Technical Reports

Massachusetts Division of Marine Fisheries
Technical Report TR-82

Massachusetts American Shad and River Herring

Monitoring Report: 2019

John J. Sheppard and Bradford C. Chase

Massachusetts Division of Marine Fisheries
Department of Fish and Game
Executive Office of Energy and Environmental Affairs
Commonwealth of Massachusetts

June 2024

Massachusetts Division of Marine Fisheries Technical Report Series

The Massachusetts Division of Marine Fisheries Technical Reports present information and data pertinent to the management, biology, and commercial and recreational fisheries of anadromous, estuarine, and marine organisms of the Commonwealth of Massachusetts and adjacent waters. The series presents information in a timely fashion that is of limited scope or is useful to a smaller, specific audience and therefore may not be appropriate for national or international journals. Included in this series are data summaries, reports of monitoring programs, and results of studies that are directed at specific management problems.

All Reports in the series are available for download in PDF format at:
https://www.mass.gov/service-details/marine-fisheries-technical-reports

Recent Publications in the Technical Series:

- TR-81: Nelson, G. A. 2023. **Massachusetts Striped Bass Monitoring Report for 2022.**
- TR-80: Sheppard, J.J., C. Reusch, C. Rhodes, M. Gendron, and E. Perry. 2023. **River Herring Spawning and Nursery Habitat Assessment: Acushnet River Watershed, 2019-2020.**
- TR-79: Nelson, G. A. 2022. **Massachusetts striped bass monitoring report for 2021**.
- TR-78: Chase, B.C., and C. Reusch. 2022. **River Herring Spawning and Nursery Habitat Assessment: Mattapoisett River Watershed, 2013-2014.**
- TR-77: Archer, A.F., and Chase, B.C. 2022. **River Herring Spawning and Nursery Habitat Assessment**.
- TR-76: Nelson, G. A. 2021. **Massachusetts striped bass monitoring report for 2020**.
- TR-75: Nelson, G. A. 2020. **Massachusetts striped bass monitoring report for 2019**.
- TR-74: Schondelmeier, B. P., W. S. Hoffman. 2020. **Characterization of the Massachusetts Spring Longfin Squid Fishery**.
- TR-73: B. C. Chase, J. J. Sheppard, B. I. Gahagan, and S. M. Turner. 2020. **Quality Assurance Program Plan (QAPP) for Water Quality Measurements for Diadromous Fish Monitoring**.
- TR-72: Livermore, J., B. C. Chase, M. Bednarski, and S. Turner. 2020. **River Herring Spawning and Nursery Habitat Assessment: Mill River Watershed, 2012-2014**.
- TR-71: Pugh, T. L., and R. P. Glenn. 2020. **Random Stratified Ventless Trap Survey for American Lobster 2006-2016**.
- TR-70: Nelson, G. A. 2019. **Massachusetts striped bass monitoring report for 2018**.
- TR-69: Whitmore, K. A., E. M. Moore, and E. J. Brewer. 2019. **Characterization of Fishing Activity and Trap Loss in the Massachusetts Recreational American Lobster Fishery**.
- TR-68: Nelson, G. A. 2018. **Massachusetts striped bass monitoring report for 2017.**
- TR-67: Chosid, D. M., M. Pol, B. P. Schondelmeier, and M. Griffin. 2019. **Early Opening Experimental Fishery for Silver Hake/ Whiting in Small Mesh Area 1 and the Western Raised Footrope Exemption Area.**
- TR-66: Nelson, G. A., S. H. Wilcox, R. Glenn, and T. L. Pugh. 2018. **A Stock Assessment of Channeled Whelk (*Busycotypus canaliculatus*) in Nantucket Sound, Massachusetts**.
- TR-65: Nelson, G. A. 2017. **Massachusetts striped bass monitoring report for 2016**.
- TR-64: Nelson, G. A. 2016. **Massachusetts striped bass monitoring report for 2015**.

Massachusetts Division of Marine Fisheries
Technical Report TR-82

Massachusetts American Shad and River Herring

Monitoring Report: 2019

John J. Sheppard and Bradford C. Chase

Massachusetts Division
of Marine Fisheries
836 South Rodney French Boulevard
New Bedford, MA 02744

June 2024

Commonwealth of Massachusetts
Maura Healey, Governor
Executive Office of Energy and Environmental Affairs
Rebecca Tepper, Secretary
Department of Fish and Game
Tom O'Shea, Commissioner
Massachusetts Division of Marine Fisheries
Daniel J. McKiernan, Director

Acronyms	
ASMFC	Atlantic States Marine Fisheries Commission
CRASC	Connecticut River Atlantic Salmon Commission
CT DEEP	Connecticut Department of Energy and Environmental Protection
CPUE	Catch-per-unit-effort
DER	Massachusetts Division of Ecological Restoration
DFW	Massachusetts Division of Fisheries and Wildlife
DMF	Massachusetts Division of Marine Fisheries
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
FMP	Fishery Management Plan
GARFO	Greater Atlantic Regional Fisheries Office
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MFAC	Massachusetts Marine Fisheries Advisory Commission
MRIP	Marine Recreational Information Program
MRTC	Merrimack River Technical Committee
MWT	Mid-water Trawl
NEFOP	Northeast Fisheries Observer Program
NH DFG	New Hampshire Department of Fish and Game
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O&M	Operation and Maintenance
QAPP	Quality Assurance Program Plan
SAFIS	Standard Atlantic Fisheries Information System
SFMP	Sustainable Fishery Management Plan
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

DMF staff assisting the Plymouth Department of Marine & Environmental Affairs and the Woods Hole Sea Grant to capture river herring in Town Brook, Plymouth. Each fish was fitted with passive integrated transponders (PIT) and released to evaluate the efficiency of fish passage improvements on the brook. Photo by John Sheppard.

Abstract

The Massachusetts Division of Marine Fisheries (DMF) is the agency responsible to monitor and manage diadromous fish populations in the coastal waters of Massachusetts. Included in this role is participation with the Atlantic States Marine Fisheries Commission (ASMFC), the interstate fisheries management authority that coordinates the management of marine species that migrate across state boundaries. Annual compliance reports are provided to the ASMFC on DMF's management and monitoring activities with river herring and American Shad. This technical report reports on the status of American shad and river herring management and monitoring by DMF for 2019 and is based on the ASMFC annual report (Sheppard et al. 2020) with more details on monitoring and restoration activities to provide this information to a wider public audience. A highlight of 2019 was increased sizes of river herring spawning runs in most coastal regions of Massachusetts. Unexpectedly, given the significant drought of 2016, increased spawning runs lead to the highest counts seen among monitored rivers since the river herring harvest ban in 2005. For the first time in this period, four rivers exceeded a half million fish (Mystic River, Monument River, Herring River, Harwich, and the Nemasket River). The Stony Brook in Brewster and Herring Brook in Pembroke set time series highs with over 400,000 fish. The Herring River run in Harwich was the first monitored run since the Nemasket River in 2002 to exceed a million fish.

Introduction

To successfully monitor and manage a fishery, information about that species' life history, reproductive behaviors, and population biology is necessary. While the basic biology of river herring and shad are relatively well understood, the nature of their reproductive strategy makes it imperative to have annual data specific to the spawning population size and demographics for as many river systems as possible. Spawning populations of anadromous shad and river herring migrate from the marine environment and return to their natal rivers to complete their reproductive cycle; a behavior that exposes each spawning population to unique risks associated with their travels through marine, migratory, spawning and nursery habitats. Providing assistance along these pathways is one of the oldest natural resource management practices in New England.

River herring, comprising alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*), are anadromous forage fishes that play a significant role in supporting commercial fisheries and broader ecosystem functions (Hall et al. 2010; Limburg and Waldman 2009). The historical coastal range of the anadromous alewife was from South Carolina to Labrador, Nova Scotia, and northeastern Newfoundland (Berry 1964; Winters et al. 1973; Burgess 1978). However, more recent surveys indicate that they do not currently occur in the southern range south of North Carolina (Rulifson 1982; Rulifson et al. 1994). Blueback herring range from the St. Johns River, Florida (Hildebrand 1963; Williams et al. 1975) to the Miramichi River, New Brunswick (Bigelow and Schroeder 1953; Leim and Scott 1966). Although alewife and blueback herring co-occur throughout much of their respective ranges, alewife are typically more abundant than blueback herring in the northern portion of their range (Schmidt et al. 2003). Alewife are the dominant (≥ 90%) river herring species in New England, (DiCarlo 1981; Gibson 1982; Greenwood 1982; Flagg and Squires 1983). The dominance may occur, in part, because alewives spawn along the shoreline areas in the freshwater ponds which form the headwaters of most coastal streams in New England (Loesch 1987). In contrast, blueback herring spawning show flexibility in habitat selection, trending towards more riverine or swifter flowing habitats (Collette and Klein MacPhee 2002).

Mature adult river herring make latitude-dependent migrations from the ocean to freshwater lakes to spawn each spring between March and June (Loesch 1987; Turner et al. 2015). Alewife spawning occurs over a broad range of temperatures ranging as low as 4.2°C in Chesapeake Bay (Mansueti and Hardy 1967) with spawning ceasing at temperatures as high as 27.8°C (Edsall 1970). Blueback herring are reported to spawn at temperatures ranging from a minimum of 13°C (Hawkins 1979; Rulifson et al. 1982) to a maximum of 27°C (Loesch 1968). Longevity of river herring increases with increasing latitude. Spawning stocks of river herring are made up primarily of 3-8 year old fish with males more abundant at age classes 3-5, whereas females live longer and thus dominate the older age classes (Loesch 1987). Alewives aged nine years have been captured in North Carolina (Street et al. 1975; Johnson et al. 1977), but 10-year-old fish have been recorded in Nova Scotia (O'Neill 1980). Age of blueback herring increases northerly with ages up to 7 and 8 years in Florida and South Carolina, respectively (Rulifson 1982), 9 in North Carolina (Street et al. 1975), and 10 in Nova Scotia (O'Neill 1980).

The American shad (*Alosa sapidissama*) is a larger related species to river herring that range in size from 2 to 8 lbs during spawning runs that ranges from northern Florida to Newfoundland (Greene et al. 2009). Shad are most abundant in their central range from North Carolina to Connecticut (Facey and Van Den Avyle 1986). Shad spawning runs occur from late April to early July and occurs over a broad range of temperatures (Greene et al. 2009). Most spawning occurs in waters with temperatures between 12-21°C (Walburg and Nichols 1967; Leggett and Whitney 1972). Similar to blueback herring, shad spawn in rivers in tidal fresh water and upstream on substrates dominated by broad flats with relatively shallow (1-6 m) water with moderate (0.3 – 1.0 m/s) current (Collette and Klein MacPhee 2002; Greene et al. 2009). Shad runs in the northeastern United States and the Canadian Maritimes are dominated by 4- and 5-year old fish (State of Maine 1982), with maximum age for males estimated at 12 years and 13 years for females (Melvin et al. 1985). Depending on geographical location, shad may spawn once and die, or they may survive to make several spawning runs. Most American shad native to rivers south of Cape Fear, North Carolina, die after spawning (Carscadden and Leggett 1975). This may be because of physiological limits related to the southern runs having long oceanic migrations with exposure to higher water temperatures (Leggett 1969). Moreover, Leggett and Cascadden (1978) suggest that southern stocks produce more eggs per unit of body weight than northern populations to compensate for not spawning repeatedly. In rivers to the north, the incidence of repeat spawning increases with latitude (Leggett 1969).

Status and Management of American shad and river herring

American shad and river herring formerly supported important commercial and recreational fisheries throughout their range. Most information on harvest is derived from the commercial industry as recreational harvest data are scarce. Severe declines in commercial landings began coastwide in the early 1970s to less than 3% of the historical peaks in the late 1960s and have remained at persistently low levels since the mid-1990s (ASMFC 2017). Most American shad stocks are at historically low levels, and landings have plummeted from a peak of 30,000 metric kg at the start of the 20th century to a low of 0.6 million kg in 1996 (Greene et al. 2009). Coastwide landings for river herring increased sharply from lows in the early 1940s during World War II to more than 50 million pounds by 1951 and peaked at 75 million pounds in 1958 (ASMFC 2017). Severe declines in landings began coastwide in the early 1970s and remained at persistently low levels since the mid-1990s (ASMFC 2017). In concert with the decline in landings, it was estimated that American shad historically ascended at least 130 rivers along the Atlantic coast to spawn, but today fewer than 70 systems have runs (Limburg et al. 2003). In response to the decline in alosine stocks, the ASMFC developed a cooperative Interstate Fishery Management Plan for American shad and river herring in 1985 which set population monitoring and management standards to be met by the states (ASMFC 1985).

In 1998, the ASMFC adopted Amendment I to the Interstate Fishery Management Plan for shad and river herring (ASMFC 1999). The goal of Amendment 1 is to protect, enhance, and restore East Coast migratory spawning stock of American shad, and river herring in order to achieve stock restoration and maintain sustainable levels of spawning stock biomass (ASMFC 2007). Under this amendment, states are required to implement various surveys to characterize alosine stocks including adult spawning stock surveys. As part of these surveys, states are required to take representative samples of adults to determine sex and age composition as well as repeat spawning (ASMFC 1999). Furthermore, all states are required to calculate mortality and/or survival estimates, while monitoring and reporting data relative to landings, catch, effort, and bycatch (Munger et al. 2004).

The stock assessment for American shad (ASMFC 2007) examined commercial, recreational and population demographics data from 31 rivers coast-wide and the results suggest declines in many Atlantic coastal stocks of American shad, especially in the mid-Atlantic and southern New England states. Similar to the results of the 2007 assessment, the 2020 benchmark assessment examined 38 rivers and found coast-wide populations to be depleted (ASMFC 2020). In concert with declining stocks, the assessment indicated total mortality estimates generally exceeded the recommended threshold (Z_{30} = 0.98) for most years in the rivers assessed. The assessment suggests many causes for this decline including bycatch in ocean fisheries, former mixed stock harvest from coastal and estuarine locations, increased predation on juvenile and adult shad, losses from down river passage at dams and hydroelectric facilities, as well as coast-wide changes in environmental conditions (ASMFC 2007). In addition, the benchmark assessment found that shad recovery has been limited by restricted access to spawning habitat, with 40% of historic habitat in the U.S. and Canada blocked by dams and other barriers (ASMFC 2020).

River herring were designated as a Species of Concern under Endangered Species Act review processes in 2007, and a petition was filed in 2011 to the National Marine Fisheries Service (NMFS) to list alewife and blueback herring under the Endangered Species Act (ESA) as endangered throughout all or a significant portion of their ranges. A coast-wide stock status review conducted by NMFS in 2013 (78 FR 48943) and repeated in 2017 (84 FR 28630) determined that listing alewife and blueback herring as threatened or endangered was not warranted (NMFS 2019). In these findings, the River Herring Status Review Team (SRT) noted river herring are at historically low levels of abundance and have been subjected to long-term habitat impacts and over-fishing and identified several factors inhibiting recovery efforts including anthropogenic habitat alterations, predation by native and non-native predators, and exploitation by fisheries (ASMFC 2017; German et al. 2023).

