstacle.

Dam removals represent change and uncertainty. Local residents and landowners abutting a potentially affected waterway by dam removal raised concerned about post removal condition, the loss of current use, impacts to current aquatic resources (fish, freshwater clams, birds, wetlands), and erosion. These concerns lead to long delays and, in one instance, lawsuits. The resultant dam removal was successful due to persistence in the regulatory and legal processes, as well as a willingness to address resident's concerns.

The backbone of restoration in the Kennebec watershed was built off the regulatory process under the FPA. This process can take many years and require persistence, patience, and diligence among the stakeholders striving to restore river herring and other aquatic resources. It requires an understanding of the regulations and case law behind past FERC orders. When licensing and associated negotiations take years to advance, staff turnover, loss of institutional knowledge, and burnout become problematic. Clear administrative records and strong partnerships mitigate these challenges.

### C 1.3.5 Lessons Learned

For a watershed scale project to succeed, it needs a multi-prong approach that includes community support and outreach, diverse partnerships, an understanding of the regulatory process, a management plan, and persistence for achieving the goal.

### C 1.3.6 Supplemental Information

[The Revelator: How Removing One Maine Dam 20 Years Ago Changed Everything]

[NRCM: 20 Years Ago, Edwards Dam Removal Sparked a Movement for Free-flowing Rivers]

[American Rivers: Twenty years of dam removal successes – and what's up next]

## C 1.4 Coonamessett River Passage and Habitat Improvement

### C 1.4.1 Background

*Historical Context*

The Coonamessett River, a three-mile-long, low-gradient coastal river discharging to Vineyard Sound in southeastern Massachusetts, has incurred an extensive history of passage barrier impacts to river herring and herring population declines. Historical records document the first grist mill was constructed by Philip Dexter in the lower river in 1700. By 1795, three expanded grist mills and dams were functioning on the lower river. In 1798, the infamous "Herring Wars" began when local residents fought against the mill damming of the river for cloth production, at the expense of a disappearing river herring population, which served as both a local food source and commodity. The Herring Wars culminated in a fatality when a cannon, packed with river herring, exploded, blasting iron shrapnel and killing one of the herring activists. Over the years, the mill products and production changed with the times. In 1833, Alexander Clark established a woolen manufactory at the Lower Mill site, but by 1880, the facility was serving as a shoddy (spinning of reused woolens) mill. Some progress for herring passage was made with an agreement between the Pacific Woolen Factory, owner of the Lower Dam, and Town herring agents in 1846, installing in-stream features and establishing flows to facilitate river herring to pass these low-height river barriers. In 1890, Howard and Henry Russell Swift took ownership of the dams to establish a commercial cranberry operation, where the dams were used to control water flow for cranberry production. Cranberry fields were established by converting the natural wetlands bordering the river, with construction of a series of lateral and perimeter drainage ditches and placement of sand fill of existing wetlands. Cranberry production continued for decades, until 1971 when the Town of Falmouth purchased 110 acres of the cranberry operations for public open space conservation. The last cranberry operations on the lower Coonamessett ceased in the early 2000s (2005 for Lower Bog, and 2011 for Middle and Upper Bogs), and the Town of Falmouth began a river restoration campaign in earnest, engaging many partners in securing technical support and funding for river and migratory fish passage restoration. Data collection (fish counts, river flow, and botanical surveys) began in 2005, and a feasibility study was completed in 2011-2012. The initial dam removal, one of several of the highly successful, multi-phased Coonamessett River watershed restoration, began in 2017. The first barrier was removed in 2018, more than 300 years after the first dam was built! Middle Bog dam was removed and the culvert replacement at John Parker Road was completed in 2020 fully restoring river herring passage in the lower river.

Of note, a thorough historical review of the project area was completed by Public Archaeological Laboratory, an experienced historical consultant for the Coonamessett River restoration, in conformance with Section 106 of the National Historic Preservation Act (NHPA), and through which project funding from NOAA (Lead Federal Agency for the consultation) and USFWS (participating federal agency), constituted a federal action. The NHPA Section 106 historical assessment and report (PAL 2016) were completed in accordance with Massachusetts Historical Commission (MHC) Guidelines and is available through the Town of Falmouth. The historical documentation was a component of a formal Section 106 Memorandum of Agreement (MOA) among MHC, NOAA, and other signatory concurring parties for the reporting, as well as public educational signage as mitigation for impacts to historical resources.

### C 1.4.2 Restoration Goals and Techniques Employed

*Goals*

The focus of the Coonamessett River watershed restoration has been to implement an ecological process-based restoration. The approach includes multiple goals for this holistic watershed including:

- Eliminating multiple fish passage barriers and re-establishing river connectivity

- Restoring stream hydrology and river channel morphology, with a particular focus on both groundwater discharge and recharge in this 5-square mile, glacial outwash watershed
- Improving water quality of the river and groundwater and surface water discharge to the river
- Restoring riparian wetlands and river canopy cover, river channel, and instream habitat features
- Re-establishing lateral connectivity between the river and its floodplain; and
- Increasing ecological resiliency.

*Restoration techniques*

*Dam removal* – Two low-head, run-of-the-river dams with river-wide concrete spillways – Middle Bog Dam (Figure C 9) and Lower Dam (Figure C 10) – were removed to allow river herring to access two coastal freshwater ponds (158-acre Coonamessett Pond and 22-acre Flax Pond).

*Culvert replacement* – A failing, undersized set of metal culverts (three 18-24 in diameter pipes) under John Parker Road that served as a third barrier on the lower Coonamessett River, was replaced with a larger pre-cast concrete box culverts (24 ft wide) sized and designed to accommodate a full range of flows from low flows during extended dry periods to high flows during anomalous storms (Figure C 11).

*Wetland restoration* – A total 56 acres of former commercial cranberry bogs were restored by excavating excess sand fill and re-establishing highly species-diverse shrub and emergent wetlands with pool-and-mound micro-topography and an important native plant seedbank in the remaining peat soils (Figure C 12).

*Channel reconstruction* – Past cranberry operations straightened and made the river channel overly wide, and lateral and perimeter ditches reduced river flows. Restoration included reconstructing the river channel (4,600 ft length) to re-establish channel meanders (sinuosity to increase channel length by more than 130%) and installing instream habitat structures to reduce channel width, increase channel depth, and provide habitat complexity (Figure C 13).

The project also benefits from an important public outreach and education program instituted by the project partners (Figure C 14). This program includes public access to and around the 244-acre open space and restoration area with wetland and two river boardwalk crossings, plus foot trails with educational signage explaining various aspects of the restoration, natural history, and land and natural resource uses through the centuries.

Figure C 9 – Middle Bog Dam, 2018. The Coonamessett structures were earthen dams with low-head concrete spillways and failing culverts that were effective as herring passage barriers. Credit: Town of Falmouth, MA.


Figure C 10 – Dexter's Mill Crossing boardwalk, site of former Lower Bog Dam. Dam removal site is in the background at bridge crossing. Wetland restoration at former cranberry operation. Credit: NOAA Fisheries.

Figure C 11 – New, fish passage-friendly culvert installation at John Parker Road, May 2020. Credit: NOAA Fisheries.

Figure C 12 – Coonamessett River restoration, Lower Bog soon after dam removal, 2017 (left), and restored river and riparian wetland habitat, 2019 (right). Credit: NOAA Fisheries

Figure C 13 – Aerial photo of the restoring Coonamessett River including the Lower Bog (closest), Middle Bog, and Upper Bog (most distant) restoration areas, September 2020. Credit: Adam Soule/Coonamessett River Trust.

Figure C 14 – Public outreach and education were key components of the successful Coonamessett River restoration. Here, youth learn of the detrimental effects of barriers on river herring passage. Credit: Town of Falmouth, MA.

### C 1.4.3 Partners and Stakeholders

*Parties Involved and Contributions*

The Town of Falmouth helped organize a very robust partner team. The following is a list of some of the partners and roles in the Coonamessett River restoration.

- Town of Falmouth – The Falmouth Conservation Commission was the lead entity, working with other town departments and many project partners and coordinating with stakeholders in the watershed primarily through a series of public information meetings throughout the project phases.

- Massachusetts Division of Ecological Restoration – This state agency within the Department of Fish and Wildlife contributed substantial technical assistance and funding and fund management for the project throughout the project.

- Coonamessett River Trust (CRT) – The CRT helped to lead outreach on the restoration by providing multiple presentations to interested groups and residents in the Town. Examples of interested groups included pond associations in the watershed, the fisherman's association that helped with herring monitoring, teachers in the Falmouth school system, and classrooms of students of various ages. The CRT also led fish passage monitoring efforts beginning in 2005 and also many other monitoring activities and is continuing through post-passage restoration performance.

- The 300 Committee - Since 2005, The 300 Committee (Falmouth's land trust) has worked with the Town to establish and develop the Coonamessett River Greenway to highlight cultural, historical, aesthetic, and natural environmental assets of the river, the vast majority of which is protected conservation land open to the public.
- NOAA RC – The RC, a branch of the OHC, contributed significant technical assistance and funds for assessment, planning, design, and construction project phases.
- USFWS – The USFWS Region 5 staff provided technical assistance and project construction funding.
- Natural Resources Conservation Service (NRCS) – Early on in the project assessment phase, NRCS technical staff led soil assessments using ground-penetrating radar to identify underlying deep peat locales, as a means to avoiding construction impacts to sensitive ecological sites. In the later project construction phase, NRCS contributed substantial construction funds.

*Funding Sources*

Funding for this $4+ million project with three river herring barrier removals, riparian wetland restoration, and public access and passive recreational uses was secured from many partners and organizations including the following:

- Town of Falmouth
- Massachusetts Municipal Vulnerability Preparedness Program
- CRT
- NOAA RC
- NRCS
- USFWS

- Fish America Foundation
- Massachusetts Environmental Trust
- NFWF

C 1.4.4 Status and Outcomes

*Project monitoring and documented success*

CRT and Woodell Center (WC) scientists have provided substantial performance monitoring of the river herring run, as well as riparian plant community species surveys and stream nutrient dynamic assessments. The WC monitoring has included passive integrated transponder (PIT)-tag surveys of springtime returning adult alewife and blueback herring, with tagged fish recorded by multiple antennas situated in the lower river. The results have contributed to understanding the passage delays and efficiency at each former barrier, plus identified daily fish movement patterns and repeat spawners over multiple years of monitoring. The PIT-tag monitoring since 2015 has also supported efforts and documentation by local volunteers led by the CRT to complete visual counts at the former barriers (2005 and thereafter). Additionally, staff from the Massachusetts Division of Fisheries and Wildlife (MADFW) have been conducting seasonal electrofishing surveys of the restored river reach over multiple years to document the presence of both resident and migratory fish species presence and abundance. Data are summarized by MADFW on an annual basis.

*Factors contributing to project success*

The Coonamessett River restoration benefitted from a strong, reliable, local project leader who has a passion for the restoration and resilience of the watershed. Dr. Betsy Gladfelter has dedicated her time to build a team of partners, secure project funding and coordinate technical input, and other information exchange among the broad range of agency, non-governmental organizations, and industry partners engaged in the project. Monthly progress meetings led by the Town with partners as well as weekly site meetings with contractors, engineers, Town personnel and agency representatives during construction periods were highly beneficial to helping reach project milestones.

A robust funding stream was essential to completing this multi-phased project. The strong partnership allowed funding opportunities to develop and expand to address costs for each of the project phases.

The restoration also benefitted from experienced river restoration designers, structural engineers for culvert and bridge design and for wetland walkway design, as well as an experienced construction firm highly knowledgeable of ecological restoration practices and cost-effective implementation strategies.

*Obstacles and resolution*

Early in the project, there was vocal opposition, especially by those who advocated to preserve the historical tradition of cranberry farming. Through the years, there were multiple public meetings, including presentations at Town Meetings, as well as newspaper articles and local TV coverage to keep the public informed about the goals of the project and the progress made to date. In addition, many presentations were made to Town Boards (e.g., Historical Commission, Finance Committee, Community Preservation Committee, Committee on Disabilities, Planning Board) as well as numerous field trips to those public bodies.

*Testimonials and contacts*

Wendi B. Buesseler, President of the CRT said "One of our goals is not only to create a thriving river ecosystem, but also for the river to be an important landmark for the community of East Falmouth while nurturing student and citizen engagement and environmental stewardship of this precious jewel. Now that the dams and berms and those horrible culverts have been removed from the slower section of the river, we can see that the herring, where once they were obstructed moving up the river because of these things, now they just kind of whiz right by, and it's really an amazing thing to see."

### C 1.4.5 Lessons Learned

Strong and frequent organized communication between and among partners is key, and ensuring each organization is made aware of the importance of their contributions to the overall project.

### C 1.4.6 Supplemental Information

Lower Bog dam removal and wetland restoration (post Phase1) construction, aerial video

Middle Bog dam removal and restoration (post Phase 2) construction, aerial video

[300 Committee: Coonamessett Greenway Heritage Trail]

[Coonamessett River Trust Organization Web Page]

## C 1.5 Herring River Estuary Restoration Project on Cape Cod

### C 1.5.1 Background

*Historical Context*

Historically, the Herring River was the largest tidal estuary complex on Outer Cape Cod and included about 1,100 acres of salt marsh, intertidal flats, and open-water habitats. The Herring River system was dramatically altered in 1909 when the Town of Wellfleet constructed the Chequessett Neck Road Dike at the mouth of the Herring River with the goal of reducing the presence of salt marsh mosquitoes. The dike restricted tides in the Herring River and reduced the tide range from approximately 10ft on the downstream harbor side to about two feet upstream of the dike. By restricting the flow of ocean tides and salt water, the dike had immediate and devastating effects on the tidal system and the community benefits provided by the river and its associated estuarine wetlands.

By the mid-1930s, the Herring River, now artificially altered from a saltwater to mostly a freshwater system, was channelized and straightened. Between 1929 and 1933, the Chequessett Yacht and Country Club (CYCC) constructed a nine-hole golf course in the adjoining Mill Creek floodplain. Several homes were also built at low elevations in the former Herring River floodplain.

The Herring River estuary is now beset with a range of water quality and other ecological problems, including:

- River herring and other migratory fish species that once thrived in the river and spawned in the 125 acres of head ponds have been depleted due to poor water quality and obstructions to migratory passage
- Water quality in the river is impaired year-round
- Tidal restriction, along with stream channelization and ditch drainage, has lowered water levels above the dike causing the marsh plain to sink 2-3 ft

- Prolonged exposure of drained salt marsh peat to air causes it to decompose and release sulfuric acid into surrounding soils and receiving waters. Acid sulfate soils are a major problem covering hundreds of acres of original Herring River marshes. Absent regular saturation by salt water, these soils leach toxic acidity and aluminum into remaining surface water, killing aquatic animals
- Coastal resiliency has been diminished due to alteration of natural sediment processes and salt marsh surface subsidence
- Elimination of tidal flooding and salinity has resulted in a loss of salt marsh and other forms of estuarine habitat. Approximately ten acres out of an original 1,100 acres of salt marsh remain

*Main Restoration Projects*

The project aims to restore approximately 1,000 acres of the Herring River estuary in two phases. Phase 1 will restore approximately 570 acres, will take about three years to construct, and will take multiple years to incrementally reintroduce tidal flow to the floodplain. During Phase 1, a new 165-foot long Chequessett Neck Road Bridge and sluice gates will be constructed, as will a new Mill Creek water control structure. Both structures will initially be configured to allow partial tidal flow into Herring River and Mill Creek sub-basin up to a maximum water level specified for each respective basin. Phase 1 also includes measures necessary to protect low lying infrastructure, including raising more than 2 miles of low-lying roads.

Phase 2 will restore full tidal flow to the sub basins not included in Phase 1. This work includes performing mitigation measures necessary to ensure that infrastructure protection to increased tidal flows in those sub basins.

C 1.5.2 Restoration Goals and Techniques Employed

*Goals*

- To the extent practicable, given adjacent infrastructure and other social constraints, re-establish the natural tidal range, salinity distribution, and sedimentation patterns of the former 1,100-acre estuary

- Improve estuarine water quality for resident estuarine and migratory animals including fish, shellfish, and water birds
- Protect and enhance harvestable shellfish resources both within the estuary and in receiving waters of Wellfleet Harbor
- Restore the connection between the estuary and the larger marine environment to recover the estuary's functions as (1) a nursery for marine animals and (2) a source of organic matter for export to near-shore waters
- Remove physical impediments to migratory fish passage to restore once-abundant river herring and eel runs
- Re-establish the estuarine gradient of native salt, brackish, and freshwater marsh habitats in place of the invasive non-native and upland plants that have colonized most parts of the degraded floodplain
- Restore normal sediment accumulation on the wetland surface and the accumulation of below ground organic material (peat) to counter subsidence of the former saltmarsh and to allow the Herring River marshes to accrete in the face of sea-level rise
- Re-establish the natural control of nuisance mosquitoes by restoring tidal range and flushing, water quality, and predatory fish access
- Restore the expansive marshes and tidal waters that were once a principal maritime focus of both Native Americans and European settlers of outer Cape Cod in a manner that preserves the area's important cultural resources
- Minimize adverse impacts to cultural resources during project construction and adaptive management phases
- Minimize adverse impacts to surrounding land uses, such as domestic residences, low-lying roads, wells, septic systems, commercial properties, and private property, including CYCC
- Educate visitors and the general public by demonstrating the connection between productive estuaries and salt marshes and a natural tidal regime

- Improve fin-fishing and shell-fishing opportunities
- Enhance opportunities for canoeing, kayaking, and wildlife viewing over a diversity of restored wetland and open-water habitats

*Restoration techniques*

*Chequessett Neck Road Bridge-* Replacing the existing Chequessett Neck Road dike and culverts (Figure C 15) with a new bridge and electrically controlled sluice gates (Figure C 16) is the restoration project's main tidal restoration element. A portion of the existing earthen dike and three-bay culvert structure at Chequessett Neck Road will be removed, and a new 165-foot-wide bridge with adjustable sluice gates will be installed. The new bridge and sluice gates will allow for the gradual transition from the current restricted tidal flushing regime to conditions more closely resembling the river's natural flow prior to construction of the Chequessett Neck Road dike. The new bridge will be equipped with a fishing platform and an adjacent area will be installed for canoe and kayak access to the river.