DMF, within the Department of Fish and Game, under the Executive Office of Energy and Environmental Affairs, is responsible for the management of the Commonwealth's living marine resources. Among these resources are the anadromous American shad, (*A. sapidissima*) and river herring, alewife (*A. pseudoharengus*) and blueback herring (*A. aestivalis*). Massachusetts General Laws in Chapter 130 establish the Director of DMF as responsible for regulation of river herring resources and fisheries of the Commonwealth. Shad management is divided with DMF managing marine waters and the Division of Fish and Wildlife (DFW) managing inland waters. Subsequently regulations were established to protect shad and river herring populations and manage these fisheries. These regulations set catching days, daily catch limits and gear restrictions.

Following a drought in the early 2000s, most of Massachusetts' river herring runs experienced spawning run declines, some reaching historic lows (Sheppard et al. 2010). On November 9, 2005, the Massachusetts Marine Fisheries Advisory Commission (MFAC) approved a three-year moratorium on the harvest, possession and sale of river herring in response to the severe population declines in the coastal rivers of the Commonwealth. On October 2, 2008, the MFAC approved the continuation of a moratorium for another three years through 2011. Subsequent monitoring and biological sampling indicated a low to modest recovery of river herring spawning runs in Massachusetts' rivers, however, overall run sizes remained well below historic levels and mortality remained high. For these reasons, the moratorium was extended indefinitely due to a lack of recovery of river herring runs in Massachusetts and surrounding regions.

DMF has been monitoring and counting river herring spawning runs since 1980 (Brady 1987a, b) and American shad spawning runs cooperatively with DFW and the United States Fish and Wildlife Service (USFWS) since 1967 in the Connecticut River (CRASC 2017) and since 1983 with the completion of the fish passage facility at the Essex Dam on the Merrimack River (MRTC 1997; MRTC 2010). In 2004, DMF initiated a program funded by NMFS (Grant No. NA03NMF4050253) to study the biological characteristics of shad and river herring populations in several Massachusetts coastal rivers (Sheppard et al. 2010) by collecting population demographics data (sex ratios, size, age, repeat spawning, mortality and survivorship data) to augment existing monitoring and counting efforts. Subsequently, DMF committed to managing at least one monitoring station in each of the major coastal drainage areas in Massachusetts that matched biological sampling with higher technology (electronic or video) spawning run counts. This goal was achieved in 2015 with eight such monitoring stations established.

A comprehensive stock assessment of river herring stocks based on historical data (enumeration of run size, basic biological data including sex, size and age data, and age-based population modeling) from various Massachusetts coastal rivers was conducted by DMF biologists. This report (TR-46, Nelson et al. 2011) is available on the DMF website: mass.gov/info-details/marine-fisheries-technical-reports. As a requirement of Amendment 3 to the ASMFC Interstate Management Plan for shad, DMF developed and submitted a Sustainable Fishery Management Plan for American shad in Massachusetts coastal rivers (Sheppard and Chase 2012) and was updated in 2018 (Sheppard and Chase 2018). In addition, and in fulfillment to Amendment 3, DMF developed a Habitat Plan for American shad for the Connecticut River (CRASC 2014) and for Massachusetts coastal rivers (DMF 2014). Annual reporting of American shad commercial and recreational landings, as well as spawning run size and population demographics data from shad samples collected from the Connecticut and Merrimack rivers are reported to the ASMFC in annual compliance reports. This technical report is a synthesis of historical and current landings, harvest and biological data from both Nelson et al. (2011), Sheppard et al. (2010) and the annual compliance report in 2019 for American shad (Part I) and river herring (Part II). This report includes updates on monitoring, biological sampling, regulations, enforcement and restoration efforts to conserve and manage these populations in Massachusetts watersheds.

Part One. American shad monitoring report - 2019

Management Changes - 2019. No changes were made in Massachusetts regulations in 2019 related to the harvest and possession of American shad (see current regulations in **Appendix A**). In keeping consistent with previous years, no directed commercial fisheries for American shad occur in Massachusetts waters. Recreational fisheries for American shad are permitted in Massachusetts waters with harvest and possession limits allowed only in two rivers, the Connecticut River and the Merrimack River, in accordance with the Massachusetts American Shad Sustainable Fishery Management Plan (SFMP, Sheppard and Chase 2018).

De Minimis Status. As outlined in Sections 3.2 and 7.1.3 of Amendment 3 to the Interstate Fishery Management Plan (FMP) for Shad and River Herring (ASMFC 2010), States that report commercial landings of American shad that are less than 1% of the coast-wide commercial total are exempt from sub-sampling commercial and recreational catch for biological data. Landings from 1990 – 2019 are such that Massachusetts qualifies for *de minimis* status (**Table 1**).

Table 1. Massachusetts American shad landings in pounds as percentage of Atlantic States shad landings (1990–2019). These data were used to determine the *de minimis* status for the Atlantic States Marine Fisheries Commission. Data source: *Pers. Comm.*, NMFS Statistic and Economic Division.

Year	MA Landings (lbs)	Other Atlantic States (lbs)	MA % American Shad
1990	5,605	3,553,473	0.16
1991	638	2,808,898	0.02
1992	308	2,435,127	0.01
1993	423	2,105,863	0.02
1994	286	1,493,906	0.02
1995	454	1,653,322	0.03
1996	134	1,583,079	0.01
1997	752	1,837,170	0.04
1998	1,765	2,174,226	0.08
1999	223	1,067,312	0.02
2000	268	890,624	0.03
2001	1,051	722,178	0.14
2002	424	1,471,850	0.03
2003	1,109	1,509,898	0.07
2004	530	1,136,527	0.05
2005	0	302,435	0.00
2006	102	193,855	0.05
2007	44	168,993	0.03
2008	31	100,901	0.03
2009	0	88,165	0.00
2010	0	105,477	0.00
2011	215	94,833	0.23
2012	10	118,189	0.01
2013	0	141,832	0.00
2014	0	40,256	0.00
2015	0	43,259	0.00
2016	0	14,075	0.00
2017	0	26,330	0.00
2018	0	18,433	0.00
2019	0	11,669	0.00

Note: American Shad landings in Massachusetts during the past decade were well below the level of *De minimis* status (less than 1% of coast-wide commercial landings).

Commercial Fishery – 2019

No commercial ocean intercept fisheries for anadromous alosines are conducted in Commonwealth waters, Territorial Seas, or adjoining Exclusive Economic Zone (EEZ) waters. Under current regulations, no commercial fishery for American shad presently operates within the Commonwealth of Massachusetts. Under Massachusetts Marine Fisheries Laws, MGL Chapter 130: and Title 322 CMR (1987), harvest and possession are limited to three fish from the Connecticut and Merrimack Rivers (moratorium elsewhere) taken by hook and line. Section 4.12 of the CMR prohibits the landing of net caught shad, even when taken outside of Massachusetts waters in the EEZ or in the territorial seas of another state.

Incidental Harvest. Reported Massachusetts's landings from 1990 through 2019 are presented in Table 1. The NMFS figures reported are landed illegally and not a directed fishery. Massachusetts dealers reported no American shad landings in 2019.

Bycatch: DMF participates in a port-side monitoring program to identify and quantify incidental bycatch of American shad, alewife and blueback herring in Atlantic herring and Atlantic mackerel mid-water trawl (MWT) fisheries. The port-side sampling program is conducted in collaboration with the National Oceanic and Atmospheric Administration (NOAA) Fisheries Sampling Branch's Northeast Fisheries Observer Program (NEFOP), who conduct at-sea sampling. Based on the river herring bycatch calculations conducted by the Greater Atlantic Regional Fisheries Office (GARFO) quota monitoring staff, the mid-water trawl herring fishery caught 24.7 mt of river herring/shad in Area 1A (Gulf of Maine), 19.4 mt in the Cape Cod area (NMFS Statistical Area 521), and 120.4 mt in Area 2 (southern New England). Fishermen using bottom trawl gear to target Atlantic herring caught 14.8 mt in Area 2. Meanwhile, the coastwide Atlantic mackerel fishery, which uses both mid-water trawl and bottom trawl gear, caught 91.5 mt of river herring/shad in 2019 (GARFO, *pers. comm.*). DMF sampled four out of 10 MWT vessels that landed in MA, for a total of 14 trips (out of approximately 53) and 1,361 mt of 5,257 mt of Atlantic herring and Atlantic mackerel landings sampled. It should be noted that due to circumstances within the fishery in 2019, sampling may not be completely representative of catch in the fishery. For parts of the year the majority of the catches were landed in other states where portside sampling is not conducted. The extrapolations of bycatch should be regarded with caution and not used to inform additional findings. More information is available from the DMF Fisheries Dependent Sampling Project upon request.

Recreational Fishery – 2019

Recreational angling for shad occurs primarily in the two largest rivers in Massachusetts, the Connecticut and Merrimack rivers. Shad are also targeted in the North and South rivers of Pembroke and Marshfield and the Palmer River, Rehoboth, at low levels of catch and effort. Coastal runs of American shad in the state are relatively small compared to other systems on the East Coast. Fisheries are catch and release, except in the Merrimack and Connecticut rivers, where the daily bag limit per angler is three shad. River systems with the largest potential (Connecticut and Merrimack rivers) to support American shad runs are considered to be in the ongoing process of restoration. Both river systems have multi-state and multi-agency anadromous fish management and restoration plans in effect (CRASC 2017; MRTC 2010). No fishery creel surveys specifically target shad in coastal Massachusetts. Recreational fisheries catch estimates are provided for marine species by the NOAA Marine Recreational Information Program (MRIP).

Landings, effort and methods of estimation. In 2019, MRIP reported fishing activity for American shad but reports zero harvested in Massachusetts waters with no length or age data reported (**Table 2**). MRIP estimates that Massachusetts recreational anglers took 4,436 trips in which American shad was the primary or secondary target during 2019 (all from shore in September – October).

Hook & Release Mortality. MRIP estimates that anglers in Massachusetts released alive 4,239 shad (PSE 92.2) in 2019. There are no studies involving hook and release mortality of American shad in Massachusetts waters to estimate dead discards. A summary of all shad harvest and losses from 1998 to 2019 is provided in **Table 2**, using data from the NMFS Resource Statistics Division, Woods Hole, and DMF.

Brood Stock Captures. Approximately 2,401 American shad were trapped at the Holyoke Dam fish lift, Connecticut River (**Table 2**) for restoration efforts (see American shad propagation). No shad stocking transfers occurred from the Merrimack River in 2019.

Research Captures. Approximately 247 American shad (180 shad from the Merrimack River and 67 shad from the Connecticut River) were collected for biological sampling and agency studies.

Fishery-Independent Monitoring

Merrimack River. Massachusetts is required by ASMFC to conduct mandatory fishery-independent monitoring of American shad in the Merrimack River (ASMFC 2020) including:

- An annual spawning stock survey (i.e., passage counts, CPUE, or other abundance index) and representative subsampling to describe size, age, and sex composition of spawning stock;
- Calculation of mortality and/or survival estimates where possible.
- Juvenile shad abundance survey/index (there is no current juvenile shad monitoring on the Merrimack River and this requirement is presently exempted by ASMFC).

Table 2. Harvest and losses of American shad by commercial and recreational fisheries in Massachusetts (number of fish from MRIP Type A+B Harvest with Percent Standard Error (PSE)). Data source: *Pers. Comm.*, NMFS Marine Recreational Information Program).

Year	Commercial	Recreational MRIP (PSE)*	Illegal Harvest	Scientific Studies	Stocking
1998	0	1,144 (100)	588	100	1,000
1999	0	0	74	250	1,000
2000	0	3,725 (67.3)	89	250	2,000
2001	0	1,326 (71.2)	0	250	3,000
2002	0	NA	141	225	3,500
2003	0	NA	370	250	4,000
2004	0	0	179	300	4,000
2005	0	NA	0	600	2,000
2006	0	22,287 (81.9)	34	900	2,000
2007	0	0	15	1,700	4,000
2008	0	0	10	1,400	4,000
2009	0	0	0	1,200	6,200
2010	0	NA	1	1,000	4,100
2011	0	0	72	750	3,600
2012	0	NA	3	1,200	5,000
2013	0	0	0	1,300	3,200
2014	0	NA	0	720	2,700
2015	0	0	0	1,180	3,900
2016	0	NA	0	1,330	6,430
2017	0	2,042 (59.5)	0	500	3,540
2018	0	NA	0	99	2,234
2019	0	0	0	247	2,401

Notes: Illegal Harvest = pounds (3lb average weight Merrimack River shad)
*A PSE >50 indicates an imprecise estimate
NA – Data not available

Anadromous fish are managed by the Merrimack River Anadromous Fish Restoration Program that is represented by the USFWS, NMFS, DMF, DFW, and NH Department of Fish and Game (NH DFG) representatives. Monitoring and sampling for American shad is conducted by the Essex Dam licensee with oversight from DMF and USFWS. The annual spawning stock survey and biological sampling occurs at the fish lift at the river's lowermost dam, Essex Dam, in Lawrence (rkm 48). During the 2019 spring spawning run, 18,653 shad were counted at the fish lift, below the time series average of 27,672 fish (**Figure 1a**; **Appendix Table 1**).

A total of 180 adult shad were sacrificed over 13 separate collection days from May 20 to July 1 for sex composition, total and fork length, wet body weight, and age data (**Appendix Table 2**). Female and male mean length and mean age are depicted in **Figure 2**. Early in the time series, the mean size of females increased with a peak in 2003 (499 mm FL; 1.92 kg) and has declined since (time series mean: 454 mm FL; 1.40 kg, **Figure 2A**). However, mean size of females has trended upward between 2016 – 2018 before decreasing to 439 mm FL (1.40 g) in 2019. Mann-Kendall analysis (τ = 0.20, p = 0.37) indicates no discernable trend in mean length of females throughout the sampling period. Mean size of males has been variable throughout the monitoring period (mean: 416 mm FL; 1.00 kg, **Figure 2A**) with a time-series high in 2003 (439 mm FL; 1.16 kg) and a time series low of 385 mm FL (0.73 kg) in 2019. No significant trend in mean size of males over time could be identified (τ = 0.25, p = 0.20).

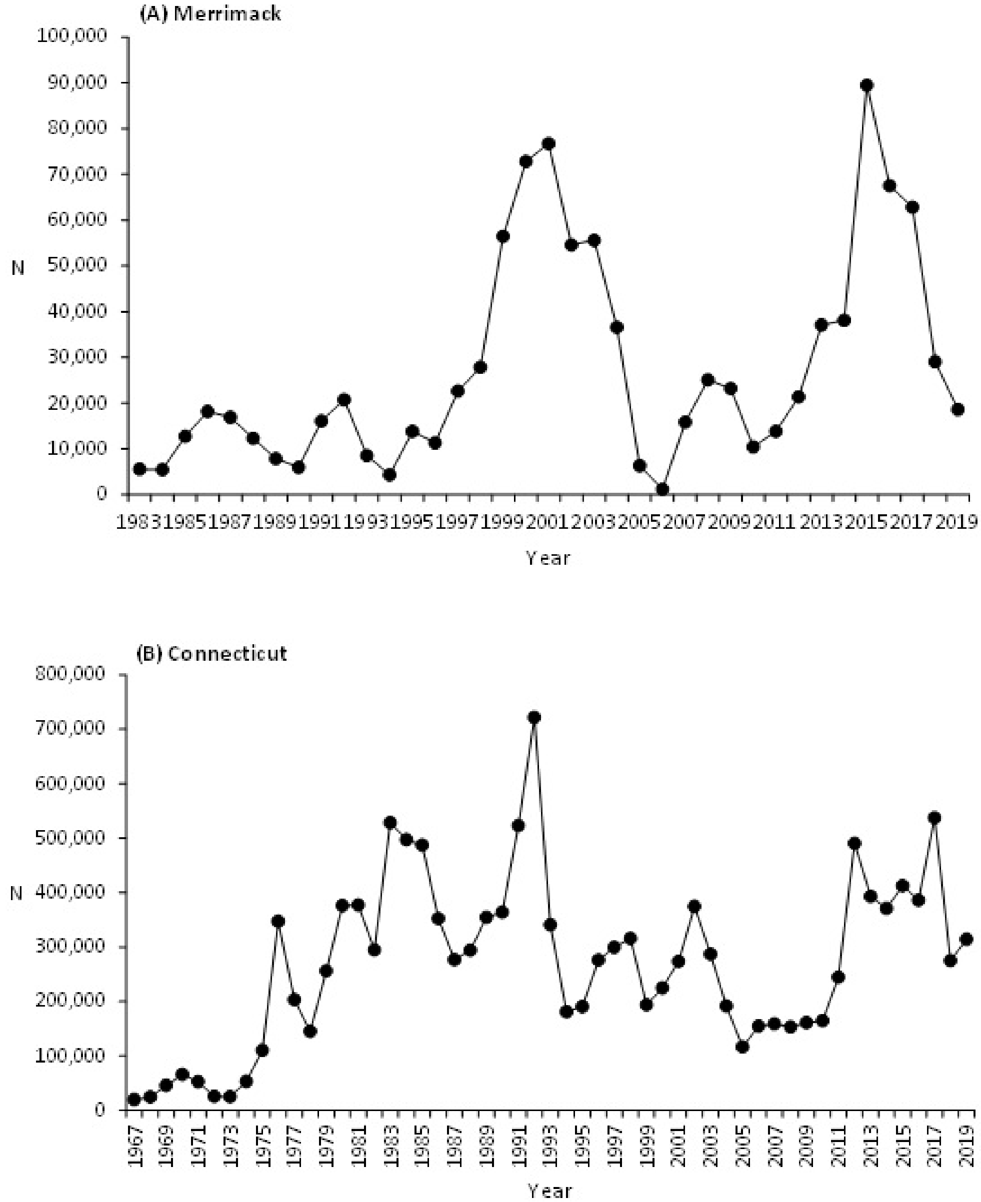

Figure 1. Annual passage of American shad reported from the (A) Essex Dam Fish Lift on the Merrimack River, Lawrence (1983 – 2019), and from the (B) Holyoke Fish Lift on the Connecticut River, Holyoke (1967 – 2019).

In 2019, scale samples from 180 shad were aged. Mean age of females is variable throughout the monitoring period (mean: 5.8 years) with a peak of 6.7 years in 2003 and a time-series low of 5.0 years in 1993 (**Figure 2B**; **Appendix Table 2**). Mean age of females has shown an increasing trend in the past five years (2014 – 2019). Mann-Kendall analysis ($\tau = 0.20$, $p = 0.43$) indicates no discernable trend in mean size of females over time. Mean age of males has also been variable with a mean of 5.2 years and a peak of 6.0 years in 2001 and time-series lows of 4.4 years in 1992 and 2007 (**Figure 2B**; **Appendix Table 2**). Mean age of males has been stable between 2016 – 2018, then decreased to 4.9 years in 2019. No trend in mean size of males was detected ($\tau = -0.10$, $p = 0.70$). It should be noted that sample sizes in the early 1990s were too low to provide robust age information.

Reading of 2019 scales indicated that 86% of males were virgin spawners, 9% had spawned once, 3% (three fish) had spawned twice, and 3% (three fish) had spawned three times. Among females, 68% were virgin spawners, 20% had spawned once, and 12% (eight fish) had spawned twice. Refer to Slater (2020a) for additional information on the Merrimack River shad monitoring.

The annual survival rate (S) was estimated using the Chapman-Robson method on pooled age data (**Appendix Table 2**). The Chapman-Robson method is a non-regression probability-based estimator that has been shown to be more accurate and less biased than the standard linear regression-based "catch curve" (Chapman and Robson 1960, Murphy 1997) especially when the sample size is small. Ages 5 through 9 were used in the

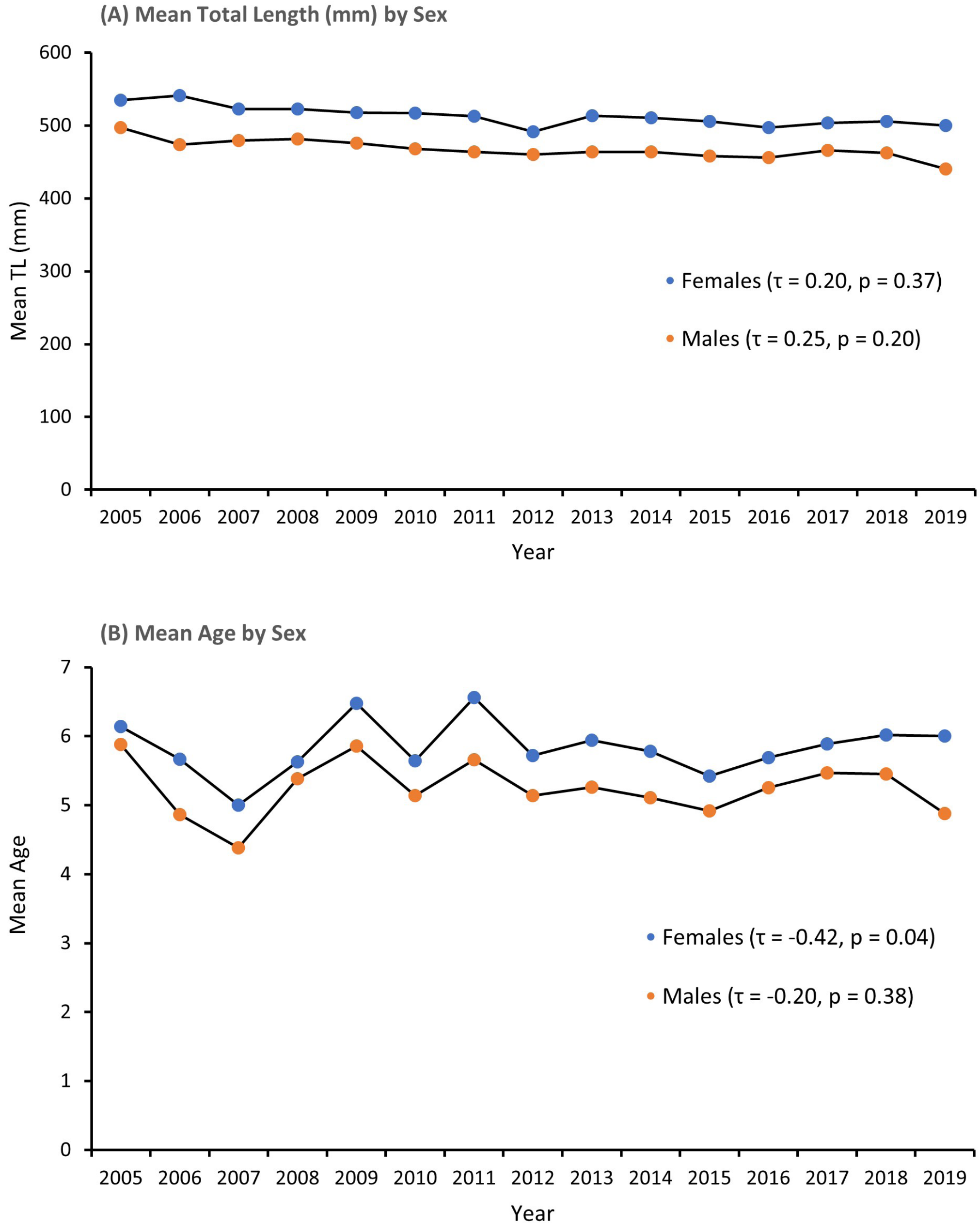

Figure 2. Mean total length (A) and mean age (B) of American shad sampled from the Merrimack River (2005 – 2019).

analysis and in 2019, and total mortality (Z) was estimated at 0.8 (S = 0.5). Annual mortality rates and associated standard error (SE) are plotted in **Figure 3**. A Mann-Kendall analysis (τ) was applied to identify any trends in total mortality over the course of the monitoring period. Results indicated an increase in total mortality over time ($\tau = 0.38$, $p = 0.03$). Z was stable with no discernable trend from 2001 through 2011, then increased from 2012 to a time series high in 2016 (Z = 2.38), then declined from 2017 through 2019.

Connecticut River. Massachusetts is required by ASMFC to mandatory conduct fishery-independent monitoring of American shad in the Connecticut River including:

- An annual spawning stock survey (i.e., passage counts, CPUE, or other abundance index) and representative subsampling to describe size, age, and sex composition of spawning stock;
- Calculation of mortality and/or survival estimates where possible; and
- Juvenile shad abundance survey/index.

Shad have been managed cooperatively on the Connecticut River since 1967 by the Connecticut River Atlantic Salmon Commission (CRASC) under restoration objectives established in an approved shad management plan (CRASC 2017). Monitoring and sampling for American shad is conducted by DFW in partnership with the

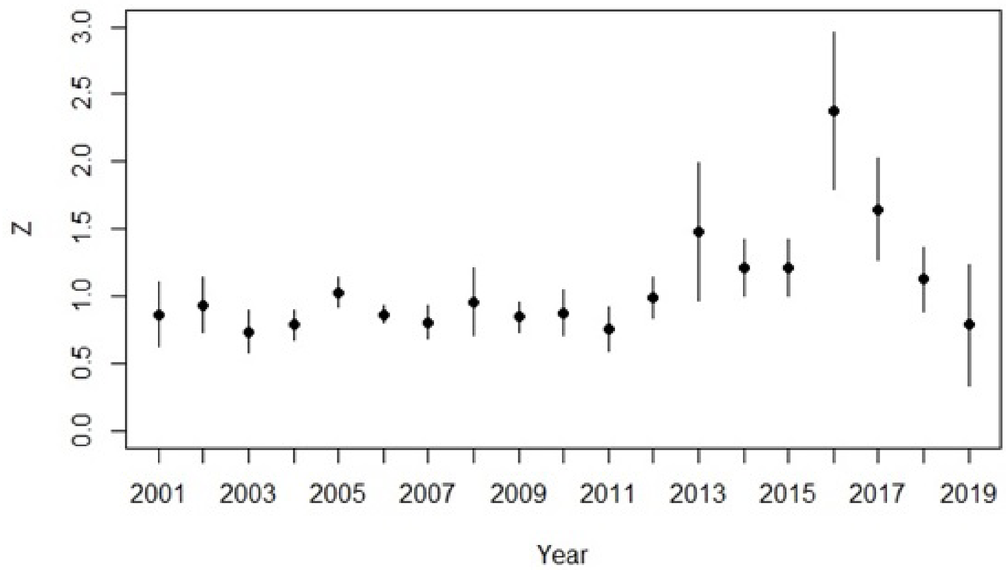

Figure 3. Instantaneous (total) mortality rate (Z) and associated standard error (SE) for American shad from the Merrimack River, 2001 – 2019.

Connecticut Department of Energy and Environmental Protection (CT DEEP) and the USFWS.

The annual spawning stock survey and biological sampling occurs at the Holyoke Dam fish lift. During the 2019 spring spawning run, 314,361 shad were counted at the fish lift; exceeding the time series average of 269,755 fish (**Figure 1b**; **Appendix Table 1**). The total number of shad lifted in 2019 was 316,829, including shad transported to other rivers to augment restoration efforts (2,401) and sacrificed for biological sampling and agency studies (67). Shad counts peaked in 1992, followed by a prolonged declining trend until recent improvements with counts exceeding 300,000 annually for 2012–2017. A total of 1,102 American shad were sampled over 48 days from May 9 through June 30 for fork length, weight, sex, and scale samples. Refer to Slater (2020b) for additional information on the Connecticut River shad monitoring.

Small coastal river monitoring. Limited information is available on the status of American shad populations and fisheries in small coastal rivers in Massachusetts. A pilot electrofishing study was initiated by DMF in 2016 to monitor the presence and abundance of American shad in the South River and Indian Head River (tributaries to the North River in the South Shore Drainage Area); where small spawning runs of shad continue to attract hook and line fishing each spring. Electrofishing monitoring continued in 2019 in both rivers from the head of tide to the first obstruction, to collect spawning adult shad. Biological information, including sex, size, age and genetic samples were collected from individual shad. Scales were collected from shad to provide information on age structure, repeat spawning, mortality, and survivorship of these two populations. Anal fin samples were collected and archived for future genetic research.

Eighteen sampling trips were made to the Indian Head River between May and June 2019 (**Appendix Table 3a**). High flows prevented sampling during the last week of April. A total of 344 shad were observed, of which 124 were captured (including 6 recaptures). Males (N = 86) ranged from 382 – 552 mm TL and females (N = 32) ranged in size from 407 – 587 mm TL. The ratio of males-to-females in the three years of monitoring has been consistent with males dominating the catches (mean ratio: 2.3:1.0). Age samples of Indian Head River shad ranged from 3 – 9 years with mean age of 5.5 years for males and 5.5 years for females. Reading of 2019 scales indicated that 45% of males were virgin spawners, 12% had spawned once, 29% had spawned twice, 8% had spawned three times, and 1% (one fish) had spawned four times. Among females, 56% were virgin spawners, 13% had spawned once, 16% had spawned twice, and 6% (two fish) had spawned three times. Combined sex ages 5 - 9 were used to estimate mortality and survivorship (the Chapman-Robson method), and Z was estimated at 0.71 (S = 0.49).

Nineteen sampling trips were made to the South River between April and June 2019 (**Appendix Table 3b**). A total of 126 shad were observed, of which 84 were captured (including 7 recaptures and 4 shad released without processing). Males (N = 48) ranged from 374 – 546 mm TL and females (N = 32) ranged from 444 – 582 mm TL. The ratio of males-to-females in the three years of monitoring has been consistent with males dominating the catches (mean ratio: 2.1:1.0). Age samples of South River shad ranged from 3 – 9 years with mean age of 5.3 years for males and 5.6 years for females. Mean ages for both sexes decreased from 2018. Reading of 2019 scales indicated that 63% of males were virgin spawners, 8% had spawned once, 21% had spawned twice, and 8% (four fish) had spawned three times. Among females, 72% were virgin spawners, 16% had spawned once, 3% (1 fish) had spawned twice, 6% (two fish) had spawned three times, and 3% (1 fish) had spawned four times. Ages 5 through 9 were used to estimate mortality and survivorship (the Chapman-Robson method), and Z was estimated at 0.71 (S = 0.49).

Indices of abundance (catch-per-unit-effort, CPUE) for each river system were calculated to examine trends over the course of the spawning run (**Figure 4**). Mean Geometric CPUE scores were 0.4 shad/minute for both rivers. These scores indicate an increase in mean CPUE in the South River from 2018, with no change at the Indian Head River from 2018. Additional analyses of gear efficiency including capture efficiency and capture probability as well as determining minimum sample sizes were conducted to assist the goals of developing standardized sampling protocols and long-term indices of population demographics.