Figure C 15 – Current Chequessett Neck Road Bridge and culvert structure. Credit: National Park Service.

Figure C 16 – Conceptual rendering of redesigned Chequessett Neck Road Bridge. Credit: Fuss & O'Neil.

*Mill Creek Water Control Structure*- Phase 1 includes partial restoration of the Mill Creek sub-basin, up to approximately 21 acres of tidal wetlands. A water control structure equipped with slide/flap tide sluice gates will be constructed across Mill Creek near the entrance to Lower Herring River. This structure will enable a controlled re-introduction of tidal exchange while protecting structures on private properties.

*Removal of High Toss Road causeway*- The Herring River passes under the western portion of High Toss Road, the second road that crosses the river, approximately one mile upstream from Chequessett Neck Road. Complete removal of the earthen causeway and culvert crossing of Herring River at High Toss Road is a tide control component of the Project. A new Herring River channel will be excavated to its prior width of approximately 30 ft to match the natural channel width and depth above and below the roadway crossing for tidal water conveyance.

*Pole Dike Road Water Control Structure*- The proposed design at the Pole Dike Road crossing is to raise the roadway at the crossing from 4.7 ft to 8.8 ft and to increase the size of the culvert from a 36 in diameter pipe to an eight-foot high by seven-foot-wide box culvert with a combination flap/slide gate. The combination flap/slide gate will be able to regulate tidal flow to the Upper Pole Dike sub-basin, thereby restricting flood tide flow and limiting water surface elevations.

*Elevation of more than two miles of low-lying road segments-* The Project area consists of several low-lying roadways that are vulnerable to high tide water levels with restored tidal flow. To prevent overtopping during the storm-of-record, segments of these roadways will be elevated to a minimum of six inches above the predicted water surface elevation during the modeled storm-of-record.

*Reconfiguration of CYCC golf course-* CYCC is a semi-private club with a nine-hole golf course located in the Mill Creek sub-basin of the Herring River. Currently, portions of the CYCC golf course experience occasional flooding by groundwater and surface water in the area of Mill Creek. Raising and renovating portions of the five lower fairways, tees, greens, roughs, sand traps and to mitigate against higher water levels.

C 1.5.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- Town of Wellfleet, MA – Owner of the major infrastructure that will be rebuilt by the project and project co-proponent.
- U.S. National Park Service Cape Cod National Seashore – Owner of about 95 percent of the land to be restored under Phase 1, project co-proponent, funder of numerous studies and NEPA permitting.
- Friends of Herring River – Secured/administered grants from various sources, issued and oversaw numerous design and permitting contracts, conducted stakeholder outreach, community engagement, and coordinated with federal/state/local entities for permitting of projects.
- NOAA RC – Provided funding for all phases of project design and permitting, and provided technical assistance.
- NRCS – Provided funding for various project aspects and technical assistance.
- USFWS – Provided funding for various project aspects and technical assistance.

- Massachusetts Division of Ecological Restoration – Provided funding for various project aspects and technical assistance.

### C 1.5.4 Status and Outcomes

*Habitat monitoring and herring passage performance*

A number of studies (Alcott et al. 2021a; Alcott et al. 2021b) have documented that migratory fish in the Herring River estuary are impeded from reaching their upstream spawning ponds by a number of undersized culverts that result in high flow velocities and with predators, such as snapping turtles, using the culverts as ideal places to prey on river herring. Volunteer herring counts continue annually pre-construction and will continue post-construction.

*Factors contributing to project success*

This multifaceted, highly-complex project has been successful to date for a number of reasons, the largest being an active non-profit group (Friends of Herring River) dedicated to receiving the grant funds and managing the numerous project contracts, and the hiring of an excellent project coordinator.

### C 1.5.5 Supplemental Information

Friends of the Herring River Organization Web Page

## C 1.6 Pawcatuck River Restoration

### C 1.6.1 Background

The Pawcatuck River is low-gradient, nearly 35 miles long, and one of Rhode Island's highest quality rivers, with a 307-square-mile, largely forested watershed in southwestern Rhode Island and small portion of southeastern Connecticut. The Wood River is its largest tributary, and the Chipuxet (Charles) River is another significant tributary, discharging from 1,043-acre Worden Pond, a glacial outwash lake and Rhode Island's largest freshwater body. Other numerous large lakes and ponds (including Chapman Pond, Watchaug Pond, Thirty Acre Pond, and Hundred Acre Pond) with outlet streams connected to the river or its tributaries contribute to a total of nearly 1,800 acres of high-quality lentic spawning and rearing habitat for use by alewife. The Chipuxet and Queen Rivers join in the Great Swamp, Rhode Island's largest swamp, to form the Pawcatuck, and the river discharges to Little Narragansett Bay. The Wood-Pawcatuck River and seven tributaries were designated as a Wild and Scenic River by the National Park Service in 2019.

*Historical Context*

*Lower Pawcatuck River* - The Pawcatuck River is historically known for significant runs of river herring, American shad, and Atlantic salmon; particularly during early European colonization and prior to colonization. In one documented case, early colonists witnessed Narragansett and Niantic tribes vying for upriver migrating fish at the base of a falls in 1636. The Pawcatuck has been substantially modified by a number of mainstem, run-of-the-river dams over the past 250+ years. In the Town of Westerly, a grist mill dam is known to have been constructed and owned by Samuel Maxson and John Davis at Potter Hill, as early as 1762. Another grist mill and dam, owned by Peter Crandall and located about a mile upstream of Potter Hill, was purchased by John Davis. Davis later relocated his mill to the Westerly side of the Pawcatuck River at Potter Hill. Shortly after this move, a saw mill, located on the eastern side of the river (the Town of Hopkinton) was also relocated to the Westerly side at Potter Hill and dam site. Ownership of the Potter Hill dam site changed hands over time, and by 1810, Joseph Potter purchased the property to start a cotton mill. The mill output was expanded to a cotton spinning and dressing mill and continued to be operated by the Potter family through 1843. The mill and dam were sold multiple times, changed in types of goods produced, and expanded in production over time. In 1902, the Pawtucket Woolen Mill Company purchased the facility, and in 1903, the company rebuilt Potter Hill dam. The Westerly Woolen Mill was the last commercial facility at Potter Hill, operating until 1958. No further operation, maintenance or management of the dam has been provided since the business closed.

The state of Rhode Island installed a Denil-type technical fishway on the east side (Hopkinton) of the Potter Hill dam in the early 1970s, and which has been operated and maintained by the Rhode Island Department of Environmental Management (RIDEM) to present. Other than minor modifications to the baffles in 2016, the fishway functions with limited passage efficiency due to the poor location of the entranceway, situated in the dam spillway plunge, and the limited operating range of the flow through the fishway for passing fish. In 1992, the idle and defunct mill and dam were purchased by Renewable Resources, Inc., but no improvements have been made to the structures since the purchase. Currently, the mill building structures are in a decrepit state, the low-level dam drain gate is non-functional, and the raceway is leaky. The Rhode Island Superior Court recently assisted the Town of Westerly by appointing a special master to address the ownership and needs for the dilapidated mill and dam. In 2020, the Town of Westerly secured a grant award from NOAA to complete and alternatives analysis to identify and implement a preferred alternative for improving migratory fish passage, restoring ecological riverine conditions, reducing flood risk, and increasing community resilience. Discussions on dam removal have stalled, and the Town of Westerly put the project on hold in early 2022.

The village of Bradford is located approximately 7 miles upriver of the Potter Hill dam. Construction of grist mills and dams began in the village of Bradford in 1758. For the Bradford Dyeing dam site, textile manufacturing and a wood carding mill began operations sometime after 1819. The date of the dam construction is uncertain, but was likely built between 1819 and 1846 to divert river flows to the raceway traversing under the textile mills as a source of waterpower. The mill was rebuilt in 1864, and textile manufacturing continued at the site until 1902, at which time, new owners shifted operations to textile finishing and dyeing. The dam (with a poorly functioning Denil fishway installed in the 1970s) was damaged in a recent (2010) flood event, and project partners began to assess the barrier removal in 2015. The dam was removed and replaced with a river-wide, NLF completed in 2018.

*Upper Pawcatuck River* - Three mainstem dams have been the focus of the upper Pawcatuck passage restoration. The uppermost dam located in the village of Kenyon provided power to a saw mill as early as 1772, and by 1844, the village was renamed Kenyon's Mills, utilizing the stone dam on the upper Pawcatuck. The Kenyon Mill dam, with granite-rubblestone spillway, was last rebuilt during the 1940s-1950s, and has been maintained until recently when the dam was replaced with a river-wide, NLF, as a fire suppression water supply for Kenyon Industries. A grist mill, known as Clarks Mill, was known to have existed at the Upper Shannock Falls dam, the next downstream dam, in the village of Shannock, by 1747. Shannock village changed rapidly in size once the Stonington-Providence Railroad was completed in 1837, facilitating the development of textile mills in Shannock. The Lower Shannock Falls dam was known to support a grist mill by 1833, and was later replaced by a textile mill built by John Knowles in 1840. The Knowles Mill, later part of the Carmichael Mills at the Lower Falls dam, burned down in 1884. Columbia Narrow Fabrics Company ran the upper mill until 1968 when operations ceased.

Grant funds were secured from NOAA through the American Recovery and Reinvestment Act (ARRA) of 2009 to address fish passage at these three dams: Lower Shannock Falls dam was removed in 2010 (with backwater weirs reconstructed in 2011), a Denil fishway was installed at Upper Horseshoe Falls dam in 2012, and a river-wide NLF was completed at the Kenyon Mill site in 2013.

*Main Restoration Projects*

For downstream to upriver, the following projects have been completed or are currently under consideration (overall the period of 2006-2022) for fish passage barrier removal (Figure C 17):

- White Rock dam removal, along with the modification of the Griswold Mill raceway to prevent diversion of non-flood flows into the raceway were completed in 2015.
- Potter Hill dam is under consideration by the Town of Westerly and its partners on a preferred alternative for final design and implementation. A NOAA grant was awarded to the Town of Westerly in 2020 to initiate an alternatives analysis; the analysis was completed in early 2022, but no decision was made to advance a preferred alternative.
- Bradford Dyeing dam and poorly-functioning technical fishway were removed in 2018 and replaced with a river-wide, step-pool NLF.
- Lower Shannock Falls dam, owned by the Towns of Richmond and Charlestown, was removed in 2010. The fish passage project also included a set of three boulder weirs installed in the steep-gradient reach downstream of the dam removal to address a fish passage velocity barrier. These weirs were reconstructed in 2011 to increase passage efficiency by river herring and other migratory fish.
- Horseshoe Falls dam included the repair of this privately-owned dam and installation of a Denil fishway on river-left (Charlestown), along with an innovative eelpass incorporated into the fishway design. The fishway project was completed in 2012. The fishway has an 11.5foot lift, 31 baffles, and flow capacity of ~38 cfs to pass river herring to the upper river.
- Kenyon Mill dam was removed in 2012 and replaced with a river-wide, step-pool NLF, completed in 2013.

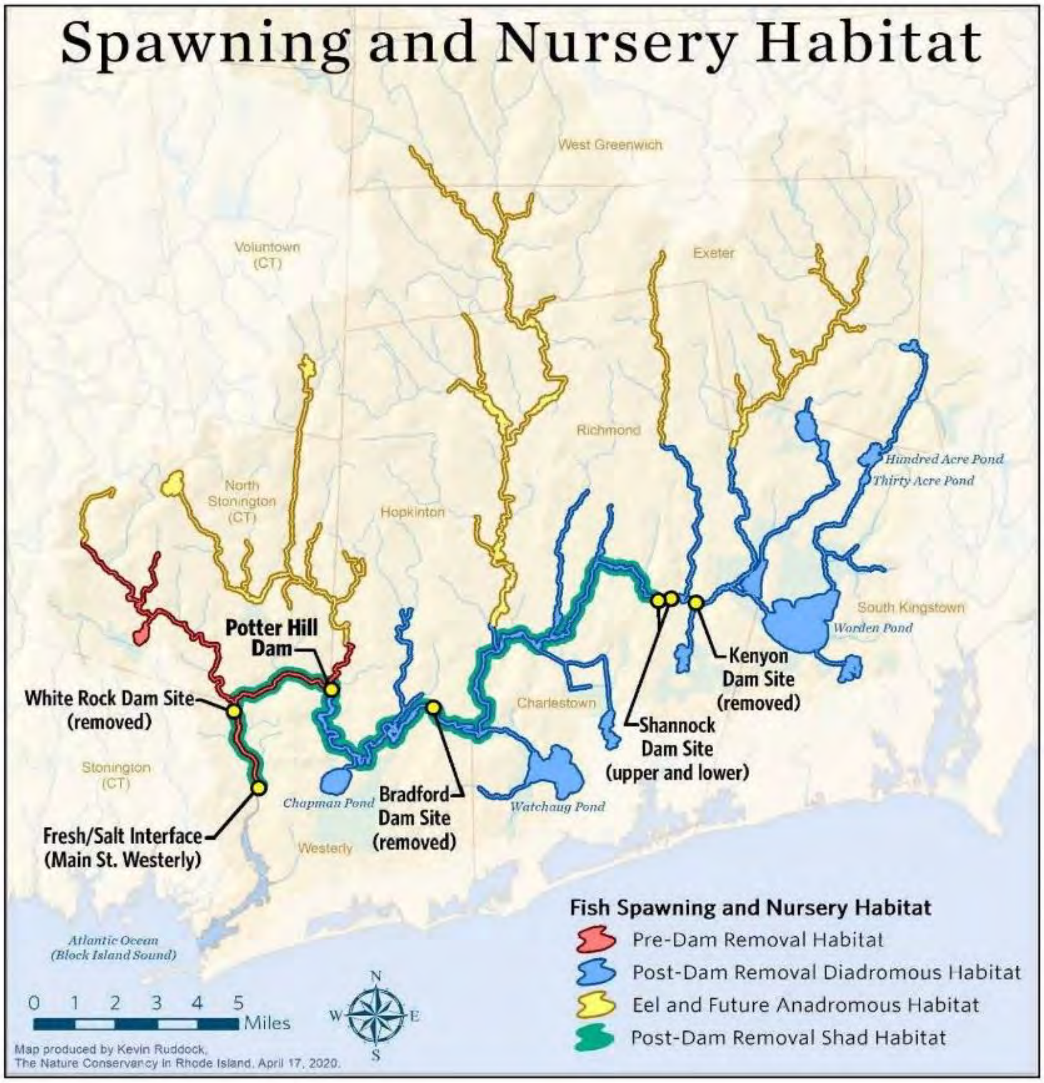


Figure C 17 – Pawcatuck River fish passage sites and riverine habitats benefiting diadromous fishes. Credit: Ken Ruddock/ TNC.

C 1.6.2 Restoration Goals

- Provide effective passage for both migratory (diadromous) and resident fish species
- Improve riverine habitats
- Maintain or enhance aesthetic values
- Address dam safety and reduce public safety hazard risk
- Minimize dam maintenance

- Consider and address cultural resources associated with the mill and dam structures

### C 1.6.3 Restoration Techniques Employed

*Dam removal* – Full dam removal was completed for the White Rock dam (Figure C 18; Westerly, RI and Stonington, CT) and the Lower Shannock Falls dam (Figure C 19; Richmond and Charlestown, RI). The White Rock dam removal included installation of a berm structure to eliminate non-flood river flows from being diverted through a long, broad raceway.

*Nature-like fishway* – River-wide step-pool NLFs were installed at the Kenyon Mill (Figure C 20 and Figure C 21; Richmond and Charlestown, RI) and Bradford Dyeing dam (Figure C 22 and Figure C 23; Hopkinton, RI) removal sites. Backwatering boulder weirs were also installed in a steep-gradient reach immediately downstream of the Lower Shannock Falls dam removal (Figure C 24).

*Technical fishway* – A Denil fishway and eelpass were installed on river left at the Horseshoe Falls dam (Figure C 25; Charlestown, RI). In 2016, modifications were made to an existing, poorly functioning Denil fishway, originally constructed in the early 1970s, on river-right of the Potter Hill dam (Figure C 26; Westerly, RI). These modifications included replacement of fishway baffles with updated notch invert elevations, and removal of flow-obstruction boulders immediately downstream of the fishway entrance.

Figure C 18 – White Rock dam removal: Existing dam and accumulated sediment behind dam (left) and dam removal with upstream port-a-dam to divert flows into raceway, October 2015. Credit: NOAA Fisheries.