In-stream habitat data was collected in this monitoring effort to characterize and describe riparian and in-water features of the sampling areas in both rivers. Both the Indian Head and South rivers are prone to tree falls and debris jams that left unattended can obstruct diadromous fish passage. The DMF Fishway Crew conducted field reconnaissance followed by stream maintenance in both rivers under collaborative efforts with DMF and the Town herring wardens to remove obstructions to fish passage prior to the start of the spawning run.

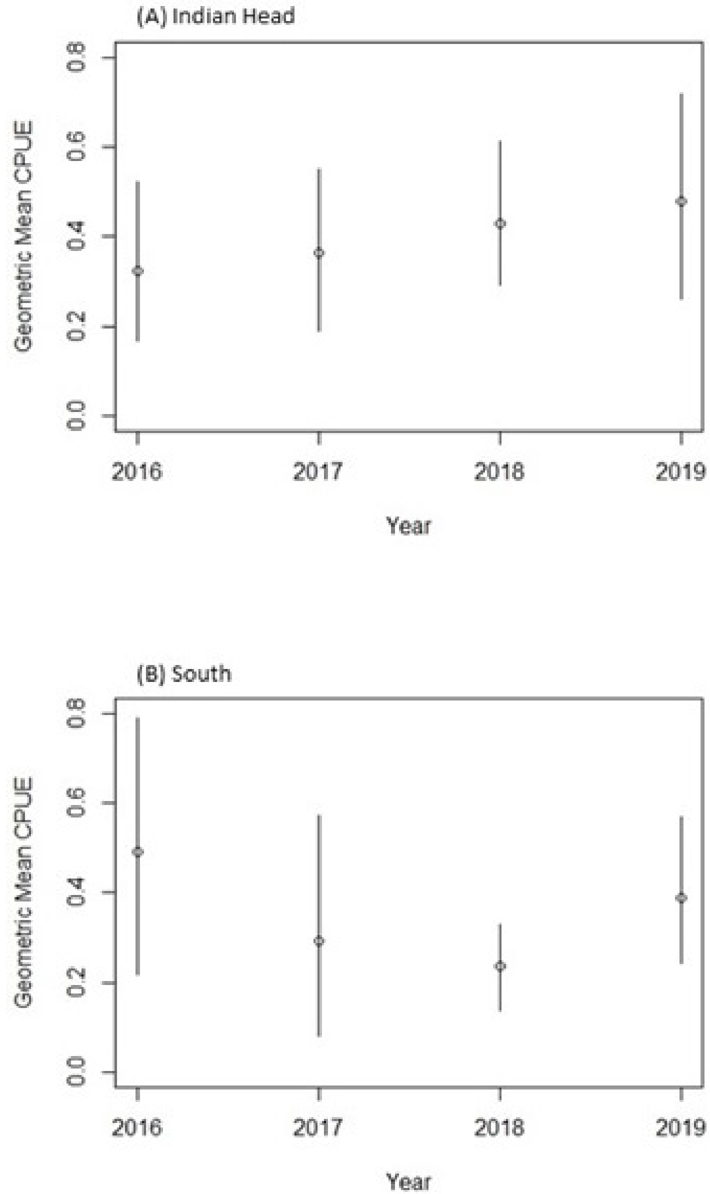

Figure 4. Geometric mean catch-per-unit-effort (N_{shad}/min.) scores with 95% C.I. of American shad sampled from electrofishing surveys in the (A) Indian Head and (B) South Rivers (2016 – 2019).

American Shad Propagation

Merrimack River. Efforts for the restoration of the Merrimack River American shad population have been ongoing since 1969. Restoration efforts are overseen by the USFWS, Central New England Anadromous Fish Program. In 2004, the DMF and DFW partnered with the USFWS to develop an experimental hatchery operation for American shad of the Merrimack River system. The Massachusetts American Shad Propagation project was formed with the objective to restore shad populations to the Charles River and secondarily the Neponset River, and to create local in-river sport fisheries. The project includes the development of a shad fry stocking program in conjunction with fish passage improvements. Charles River shad stocking concluded with no shad fry transplanted into the Charles River in 2019 (Slater 2020a). Efforts in 2019 focused on augmenting existing shad populations within the Merrimack River watershed.

Connecticut River. Efforts for the restoration of the Connecticut River American shad population have been ongoing since 1967. Restoration efforts are overseen by the USFWS, Connecticut River Coordinator's Office in partnership with CRASC. Since 2006, approximately two to five thousand American shad have been collected at the Holyoke lift for within basin and out-of-basin restoration efforts.

In 2019, 2,401 American shad were trapped at the Holyoke Dam fish lift, Connecticut River (Slater 2020b). Of these shad, 388 were trucked to the USFWS Nashua Fish Hatchery for spawning. A total of 3,423,816 fry were subsequently released into three rivers, 2,829,219 into the Lamprey River, 323,442 into the Nashua River, and 271,155 into the Merrimack River. 350 post-spawned shad were subsequently released into the Nashua River in New Hampshire. The remaining broodstock were received by the CT DEEP (496), Rhode Island Division of Fish and Wildlife (472), and the United States Geological Survey (USGS) Conte Anadromous Fish Research Center (1,295).

Recent Progress on Habitat Monitoring and Restoration

American shad spawning runs occur in two large rivers: Connecticut River and Merrimack River. Six moderate sized coastal rivers representing three major drainage areas are known to support shad spawning runs in Massachusetts: the Palmer River (Narragansett Bay), Jones River (South Shore), North River (South Shore), South River (South Shore), Neponset River (Boston Harbor), and Charles River (Boston Harbor). The DMF American Shad Habitat Plan for Coastal Rivers (Chase et al. 2021) identifies the Charles River, Neponset River, and Taunton River as restoration priorities. The Taunton River supported a historical shad run and fishery; the current population status is uncertain.

Charles River. DMF participated with local partners and the Watertown Dam owner, the MA Department of Conservation and Recreation, in a feasibility study to evaluate improvements to fish passage at the Watertown Dam on the Charles River.

Taunton River. Monitoring for shad in the Taunton River continued in 2019. Seining from previous years was continued in tidal portions of the watershed and was expanded to include monthly boat electrofishing surveys (June – October) in reaches above tidal influence, in collaboration with DFW. A total of 6 juvenile American shad were captured in August 2019 and one was captured in October (sampling in October was limited due to equipment problems). All shad were caught during boat electrofishing.

Law Enforcement Activity – 2019

The Massachusetts Environmental Police reported no violations pertaining to American shad in 2019.

Monitoring Plans for 2020

Monitoring of American shad will continue as described above with the following exceptions: 1) the onset of the MRIP intercept survey in Massachusetts was postponed until May 20 due to COVID-19 safety measures; 2) DMF in partnership with the USFWS will resume collecting American shad from the Charles River to collect population demographics data as well as to conclude an age validation study. Seining and boat electrofishing monitoring for shad will continue in the Taunton River to support consideration of future stocking efforts in that watershed.

Part Two. River herring monitoring report – 2019

Management Changes - 2019. No changes were made in Massachusetts' recreational regulations in 2019 related to the harvest and possession of river herring (see current regulations in **Appendix A**).

Commercial Fishery – 2019

The harvest, possession, or sale of river herring in the Commonwealth or in the waters under the jurisdiction of the Commonwealth is prohibited, except for a 5% bycatch tolerance (by count) for bait fisheries conducted in Federal waters. To accommodate the bait harvesting fisheries, the MFAC approved a river herring tolerance (up to 5%, by count, of a batch of fish). These landings are permissible as defined by 322 CMR 7.01(1)(i), and 322 CMR 7.01(3)(a). No direct commercial fisheries exist for river herring in Massachusetts. The NMFS reporting for alosines has included indirect, direct and illegal landings in the past. The Standard Atlantic Fisheries Information System (SAFIS) Dealer Database reports no harvest in 2019 under the species codes or blueback herring, river herring, and alewife.

Recreational Fishery – 2019

The harvest of river herring for recreational has been prohibited statewide since 2006. Spawning runs can be opened to harvest when authorized by the Director, provided the run has a SFMP approved by the ASMFC. Effective April 7, 2017, new regulations at 322 CMR 6.17 were enacted that created standards for opening spawning runs to the sustainable harvest of river herring. No runs were opened in 2019 (or prior years). The Nemasket River run in Middleborough and Lakeville has an ASMFC-approved SFMP (DMF and MLHFC 2016), although the Middleborough-Lakeville Herring Fishery Commission elected not to have a harvest in 2019.

Landings, effort and methods of estimation. The Marine Recreational Information Program estimates 2,090 river herring (PSE 71.4) were harvested in MA in 2019. This data represents misidentified or illegal harvest. Of the estimated 2,090 fish harvested, 1,711 (PSE 71.3) were landed by charter boats and 319 (PSE 101.6) by private/rental vessels. Upon further investigation of the 10 records, two of these records occurred within state territorial waters (23 fish caught and used as bait or thrown back alive), the remaining records occurred in federal waters. The records were obtained from verbal reports from anglers who identified them as blueback herring and were not identified or verified by MRIP samplers. The low sample numbers contribute to the high PSE (> 50%) which indicates the survey estimates are highly variable. Because there is no legal directed fishing of river herring in Massachusetts waters, no confirmed identification of the species, and the MRIP extrapolation methods, the accuracy of these estimates must be regarded with caution.

Hook & Release Mortality. MRIP estimates that 318 (PSE 98.3) river herring were caught and released alive in 2019. There are no studies involving hook and release mortality of river herring in Massachusetts waters to estimate dead discards.

Native American Sustenance Harvest. In 2010, DMF entered into an agreement with the Wampanoag Tribe of Massachusetts to exempt tribal members from the state's river herring harvest moratorium. Tribal harvest was reported to DMF during 2010-2013, but not since that time. Tribal harvest was known to occur at several river herring runs in 2019, although harvest numbers are not known.

Research Harvest. DMF conducts annual biological sampling of river herring by collecting adults on spring spawning runs at eight rivers. During the 2019 spring spawning run 4,075 adult river herring (3,293 alewives; 782 blueback herring) were collected for sex composition, total and fork length, wet body weight, and age data.

River Herring Propagation

DMF conducts a trap and transport stocking program for alewife and blueback herring. The three major objectives are to: 1) maintain and enhance existing populations, 2) restore historically important populations and 3) create new populations where feasible. A DMF stocking protocol was developed and implemented in 2013 (https://www.mass.gov/doc/herring-stocking-protocol/download) that provided criteria for stocking decisions and a focus to allow remnant populations present at restoration sites to naturally re-colonize habitat prior to the introduction of donor stock genetics. Stocking of gravid river herring where river access has been provided or improved is generally conducted for three or more consecutive years per system. In 2019, a total of 4,006 pre-spawn adult river herring were trapped and transported via our stocking truck (**Table 1**) or lifted above a barrier into four

Table 1. DMF River herring trap and transport operations for 2019.

Donor System	Recipient System	Transfer Type	N Transferred
Nemasket River	Kickemuit River (Kickemuit Reservoir, RI)	OBS	1,000
Nemasket River	Ten Mile River (Turner Reservoir, RI)	OBS	1,000
Nemasket River	Three Mile River	W	500
Monument River	Boat Cove Creek (Mill Pond)	W	750
Parker River	Parker River (Pentucket Pond)	I	356
Parker River	Ipswich River	W	250
Merrimack River	Sudbury River	OBI	2,150
Merrimack River	Merrimack River (NH)	I*	990
Merrimack River	Nashua River (NH)	W*	2,465
Merrimack River	Nissitissit River (NH)	W*	2,965
Merrimack River	Winnipesauke River (NH)	W*	16,475
Merrimack River	Cohas Brook (NH)	W*	1,550

Transfer type codes: I – in-river; W – between rivers within watershed; OBI – out-of-basin (intra-state); OBS – out-of-basin (between states); RS – research set-aside
* Denote within-river and within-watershed transfers between states

coastal systems in the Commonwealth. A majority of the river herring were transported out of Massachusetts to neighboring states under cooperative agreements.

Fishery-Independent Monitoring

A central feature of DMF's monitoring of diadromous fish since the 1980s has been recording information on spring spawning runs of river herring in coastal Massachusetts. The objectives are to track population abundance and demographics and provide data that can support population restoration and sustainability. In 2010, a goal was set by the Diadromous Fish Project to establish at least one station in each of the state's major coastal drainage area that had electronic or video counting and biological sampling. This goal was met in 2015. Additionally, DMF provides technical assistance to numerous local efforts to conduct volunteer visual counts of river herring spawning runs. This assistance includes technical design and analysis of visual count data to produce spawning run estimates (Nelson 2006; https://www.mass.gov/files/documents/2016/08/om/tr-25.pdf.

Massachusetts Coastal Streams. DMF collects samples annually to examine biological characteristics of river herring (alewife and blueback herring) populations from each of the major coastal drainages in Massachusetts at locations with herring run counts. Herring were collected weekly at each river and species, sex, total length, fork length, weight, and age were recorded for each fish (**Appendix Table 4 and 5**). Four rivers were monitored from 2004–2019 (Monument River, Mystic River, Nemasket River and Town Brook). Additional stations were added to provide better coverage of coastal drainage areas (Parker River, Newbury in 2012, Herring River, Harwich in 2013, Merrimack River, Lawrence in 2014, and the Back River, Weymouth in 2015) and will be maintained annually. Of these six stations all record both alewife and blueback herring, except Town Brook and Nemasket River, where sampling has only captured alewife. The following results focus on size, age and mortality data from the original four rivers and the Parker River and Herring River. Trends in mean size and age were analyzed using a Mann-Kendall trend analysis.

Alewife Length and Age. The overall trend for alewives indicates increases in mean size for both sexes in the Mystic River (**Figure 1c, i**). In all other rivers, no discernable trend in mean size is evident in either sex. The overall trend for mean age for male and female alewife for the 16-year time series is a low to modest decline in the Nemasket, River (**Figure 2a, g**), and Town Brook (**Figure 2d, j**). Mean age of both sexes indicated increasing trends in all rivers from 2013 – 2016 but have since declined. In the Monument River (**Figure 2b, h**), a weak positive trend was evident in the mean size of males (τ = 0.28, p = 0.15) and females (τ = 0.35, p = 0.08). In the Parker River (**Figure 2e, k**), no overall trend is evident in the mean age of either sex with the mean age of females stable at 4.0 years between 2016 – 2019. Mean age of both sexes in the Herring River are variable with no discernable trend overall (**Figure 2f, l**).

Blueback Length and Age. Mean size of blueback herring in the Mystic River indicates an increasing trend for both sexes throughout the monitoring period (**Figure 3b, f**). The number of blueback herring sampled from the Parker River in 2019 is insufficient to include in the analyses. In the Herring River, mean size of males (**Figure 3d**) indicated an insignificant but increasing trend (τ = 0.43, p = 0.23) while no discernable trend is evident in females (τ = 0.20, p = 0.65; **Figure 3h**). Results indicate a significant decreasing trend in mean age of females (τ = -0.47, p = 0.02) in the Mystic River throughout the monitoring period (**Figure 4f**). Mean age of Monument River blueback herring is also variable, with mean age of females declining significantly throughout the monitoring period (τ = -0.42, p = 0.04; **Figure 4e**) while no discernable trend is evident in males (**Figure 4a**). There is no discernible trend in mean age for both sexes in the Parker or Herring rivers (**Figure 4c, g** and **Figure 4d, h**, respectively).

Mortality. Estimates of instantaneous mortality rates (Z_m) and survivorship (s) were derived from the Chapman-Robson method. Annual estimates of mortality were generally high ($Z \geq 1.0$), exceeding Z40 thresholds (Z_{40} range: 1.06 – 1.23; ASMFC 2017) for river herring populations in all rivers studied, with few annual estimates below 1.0 (**Appendix Table 4 and 5**). Mean estimates for alewives are highest in the Monument River (Z_m = 1.72), the Herring River (Z_m = 1.65) and the Merrimack River (Z_m = 1.48). Mean Z-estimates were lowest for alewife in the Mystic River (Z_m = 1.26) and Parker River (Z_m = 1.26). Z-estimates and associated SE for each river is shown in **Figure 5**. Mann-Kendall trend analysis identified a significant decline in alewife mortality in the Mystic River (τ = -0.49, p = 0.02; **Figure 5b**). No significant trend was evident in all other rivers monitored. Mean Z-estimates of blueback herring from the Monument River (Z = 1.48), Mystic River (Z = 1.51) and the Parker River (Z = 1.43) are high in most years studied. The Mann-Kendall trend analysis was conducted for only the Monument, Mystic and Parker rivers as all other rivers could not produce representative age sample sizes (see **Appendix Table 5**). Results (**Figure 6**) indicated Z is highly variable with no discernable trend in the three rivers monitored.

Time Series Monitoring of Spawning Runs. DMF has monitored river herring spawning runs since 1980 and developed long-term counting stations for select rivers in the Commonwealth through collaborations with DFW and USFWS and non-government organizations. Seven rivers representing seven major watersheds (**Figure 7**) have a minimum of twenty years of counts using a similar counting method. Three rivers (Monument River, Bourne; Mattapoisett River, Rochester; and Town River, Bridgewater) are monitored using electronic counters. Two rivers (Merrimack River, Lawrence; and Connecticut River, Holyoke) are monitored using a fish lift. Run size in the Back River (Weymouth) was estimated using a visual count from 1986 – 2014, then using an electronic counter from 2015 – 2019. Run size in the Parker River (Newbury) was estimated using visual counts between 1997 – 2012, electronic counter in 2013, and video from 2014 – 2019. Eight rivers representing five major watersheds have spawning run size estimates with a minimum of ten years using a consistent counting method (**Figure 8**). Of these, three rivers (Acushnet River, Acushnet; Agawam River, Wareham; and Wankinco River, Wareham) are monitored using electronic counters, and five rivers (Marstons Mills River, Barnstable; Stony Brook, Brewster; Jones River, Kingston; Nemasket River, Middleborough; and Town Brook, Plymouth) with visual counts.

Among the long-term time series for river herring spawning runs several had series high records during 2000-2003, followed by decreases in run sizes in most rivers from 2000-2005 (Figure 7 and Figure 8). The larger rivers, the Connecticut River and the Merrimack River had earlier series highs. The declining counts following 2000 were influential on the management decision to close river herring harvest in 2006. Nelson et al. (2011) cites various potential causes of these declines including environmental changes, predation, bycatch in fisheries, illegal harvest and watershed alterations. A general increasing trend in spawning run counts occurred in most rivers between 2006 and 2014 (Figure 8). In 2019, run sizes increased in most rivers monitored including over a million fish counted at the Herring River, Harwich, and time-series highs in the Agawam River (102,105), Town Brook (230,860), Herring Brook, Pembroke (476,609), and Stony Brook (434,583).

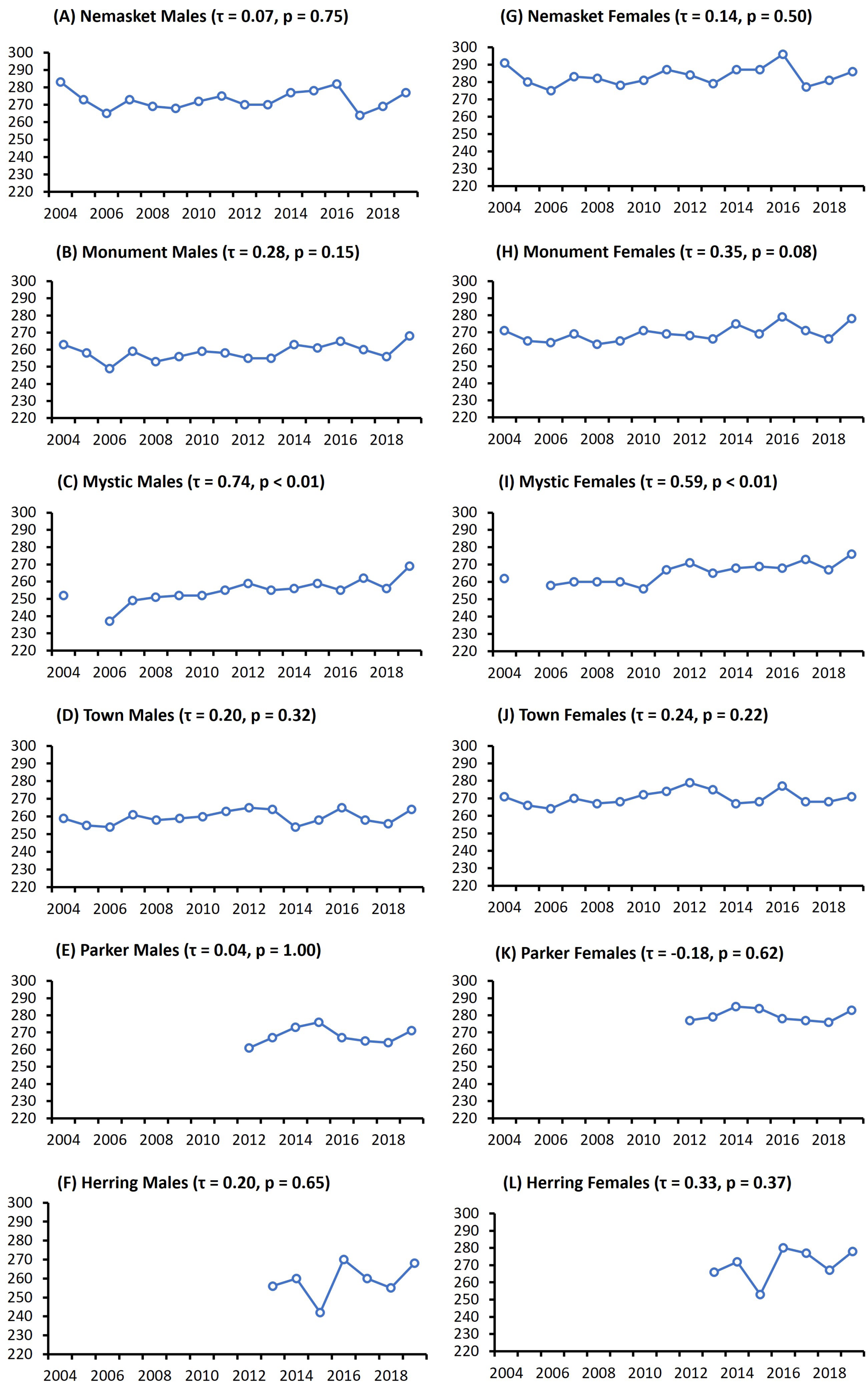

Figure 1. Annual mean size (TL mm, in y-axis) of alewives from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in mean size over time.

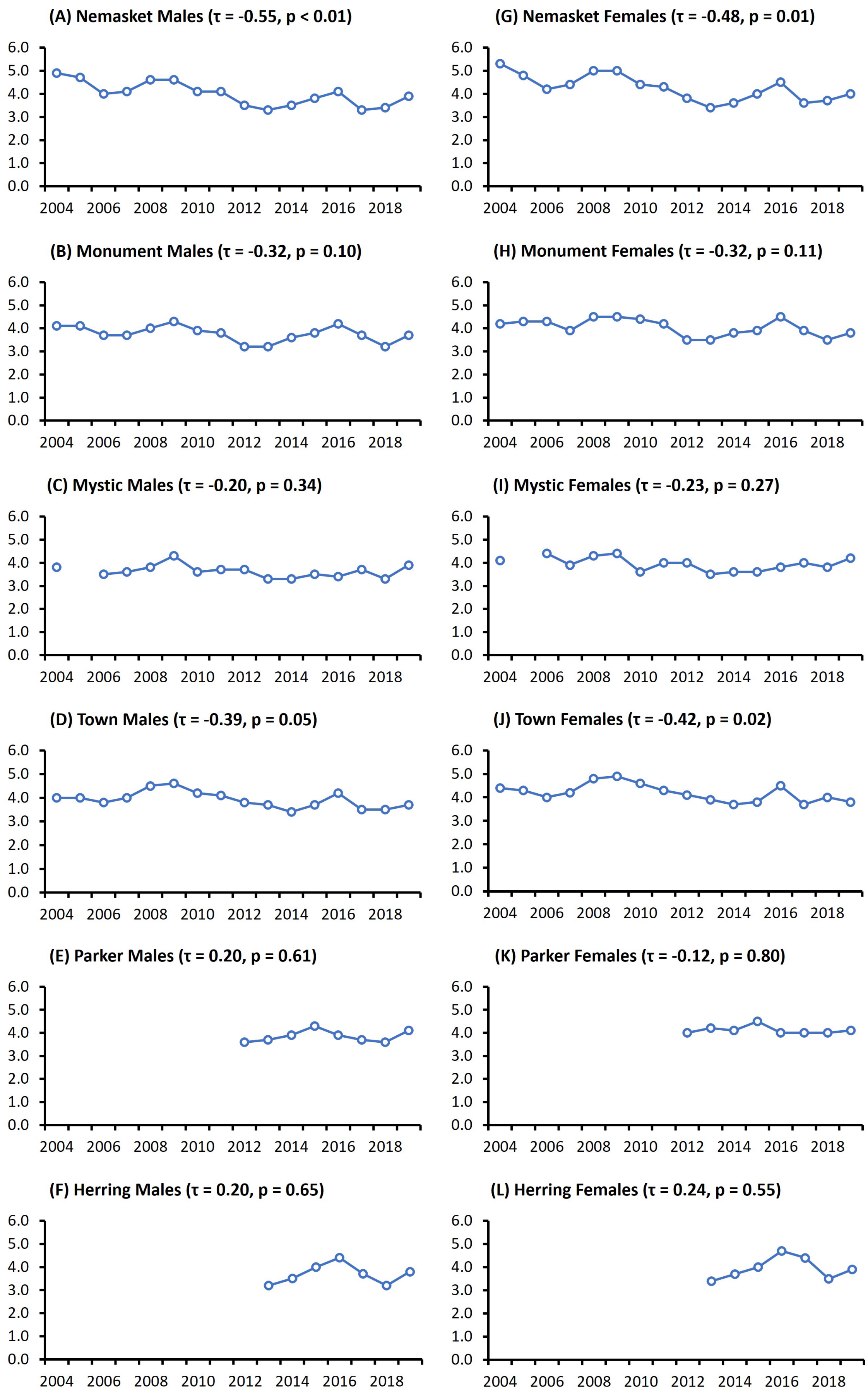

Figure 2. Annual mean age (in y-axis) of alewives from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in mean age over time.

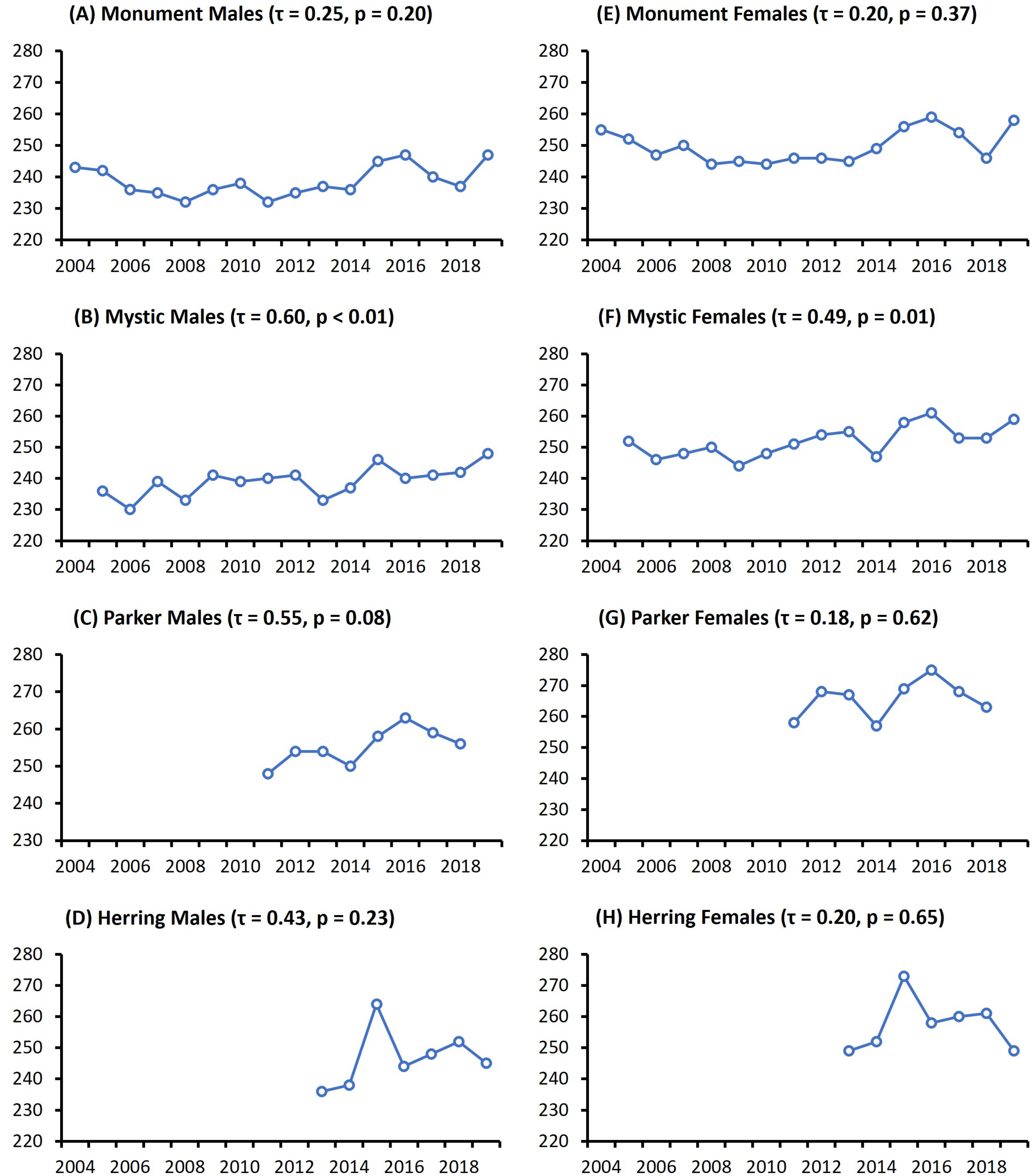

Figure 3. Annual mean size (TL mm, in y-axis) of blueback herring from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in mean age over time.