Figure C 19 – Lower Shannock Falls Dam removal. Existing dam (left – 2008) and river restored after dam removal (right – 2011). Credit: NOAA Fisheries.

Figure C 20 – Kenyon Mill Dam, pre-removal (left – 2010) and NLF under construction (right – 2013). Credit: NOAA Fisheries.

Figure C 21 – Kenyon Mill step-pool NLF, uppermost fish passage site, completed 2013. Credit: NOAA Fisheries.

Figure C 22 – Bradford Dyeing Dam pre-removal (left) and installation of NLFs (right) in 2017. Credit: NOAA Fisheries (left) and Ayla Fox/TNC (right).

Figure C 23 – NLF at Bradford Dyeing site, spring flows, 2022. High fish passage flows have submerged the lower weirs, attributed to downstream backwatering. Credit: NOAA Fisheries.

Figure C 24 – Modification of the backwatering weirs downstream of Lower Shannock Falls Dam removal to improve passage efficiency (left – 2011) and view of the backwatering weirs during low fish passage flows (right – 2012). Credit: NOAA Fisheries.

Figure C 25 – Horseshoe Falls dam with Denil fishway and eelpass, completed 2012. Credit: NOAA Fisheries.

Figure C 26 - Potter Hill dam in April 2022. Narrow spillway encumbers excessive flows, creating broad hydraulic at toe of spillway. Existing fishway (circa early 1970s) functions poorly due to location of the entranceway (lower center of photo) and truncated operational flow range. The removal of the decrepit mill (background, river left) and last mainstem dam remain under consideration by the Town of Westerly and Rhode Island Superior Court in 2022. Credit: NOAA Fisheries.

### C 1.6.4 Partners and Stakeholders

*Select Parties Involved and Contributions*

- Wood Pawcatuck Watershed Association (WPWA) – The WPWA is a local advocacy group that supported this set of fish passage restoration projects in the watershed. The WPWA also worked tirelessly to have the Wood-Pawcatuck designated as a Wild and Scenic River by the National Park Service in 2019. Staff from WPWA also help to support the Wood-Pawcatuck Wild and Scenic River Stewardship Council which serves as a strong advocate group to restore and protect the natural resources and resource values of the watershed.

- TNC – The TNC-Rhode Island Chapter contributed matching funds to the upper river fish passage projects funded through the ARRA of 2009. TNC also led the efforts to remove the White Rock dam (2015) and to replace the Bradford Dyeing dam with a river-wide NLF (2019).

- NOAA RC – The RC awarded ARRA funds for implementation of the three upper river fish passage projects, and awarded other grant funds to the Town of Westerly to address the Potter Hill dam project. The NOAA GAR office also provided key technical assistance for these six mainstem fish passage projects (2006-2022).

- USFWS – The USFWS Charlestown, Rhode Island and Hadley, Massachusetts offices provided technical assistance, including engineering design input, for these fish passage projects, plus contributed funds for the Lower Shannock dam removal, Bradford NLF, a 2-year telemetry study completed by USGS to evaluate fish passage on the Pawcatuck River sites, and the Potter Hill dam project.

- USGS – Research staff from the USGS Conte Fish Research Laboratory in Turners Fall, Massachusetts developed the assessment methods and field protocols and completed the 2-year telemetry study to evaluate fish passage efficiency and effectiveness at multiple passage sites on the Pawcatuck River (see Haro 2020).

- Coastal Resources Management Council (CRMC) – This state agency was the lead recipient for the ARRA grant award, and coordinated the various project partners and fund allocations for the upper Pawcatuck River projects, but also three other river herring passage projects on the Ten Mile River located in East Providence, Rhode Island.
- Southern Rhode Island Conservation District – Staff provided administrative support to the Town of Westerly, and in particular, led public outreach efforts in communicating with watershed stakeholders.
- University of Rhode Island (URI) – Faculty and graduate students from the URI-Department of Natural Resource Sciences participated in the 2-year fish passage telemetry evaluation of multiple river herring passage sites, an assessment of wetland and river conditions associated with the Bradford Dyeing NLF installation and the Potter Hill dam project.
- Connecticut Department of Energy and Environmental Protection (CTDEEP) – provided technical and permitting assistance for the White Rock dam removal.

*Select Funding Sources*

More than $10 million has been secured for the Pawcatuck River fish passage restoration since 2005. The following are key funders and fund recipient organizations which collectively helped with passage restoration efforts in this highly valuable southern New England watershed:

- NOAA, ARRA fund award (~$3.5M) for three upper river fish passage projects, and the Potter Hill dam project in the lower river
- TNC – contributed funds for the upper river fish passage projects and secured funding for the White Rock dam removal and Bradford Dyeing NLF installation
- NFWF – awarded funds to TNC for managing contracts to design, permit and implement multiple mainstem projects
- USFWS – contributed funds for the lower river fish passage projects, plus funded the USGS and URI to complete the 2-year fish passage telemetry evaluation

#### C 1.6.5 Status and Outcomes

*Project monitoring and documented success*

The USGS conducted a two-year telemetry study (2018-2019 fish run seasons) to evaluate alewife and American shad passage at each of the passage sites on the mainstem. The telemetry study included use of both PIT tags and radio telemetry to evaluate river herring and shad passage and passage efficiency, and reveal other key watershed use and spawning habitat information. Tagged fish were released both downstream of the White Rock Dam removal site and upstream of the Potter Hill dam to account for anticipated poor passage at the Potter Hill dam fishway. Both PIT and radio antennae were installed both downstream and upstream of each passage site to evaluate passage efficiency. Mobile tracking using a radio antenna and canoe was conducted to pinpoint potential American shad spawning areas. The passage monitoring occurred throughout the run period to include all alosine target species, and receiver data were downloaded in the field onto laptop, 2-3 times per week. Over the 2-year study, a total of 650 alewife were PIT (n = 447) and radio (n = 193) tagged, along with 89 American shad that were radio tagged to evaluate the passage sites. Results revealed the distance of river assent, river reach transit time, tagged fish pass and fail attempts, and passage efficiency at each passage site (Haro 2020).

*Factors contributing to project success*

Early and routine coordination with dam owners are key to securing essential owner acceptance to allow a defunct dam to be removed or modified to accommodate a fish passage structure. Project partners had successful outcomes with private owners of the White Rock, Bradford, Horseshoe Falls, and Kenyon Mill dams. For the Kenyon Mill dam, Kenyon Industries was supportive of a dam removal, provided the partners could implement a strategy to maintain a source of water for fire suppression in case of an emergency. The Kenyon Mill corporate owner supported dam removal or NLF alternatives, and the partners often held on-site meetings with the mill staff to advance the design and implementation. Ultimately, the NLF alternative was selected to maintain the upriver water surface elevation, to sustain shallow water wells of private residences. The Lower Shannock Falls dam was owned by two towns, but project partners were able to explain the public hazard risk associated with the defunct, failing structure, and secured timely favorable support from municipality officials to remove the dam.

*Obstacles and resolution*

Owner coordination for the Potter Hill dam project has been challenging. The defunct dam and mill have been in private ownership by an individual since 1992. The owner sought to rebuild the mill as a commercial office and restaurant facility, and the dam for generating hydropower, but lacked the funds and state and federal regulatory authorizations to advance the project. The Potter Hill project, the last remaining fish passage barrier on the mainstem, stalled (2022) due to misinformation by opponents to the project presented during several Town of Westerly Town Council meetings. The lack of understanding of technical issues by the some of the public and Town Council resulted in the project being put on hold. This has included consideration by the Town Council of whether to take control and ownership of the failing dam, mill and raceway. Efforts to complete efficient and effective passage at the Potter Hill dam continue.

### C 1.6.6 Lessons Learned

- A Letter of Map Revision (LOMR) is required by the Federal Emergency Management Agency (FEMA), with an increase or decrease in flood elevation associated with a barrier removal. The FEMA requirements for preparation and processing of LOMR need to be fully considered in a project budget for engineering services to complete the requisite documentation.
- Operation and maintenance considerations are often required for any type of fishway, but technical fishways in particular require preparation, implementation, and adherence to an Operations and Maintenance Plan to allow efficient passage to be sustained for a properly designed and constructed technical fishway.
- Strong communication among project partners and watershed stakeholders is essential to advancing a project. One key communication focus is to simplify complex ecological or engineering issues for clear understanding by all stakeholders, and to provide timely and clear responses to stakeholder concerns regarding dam removal and other fish passage alternatives.

### C 1.6.7 Supplemental Information

WPWA: Studies and Reports

WPWA: Lower Shannock Falls Dam Removal 2010

WPWA: Horseshoe Falls Dam Fish Ladder 2011

WPWA: Kenyon Mill Dam Fish Passage 2012

WPWA: Upper Pawcatuck River Feasibility Study

TNC: Removing Bradford Dam

WP Wild and Scenic Rivers Council: Organization Web Page

WP Wild and Scenic Rivers Council: Wood-Pawcatuck Watershed Description

Atlantic Coastal Fish Habitat Partnership: Improving Fish Passage Through the Removal of the Bradford Dam, Pawcatuck River, Westerly, Rhode Island

Presentation on Advancing Anadromous Fish Passage Efficiency – Lower Shannock Falls Dam Removal. Pawcatuck River, Rhode Island

Presentation on Evaluating Diadromous Fish Passage at Lower Shannock Falls Dam Removal and Nature-like Weirs. Pawcatuck River, Rhode Island

CRMC: CRMC receives funding from NOAA for Upper Pawcatuck River Restoration

Eco-RI Media Article: Removal of Potter Hill Dam Would Improve Pawcatuck River Fish Passage, Reduce Flooding Risks

## C 1.7 Columbia Dam Removal on the Paulins Kill

### C 1.7.1 Background

*Historical Context*

As the third-largest tributary draining into the Delaware in New Jersey, the Paulins Kill has a major impact not only on the lives of the people and wildlife that live in its watershed, but also on those that rely on nearby stretches of the Delaware. The Paulins Kill in Sussex and Warren counties is a 41.6 mile tributary of the Delaware River. Positioned in the forested and agricultural landscape of rural northwestern New Jersey, the Paulins Kill and its watershed connect the more pristine forests and headwaters of the Kittatinny Ridge, across the Limestone Valley where small towns and farms dot the landscape, to its confluence with the Delaware River.

In 2017, TNC updated an analysis carried out with the Northeast Association of Fish and Wildlife Agencies to identify dams in the northeast region having the highest impact on migrating fish. The Columbia Dam (Figure C 27) was ranked in the top five percent of all dams (over 14,000) prioritized for removal. The Columbia Dam was built by the Jersey Central Power and Light Company (JCP&L) in 1909; the 18-foot high, 330-foot-long structure impounded a 32acre reservoir that stretched 1.5 miles upstream of the dam. When first constructed, the dam created a pond for ice harvest and provided energy to light the towns of Columbia, NJ and Stroudsburg, PA. The State of New Jersey owned the dam (sold by JCP&L in 1955) and 1,098 acres of land in the vicinity; collectively managed as the Columbia Wildlife Management Area. The Columbia Dam was privately leased to Great Bear Hydropower for operation between 1986 and 2016, when the FERC license was surrendered.

Figure C 27 – The former Columbia Dam. Credit: Jeff Burian/ TNC.

C 1.7.2 Restoration Goals and Techniques Employed

*Goals*

- Increased abundance of migratory fish including American shad, river herring, sea lamprey and American eel upstream of the dam

- Increased relative abundance and diversity of riverine fish species
- Increased abundance of macroinvertebrates and mussels which are indicative of good water quality
- Improved water quality in the lower Paulins Kill, particularly with respect to temperature and dissolved oxygen
- Increased recreational fishing and boating in the lower Paulins Kill

*Restoration techniques*

Prior to the removal of the Columbia Dam, a downstream remnant dam was removed. This dam was constructed in 1901 but failed the following year (Figure C 27).

*Dam Removal* - The removal of the Columbia Dam was planned as a staged lowering. Saw-cutting, followed by use of a hydraulic hammer. Initially removed a forty-foot-wide notch in July of 2018. The notch was lowered and widened over several months versus the planned several weeks due to high water conditions and delay of approvals from county engineer's office. Dam lowering/removal needed to be done in conjunction with scour protection installation under Route 80. The last bit of the apron and base of the dam (below grade) were completed April 4, 2019 (Figure C 28).

*Sediment Management* - The impoundment contained 300,000 cubic yards of sediment and was ~1.5 miles in length. Princeton Hydro was contracted by American Rivers to design and permit the removal and then contracted by TNC to provide engineering oversight during the removal. Project partners also included USFWS, New Jersey Department of Environmental Protection (NJDEP), New Jersey Division of Fish and Wildlife Service (NJF&W), RiverLogic Solutions, and SumCo Eco-Contracting. The construction was initiated in June of 2018. A passive sediment management approach was used, where ~17 percent of the accumulated sediment was deliberately allowed to mobilize downstream. The Delaware River was able to receive and transport this sediment with little or no adverse impacts to natural resource and recreational values.

*Scour Prevention* - Brugler Road Bridge Stone triple-arch bridge built in 1850 and on the National Register of Historic Places. Constructed rock vanes downstream to maintain the water elevation and prevent scour (Figure C 30 and Figure C 31). Warrington Road Bridge Pony truss historic bridge. Scour protection installed upstream and downstream. Protection included gabion boxes, rock and concrete installed along the concrete scour wall and extend up to the existing gabions (Figure C 32).

*I-80 Overpass* - The I-80 overpass caused a constriction of the river which caused higher velocities over a 300 ft-long section that also experienced a five-foot change in elevation. Bank armoring at Route I-80 overpass was installed downstream of the overpass on river left to protect the bank against increased stream velocities. In order to facilitate fish passage under the Route I-80 Bridge six rock vane structures were installed. The structures provide the depth and velocities needed to allow for the passage of American Shad and other target species under the Route 80 bridge underpass.

*Warrington Access Road* - A length of bank on river left was protected with toe boulders to the base water surface elevation and coir fabric wrapped soil lifts with dormant stake planting to top of bank to stabilize or protect banks from scour and erosion, maintain the flow capacity of the stream, reduce offsite effects from sedimentation, improve water quality and protect access road (infrastructure) (Figure C 33).

*Floodplain Restoration* - A total of approximately 35 acres of floodplain were dewatered with the removal of the Columbia Dam. Seed stored in the sediment began germinating within weeks. Restoration efforts include planting over 10,000 trees, willow stakes and whips. Brush trenches, dormant willow cuttings installed in 35 rows spaced 10 ft apart with a total length of 5,000 ft, were installed to protect the integrity of the floodplain by reducing flood flow velocity from the main channel (Figure C 33).

Figure C 28 – The former Columbia Dam site, post removal. Credit: Jeff Burian/ TNC.

Figure C 29 – Removal of remnants from the Columbia Dam. Credit: Beth Styler Barry/ TNC.

Figure C 30 - Brugler Bridge rock vane construction Credit: Beth Styler Barry/ TNC.

Figure C 31 - Brugler Bridge rock vane construction, view from downstream. Credit: Beth Styler Barry/ TNC.

Figure C 32 – Warrington Bridge scour protection, view from above. Credit: Dave Zuckerman/ Columbia Volunteer Drone Team.

 

Figure C 33 – Road area streambank protection (left) and riparian plantings (right) including 10,000 trees, willow stakes and whips. Credit: Beth Styler Barry/ TNC.

C 1.7.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- The State of New Jersey
- NJDEP
- NJDEP Office of Natural Resource Restoration
- NJDEP NJF&W
- USFWS
- Academy of Natural Sciences of Drexel University
- American Rivers
- Biodrawversity
- Dr. Barbara and Mr. Thomas Brummer
- Ducks Unlimited (DU)
- Betty Wold Johnson

- Leavens Foundation
- Montclair State University
- NFWF
- NRCS
- NJ Corporate Wetlands Restoration Partnership
- NJDEP Bureau of Dam Safety
- John and Margaret Post Foundation
- Princeton Hydro
- RiverLogic Solutions
- Charles and Susan Snyder
- SumCo Eco-Contracting
- Tom's of Maine
- TU
- USGS
- Warren County Engineers
- Warren County Freeholders

*Select Funding Sources*

Funding for this project (Table C 2) was provided by generous support from private donors, USFWS, NJDEP (Office of Natural Resource Restoration), United States Department of Agriculture (USDA) NRCS, the Corporate Wetlands Restoration Partnership, NFWF, Atlantic Coastal Fish Habitat Partnership (ACFHP), DWCF, Leavens Foundation, and Tom's of Maine.

Table C 2 – Public and Private Funding Sources for the Columbia Dam Removal on the Paulins Kill, Columbia NJ.

| Public Funders | |
|---|---|
| ACFHP | $ 50,000 |
| NJDEP NRDA I | $ 3,926,960 |
| NJDEP NRDA II | $ 1,045,928 |
| National Fish Passage Program (NFPP) | $ 50,000 |
| NFWF Bring Back the Natives | $ 100,000 |
| NRCS Regional Conservation Partnership Program | $ 567,500 |
| NFWF DWCF | $ 249,824 |
| Total | **$ 5,990,212** |
| **Private Funders** | |
| Toms of Maine | $ 20,000 |
| Coastal Wetlands Restoration Partnership | $ 25,000 |
| TNC Private Donors 2013 - 2022 | $ 1,000,000 |
| Total | **$ 1,045,000** |

### C 1.7.4 Status and Outcomes

*Project monitoring and documented success*

American shad were photo-documented 10 miles upstream, below the next dam, 17 days after removal. The shad have successfully passed the restored dam site, the fish passage structures under Route I -80 and the two rock vanes at Brugler Road, which suggests that the design team engineers at Princeton Hydro and USFWS, with review and input from partners at NJF&W and American Rivers, were successful. It also confirms that the installation of those structures by SumCo Eco Contracting and RiverLogics was properly completed. The return of American shad to spawn in the Paulins Kill for the first time in over a century this past spring was a major milestone in the success of this long-planned and complex project. Other than American shad, sea lamprey were observed and photographed mating approximately eight miles upstream about 18 months after removal. Relative abundance and the ranges of age and size distributions of eels have also increased following removal

*Obstacles and resolution*

The biggest challenges on this project were caused by the manipulation of the river channel over the last century by the railroad and the Route I-80 crossing. This locked the river into a bend and constrained the channel to the point of an elevation change. To tackle the challenge of fish passage under the Route I-80 Bridge USFWS, NJF&W and TNC's engineer Princeton Hydro designed and installed six rock vane structures. The structures provide the depth and velocities needed to allow for the passage of American shad and other target species.

#### C 1.7.5 Lessons Learned

- A multi-disciplinary team will allow challenges to be addressed efficiently and in creative ways.
- Newly revealed floodplain will revegetate quickly. Think about site conditions and sediment types, plant natives and expect consolidation.
- Anticipate potential project delays in working with local government partners and regulators.
- Communicate often with consultants and contractors to find workarounds in construction schedule during bad weather.
- Document success. Water chemistry and temperature should be monitored before and after. Habitat and macroinvertebrate community metrics can be used as an indicator of overall ecosystem improvement.
- Threatened and endangered species, as designated by state/federal agencies, monitoring will involve special considerations and project team should work closely with regulators.
- Infrastructure in impoundments or below the dam must be carefully considered and can increase project costs.

#### C 1.7.6 Supplemental Information

TNC: Restoring the Paulins Kill River

### C 1.8 Patapsco River Dam Removal at Bloede Dam

#### C 1.8.1 Background

*Historical Context*

The watershed of the mainstem Patapsco River (HUC-8: 02130906, 02130907, 02130908) encompasses 368 square miles in the eastern Piedmont of Maryland, entering the Chesapeake Bay at what is now Baltimore, Maryland. Indigenous peoples arrived in the area more than 10,000 years ago. Upon contact with 16th century European explorers, the majority of the peoples in the Chesapeake region spoke languages from the extensive Algonquin language family (Tayac et al. 2006). By the late 18th century, the Patapsco River valley was a hub of early industrial development, as evidenced by the construction of Maryland's first iron furnace, the Elkridge Furnace, in 1755. Continuing development was marked by the construction of the mainline of the Baltimore and Ohio Railroad, completed in 1834, which initially ran up the Patapsco River valley between Baltimore and Ellicott City, Maryland before extending further westward in the mid-19th century. In 1906, the Bloede Dam was constructed on the mainstem Patapsco River to provide power to local industry. It was the nation's first hydropower project where the turbines were housed within the dam spillway.

The steep Patapsco River valley was highly susceptible to erosion from human land alteration and concerns from regional industry led to the implementation of a forest preserve in 1907, which eventually became Maryland's first state park - Patapsco Valley State Park. This park extends 32 miles along the river valley and supports a variety of historic landmarks and recreational opportunities. Despite the conservation of the mainstem river corridor, this watershed had already experienced extensive deforestation during the late 19th century which led to the extensive siltation of the deep-water port at Elkridge, Maryland. In fact, sediment accretion behind the Bloede dam was one factor leading to the cessation of hydropower operations in 1924.

Today, the effect of these historical watershed changes remains evident. Under most flows, it is possible to wade across sections of the river that historically supported deep water shipping and navigation during the colonial era. The watershed is densely populated, with approximately 16% of lands being characterized as "impervious" land cover (USGS 2016). The largest city in the watershed Ellicott City, Maryland recently experienced a series of extensive (i.e., 1,000-year flooding events) flash-floods in 2016 and again in 2018, influenced to some degree by the river valley topography and increased impervious surface cover.

*Patapsco River Dam Removal Projects*

In the early 2000s, American Rivers along with the MDNR, Friends of Patapsco Valley State Park, and NOAA worked to remove two mainstem dams located upstream of the Bloede Dam. In 2010, the Simkins Industrial Dam was removed. The Union Dam, which was initially breached by heavy precipitation associated with Hurricane Agnes in 1972, was also fully-removed in 2009 as a part of this effort. These two dams were planned, designed, demolished, and monitored primarily using funds available from NOAA via the American Reinvestment and Recovery Act of 2009.

The removal of these two dams upstream along with dam safety concerns led to increased calls for the removal of Bloede Dam in the years following. Specifically, damages sustained by the Bloede Dam during Hurricane Agnes in 1972 led to increased maintenance costs for the State of Maryland. Dam safety concerns also stemmed from several fatalities at this dam due to unauthorized swimming activities in Patapsco Valley State Park and the river hydraulics created by the dam. This totaled at least nine fatalities in the period between 1980 and the dam's removal. Through an extensive effort by the aforementioned partners and others identified in *Appendix C 1.8.1*, the Bloede dam was removed in 2018-2019. We describe that process including challenges and approaches below.

### C 1.8.2 Restoration Goals and Techniques Employed

The goals of these barrier removals were to enhance public safety and recreation opportunities while also providing for passage of native diadromous fishes in the watershed. This was achieved through three barrier removals on the mainstream Patapsco River. These projects also necessitated several adjacent infrastructure projects (e.g., sewer line replacement, culvert replacement). Efforts began with the Union Dam and Simkins Industrial Dam because they were less technically-complex than the lowermost dam removal. Furthermore, the removal of these upstream barriers provided greater justification for the Bloede Dam removal project because the fish passage benefits were immediately realized throughout much of the mainstem river. This was important because the Bloede removal project also presented a greater disruption to state park facilities (e.g., trails) and required additional support for planning, design, and construction.

The removal of Bloede Dam was technically complex and necessitated extensive planning and the involvement of a diverse team of experts. One primary complication was the location of a sewer main along the river bank near Bloede Dam. This line ran through the foundation of the dam and had to be rebuilt independently of the structure to be removed. This required installing a new foundation for the line on native bedrock. Originally, the sewer line was laid in sediment that was deposited by the river in the impoundment area; had the dam failed during any storm event, the sewer line would have likely breached with the dam. Once the sewer line was completed, the initial breach of the dam was accomplished using explosive demolition (Figure C 34). This process was also technically complex because it required an extensive amount of interagency coordination, planning, and approvals to complete. However, it was chosen because there was limited room to work on the initial breach from the river banks due to the steep character of the valley and location of the sewer lines. The blasting also enabled the removal of concrete floor slabs located at the very base of the dam. These structures would have been difficult to access with mechanical methods and would have presented additional safety concerns. Once the initial breach was established (Figure C 35), the remainder of the barrier removal was completed using mechanical methods. Due to the technical complexity of this project, the American Council of Engineering Companies honored the Patapsco Interceptor Relocation and Bloede Dam Removal, Catonsville, Maryland, at its 2021 Engineering Excellence Awards.

Figure C 34 - Initial Breaching of the Bloede Dam via explosives Credit: Elevate Media, Inc. and MDNR.


Figure C 35 - Bloede Dam after initial breaching. Credit: Jim Thompson/ MDNR.

In addition to barrier removal, stocking efforts were undertaken to facilitate species recovery for river herring. This included several years of stocking by MDNR. Extensive efforts were undertaken to study the effects of barrier removal. This included pre-removal surveys of impounded sediments, modeling to describe the movements of sediments following barrier removal, and a suite of biological surveys. These data have contributed to an in-depth understanding of the natural and geomorphic changes to the Patapsco River associated with these barrier removals.

### C 1.8.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- American Rivers – managed removal projects, provided technical assistance, generated public informational material, facilitated interagency coordination
- NOAA – Funding for completion of design and permitting stages through the OHC, provided extensive technical assistance on the engineering design and construction

- MDNR, Maryland Park Service – provided logistical support, access to park facilities, enforced area closures, and developed outreach materials
- USFWS – Provided funding and technical assistance for the Bloede dam removal project
- For Bloede dam specifically, the lead engineering firm was Inter-Fluve, Inc., with support from the firms Hazen & Sawyer (sewer line relocation engineer), Kiewit Corporation (construction firm), and KCI Technologies Inc. (construction management engineer)
- Monitoring efforts were completed by MDNR Resource Assessment Service (Maryland Geological Survey, Maryland Biological Stream Survey), USGS, University of Maryland Baltimore County, and the Smithsonian Environmental Research Center (SERC)

*Select Funding Sources*

The Simkins Industrial Dam and Union Dam were both removed primarily using funding from NOAA resulting from the American Reinvestment and Recovery Act of 2009. Union dam costs were approximately $1.5 million and Simkins was $872,000. MDNR, the USDA NRCS, and Simkins Industries also contributed to the design and construction of the Simkins Dam removal.

The total cost to remove Bloede Dam was $17.9 million. Funding sources included the following:

- NOAA invested almost $9 million from their Community-Based Restoration Program and Damage Assessment, Remediation and Restoration Program.
- The Maryland DOT State Highway Administration funded $5 million and was permitted to incorporate this project into their Umbrella Mitigation Banking Instrument. This represented the first occurrence of barrier removal as a compensatory mitigation approach in Maryland and has informed other mitigation banking proposals. Credit release was tied to several biological indicators (e.g., river herring upstream of the former dam).
- USFWS contributed through a grant administered by the NFWF as part of the Hurricane Sandy Coastal Resiliency Competitive Grant Program and through the Hurricane Sandy Disaster Relief Appropriations Act of 2013.

- The remainder of the Bloede Dam removal project was funded with grants from MDNR, the Coca Cola Foundation and Keurig-Green Mountain.

### C 1.8.4 Status and Outcomes

*Project monitoring and documented success*

A variety of state/federal partners and research institutions have been heavily involved in monitoring and modeling efforts to estimate and describe the changes associated with multiple dam removals. For example, the State of Maryland instituted several concurrent biological monitoring programs to describe shifts in migratory fish distributions, fish assemblage composition, benthic macroinvertebrate assemblages, and instream habitat for these organisms (Figure C 36). Initial reports (see Harbold et al. 2021) describe greater occurrence of diadromous species (e.g., American eel, river herring) upstream of the former dams, although the densities of river herring are still below those commonly observed downstream. These upstream detections have been corroborated by eDNA surveys completed by the SERC, who have also used sonar technologies to generate population estimates for the Patapsco River runs of river herring (for methods, see Ogburn et al. 2017). These studies provide initial positive documentation of increasing diadromous fish dispersion upstream of former barriers and research is ongoing to document longer-term run dynamics and habitat use.

Several entities including the Maryland Geological Service, USGS, and NOAA RC staff have worked to describe the movement of riverine sediments following barrier removal. Prior to Bloede Dam removal, Collins et al. (2017) described the evacuation times for impounded sediments from Simkins Dam, which provided insights to potential dynamics at Bloede. Cashman et al. (2021) described the observed changes to sediments in the Patapsco River from dam removal using USGS stream gage data. Initial results suggest that the majority of the impounded sediments have dispersed throughout the lower mainstem Patapsco River within a relatively short period of time.

Figure C 36 - Electrofishing operations conducted by the MDNR following Bloede Dam removal have documented river herring upstream of the dam (right), but not yet below the last remaining dam on the mainstem river – Daniels Dam (left). Credit: William Harbold/ MDNR.

*Factors contributing to project success*

A variety of factors contributed to stakeholder support for these barrier removals. First, several dams and the majority of the surrounding lands, including the impoundments, were primarily owned by the State of Maryland as part of Patapsco Valley State Park. This minimized the need for coordination with landowners. Furthermore, aforementioned safety concerns also increased support for removal from the State of Maryland and others. Together, these factors ensured that the community support was sufficient to facilitate the projects. Project success was also largely attributable to a dedicated team of interagency personnel who pursued these projects for over a decade. These organizations facilitated funding sources, provided technical guidance, and dedicated considerable staff resources to ensure project success.

*Obstacles and resolution*

The location of an existing sewer line, which bisected the Bloede Dam on the river's north bank, required extensive engineering and construction expertise to disentangle the sewer line infrastructure from the dam. In this case, the removal of the sewer line was far more costly than the barrier removal. This was overcome by additional funding made available through partner agencies.

There was significant concern that the removal of these dams would release sediments that could impact the health of areas downstream, including the broader Chesapeake Bay. The impounded sediments were sampled extensively to determine the extent to which they contained clays and other fine-grained materials to which nutrients and pollutants are commonly bound. In the case of Bloede Dam, these materials were primarily sand and gravel and were deemed to not pose a significant water quality risk.

Recreational anglers were concerned that the release of sediments from Bloede Dam would diminish smallmouth bass habitat downstream of the dam. Geomorphological modeling was completed to estimate sediment transport from the former impoundment and the impacts to fish habitat below the dam were indicated to be relatively ephemeral. MDNR continues to collect data specifically on sportfish species to document the changes following Bloede Dam removal.

Several stakeholders were interested in preserving the history of Bloede Dam. To ensure that the history was preserved and presented to the public, the partners collected information prior to and during dam removal and installed informational placards following project completion. One unique product from this work was the development of a Historic American Engineering Record and 3D digital model of the Bloede Dam structure. Each of these products are housed at the Library of Congress. This information was provided to and approved by the Maryland Historical Trust under Section 106 of the NHPA.

The Bloede Dam removal required the temporary closure of the Grist Mill Trail in Patapsco Valley State Park, which was extensively used by a variety of stakeholders, including people commuting via bike. This closure was maintained by Maryland Park Service to ensure a secure and safe working area.

*Testimonials and contacts*

Serena McClain, project manager and director of river restoration for American Rivers after the removal of Bloede Dam stated: “The Patapsco River is free, after years of hard work by so many. It’s wonderful to see the Patapsco rushing back to life, and to watch park visitors discover and enjoy the free-flowing river. This major river restoration project would not have happened without the collaboration and dedication of many public and private partners. This success is proof that when we come together, we can accomplish great victories for our rivers and our communities that will resonate for generations to come.”

The Secretary of MDNR Jeannie Haddaway-Riccio, said: “Removal of the Bloede Dam has been a long-term priority for both public safety and environmental reasons, so the department is very grateful for the strong partnerships that have finally made it a reality. Completion of this project means improved safety for our park visitors, restoration of the Patapsco River System, and healthier habitats for aquatic species - all of which are important to our department."

William Harbold who has sampled fish assemblages in the Patapsco River with MDNR since the removal of Union and Simkins dams, said of the first river herring captured upstream of the former Bloede Dam: "That single fish was able to swim unimpeded from the Atlantic Ocean to that spot in the Patapsco River. That's something that hasn't been possible for well over 100 years, maybe longer. It's quite possible that we were the first people to see a wild, freely migrating herring in that part of the Patapsco in over a century. I personally think that's pretty cool."

#### C 1.8.5 Lessons Learned

This project required extensive collaboration and dedication to reach completion. The sustained involvement of expert staff from state, federal, and private partners was essential. Furthermore, dam safety and maintenance concerns helped drive removal as the preferred option. Lastly, implementation of multiple dam removals on a single river or as part of an overall watershed restoration initiative happens on the order of decades not months or even years. The first known study to investigate the removal of Bloede Dam was written in 1980 yet it took another 38 years for dam removal to occur.

#### C 1.8.6 Supplemental Information

For additional information on efforts in the broader Patapsco River watershed, see:

Bloomberg: In a Town Shaped by Water, the River Is Winning

Maryland DNR: The Patapsco River and Valley

Maryland DNR: Video on Removing the Simkins Dam

For additional information on the Patapsco dam removal projects, see:

American Rivers: Removing Bloede, American Rivers' Quest to Free the Patapsco River

American Rivers: Bloede Dam Removal Receives Engineering Accolades

NOAA Fisheries: With Removal of Bloede Dam Complete, Patapsco River Flows More Freely

Bay Journal: With the Patapsco's Bloede Dam gone, fish heading upstream

Maryland DNR: Simkins Dam Completed Project

[USFWS: Bloede Dam removal project complete: Patapsco River surges back to life]

[Chesapeake Bay Magazine: Dam Right – The Bloede Dam Removal and the Chesapeake's Forgotten First Fishery]

[Bay Journal: Dam removal yields an eel bonanza on Maryland's Patapsco River]

## C 1.9 Embrey Dam Removal: Upper Rappahannock Diadromous Fish Restoration

### C 1.9.1 Background

*Historical Context*

At 2,715 square miles (7,032 square km), the Rappahannock Drainage is one of two drainages (York Drainage) that occur entirely within the Commonwealth of Virginia. The Rappahannock heads in the Blue Ridge and then runs through the Piedmont and Coastal Plain (Jenkins and Burkhead 1993). The Rappahannock River main stem is 184 miles (296 km) long and is host to four species of anadromous clupeids, all members of the *Alosa* genus (alosines): alewife, blueback herring, American shad and hickory shad. Other important anadromous fishes that utilize the Rappahannock are the striped bass and the sea lamprey. The catadromous American eel rounds out the list of ecologically important diadromous fishes in the Rappahannock and its tributaries.