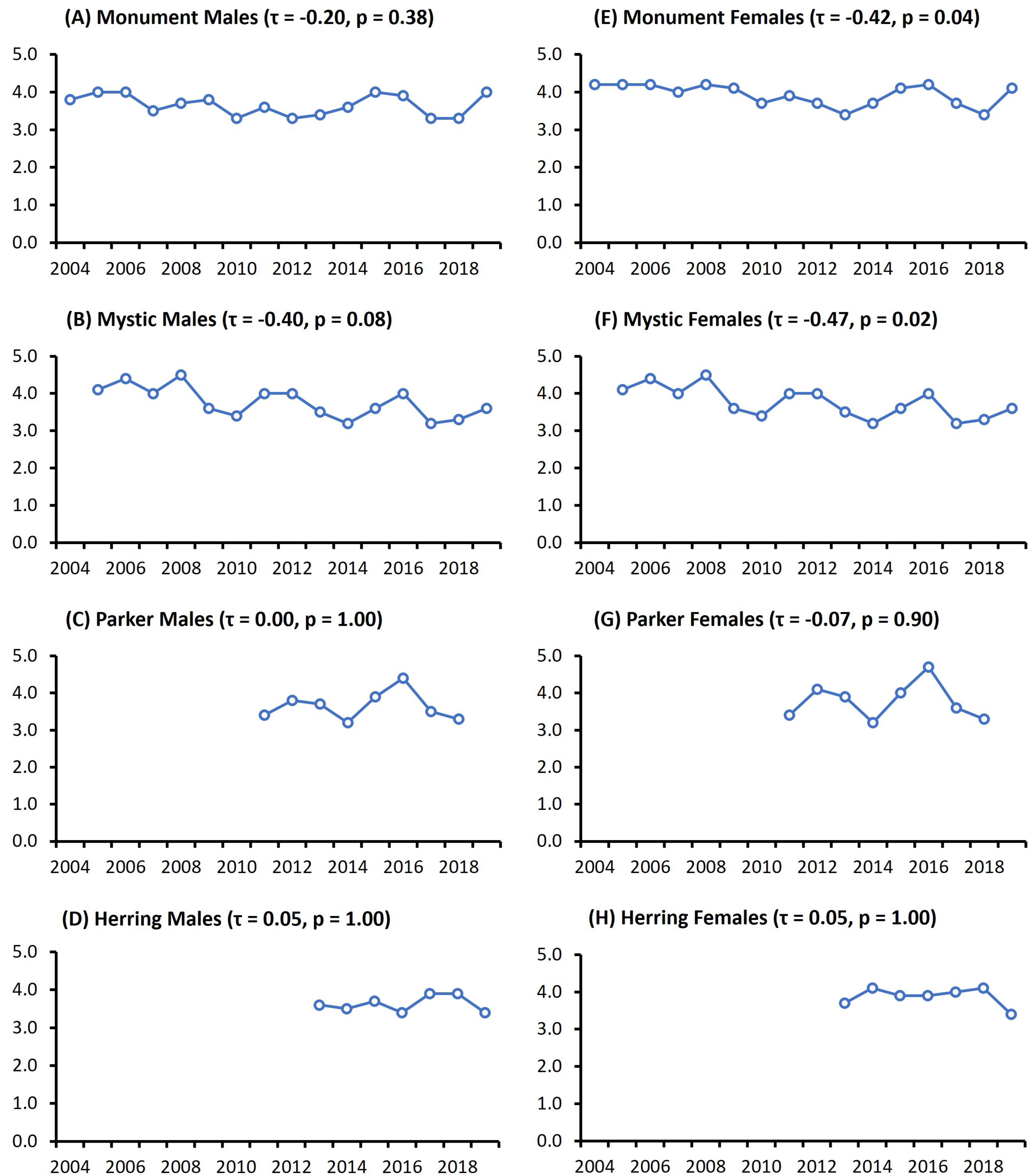

Figure 4. Annual mean age (in y-axis) of blueback herring from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in mean age over time.

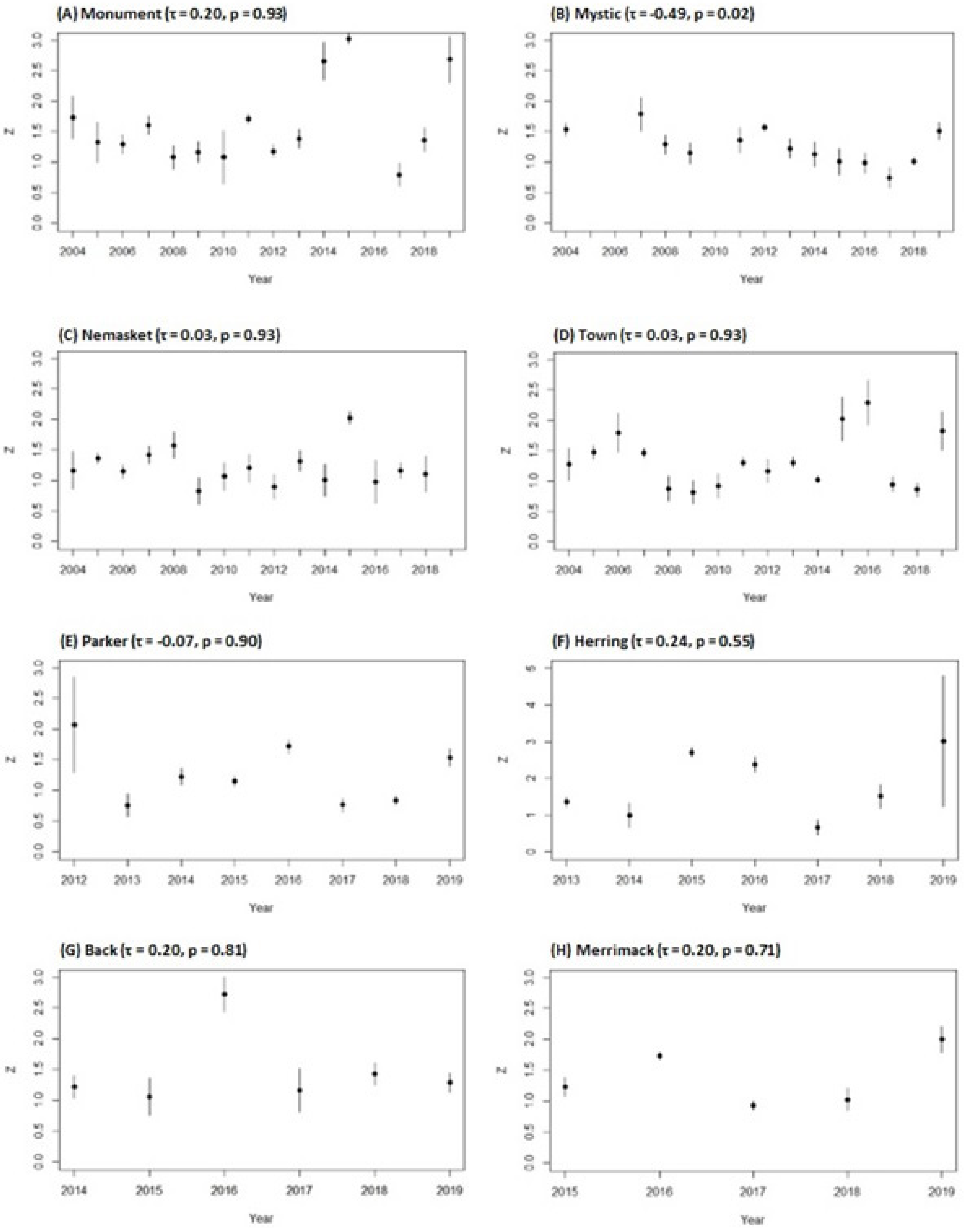

Figure 5. Alewife instantaneous (total) mortality rate (Z) and associated standard error (SE) from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in Z over time.

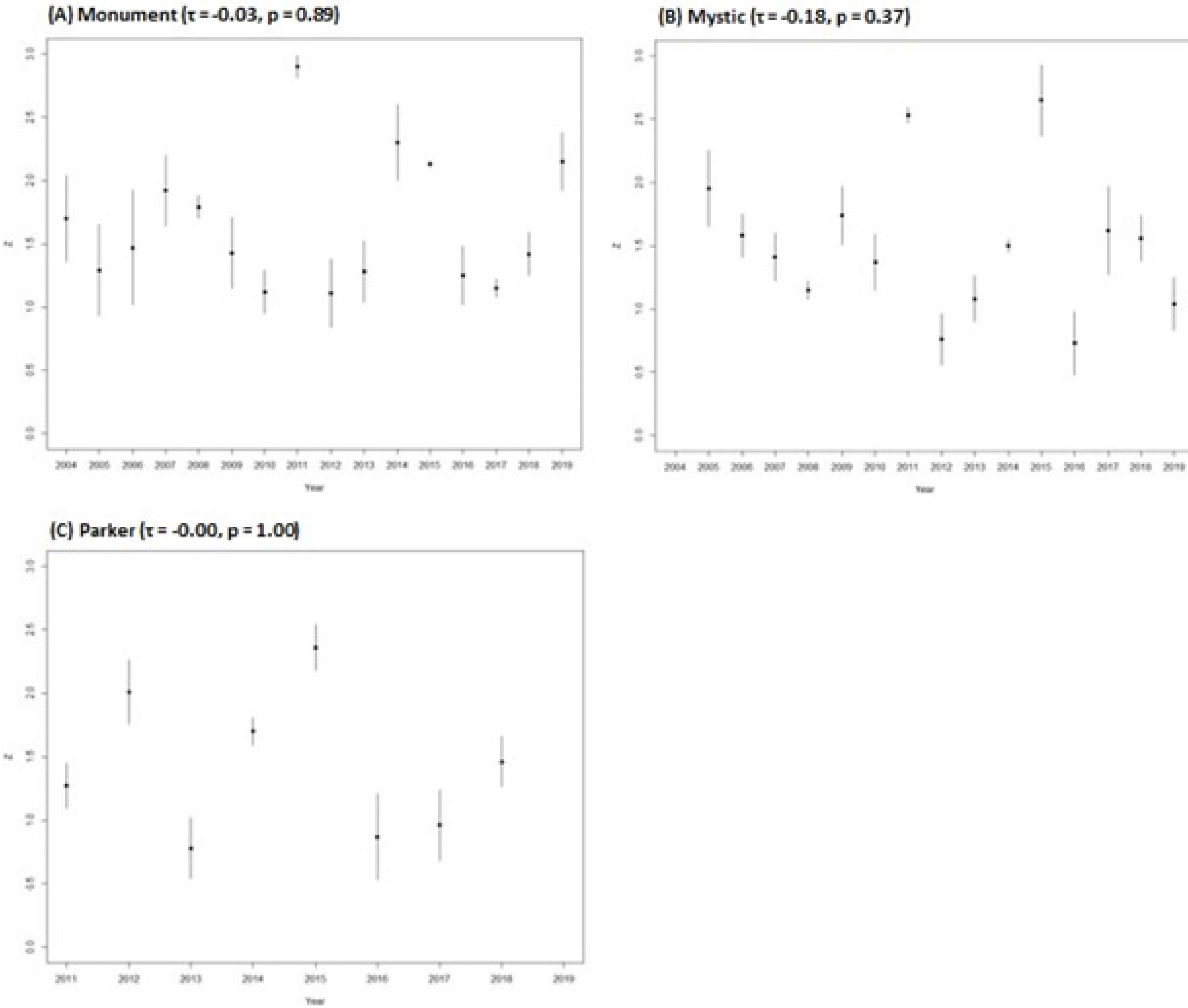

Figure 6. Blueback herring instantaneous (total) mortality rate (Z) and associated standard error (SE) from select Massachusetts rivers. Mann-Kendall trend analysis (τ) was conducted to identify trends in Z over time.

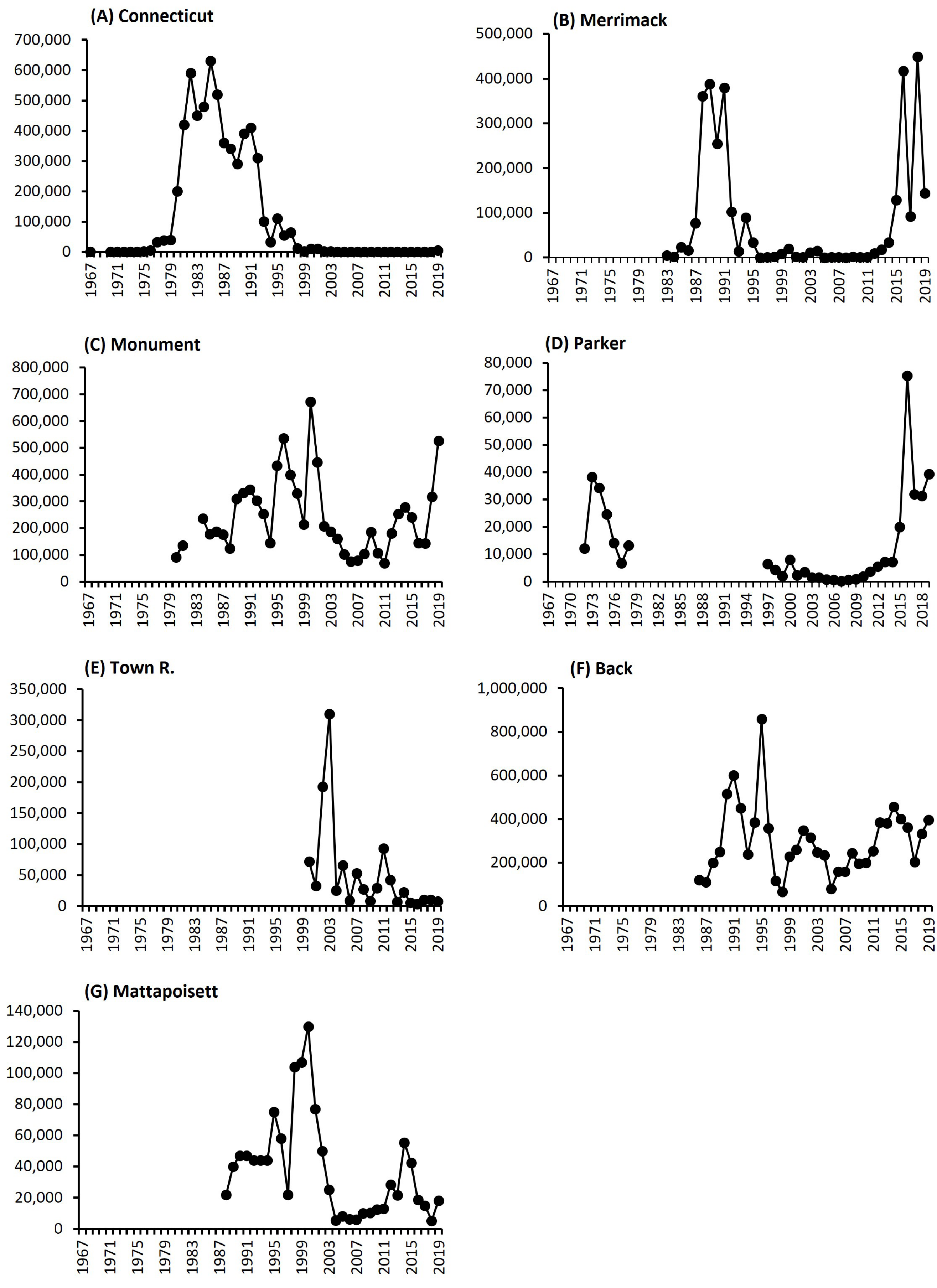

Figure 7. Spawning run size estimates (N, y-axis) from select rivers (20+ year time series, x-axis) in Massachusetts (1980 – 2019).