Historically, the Rappahannock like the other Chesapeake Bay tributaries, supported tremendous populations of diadromous fishes. Indigenous People relied heavily on the spring runs of migratory fishes that brought marine derived nutrients up into Atlantic slope streams and rivers. In 1608, Captain John Smith sailed up the Rappahannock on his second voyage from Jamestown and reported a river teeming with fish and game (Star 2004). Early European Colonists also learned to harvest herring and shad that became part of their survival diet. In 1613 Alexander Whitaker wrote: "The rivers abound with fish both small and great. The sea-fish come into our rivers in March… great schools of herring come in first; shads of a great bigness follow them." (Dennen 2004a, 2004b, 2014). Robert Beverley, a historian, wrote in 1705: "In the spring of the year, herrings come up in such abundance… to spawn, that it is almost impossible to ride through, without treading on them" (Beverley and Elkins 1705).

As the human population increased across the landscape the demand for resources also naturally increased. Various factors that came with an expanding population and industrial base contributed to the decline of anadromous fish stocks including the river herring. Among those factors was the loss of spawning and rearing habitat due either to water quality degradation or the loss of access to critical habitat.

Disruption of aquatic connectivity resulted from the construction of dams throughout the region to harness river power and in some cases to meet other industrial and agricultural demands. The Rappahannock was no exception. In 1854-1855, an eighteen-foot-tall crib dam was constructed of wood and stone at river mile 111 (approximate) in the City of Fredericksburg (the City) to divert water into a riverboat navigation canal. In 1889, the Fredericksburg Water Power Company converted the crib dam and canal to a facility for generating electricity. Twenty years later, Embrey Dam (Figure C 37) was constructed immediately downstream of the 1855 dam to upgrade Fredericksburg's 20-year-old hydroelectric facility. A new power plant was installed two miles downriver from the dam at the terminus of the canal. Embrey engineers employed an Ambursen design (slab and buttress) and it was constructed of reinforced concrete. It stood 22 ft tall and stretched 1,070 ft across the Rappahannock River. This new facility initiated a new scale of generating electric power for public consumption. Embrey Dam harnessed the river for hydroelectricity into the late 1960s (Sanford 1997) until its removal in 2004-2005 along with the 1855 crib dam.

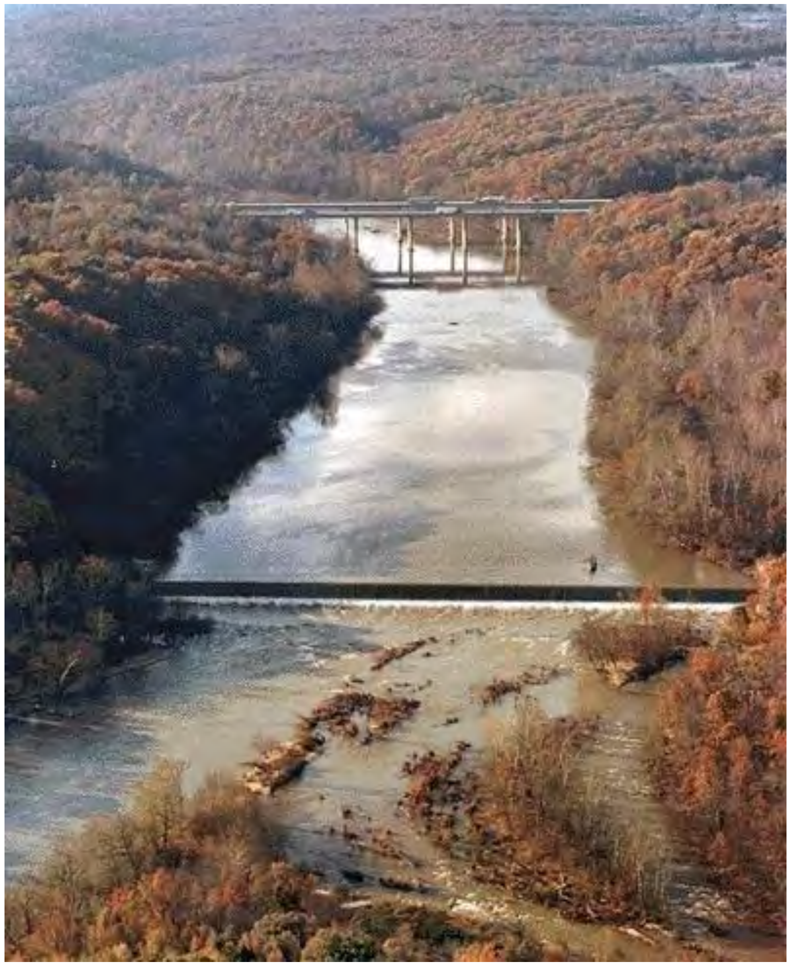

Figure C 37 – Aerial view (looking upstream) of the Embrey Dam on the Rappahannock River, VA. Credit: USACE.

*Main Restoration Projects*

*1910 Embrey Dam and 1855 Crib Dam Removal Project* - Virginia is a signatory of the original 1987 Chesapeake Bay Agreement (Chesapeake Executive Council 1987) and all subsequent agreement updates (CBP 2022). The original agreement committed the Bay states to "provide for fish passage at dams, and remove stream blockages wherever necessary to restore natural passage for migratory fish." The original habitat-reopening goal (primarily large, main stem habitat) was 1,357 miles of Bay tributaries by 2003 (a goal exceeded). As early as the mid- to late-1980s the VADWR (formerly Virginia Department of Game and Inland Fisheries) was communicating the need for fish passage to the City of Fredericksburg, owners of Embrey Dam. The USFWS worked with VADWR to determine the number of miles of habitat in need of reopening on the main stem Rappahannock River and Rapidan River with passage at Embrey (Figure C 38), which is a critical component of the Chesapeake Bay goal.

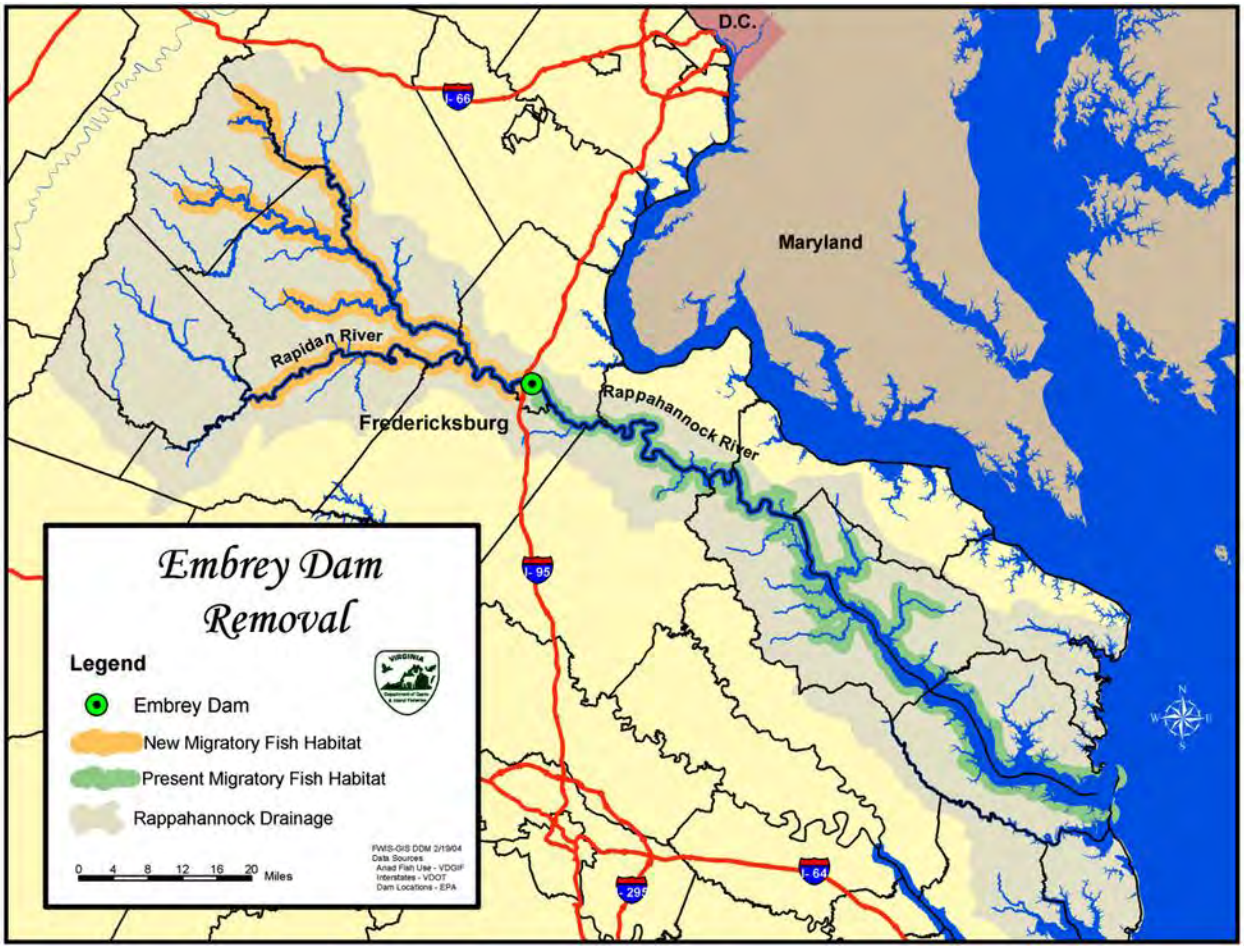


Figure C 38 – Map displaying migratory fish habitat access within the Rappahannock drainage, above and below the former Embrey Dam. Credit: VADWR.

Both dam removal and technical fishway construction (e.g., lift) were considered early on. Fredericksburg relied on Embrey Dam to feed water down the canal to their Kenmore drinking water treatment facility at the time so the dam removal option would be contingent on finding an alternate drinking water source. The city also had initial conversations with the USACE in the early 1990s about their potential involvement.

In 1996, the Fredericksburg City Council approved a path toward an alternate drinking water supply meaning Embrey Dam would become obsolete. Dam removal became a viable alternative. It is also important to note that Fredericksburg took measures to protect their water supply by acquiring significant riparian land for several miles up the Rappahannock and Rapidan rivers (see City of Fredericksburg 1997).

In 1997, the VADWR hired a Richmond based engineering and consulting firm to conduct a technical alternatives analysis to consider fishway construction or dam removal. The conclusion was that dam removal was feasible and would be much less expensive than fishway construction and its long-term operation and maintenance costs (Timmons 1997). Funding for removal of a dam the size of Embrey was uncertain. Almost simultaneously, Senator John Warner and the City of Fredericksburg invited the USACE to study Embrey Dam and potential restoration and funding solutions. The Friends of the Rappahannock were playing an important role in building relationships among the parties as the partnership materialized. A strong partnership amongst several local, state, and federal agencies along with NGOs formed to work through the process. The local community also was invited to participate in public meetings. Ultimately, the USACE Final Decision Document (USACE 2002) recommended removal of Embrey Dam and the 1855 Crib Dam from the river to restore fish passage and the natural function of the Rappahannock River.

Additional information about the project's development and execution are included in this document. Providing complete details, full timeline history, and news references involving a project of this size would exceed the scope of this document. Therefore, the purpose is to highlight key steps taken along the way from inception to project completion and success documentation.

C 1.9.2 Restoration Goals

- Reopen 106 miles of the Rappahannock and Rapidan rivers to anadromous fish including alewife and blueback herring and to the catadromous American eel.
- Increase spawning and rearing habitat for anadromous fish including alewife and blueback herring.
- Increase rearing habitat for juvenile American eel.
- Restore the Rappahannock River, in this reach, to its natural form, flow and function.
- Remove an obstruction to recreational users of the river.

C 1.9.3 Restoration Techniques Employed

*Pre-removal sediment dredging* - In 1994, the VADWR hired independent contractors to sample and analyze the sediments built up behind Embrey Dam. The Virginia Department of Environmental Quality (VDEQ) worked with VADWR to design the sampling plan and to interpret the results. The sediments were free of any hazardous contaminants. In 1997, the USACE concurred with the VADWR/VDEQ sediment study results but recommended pre-removal dredging. The Rappahannock River Basin Commission (made up of counties and cities bordering the Rappahannock) were very concerned about sediment loads moving downstream. Ultimately, it was decided that the bulk of sediment behind Embrey Dam would have to be removed prior to dam removal.

In the summer of 2003, the USACE contracted the construction of a dredge spoils containment site on the top of the hill adjacent to the dam pool on the south bank of the Rappahannock River. The City of Fredericksburg purchased the land from a local developer for this purpose. Hydraulic dredging and storage commenced in August of 2003. Hurricane Isabel caused flooding and the subsequent deposition of a large volume of sediment essentially undoing the dredging work that had been conducted before Isabel. Dredging resumed with a net result of removing and storing approximately 250,000 cubic yards of sediment from behind Embrey Dam. In order to ensure that the pool would drain upon breaching Embrey a corresponding section of the crib dam was removed during dredging operations.

*Explosion Event* - The U.S. military designed and executed the demolition under the Innovative Readiness Training program. U.S. Air Force Reserve demolition experts designed the explosion of 10, approximately 14’ wide sections of the Embrey Dam. A U.S. Army Ranger dive team drilled the dam (included some drilling where the team was in the water on the downstream side of the dam) and set and wired the charges in preparation for the initial explosion. On February 23, 2004, approximately 3,500 people descended on the banks of the Rappahannock River at a pre-planned safe distance to witness the demolition. At the end of the large crowd count down Senator John Warner pushed the ceremonial plunger and the dive team set off the charges. The section charges were set to go off milliseconds apart to limit the effect of the explosion on the surroundings (a few distant buildings and I-95 bridge located 0.5 miles upstream). During the initial explosion a piece of debris severed the wiring so only one section detonated. Within one hour, the dive team reset the charges and the final, larger explosion (Figure C 39) took place with multiple news media on the ground and in the air to report on the event. See the additional information section below for a video that shows the first explosion that took out one bay followed by several angles of the second, much larger explosion that finished the job (see Figure C 40 and *Appendix C 1.9.6*).

Figure C 39 – The second explosion set off during the demolition day event to breach the Embrey Dam. Credit: VADWR.

Figure C 40 - The U.S. Air Force Reserve inspecting the results of the explosions. Credit: Alan Weaver/ VADWR.

*Mechanical Removal* - Over the year following the explosion, a contractor hired by the USACE mechanically removed the remainder of the Embrey Dam and the remnants of the 1855 crib dam (Figure C 41). This required the construction of an access causeway across the channel to move large equipment and to haul off the concrete and wood debris from the dams. Large corrugated metal pipes incorporated into the causeway passed river flow during mechanical removal. The project was completed in March of 2005 (Figure C 42) in time for the majority of the spring run of migratory fish.

Figure C 41 – Mechanical removal of the remaining structural pieces of the Embrey Dam. Credit: Alan Weaver/ VADWR.

Figure C 42 – Aerial view of the restored portion of the Rappahannock River post-removal of the Embrey Dam. Credit: USACE.

*Disposition of the historic canal* - Part of completing the dam removal project included creating an earthen terminus to the upstream end of the historic canal that served originally as a navigation channel, later to supply water for hydropower and finally drinking water. In order to be able to maintain the water level in the canal, the USACE installed an intake screen in the river just below the old powerhouse. An aeration system is in place to prevent potential stagnation. This essentially repurposed the canal as a long narrow pond.

*Historical Preservation and Documentation* - In 1993, the VADWR contracted the Center for Historic Preservation at Mary Washington College (Fredericksburg) to conduct a Phase 1 archeological resources study in anticipation of dam alteration to achieve fish passage. The final revision was submitted in 1997 (Sanford 1997). This study concluded that Embrey Dam and its environs are potentially significant resources and recommended additional recording, documentation and partial preservation should the dam be altered to achieve fish passage.

When the path toward dam removal became apparent, the USACE completed the additional steps necessary to satisfy Section 106 requirements. The USACE submitted their historic resources report to the Virginia Department of Historic Resources (VDHR) in January of 2001. The VDHR accepted the report that, coupled with the Sanford (1997) study, led to the development of a MOA to address efforts for mitigating the destruction of Embrey Dam. Ultimately, in April of 2002, a Historic Resources MOA was signed by the VDHR, the USACE, the City of Fredericksburg, and Stafford County. The MOA outlined the mitigation measures required during dam removal and partial preservation of historic resources.

The City of Fredericksburg arranged for professional salvagers to create mementos from the pieces of the wooden crib dam preserved underwater for over a century. A well-known carpenter personality created a colonial style corner table out of wood from the crib dam. There is a photo of this corner table displayed on an actual antique corner table at the Kenmore House Museum in Fredericksburg.

The base of the 1855 crib dam abutment that remains in the north half of the river channel was heavily armored with rip-rap for preservation. On the south bank of the river, the remnants of the 1855 crib dam stone abutment remain. Interpretive signage is in place for public visitors to learn about the dam removal and some of the history of the area as it relates to the former dams.

C 1.9.4 Partners and Stakeholders

*Select Parties Involved and Contributions*

- VADWR – Secured and administered Commonwealth of Virginia funds for state sponsored planning studies and for a significant portion of the non-federal match for the USACE feasibility study; coordinated with federal, other state, local and NGO entities on all phases of the removal project; conducted pre-removal fish community sampling and continues to conduct post-removal sampling.

- City of Fredericksburg – Owners of the dam; coordinated with federal, state, other local and NGO entities on all phases of the project; provided a portion of the USACE study non-federal match; made key decisions as the owner that were critical to pursuing dam removal; led the planning of the demolition day events.

- Friends of the Rappahannock River – Main NGO advocate for the removal of the dam; provided assistance with community outreach and provided sampling access to the river (pre and post removal); lobbied for expedition of the USACE planning process; co-hosted the spring 2000 demonstration bucket brigade with American Rivers.

- Stafford County – the dam was geographically located within Stafford County; coordinated with federal, state, other local and NGO entities throughout the project; provided a portion of the USACE study non-federal match.

- American Rivers – NGO advocate for the removal of the dam; provided assistance with outreach; lobbied for expedition of the USACE planning process; co-hosted the spring 2000 demonstration bucket brigade with Friends of the Rappahannock.

- USACE – Conducted a Reconnaissance study (full federal funding); conducted a Feasibility study (50:50 federal: non-federal funding), produced the Final Decision Document for removal and by way of legislation by the U.S. Congress (Senator John Warner) fully funded and conducted the Removal Phase; completed the permitting process including historical investigations and mitigation measures.

- U.S. Air Force Reserve demolition experts – Designed the 2004 explosion

- U.S. Army Ranger Dive Team – drilled for, set, and wired the charges, and executed the initial demolition explosions; code-named the project "Operation Noah Shiva" after Noah from the Bible that survived the great flood while protecting the animals and the Hindu goddess Shiva that represents destruction and rebirth (Dennen 2004a, 2004b, 2014).
- USFWS – provided technical support throughout the history of the project including early habitat restoration potential mapping and Chesapeake Bay Program Fish Passage Workgroup leadership.
- The Outdoor Center (river paddling outfit near Embrey owned and operated by William and Denise Micks) – supported the dam removal project through their business.
- The citizens of Fredericksburg and the surrounding community – key stakeholders.
- Paddlers, boaters, anglers and all other recreational users of the Rappahannock River – key stakeholders.

*Select Funding Sources*

- United States Federal Government via the USACE
    - Reconnaissance phase (100% federal)
    - Feasibility study (federal share; 50%)
    - Implementation (100% federal; via reauthorization of the Water Resources Development Act)
- Commonwealth of Virginia via VADWR
    - Original Phase I Historical Study
    - State sponsored Technical Alternatives Analysis and Sediment Fate Transport Study (filed as Virginia Senate Document 18)
    - USACE Feasibility Study (large portion of non-federal share)
    - Project coordination and outreach
    - Pre and post fisheries monitoring

- City of Fredericksburg
    - Project coordination and outreach as owner of dam
    - USACE Feasibility Study (portion of non-federal share)
    - Led team to plan and fund the demolition day events
- Stafford County
    - USACE Feasibility Study (portion of non-federal share)

### C 1.9.5 Status and Outcomes

*Project monitoring and documented success*

Ultimately, 2,247 Upstream Functional Network miles became accessible by the removal of Embrey Dam (Martin and Apse 2013). In the spring of 1995 VADWR initiated a migratory fish monitoring effort below Embrey Dam (Figure C 43). Several years of annual boat electrofishing prior to removal documented the presence of all four alosines immediately downstream of the dam. Additional anadromous species, striped bass and sea lamprey, were also documented below the dam. The catadromous American eel was also documented below and upstream of the dam. Access was likely through an old pool and weir fishway built into the Embrey Dam that was not conducive for anadromous fish passage but did provide for a minimal amount of upstream eel passage.

Figure C 43 – Electrofishing below the Embrey Dam prior to removal. Credit: VADWR.

From 1996 to 1999 Virginia Commonwealth University, working for the VADWR using EPA Chesapeake Bay Program funds, conducted an impediment survey on tributaries of the Rappahannock near Embrey Dam both downstream and upstream of the dam. The first impediment whether it was an impassable road crossing or a dam was catalogued and described. Fish sampling was conducted in the downstream tributaries to further identify herring blockages and a herring habitat model was developed (McIninch and Garman 1999).

Timeline of fish passage documentation post Explosion Day Event (2004):

- In March 2004, shortly following the initial blast opening up a large whole in the dam, VADWR biologists documented hickory shad in the former pool indicating initial passage success.
- In April of 2004, VADWR biologists documented blueback herring in the recently restored pool indicating more initial passage success.
- In May of 2004, VADWR biologists documented an American shad five miles upstream of the Embrey/crib dam removal construction site.
- In the spring of 2008 VADWR biologists documented the presence of American shad 28 miles upstream of the former dam at Kelly's Ford.
- In the spring of 2009 VADWR biologists documented the presence of blueback herring at Kelly's Ford. In subsequent sampling years blueback herring have been documented at Kelly's Ford. It is also important to note that sea lamprey sub-adults preparing to out-migrate were found in abundance at Kelly's Ford in 2009. Sampling indicates that small striped bass adults make it as far as Kelly's Ford.
- All four alosines are routinely documented in the Motts Run reach of the Rappahannock that is approximately five miles upstream of the former dams.

During post-installation monitoring of Stafford County's Rocky Pen Run Reservoir municipal water intake on the Rappahannock River from 2014 to 2016 Virginia Commonwealth University documented the presence of river herring eggs (both species) in the river and within the intake system. An individual early juvenile blueback herring (23 mm) was discovered within the intake system in 2015. It is assumed that it hatched post-entrainment (Garman 2014, 2015, 2016).

Studies employing eDNA (e.g., Plough et al. 2018) have documented presence of river herring 64 miles upstream of Embrey on the Rappahannock and suggest they reach as far as the Rapidan Mill Dam that is 49 miles upstream of Embrey. Based on the number of replicates found at these locations it was likely a small number of river herring that made it that far upriver, but the fact that herring eDNA was found that far upriver strongly suggests that herring are utilizing a significant amount of the habitat reopened by the removal of Embrey Dam. This also triggers the need to conduct fish collections at these important locations.

VADWR annual boat electrofishing catch-per-unit-effort (CPUE) in the upper tidal Rappahannock indicates that the river herring run strength has been steadily increasing since 2004. The specific blueback herring trend shows a dramatic and steady increase while the alewife trend is steady to downward. The American shad and hickory shad trends are also increasing (Alan Weaver, VADWR personal communication/unpublished data).

An increase in the American eel population in the watershed upstream of Fredericksburg was attributed to safe and rapid passage of elvers at the Embrey location compared to greatly reduced passage efficiency when the dams were in place (Hitt et al. 2012).

*Factors contributing to project success*

- The 1855 crib dam became obsolete when Embrey Dam was completed in 1910. Hydropower operations ceased in the 1960s making Embrey Dam obsolete as a hydropower dam. VADWR's fisheries data collection below the dam established the need for fish passage at Embrey Dam.
- The City of Fredericksburg entered into a joint venture with Spotsylvania County to withdraw municipal water from the Rappahannock from a natural pool area five miles upstream of Embrey Dam. A water treatment plant was built adjacent to the existing Motts Run Reservoir making the City's Kenmore Water Treatment Plant that was fed by the Embrey canal obsolete. Embrey no longer had any practical use.
- The sediments behind Embrey Dam did not contain any hazardous materials. This allowed for safe sediment dredging and some sediment release during removal operations.

- The City of Fredericksburg, as the owner of the dam, was very cooperative and influential during the process. Once it was determined that the dam no longer served a practical purpose, the City was on-board with removal. The Commonwealth of Virginia, via the VADWR, allocated significant financial and staff resources to provide multiple level coordination, technical assistance and outreach.
- The Friends of the Rappahannock River played the significant role of the local group that was very influential and helpful in garnering support for the removal project.
- American Rivers played the significant role of the national organization that was influential in promoting the removal project.
- Local paddling businesses supported the removal (The Outdoor Center and Clore Brothers).
- Spotsylvania County's joint water treatment intake and plant at Motts Run was a key factor. Stafford County's support of the removal project via financial contributions to the USACE study was a substantial contribution.
- Having the support of Virginia's federal senators, John Warner and Chuck Robb, as well as State Senator Ed Houck, was a key factor in achieving project success. Senator Warner was able to pass legislation to obtain full federal funding for the implementation of the removal.
- The USACE Norfolk District allocated the necessary resources to determine a federal interest, conducted the feasibility study and adapted to changing conditions such as implementing the project at full federal expense.
- The U.S. military units (Air Force Demolition Experts and Army Ranger Dive Team) did an outstanding job designing and implementing the initial explosive breaching of ten sections of the Embrey Dam.
- The cooperative partnership that formed amongst all of the key entities demonstrated just how important multi-discipline and multi-level partnerships are for an undertaking such as the removal of Embrey Dam.

- Although not everyone in the community was in favor of the dam removal, the fact that the project continued to gain local community support coupled with overwhelming regional support demonstrates that when a removal project provides significant benefits even above and beyond fish passage large projects can be accomplished.
- During a bucket brigade event on April 21, 2000 both Virginia Senators, John Warner and Chuck Robb, assisted the VADWR in collecting blueback herring, hickory shad and American shad from an electrofishing boat to then bucket around the dam to be released upstream. This promotional event co-hosted by Friends of the Rappahannock and American Rivers helped to garner additional public support for the removal. VADWR Conservation Police Officers provided boating safety support during the event.

*Obstacles and resolution*

Embrey Dam provided the depth to feed water down the obsolete hydropower canal to Fredericksburg's Kenmore municipal water treatment plant in town. The City needed to keep the dam in order to secure their main water supply so removal was not originally an option for provision of fish passage. The City eventually collaborated with Spotsylvania County to build a water treatment on the existing Mott's Run Reservoir. This action made Embrey Dam obsolete and opened the door to pursue dam removal.

The Rappahannock River transports a significant amount of sediment. The amount of sediment retained behind the dam had reached equilibrium. High flow events would scour and flush some built up sediment downstream and then new sediments would deposit after the high flow subsided. Embrey Dam was a run-of-the-river barrier. The dam did not actually provide a net gain in sediment retention during high flow events. The head of tide is approximately one mile downstream of the dam location and this upper tidal reach is a natural sediment deposition area. The local community did not want the removal of Embrey Dam to result in additional sediment buildup in the upper tidal reach. This area is a popular recreational area (fishing, boating, swimming, etc.). Even though the release of sediment during dam removal would have been a temporary disturbance, the partners decided that pre-removal dredging would at least show a good faith effort to ameliorate the sediment problem as much as possible. Sediment buildup in the non-tidal/tidal interface reach continues but not because the dams are gone. Dam removal returned the system to a natural flow and sediment transport system. Upstream land use practices may be a contributing factor along with the natural process of rivers carrying its bed load from the mountains to the sea.

*Testimonials and contacts*

In 1999, during planning, Senator John Warner proclaimed “I would like to have the community rename the dam the John Warner Dam and blow it up the next day”. Senator Warner grew up fishing the Rappahannock River and he was very proud of his contribution to the removal of Embrey Dam. In a February 11, 2011 Richmond Times Dispatch opinion piece Senator Warner wrote: “Virginians have achieved several goals that should inspire other states. For example, the Rappahannock River, which links the Blue Ridge Mountains to the Chesapeake Bay, had its flow impeded by an abandoned electric power dam. For more than 100 years, miles of exceptional ‘white water’ rapids were covered by a dam that likewise prevented the annual spawning of ocean fish migrating up the Chesapeake Bay to the fresh water streams to breed and deposit their eggs. The river held its breath behind the iron, concrete and wood Embrey Dam. As senator, I was proud to work with many others determined to remove this outdated cement and steel barricade to nature and boaters, which let the Rappahannock resume its important role in the ecosystems. Seeing that dam come down in 2004 was one of the proudest moments of my career in public service, and I am humbled and honored that the newly uncovered rapids were named for me and others who worked over a decade as a team. Today, families can paddle through the old dam site thanks to additional access, riverside land protections, and amenities provided by the 30-mile-long Rappahannock River Water Trail.” in a Richmond Style Weekly article about his retirement said that the removal of Embrey Dam was one of his greatest and favorite accomplishments.

Wiggins (2007), recalled some highlights from the ceremony leading up to the initial demolition. Speeches were given by dignitaries of local, state and federal government. Virginia Secretary of Natural Resources Taylor Murphy said, “A new day is beginning for this river. Anglers will flock here to fish for shad, herring, and striped bass. Watermen will work their nets downstream. Canoeists and kayakers will ply these waters from the mountains to the Bay.” Senator John Warner quoted a passage from the book of Ezekiel in the Bible “There will be a very great multitude of fish, because these waters go there; for they will be healed and everything will live wherever the river goes.”

Assistant secretary of the Army for Civil Works John Paul Woodley, who, at that time, oversaw the USACE, the lead agency on the project had this to say during the blast event ceremony, "This event strengthens our relationships with our federal and state partners and other military organizations."

William "Bill" Micks, lifelong paddler, river-safety expert and co-owner of the Virginia Outdoor Center said about the dam removal event, "Something like that only happens once in a lifetime." He also went on to say, "I feel like it's one of the best things that's ever happened [to the river]" and "Anytime you can make a river, from top to bottom, free-flowing, it's a good thing" (Dennen 2014). When asked about the impact on the Rappahannock's recreational identity he responded, "It exploded. It became a destination… [paddlers] put in at Mott's Landing upstream and they know they can paddle downstream and through the fall line section, which is really exciting, it's got class two, three rapids on it down to Old Mill Park area for the takeout and not have to carry or portage around a dam" (Micks 2016).

After the second successful detonation on February 23, 2004, Director of Public Works, Doug Fawcett, who oversaw the logistics of the event said to the crowd, "You came for one blast; we gave you two!" (Dennen 2014). Doug Fawcett is now the Assistant City Manager.

Mayor Bill Beck recalled, "It was probably my most fun day in office. It was just a great event. It was something everybody supported and were really glad we were doing it." (Dennen 2014).

According to Alan Weaver, VADWR Fish Passage Coordinator, "On September 23, 2004, the Embrey Dam Removal Team received the Coastal America 2004 Partnership Award for our work to restore and protect our Nation's coastal environment. We received the award as a team from Senator John Warner in the Senate Building in Washington, D.C."

In The Free Lance Star publication "River Runs Free" (Star 2004), A. Thomas Embrey III spoke about his grandfather, Judge Alvin Thomas Embrey, for whom the dam was named. Judge Embrey was also a lawyer, state legislator, and local businessman who saw the potential of electricity and thus supported the construction of Embrey Dam. A. Thomas Embrey III said when asked if his grandfather would agree with the decision to blow up and remove the dam, "His answer would be an emphatic yes. He, too, would say 'Let the river run free.' "

Local Spotsylvania artist Robert Gramann's song "Rappahannock Running Free" from his 2009 CD "Mostly Live" celebrates the removal of Embrey Dam (see *Appendix C 1.9.6*).

### 11.1.5 Lessons Learned

A dam removal project of the magnitude of Embrey Dam took strong partnership formation early on among individuals and entities all across the spectrum. The "Embrey Partnership" developed and adapted organically from the early inception of the project through completion. It included high level federal, state and local elected officials, federal, state and local government employees from multiple disciplines, local and national non-government agency employees and two branches of the U.S. military. The local and broader community of citizens was also included throughout the process, and whether for or against the dramatic change of a dam removal they were collectively an integral part of shaping and directing the project. This included citizens with broad interests ranging from recreational anglers and boaters, to people who simply enjoy being out in nature and experiencing a healthy river, and to people who just like to know that the right things are being done to protect a public resource such as a large river like the Rappahannock.

### C 1.9.6 Supplemental Information

VADWR: Video of Embrey Dam Explosions

Local Spotsylvania artist Robert Gramann's song "Rappahannock Running Free"

## C 1.10 Lower Roanoke River Floodplain Restoration: Passage improvements on Big Swash

### C 1.10.1 Background

*Historical Context*

The Roanoke River contains important habitat for native diadromous fish species including striped bass, American shad, hickory shad, alewife, blueback herring, Atlantic sturgeon, American eel, and sea lamprey. The river drains 9,776 square miles in North Carolina and Virginia, and the lower Roanoke River floodplain represents one of the largest, intact bottomland hardwood forests on the Atlantic slope. Access to habitat has been impeded by multiple dams on the Roanoke River mainstem and by numerous manipulations throughout the extensive floodplain. The natural flow regime in the Roanoke River is altered by John H. Kerr Dam, which is operated by the USACE for flood control and hydropower production. Additionally, many of the natural connections between the river and floodplain have been blocked and other streams have been culverted during road building and logging activities conducted throughout the twentieth century. As a result of habitat degradation and overfishing, populations of many of these diadromous species have been drastically reduced from historic levels.