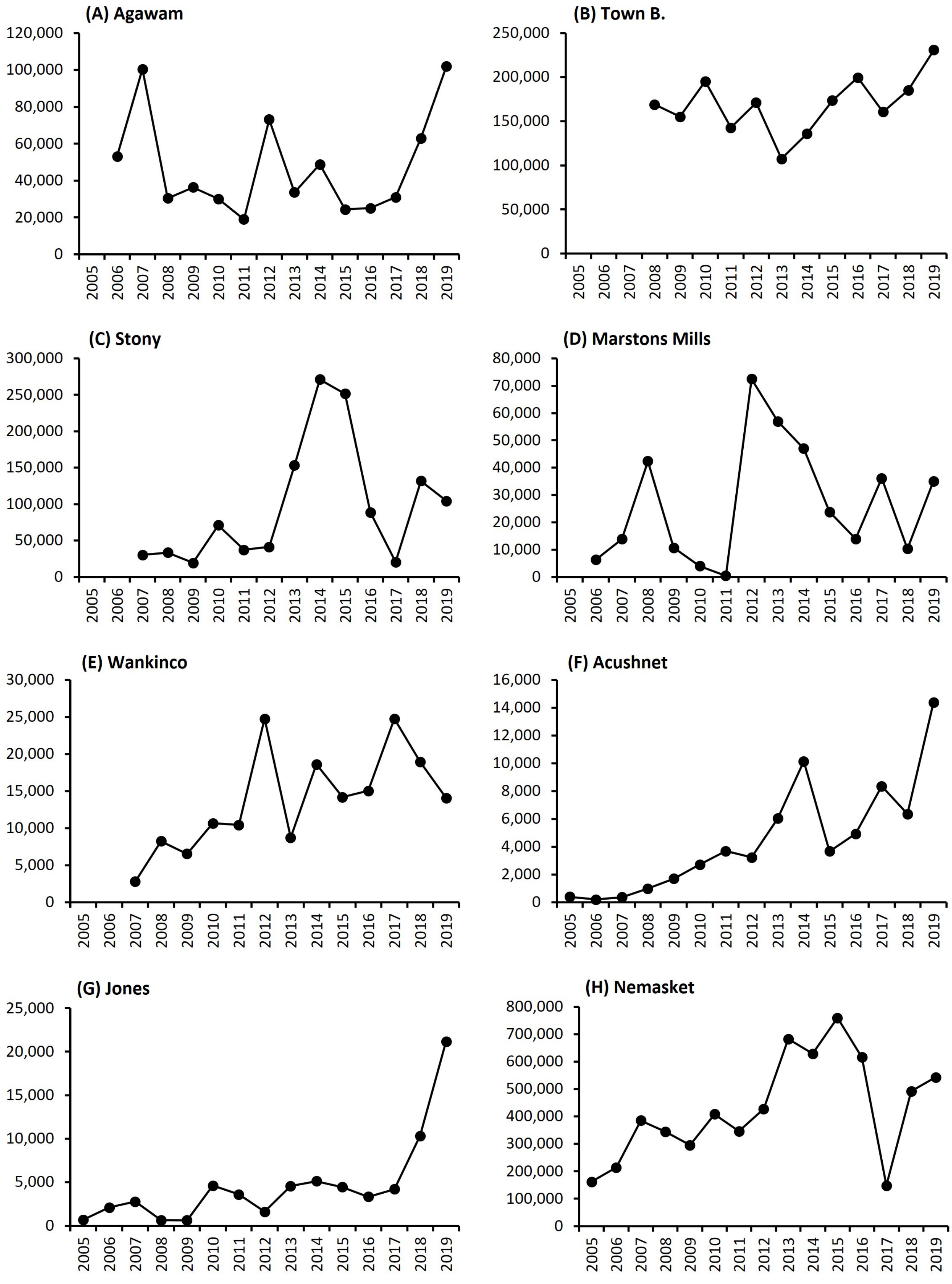

Figure 8. Spawning run size estimates (N, y-axis) from select rivers (10+ year time series, x-axis) in Massachusetts (1997 – 2019).

In 2019, a total of 18 rivers, representing nine major drainage areas in Massachusetts, were monitored with fish lifts, electronic or video systems that have the potential to record a near census of the annual spawning run. We say "near" census to acknowledge the potential for systemic counting error and station equipment failure to reduce counting accuracy. For electronic counters, our project goal is to reach an estimate of counting accuracy of ≥ 90% (daily average count check percentage). Eleven runs, including two runs using a combination of monitoring methods are presented in **Appendix Table 6** due to an extensive (≥10 years) of counts. The monitoring was conducted by DMF, watershed organizations, or cooperative efforts. In all cases, DMF provided technical assistance with counting station design and maintenance. Twelve runs were monitored using electronic counting systems, three runs were monitored using video monitoring systems, and two runs were monitored using fish lifts (one in combination with a video system).

Additionally, project staff provided technical assistance to help the Mystic River Watershed Association implement a web-based counting program that raised awareness about river herring passage and abundance, as well as helped assess the efficacy of an ongoing volunteer count. Staff installed and maintained the video counting structure at the Mystic Lakes Dam. During the season, staff provided technical assistance with videography and system maintenance to ensure footage was of suitable quality. Project staff continued to provide technical assistance to help the Lowell Parks and Conservation Trust create a video count on the lower Concord River. Staff fabricated a new counting structure placed at Centennial Dam in North Billerica. During the season, staff provided technical assistance with videography and system maintenance to ensure footage was of suitable quality. This counter has confirmed that river herring ascend the ladder at Centennial Dam highlighting the need for restoration efforts at Talbot Mills Dam.

Volunteer Visual Counting of Spawning Runs. In 2019, a total of 32 rivers were monitored by volunteer visual counting methods managed by watershed organizations. The counts follow DMF protocols for counting methods (Nelson 2006) and DMF provides technical assistance to the efforts and generates statistical analyses of the counting extrapolations in most cases. Run size estimates with a high degree of error (PSE) or poor predictive power (as determined by power analysis, Gerrodette 1987) were excluded from **Appendix Table 6** and further analyses. The time series for many of these counts are less than 5 years old or have gaps in the time series (years of no counts or insufficient data to estimate run size). For runs with counts ≥ 5 years, the general trend is of increasing run size estimates since 2006. However, several runs have experienced a decreasing trend in run size since 2014. It is expected that some of these counting stations will become important sources of spawning run population data as the time series improves.

A comprehensive assessment of river herring stocks based on current and historical data (enumeration of run size, basic biological data including sex, size and age data, and age-based population modeling) from various Massachusetts coastal rivers was conducted by DMF biologists (Nelson et al. 2011). Although there are other runs that are monitored throughout the Commonwealth, they do not meet the above criteria and are not included in the state-wide river herring stock assessment. In the future, DMF intends to include spawning runs from additional rivers and designate them as systems representing the status of river herring populations in their respective watersheds and include these in future assessments.

Merrimack River. Massachusetts is required by ASMFC to conduct mandatory fishery-independent monitoring of river herring in the Merrimack River including:

- An annual spawning stock survey and representative biological sampling; and
- Calculation of mortality and/or survival estimates.

The annual spawning stock survey and biological sampling occurs at the fish lift at the river's lowermost dam, Essex Dam, in Lawrence (48 rkm). The Essex Dam fish elevator operated for 85 days between April 19 and July 12. In 2019, 143,541 river herring were counted at the fish lift, exceeding the time series average of 84,350 (**Appendix Table 6**). The low counts in 2005 and 2006 were excluded from the series statistics because high flows caused the lift to be inoperable for much of the spawning run.

In 2019, 162 alewives and 2 blueback herring were collected from the Merrimack River for sex composition, length, weight, and age data (**Appendix Table 4 and 5**). Estimates of instantaneous mortality rates ($Z = 1.3$) and survivorship ($S = 0.3$) were derived from the Chapman-Robson method.

Recent Progress on Habitat Monitoring

River herring spawning and nursery habitat assessment. Habitat assessments are conducted for two years during May–September to assess the suitability of habitats for river herring early life history and to contribute to habitat and water quality restoration efforts. Efforts on field assessments were reduced in 2019 to focus on an update of the project's Quality Assurance Program Plan (QAPP). The QAPP update was prepared and reviewed by project staff, and then reviewed and approved by the Massachusetts Department of Environmental Protection (MassDEP). The QAPP was next submitted to the DMF Technical Report Series for publication (Chase et al. 2020). One assessment was initiated in 2019 at the New Bedford Reservoir (Acushnet River). Habitat assessment datafiles were finalized in 2019 for James Pond, West Tisbury; Grassy Pond, Harwich; and Lovells Pond, Barnstable.

Diadromous Fish Restoration Priority List/MassDOT Diadromous Fish GIS Data Layer. A Geographic Information System (GIS) data layer was designed in coordination with the Massachusetts Department of Transportation (MassDOT) to consolidate DMF spatial information on diadromous fish, to support transportation infrastructure planning and environmental review activities, and supports DMF and MassDEP restoration planning. Efforts continued in 2019 to ground truth and update the DMF Diadromous Fish Restoration Priority List and associated GIS data layer. The list focuses on passageways for river herring, but also considers other diadromous fish species and watershed connectivity. It contains over 475 fishways, impediments, and potential restoration sites, ranked by restoration potential within the four major coastal regions of Massachusetts.

Fishway operation and maintenance plans. DMF issues Fishway Operation and Maintenance (O&M) Plans for all new and reconstructed fishways per the authority granted the Director under Chapter 130, Section 19 of Massachusetts General Laws. Seven working draft O&M plans were revisited and finalized in 2019. New O&M plans were prepared as working drafts for the Triphammer Pond fishway, Hingham, and the Baxter Grist Mill fishway, Yarmouth.

Fishway permitting. Pursuant to M.G.L. Chapter 130 §1 and 19, and 322 CMR Sections 7.01 4(f) and 14(m), DMF issues Fishway Construction Permits following the review of final engineering plans to construct, rebuild, or alter fishways. During 2019, two Fishway Construction Permits were prepared for projects at: the Baxter Grist Mill fishway, Yarmouth, and the Elm Street Dam removal project on the Jones River, Kingston.

River herring stream channel maintenance. Project staff routinely fields requests to assist Towns in maintaining passageways for river herring. The work can involve developing cooperative plans for removing debris jams and excessive plant growth in channels or responding quickly during the migration season to remove blockages that threaten sea-run fish survival. DMF prepared a stream maintenance protocol in 2016 to provide coastwide guidance for these practices (https://www.mass.gov/doc/guidelines-for-stream-channel-maintenance/download). Stream maintenance plans were drafted by project staff in 2019 and approved by Town Conservation Commissions for the Jones River, Kingston, and the Weir River, Hingham. Field work on stream maintenance in 2019 involved seven coastal river systems: Centerville River, Barnstable; Acushnet River, Acushnet; Jones River, Kingston; Island Creek, Duxbury; South River, Marshfield; Weir River, Hingham; and the Fore River, Braintree.

Fish Passage Projects

Numerous projects to improve and maintain diadromous fish passage, habitats, and populations are conducted each year. In 2019, project staff devoted time to approximately 25 individual projects in various stages of development and implementation. The following list includes completed projects and larger ongoing projects of regional significance. Project highlights for 2019 include the completion of a new fishway at the Draka Dam on the Three Mile River in Taunton, a new fish ladder at Forge Pond Dam on the Jones River in Kingston, fish passage improvements made by the DMF Fishway Crew at the historic Herring Brook Park in Pembroke, and technical assistance to three significant coastal river dam removals.

Three Mile River, Taunton. The project to construct a fishway at the impassable Draka Dam on the Three Mile River was completed in 2019, with a large effort of staff time to manage the construction contract with SumCo Ecoengineering and to monitor construction activity during October and November. The project provides fish passage at the Draka Dam for the first time in over a century and access for migratory fish to the 45 acre impoundment above the dam and for several miles of the Three Mile River. The fishway design process originated in 1997 and depended on cooperative efforts from property owners and partners to bring the project to a successful completion in 2019.

Herring Brook Park, Pembroke. The DMF Fishway Crew worked cooperatively with the Town of Pembroke to rehabilitate a fishway at the historic Herring Brook Park. The location has been known for several decades to impede river herring passage due to the elevation change at a former mill structure that includes irregular channel substrate and degraded channel walls that caused annual fish mortality among some fish attempting to pass. The crew worked closely with the Town of Pembroke Herring Fisheries Commission to repair the channel walls and install four in-stream weirs with granite blocks, install a concrete weir to manage fishway flows and flows to a water wheel, and repair components of the mill race culvert. The crew put in nine weeks of hard labor crafting an improved fishway that is integrated with the historic look of the park. This site should be appreciated by the public and migrating fish for many years.

Forge Pond Dam, Kingston. Several years of discussions with the City of Brockton, owner of the Forge Pond Dam on the Jones River in Kingston, concluded with the DMF Fishway Crew fabricating and installing a custom, wood fish ladder at the dam in March 2019. A fishway design was prepared by project staff and reviewed by the City of Brockton, resulting in a Memorandum of Understanding between Brockton and DMF. The fishway at the impassible dam provided passage for migratory fish for the first time in over a century from the Jones River to Silver Lake.

Fore River Watershed. Efforts continued on a multi-site project to restore diadromous fish to the Fore River Watershed in the Boston Harbor region. The project partners, led by the Town of Braintree and the Massachusetts Division of Ecological Restoration (DER), secured funding and contracted an engineering firm to complete design and permitting for the Armstrong Dam removal and Natural Falls fish passage improvements; due to be prepared in 2020. Specific to the Natural Falls component, project staff submitted a grant proposal to fund construction to the In-Lieu-Fee Program, and DMF funded a USFWS Fish Passage Engineering Team review of the Natural Falls design.

Horn Pond, Woburn. Recent efforts by DMF and local partners resulted in river herring entering Horn Pond in the Mystic River Watershed for the first time in over a century in 2017. This work continued in 2019 as project staff worked with the Mystic River Watershed Association and Town of Woburn to manage flows and fish passage at the Scalley Dam. The modified spillway passed about 10,000 adult river herring, thereby granting spawning fish access to more than 100 acres of habitat. Research by UMass Amherst documented successful spawning and juvenile growth within Horn Pond. Planning continued in 2019 through environmental mitigation processes to create a nature-like fishway to further improve passage at this site.

Town River, Bridgewater. DMF is partner to cooperative efforts to improve fish passage in the Town River tributary to the Taunton River. In 2019, progress on project design to remove the High Street Dam continued. Project staff is also working with the Town of West Bridgewater to conduct a feasibility study for redesigning the antiquated fish ladder at the next dam upstream at War Memorial Park.

Parker River, Newbury. The DMF Fishway Crew repaired several fishway weirs and wall sections in the Woolen Dam fishway on the Parker River in Newbury. Concrete forms were set up and poured during August. This work was part of an ongoing effort to improve fish passage at this location and others in the Parker River watershed in recent years. Site monitoring has shown steady improvements in the counts of spawning river herring in response to this work.