*Big Swash Restoration Project*

Diadromous fish restoration projects in the Roanoke River basin have mainly focused on flow regime alterations and fish passage evaluation at Roanoke Rapids Dam through Dominion Energy's FERC relicensing process. However, there remains a need to address restoration of floodplain habitat and connectivity in the lower Roanoke River basin. Industrial practices have altered floodplain habitat by draining wetlands and building roads primarily for logging operations. The area known as Big Swash is a large area of floodplain and upland habitat located on an interior bend of the lower Roanoke River near Lewiston-Woodville Township in Bertie County, NC. TNC created a conservation easement on 7,093 acres of property in Big Swash to preserve, enhance, restore, and maintain the natural features and resources for the benefit of native plants and animals, wetland habitat, water quality, and sediment control. The Roanoke-Tar River Gun Club (RTRGC) owns and operates a private refuge located within the TNC conservation easement on Big Swash. Road construction and levee building for previous logging operations fragmented or eliminated natural connections between the floodplain, tributaries, and the Roanoke River mainstem in the RTRGC property. Recent periods of heavy rainfall and flood control releases on the mainstem have led to frequent inundation of the RTRGC property preventing access by club members. The RTRGC funded an engineering study to identify flooding and drainage issues. The engineering study revealed that the floodplain alterations were restricting water flow through the property thereby increasing the time needed to drain water off the floodplain. Several undersized and/or perched culverts were identified as areas that restrict drainage and prevent fish passage into and out of the floodplain. Also, small, natural tributary "guts" plugged with earthen fill were holding back flood waters and eliminating AOP between the mainstem and floodplain habitats. TNC staff and RTRGC members developed a multi-phased restoration plan to restore floodplain function and fish passage throughout the property. The first phase of the project included installation of three bridges at road crossings where undersized culverts were located along Ware's Gut, the primary tributary of the property.

C 1.10.2 Restoration Goals and Techniques Employed

*Goals*

- Improve floodplain function and connectivity
- Reduce flood duration on RTRGC property
- Improve floodplain forest health
- Restore aquatic organism (especially river herring) passage at all water levels
- Improve water quality

*Restoration techniques*

Three road crossings with undersized culverts were replaced with bridges along Ware's Gut (Figure C 44). All work was completed on property owned by the RTRGC, and the projects were administered by TNC. The bridges needed to allow heavy equipment and vehicle passage but did not need to be designed to the DOT specifications because they were on private property. All bridges utilized the same design, which spanned approximately 34 ft across the stream with 40 ft long steel I-beams supported from concrete caps anchored by four 30 ft long wooden pilings that were driven into the soil. The bridge deck consisted of 8"x8" pine pressure treated lumber fastened to the steel beams. Each bridge was constructed during individual phases beginning with the downstream crossing and ending with the upstream crossing. Phase 1 replaced two 48" pipes and restored access to approximately 3.5 stream miles (Figure C 45). Phase 2 replaced one 60" pipe and restored access to an additional one stream mile (Figure C 46). Phase 3 replaced one 60" pipe and restored access to another one stream mile of habitat (Figure C 47). The total stream miles restored in this project was 5.5 miles, but access to the floodplain habitat for river herring spawning was much greater. The process for replacing all three bridges occurred over a three-year period.

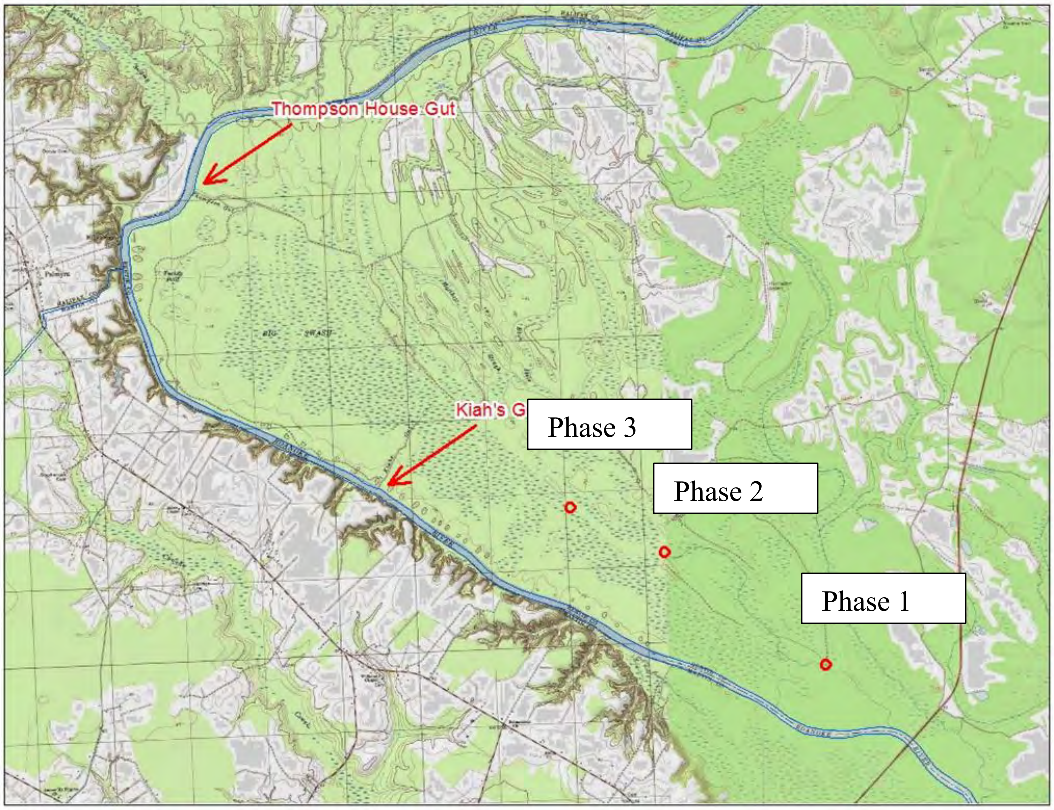


Figure C 44- Map of RTRGC. The red circles indicate the location of the bridge construction on Ware's Gut. Credit: TNC.

Figure C 45- Perched culverts (before) and bridge (after) at Phase 1 location on Ware's Gut at the RTRGC property. Credit: Aaron McCall/ TNC.

Figure C 46- Phase 2 crossing with culvert (before, left) and bridge (after, right). Credit: Aaron McCall/ TNC.

Figure C 47- Undersized culvert (before, left) and bridge (after, right) at Phase 3 location on Ware's Gut at the RTRGC property. Credit: Aaron McCall/ TNC.

### C 1.10.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- RTRGC – property owners. After several meetings, the club membership agreed to the project and was a willing participant. They funded the initial engineering study and allowed access to the property.

- TNC – owns/manages the conservation easement on the property. TNC staff administered all three phases of the project and secured funding for Phase 2. They selected the contractor, approved designs, conducted the permitting process, and oversaw construction of all three phases.

- NCWRC – As the state agency responsible for management of the fish and wildlife resources located in the project area, NCWRC staff requested and received federal funding for two phases of the project. Staff provided project oversight, grant administration, and worked directly with the cooperator (TNC) to complete the project and report to the funding agency.
- USFWS – funding agency through the 2019 National Fish Habitat Partnership and 2020 NFPP.
- NC Clean Water Management Trust Fund: provider of the conservation easement and funding for Phase 2.
- Kris Bass Engineering – North Carolina based environmental engineering firm retained by RTRGC to study the floodplain and develop a plan to reduce flooding impacts and improve fish and wildlife habitat.
- NC Earthworks INC – contractor selected by TNC for bridge design and construction of all three phases.

*Select Funding Sources*

- RTRGC provided initial funding to Kris Bass engineering for evaluation of flooding issues on the property. The resulting report was used as a guide for developing floodplain and fish passage restoration plans.
- USFWS National Fish Habitat Partnership provided the funding to NCWRC for Phase 1 of the project. This portion was an opportunistic use of funds that were initially for another dam removal project. When that project fell through, we needed to find an alternative use for the funds.
- North Carolina Clean Water Management Trust Fund provided a grant to TNC for installation of the second bridge (Phase 2). This grant was also used as non-federal cost share for the third bridge funded by USFWS.
- USFWS NFPP provided the funding to NCWRC for Phase 3 of the project.

- NFWF provided funding for GIS evaluation of barriers on the property and elsewhere throughout the basin.
- TNC provided internal funding and in-kind staff time as non-federal cost share for the project.
- USACE has provided funding for follow-up monitoring.

### C 1.10.4 Status and Outcomes

*Project monitoring and documented success*

RTRGC members routinely fish the property for hickory shad during spring. They have already reported improved success at the restoration locations indicating hickory shad are moving into the restored habitat. River herring harvest is under a moratorium, but they have told us they have seen river herring using habitat upstream of the bridges as well.

TNC and Kris Bass Engineering are monitoring water levels to assess flooding and drainage timeframes following flooding events. They have before-data for comparison with data collected after project completion.

TNC, USACE, and ECU are collecting eDNA samples throughout the property to determine river herring usage after completion of the project.

*Factors contributing to project success*

This project was a success because of open communication between all partners involved. Before the project started, there were several meetings between TNC, resource agencies, and the club leadership. TNC also met with the entire club membership to explain the benefits and request approval to begin the project. This project is a good example of coordination between private landowners, non-governmental organizations, and government agencies.

*Obstacles and resolution*

The largest hurdle to overcome was convincing the gun club members that opening Ware's Gut was a good idea. For many years, their philosophy was to keep out water from the mainstem as long as possible. Water from the mainstem moves into the floodplain through Ware's Gut and other connections to the river when moderate flooding occurs. The new water control plan from USACE Kerr Dam is causing more frequent, high magnitude flooding of the property which floods over the natural levee, and the only solution was to allow the floodwater to drain more quickly because the higher magnitude floods could not be kept out by the perched culverts in Ware's Gut. Once the club members understood the concept and approved the plans, the project went smoothly because funding partners were very willing to support the project.

*Testimonials and contacts*

In a letter written on October 13, 2021, RTRGC President David Snow offered these comments: "After TNC placed the three bridges on property owned by the RTRGC there was a very obvious increase in drainage of the flooded sections. This enabled those areas to return to normal quickly thus restoring more habitat for fish and other animals. Even though there are additional projects that could be undertaken we as stakeholders are extremely pleased with the results thus far and are very appreciative of your efforts to help us with our drainage issues."

### C 1.10.5 Lessons Learned

Planning for this project happened quickly when project partners learned of available funding. In hindsight, it would be better to have the plan in place well in advance of funding opportunities. That plan should have also included a more robust explanation of how the project success would be evaluated.

### C 1.10.6 Supplemental Information

Project reports are available upon request but are not posted on the internet. For project information please reach out to the NCWRC.

## C 1.11 Neuse River Basin Restoration

### C 1.11.1 Background

*Historical Context*

An effort to restore historically important anadromous fish spawning habitat in the Neuse River Basin was a product of research gathered and goal setting within the Albemarle-Pamlico Estuarine Partnership (APNES). Quaker Neck Dam blocked anadromous fish access to much of the mainstem river habitat and several important tributaries. Coastal America, which was a partnership between federal agencies, provided a mechanism for EPA, USFWS, NMFS and the USACE to work together. The Quaker Neck Dam was built in 1952 and was removed in 1998, while the Milburnie Dam (built in 1853) has been the most recent dam (removed in 2017) to be removed in the Neuse River Basin. Most of the Neuse River basin anadromous fish habitat is now open because of strategic and logically sequenced dam removal (Figure C 48).

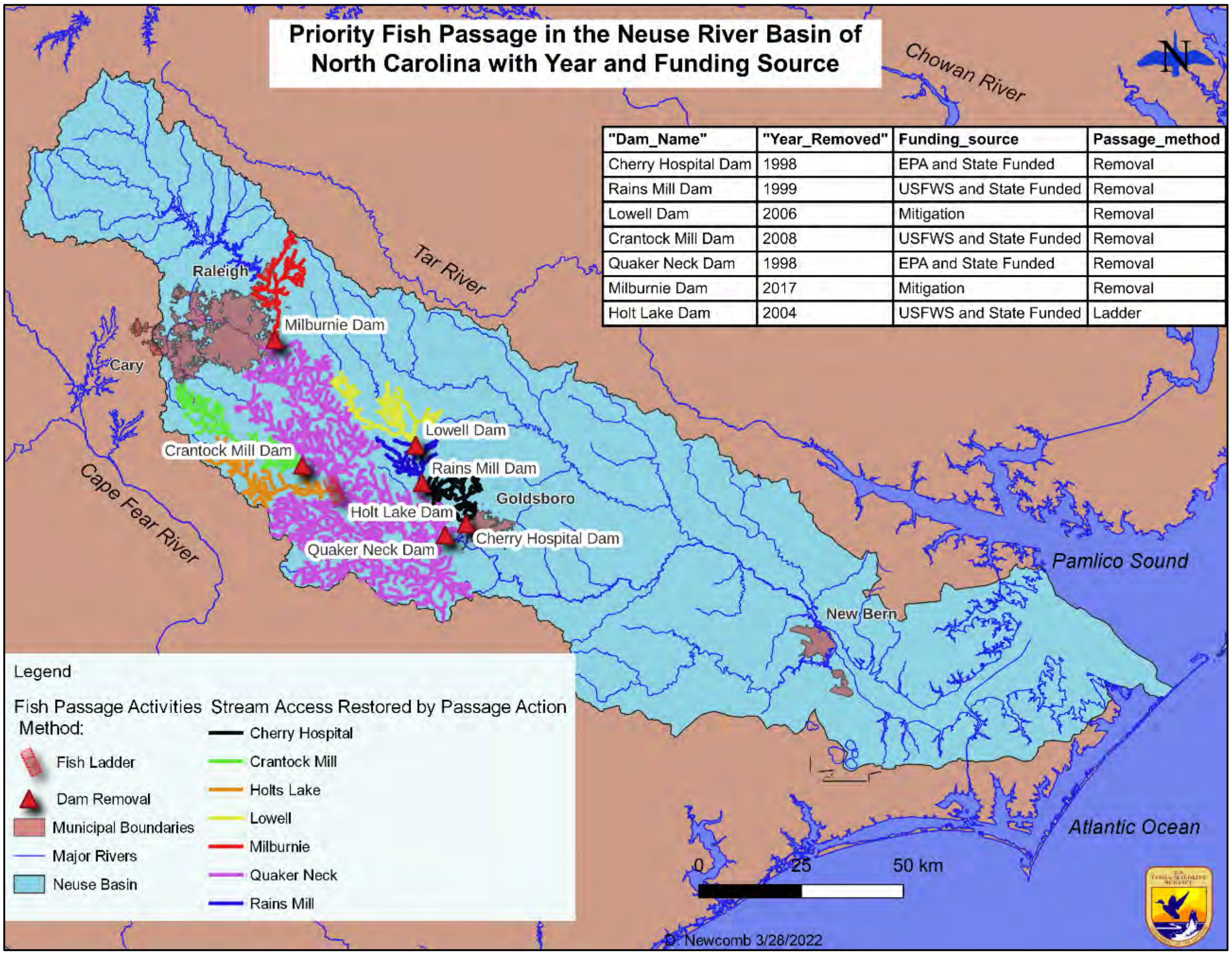


Figure C 48 – Priority Fish Passage in the Neuse River Basin, NC with year of completion and funding sources. Credit: Kelsey Ellis/ APNEP.

*Main Restoration Projects*

Quaker Neck Dam was constructed with reinforced concrete with a steel face, and was being used to help provide cooling water to an active electric plant owned by Carolina Power and Light, now Duke Power. Before the dam could be removed, the intake water elevation that was maintained by the dam needed to be maintained different way. A senior engineer with the USACE studied the issues and Coastal America provided a mechanism solve the problem. They suggested a small new sheet pile weir in the bypass canal that could replace the dam's production based on a solid understanding of friction coefficients and river hydrology. It was agreed that the sheet pile weir be built first to prove the solution would be functional before the dam was removed. Duke Power did not want to own the dam during demolition because of legal liability concerns so the state took ownership of the dam immediately prior and during removal after which there was no dam to own. The NC Coastal Federation supported the removal to benefit recreational and commercial fishing and applied for and held the federal funding necessary for the project. After Quaker Neck Dam was removed in 1998 the group was optimistic that most of the basin's anadromous fish spawning habitat could be opened by strategic dam removal.

C 1.11.2 Restoration Goals and Techniques Employed

The overarching goal of the Neuse River projects was to restore habitat access to pre-European influence for river herring and all other anadromous species. Restoration techniques included the following:

*Quaker Neck Dam Removal* - Quaker Neck Dam was constructed with reinforced concrete with a steel face, and was being used to help provide cooling water to an active electric plant owned by Duke Power. Before the dam could be removed, the intake water elevation that was maintained by the dam needed to be maintained different way. A senior engineer with the USACE studied the issues and Coastal America provided a mechanism solve the problem. They suggested a small new sheet pile weir in the bypass canal that could replace the dam's production based on a solid understanding of friction coefficients and river hydrology. It was agreed that the sheet pile weir be built first to prove the solution would be functional before the dam was removed. Duke Power did not want to own the dam during demolition because of legal liability concerns so the state took ownership of the dam immediately prior and during removal after which there was no dam to own. The NC Coastal Federation supported the removal to benefit recreational and commercial fishing and applied for and held the federal funding necessary for the project. After Quaker Neck Dam was removed in 1998 the group was optimistic that most of the basin's anadromous fish spawning habitat could be opened by strategic dam removal.

*Cherry Hospital Dam Removal* - Cherry Hospital is a regional state psychiatric hospital serving 38 counties in eastern NC. The dam was built to provide water from the adjacent Little River (major tributary to the Neuse River). The hospital was already connected to a regional source of water in 1998 so the dam was no longer needed. The dam was of modern construction, faced by steel sheet pile, earthen filled and capped with concrete. Demolition used an excavator with claw, as well as a hydraulic hammer attached to the excavator. The removal of the dam restored access to 76 miles of anadromous fish spawning habitat. Cherry Hospital Dam removal followed the removal of Quaker Neck Dam and used the same Environmental Assessment and funding mechanisms.

*Rains Dam Removal* – Like the Cherry Hospital Dam, the Rains Dam also blocked the Little River. With support from the dam owner, Rains Dam demolition began on December 1, 1999, when combat engineers from the Marine Corps Air Station at Cherry Point, NC, used C-4 plastic explosives to blast a hole in the 76 meter long, 3.7 meter high dam. The hole was sized to mimic release from an inch rain event in the upstream watershed. Three more days of blasting reduced the 71-year-old dam to rubble.

A contractor working under the direction of the North Carolina Division of Water Resources (NCDWR) cleared the site of broken concrete and other debris. The exposed mud flats were then planted with bald cypress (*Taxodium distichum*) and Atlantic white cedar (*Chamaecyparis thyoides*), with help from the NCSU Department of Horticulture.

Before its demolition, Rains Dam blocked access to 49 miles of spawning habitat for six species of anadromous fish. Removal of the Rains Dam may benefit other species as well. Populations of two endangered freshwater mollusks, the dwarf wedgemussel (*Alasmidonta heterodon*) and the Tar spinymussel (*Elliptio steinstansana*).

*Crantock Mill Dam Removal* - Crantock Mill Dam and an upstream log jam were removed in 2008 on Middle Creek (major tributary to the Neuse River). The newly opened habitat (30 miles of stream habitat) is used for spawning by American shad, hickory shad, blueback herring, striped bass and migratory suckers (*Catostomidae* spp.). The catadromous American eel also uses this habitat. Middle Creek provides habitat for the federally endangered dwarf wedge mussel which is dependent on migrating fish for reproduction. Crantock Mill Dam Removal was done thru a cooperative agreement between the USFWS NC Coastal Program and the NCDWR. The dam was privately owned and in disrepair. The demolition of the old concrete mill dam was accomplished with a track hoe with an attached hydraulic hammer and excavator with bucket and claw.

*Other Restoration Efforts in the Neuse River Watershed*

*Holt's Lake Dam Fish Passage* – Fish Passage with an Alaska Steep-pass Fishway (see Ricks et al. 2004).

*Lowell Dam Removal* – For links to a summary of this removal effort and photos of the explosion used at the Lowell Dam removal please refer to *Appendix C 1.11.6*.

*Milburnie Dam Removal* – For links to a summary of and history behind this removal effort, as well as videos of the removal process please refer to *Appendix C 1.11.6*.

C 1.11.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- APNES
- Duke Power
- Private Dam Owners
- Coastal America
- NC Coastal Federation
- USACE
- NCSU
- University of North Carolina at Chapel Hill
- Duke University
- Restoration Systems
- Neuse Riverkeeper
- American Rivers
- ASMFC
- NCDMF
- NC Museum of Natural Sciences

*Select Funding Sources*

- Funding from State and Federal, Corporate, Private, NGO and mitigation sources

C 1.11.4 Status and Outcomes

*Project monitoring and documented success*

Monitoring and passage success have been conducted by various agencies, universities, consultants, and museum collections (Tracy 2020). For information on the monitoring of alosine passage and research surrounding dam removals in the Neuse River basin see NCWRC (2020), Burdick (2005), Raabe (2014), Beasley and Hightower (2000), and Riggsbee (2006).

*Factors contributing to project success*

Respectful collaboration between different technical disciplines and interest groups, as well as public outreach and education has led to successful restoration efforts within the Neuse River watershed. An example of local public engagement with the restoration of alosines can be seen with the Shad in the Classroom project. For more information on this effort see *Appendix C 1.11.6*.

*Obstacles and resolution*

Dewatering the impoundment can be accomplished by removing the mud gates in many non-hydropower dams such as Quaker Neck Dam or by opening the gates to the turbines after removing the turbines in hydropower dams such as Milburnie Dam. Where gates are not sufficient an engineered breach can be cut with explosives or hydraulic hammer to pass the flow that would be generated by an inch rain in the watershed above the dam. Controlled dewatering of the impoundment will remove any concerns over downstream flooding if such concerns exist.

In hydropower dams there may be a deep scour hole beneath the turbine outfall. Sand and gravel that accumulate on the upside of the dam can be directed to fill the scour hole to allow the river bottom to be restored to its natural elevation by starting the demolition to the bottom of the dam immediately above the scour hole and allowing bed load transport time to fill the scour hole before demolishing the remainder of the dam.

There is often public concern about flooding when a dam is removed. On the run of the river dams with no storage capacity our experience has shown there is no increase in flooding downstream and may be a significant reduction upstream within the footprint of the area impounded by the dam.

C 1.11.5 Lessons Learned

- Use a variety of funding mechanisms and techniques (different dams require different approaches).
- Be totally transparent with dam owners and affected public.
- Prioritize main stem dams over tributary dams but remove tributary dams as opportunities arise using a basin wide approach.
- Target the historical distribution of target species.
- Recognize that main stem dams require longer time frame and commitment but are essential.
- Search the historical record.
- Listen to the dam owners and affected public and work towards a solution that is good for all or at least most.
- Confirm that there are no additional dams on tributary streams by canoeing or kayaking entire stretch which will also provide a lot of insight on habitat quality upstream of the impounded reach.
- Do not limit the focus to herring but include all anadromous species to get much broader based public support.
- Use of university system is good for at least three reasons:
    - Good source of quality research that is likely to get into the professional literature helping future projects and those in other states;
    - Local public tend to identify with and appreciate the results from students which helps build local trust;
    - Supports the development of younger individuals who will develop new and improved techniques during their careers.

C 1.11.6 Supplemental Information

NCDNER: Final Report on the Demolition of Quaker Neck Dam

For additional information on the Milburnie Dam removal projects, see:

Restoration Systems: Milburnie Dam Removal Info Kit

Restoration Systems: Milburnie Dam Removal

Restoration Systems: River Advocates Celebrate Dam Removal

APNEP: North Carolina - First in Dam Removal Part I

APNEP: North Carolina – First in Dam Removal Part II

History of Dams and Mills at Milburnie, NC

E&E News: Clean Water Act may offer 'magic key' for dam removal

For additional information on the Lowell Mill Dam removal projects, see:

Restoration Systems: Lowell Mill Dam – Johnston County, NC

Restoration Systems: Stories from the Field – Lowell Dam Explosion

For additional information on the Quaker Neck Dam removal projects, see:

APNEP: Quaker Neck Dam Report

Los Angeles Times: Dam Destruction in NC Shaking Up Northwest

Other information related to the Neuse River Basin restoration efforts, see:

Rain Mill Dam Demolition

Video on the Little River Dam removal and American shad research

NC Museum of Natural Sciences: Shad in the Classroom

C 1.12 Cape Fear River Nature-like Fishway

C 1.12.1 Background

*Historical Context*

The Cape Fear River once supported thriving stocks of migratory fish including American shad, blueback herring, striped bass, and two sturgeon species. Populations have declined substantially over the past two centuries due to poor water quality, overfishing, and blockages to historical spawning grounds near the geological fall line. The most prominent obstructions evident today are the three lock and dams in the middle portion of the river basin constructed between 1913 and 1934 and operated by the USACE. These lock and dams were built to promote commercial navigation on the river but now serve primarily to create pools of water for municipal and industrial uses.

*Main Restoration Projects*

In August 2000, the USACE committed to construct a fishway at Lock and Dam No. 1 (Figure C 49). This commitment was also included as Term and Condition No. 8 in the Biological Opinion, dated August 2000, from the NMFS. The NMFS was involved in the project from the beginning, initially reviewing design plans and helping draft monitoring studies. Through the ARRA of 2009, the USACE received funds to construct the fishway in 2010. Construction started in the summer of 2011, and the rock-arch ramp fishway was finished in the fall of 2012 (Figure C 50). Due to concerns about low passage efficiency for certain species, modifications to the NLF were proposed, accepted, and construction was completed in 2021 (Figure C 51 and Figure C 52). Cape Fear River Watch hired a design firm to reconfigure the existing in-water fishway in order to improve the effectiveness for certain fish species, especially striped bass.

Figure C 49 – Original Lock and Dam No. 1 on the Cape Fear River, NC. Credit: NOAA Fisheries.

Figure C 50 – NLF installed in place of the Lock and Dam #1 on the Cape Fear River, NC completed in 2012. Credit: USACE.

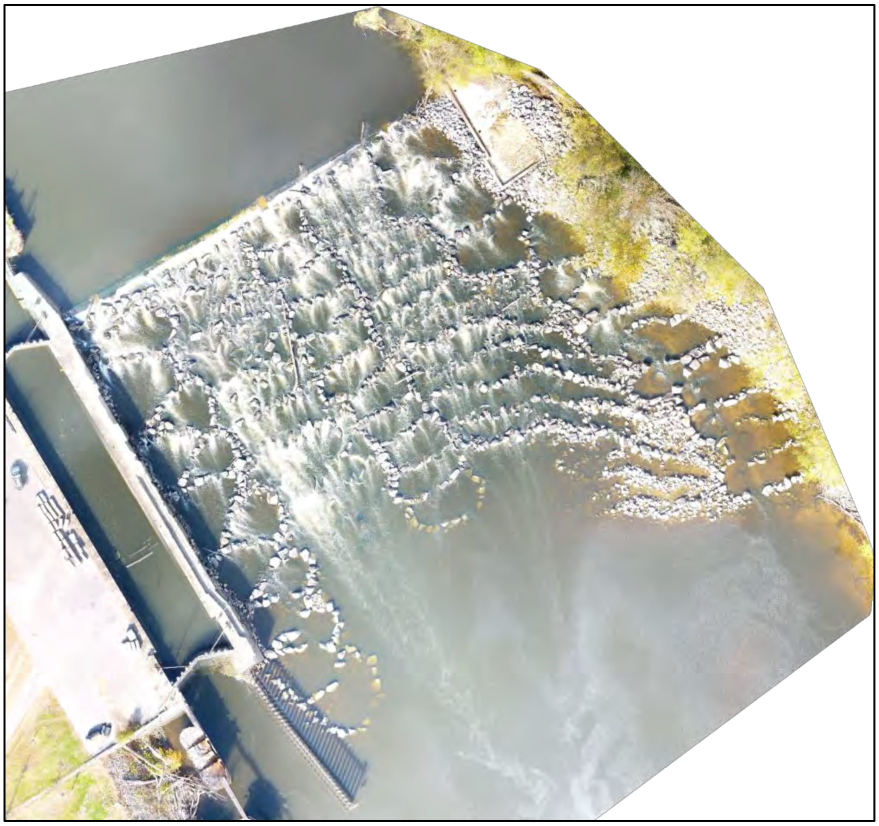

Figure C 51 – Modifications to the NLF installed in place of the Lock and Dam #1 on the Cape Fear River, NC. Modifications completed in 2021. Credit: Cape Fear River Watch.

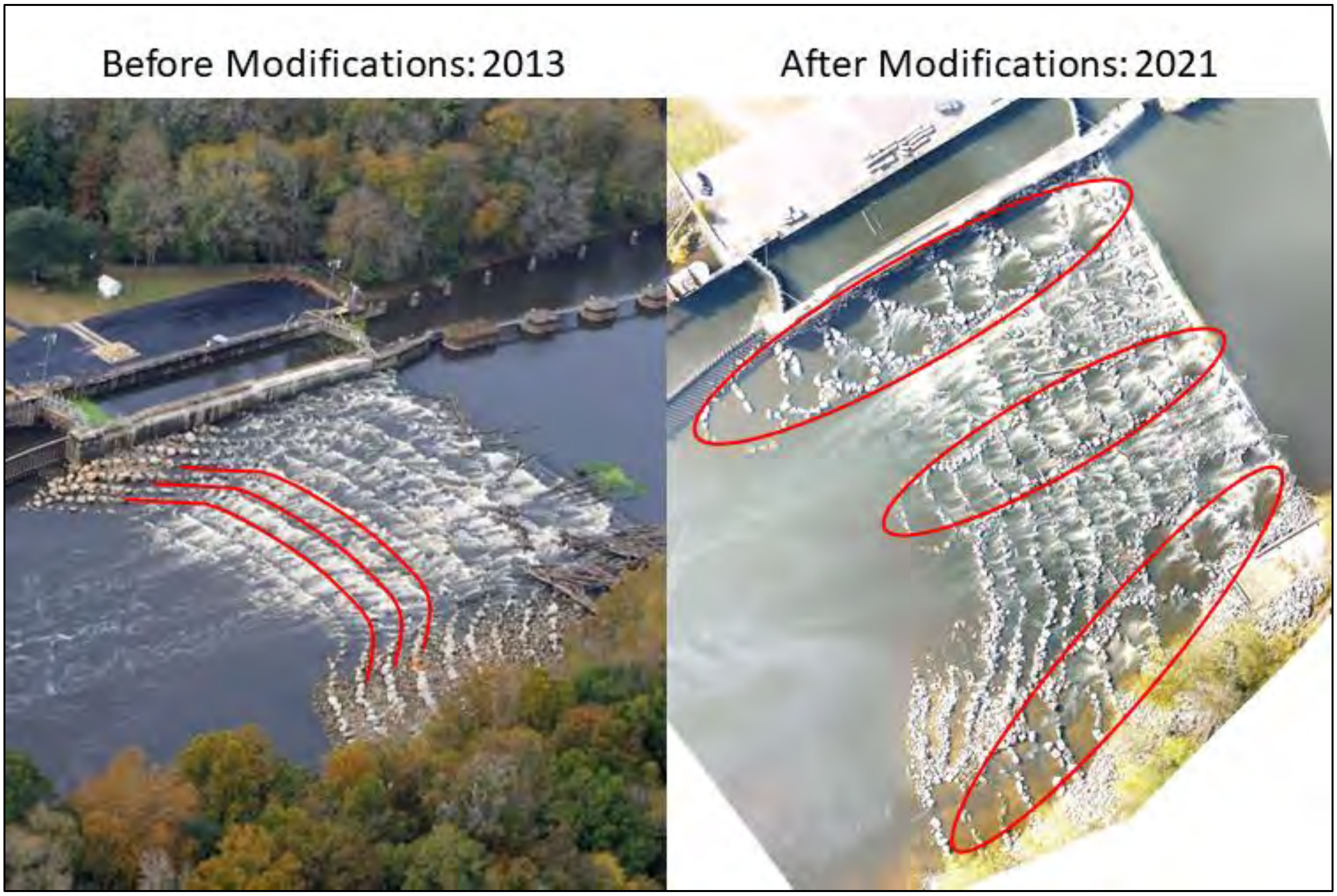


Figure C 52 – Aerial view of the NLF before (left) and after (right) modifications were completed. Credit: USACE (left) and Cape Fear River Watch (right).

C 1.12.2 Restoration Goals and Techniques Employed

The goal was to restore passage of anadromous fishes in the Cape Fear River above Lock and Dam No. 1 as the first step in restoring populations throughout the Cape Fear River basin. The fishway was designed to mimic natural river habitats in the fall zone of southeast rivers by arranging rows of large stones and grading the rows to gradually slope away from the crest of the dam structure. This design preserves the upstream pools created by the dam structure and allows anadromous fishes to pass upstream and downstream safely and effectively.

C 1.12.3 Partners and Stakeholders

*Select Parties Involved and Contributions*

- USACE – design, permitting, and construction
- NOAA Fisheries– design and permitting

- USFWS – design and permitting
- NCWRC – design and permitting
- North Carolina Division of Marine Fisheries (NCDMF) – design and permitting
- Cape Fear River Watch – obtain funding for modification
- NCSU – monitoring

*Select Funding Sources*

- The ARRA of 2009
- NC Coastal Recreational Fishing License Grant to Cape Fear River Watch to modify fishway
- NC Ports Authority

C 1.12.4 Status and Outcomes

*Project monitoring and documented success*

Scientists from NCSU studied how American shad and striped bass used the rock-arch ramp fishway to optimize the fishway. Studies from 2013-15 demonstrated that American shad numbers at the next upstream dam were significantly higher than those noted in pre-fishway years; over 60 percent of the tagged shad passed up the ramp (Raabe et al. 2019). Striped bass passage success was lower than expected with less than 30 percent of the tagged fish passing the ramp. Several Atlantic sturgeon have been seen near and in the lower part of the ramp but none have been documented using the ramp to go upriver. However, in the fall of 2014 a large sturgeon was observed leaping below Lock and Dam No.2, the first known occurrence of a sturgeon above No. 1 dam in recent times. Whether it passed up the ramp or through a lockage is unknown. Passage efficiency for blueback herring is unknown, but they have been documented below the upstream dams.

*Factors contributing to project success*

Great collaboration between USACE, the resource agencies, and NGOs. Strong support fostered by the Cape Fear River Partnership (CFRP). The CFRP was formed in 2011 with a vision of a healthy Cape Fear River for fish and people. The partnership’s mission is to restore and demonstrate the value of robust, productive, and self-sustaining stocks of migratory fish in the Cape Fear River.

*Obstacles and resolution*

Lack of funding for many years and lengthy permitting process through the USACE, especially on the modification proposal. Resolution was through persistence by the resource agencies and NGOs.

C 1.12.5 Supplemental Information

Cape Fear Partnership Web Page