Ipswich River, Ipswich. Efforts to improve fish passage at the Willowdale Dam on the Ipswich River continued. Funding was secured through the Massachusetts Department of Fish & Game (DFG) In Lieu Fee Program and designs for the new fishway and modifications to the old fishway for maximized eel passage were finalized. Construction was slated for the summer of 2020.

Baxter Grist Mill, Yarmouth. A large-scale project to rehabilitate a historic grist mill site was completed by the Town of Yarmouth in 2019. The project included grist mill improvements, dam reconstruction and a new fishway. The National Resources Conservation Service and Cape Cod Conservation District were principal partners on design and funding. Project staff was active with field data collections and early designs to replace the antiquated fish ladder, and with construction-phase site visits.

Dam Removal Technical Assistance. Three dam removals occurred in 2019 with uncommon regional significance for coastal rivers in Massachusetts: Elm Street Dam, Jones River, Kingston; Horseshoe Mill Dam, Weweantic River Wareham; and the Holmes Park Dam, Town Brook, Plymouth. These projects occur through remarkable, cooperative efforts that are driven by public funds. DMF's role is most focused on technical assistance to ensure the engineered designs meet migratory fish requirements. Substantial staff efforts were applied to the Elm Street Dam and Horseshoe Mill Dam removals in 2019 to assist designs with specific attention to rainbow smelt spawning and passage requirements and the creation of smelt spawning riffles. DMF staff also assisted in drafting post-construction monitoring plans for both sites.

Law Enforcement Activity – 2019. In 2019 fourteen violations (11 civil, 3 criminal) were reported by the Massachusetts Environmental Police involving illegal catching and possession of river herring.

Monitoring Plans for 2020

No changes to the Commonwealth's regulations pertaining to river herring are planned. Further progress towards reopening the Nemasket River to recreational harvest, per the approved Sustainable Harvest Plan, is dependent on municipal interest. Monitoring of river herring will continue status quo in 2020, with the exception of a delayed onset of the MRIP intercept survey in Massachusetts until May 20 due to COVID-19 safety measures.

Alewives transplanted from the Monument River, Bourne are released into Mill Pond, Barnstable. Photo by John Sheppard.

DMF personnel in cooperation with the Barnstable Department of Natural Resources stocked 1,000 river herring into Mill Pond, Barnstable as part of a restoration effort to augment the existing population in Boat Cove Creek. Photo by BDNR staff.

Acknowledgements

Since 2010, monitoring has been funded in part by a Sport Fish Restoration Grant (F67R) through the USFWS. We thank Ben Gahagan, Sara Turner, Matthew Gendron, Elijah Perry, Trevor Burns, James Garner, Andrew Smith and Quentin Nichols (DMF) for their assistance with monitoring, sample collection and processing. Thanks to personnel from the USFWS and DFW for procuring abundance and biological information from broodstock American shad from the Connecticut River and Merrimack River. Additional thanks to Brad Schondelmeier (DMF) for providing bycatch estimates and biological data from the Atlantic herring and mackerel MWT fishery. Special thanks to personnel from the DMF Age & Growth Project for their efforts in processing and aging of American shad and river herring samples.

References

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Fishery Management Plan for American Shad and River Herrings. Fisheries Management Report No. 6, Atlantic States Marine Fisheries Commission, Washington, D.C.

ASMFC. 1999. Amendment I to the Interstate Fishery Management Plan for Shad and River Herring. Fishery Management Report No. 35, Atlantic States Marine Fisheries Commission.

ASMFC. 2007. American Shad Stock Assessment Report for Peer Review, Volume 1. Stock Assessment Report No. 07-01 (Supplement) of the Atlantic States Marine Fisheries Commission, National Oceanic and Atmospheric Administration Award No. NA05NMF4741025.

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

ASMFC. 2017. River herring stock assessment update volume 1: coastwide summary. Atlantic States Marine Fisheries Commission, Arlington, VA.

ASMFC. 2020. 2020 American Shad Benchmark Stock Assessment and Peer Review Report. NOAA Award No. NA15NMF4740069, The Atlantic States Marine Fisheries Commission.

Berry, F. H. 1964. Review and emendation of family Clupeidae. Copeia 1964: 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.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service Fisheries Bulletin 53, Washington, D.C.

Brady, P. D. 1987a. Characterization of Monument (Herring) River anadromous alewife (*Alosa pseudoharengus*) run, Bournedale, Massachusetts, 1984-1987. Massachusetts Division of Marine Fisheries Report.

Brady, P. D. 1987b. Characterization of Monument (Herring) River blueback herring (*Alosa aestivalis*) run, Bournedale, Massachusetts, 1984-1987. Massachusetts Division of Marine Fisheries Report.

Burgess, G. H. 1978. *Alosa pseudoharengus* (Wilson), alewife. In: D. S. Lee, C. R. Bilber, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr., editors. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina.

Carscadden, J.E., and W.C. Leggett. 1975. Meristic differences in spawning populations of American shad (*Alosa sapidissima*). Evidence for homing to tributaries in the Saint John River, New Brunswick. Journal of the Fisheries Research Board of Canada, 32: 653-660.

Chapman, D.G., and D. S. Robson, 1960. The analysis of a catch curve. Biometrics 16:354-368.

Chase, B.C., J.J. Sheppard, B. Gahagan, and S. Turner. 2020. Quality Assurance Program Plan (QAPP) for Water Quality Measurements during Diadromous Fish Monitoring, Version 2.0. Mass. Div. Mar. Fish. Tech. Rep. Ser., TR-73.

Chase, B.C., J.J. Sheppard, B. Gahagan, and S. Turner. 2021. American Shad Habitat Plan for Massachusetts Coastal Rivers. Interstate Management Plan for Shad and River Herring, *Prepared for* the Atlantic States Marine Fisheries Commission by the Massachusetts Division of Marine Fisheries.

Collette, B.B., and G. Klein-MacPhee. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, 3rd Edition. Smithsonian Institution Press, Washington.

CRASC (Connecticut River Atlantic Salmon Commission). 2014. American Shad Habitat Plan for the Connecticut River. Submitted to the Atlantic States Marine Fisheries Commission, February 6, 2014.

CRASC. 2017. Connecticut River American Shad Management Plan. Connecticut River Atlantic Salmon Commission, Sunderland, MA, June 9, 2017.

DMF and MLHFC (Massachusetts Division of Marine Fisheries and Middleborough-Lakeville Herring Fishery Commission). 2016. Nemasket River Sustainable Fishery Plan for River Herring. Atlantic States Marine Fisheries Commission, Arlington, Virginia.

Code of Commonwealth of Massachusetts Regulations: CMR Title 322.

Code of Commonwealth of Massachusetts Regulations: CMR Title 321.

DiCarlo, J.S. 1981. Overview of alosid stocks of Massachusetts. In: M.J. Dadswell, R.J. Klaudia, C.M. Moffitt, and R.L. Saunders (Eds.), Common strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1: 89-103.

DMF (Massachusetts Division of Marine Fisheries). 2014. American Shad Habitat Plan for Massachusetts Coastal Rivers. Submitted to the Atlantic States Marine Fisheries Commission, February 6, 2024.

Edsall, T. A. 1970. The effect of temperature on the rate of development and survival of alewife eggs and larvae. Transactions of the American Fisheries Society 102: 376-380.

Facey, D.E., and M.J. Van Den Avyle. 1986. Species Profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) - American shad. U.S. Fish & Wildlife Service Biological Report 82 (11.45). U.S. Army Corps of Engineers, TR EL-82-4.

Flagg, L., and Squires, T. 1983. Status of alewife stocks in the state of Maine. In: M.J. Dadswell, R.J. Klaudia, C.M. Moffitt, and R.L. Saunders (Eds.), Common strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1:89-103.

General Laws Commonwealth of Massachusetts: Chapter 130.

General Laws Commonwealth of Massachusetts: Chapter 131A.

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/

Gibson, M.R. 1982. State of Rhode Island, overview of alosid stocks. In: M.J. Dadswell, R.J. Klaudia, C.M. Moffitt, and R.L. Saunders (Eds.), Common strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1: 89-103.

GARFO (Greater Atlantic Regional Fisheries Office). National Oceanic and Atmospheric Administration. Personal Communication.

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, Washington, D.C.

Greenwood, J.C. 1982. Shad and river herring abstract. In: M.J. Dadswell, R.J. Klaudia, C.M. Moffitt, and R.L. Saunders (Eds.), Common strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1: 89-103.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology. 68(5): 1364-1372.

Hall, C.J., A. Jordaan, and M.G. Frisk. 2010. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology, 26(1): 95-107.

Hawkins, J. H. 1979. Anadromous fisheries research program – Neuse River. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries Progress Report No. AFCS13-2, Raleigh, North Carolina.

Hildebrand, S. F. 1963. Family Clupeidae. In: H. B. Bigelow, editor. Fishes of the Western North Atlantic, part 3. Sears Foundation for Marine Research, Yale University, New Haven, Connecticut.

Johnson, H.B., B.F. Holland, and S.G. Keefe. 1977. Anadromous fisheries research program, northern coastal area. In: Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Department Interior Fish & Wildlife Service, FWS/OBS-82/10.58.

Leggett, W. C., and J. E. Carscadden. 1978. Latitudinal variation in reproductive characteristics of American shad (*Alosa sapidissima*): Evidence for population specific life history strategies in fish. Journal of the Fisheries Research Board of Canada 35: 1469-1478.

Leggett, W. C., and R. R. Whitney. 1972. Water temperature and the migrations of American shad. Fisheries Bulletin 70: 659-670.

Leggett, W. C. 1969. Studies on the reproductive biology of the American shad *Alosa sapidissima* (Wilson). A comparison of populations from four rivers of the Atlantic seaboard. Doctoral dissertation. McGill University, Montreal, Canada.

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

Limburg, K. E., & Waldman, J. R. 2009. Dramatic declines in north Atlantic diadromous fishes. BioScience, 59(11), 955–965.

Limburg, K. E., K. A. Hattala, and A. Kahnle. 2003. American shad in its native range. In: K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Loesch, J.G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. In: M.J. Dadswell, R.J. Klaudia, C.M. Moffitt, and R.L. Saunders (Eds.), Common strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1: 89-103.

Loesch, J. G. 1968. A contribution to the life history of *Alosa aestivalis* (Mitchill). Masters thesis. University of Connecticut, Storrs, Connecticut.

Mansueti, R. J., and J. D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay region, and atlas of egg, larval, and juvenile stages, part I. Natural Resources Institute, University of Maryland, Baltimore, Maryland.

Melvin, G.D., M.J. Dadswell, and D.J. Martin. 1985. Impact of lowhead hydroelectric tidal power development on fisheries. I. A preparation study of the spawning population of American shad (Pisces: Clupeidae) in the Annapolis River, Nova Scotia, Canada. Canadian Journal of Fisheries and Aquatic Sciences Technical Report No. 1340.

MRTC (Merrimack River Technical Committee). 1997. Strategic Plan and Status Review: Anadromous Fish Restoration Program – Merrimack River. Prepared by the Technical Committee for Anadromous Fishery Management of the Merrimack River Basin.

MRTC. 2010. A plan for the restoration of American shad in the Merrimack River Watershed. Prepared by the Technical Committee for Anadromous Fisheries Management of the Merrimack River Basin.

Munger, L.M., C. Patterson, D. St. Pierre, and S. Winslow. 2004. 2004 Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for Shad and River Herring (*Alosa* spp.). Shad and River Herring Plan Review Team. Prepared Sept. 8, 2004.

Murphy, M.D. 1997. Bias in Chapman-Robson and Least Squares Estimators of Mortality Rates or Steady-State Populations. Fishery Bulletin. 95 (4): 863 – 868.

NMFS (National Marine Fisheries Service). 2019. Status Review Report: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*). Final Report to the National Marine Fisheries Service, Office of Protected Resources. Silver Spring, Maryland.

NMFS Fisheries Statistics and Economics Division. https://www.fisheries.noaa.gov/national/sustainable-fisheries/commercial-fisheries-landings. Personal Communication.

NMFS Marine Recreational Information Program. https://www.fisheries.noaa.gov/topic/recreational-fishing-data. Personal Communication.

Nelson, G.A. 2006. A Guide to Statistical Sampling for the Estimation of River Herring Run Size Using Visual Counts. Massachusetts Division of Marine Fisheries Technical Report No. 27.

Nelson, G.A., Brady, P.D., Sheppard, J.J., and Armstrong, M.P. 2011. An Assessment of River Herring Stocks in Massachusetts. Massachusetts Division of Marine Fisheries Technical Report No. 46.

O'Neil, J.T. 1980. Aspects of the life histories of anadromous alewife and blueback herring, Marqaree River and Lake Aimsle, Nova Scotia, 1978-1979. In: Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Department Interior Fish & Wildlife Service, FWS/OBS-82/10.58.

Rulifson, R. A. 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.

Rulifson, R.A., and Huish, M.T. 1982. Anadromous fish in the Southeastern United States and recommendations for development of a management plan. In: Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Department Interior Fish & Wildlife Service, FWS/OBS-82/10.58.

Rulifson, R. A., M. T. Huish, and R. W. Thoesen. 1982. Anadromous fish in the southeastern United States and recommendations for development of a management plan. U.S. Fish and Wildlife Service, Fisheries Research Region 4, Atlanta, Georgia.

Rulifson, R. A., M. T. Huish, and R. W. Thoesen. 1994. Status of anadromous *Alosa* along the east coast of North America. In: J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Proceedings of the Anadromous *Alosa* Symposium, American Fisheries Society, Bethesda, Maryland.

Schmidt, R. E., B. M. Jessop, and J. E. Hightower. 2003. Status of river herring stocks in large rivers. In: K. E. Limburg, and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society Symposium 35, Bethesda, Maryland.

Sheppard, J.J., and B.C. Chase. 2012. Massachusetts Sustainable Fishing Plan for American Shad (*Alosa sapidissima*). Submitted to the Atlantic States Marine Fisheries Commission. Massachusetts Division of Marine Fisheries, New Bedford.

Sheppard, J.J., and B.C. Chase. 2018. Massachusetts Sustainable Fishing Plan for American Shad (*Alosa sapidissima*). Submitted to the Atlantic States Marine Fisheries Commission. Massachusetts Division of Marine Fisheries, Boston.

Sheppard, J.J., P.D. Brady, M.P. Armstrong, and G.A. Nelson. 2010. Characterizing contemporary and historic age structure of alewives (*Alosa pseudoharengus*) in Massachusetts spawning runs. Final report submitted to the National Marine Fisheries Service, NOAA Grant No. NA08NMF4050612.

Sheppard, J.J., S.T. Turner, B.I. Gahagan, and B. Schondelmeier. 2020. Massachusetts American Shad and River Herring Compliance Report: 2019. Submitted to the Atlantic States Marine Fisheries Commission, Arlington, VA.

Slater, C. 2020a. Merrimack River Anadromous Fish Investigations – Essex Dam Fish Passage Evaluation. Job Performance Report: Project Number F-45-R-39.

Slater, C. 2020b. Connecticut River Anadromous Fish Investigations. Job Performance Report: Project Number F-45-R-39.

State of Maine. 1982. Anadromous fisheries river management plan. Maine Department of Marine Resources for The Governor's Cabinet Committee on Hydropower Policy, Section 1: 1-29.

Street, M.W., P.P. Pate, B.F. Holland, and A.B. Powell. 1975. Anadromous fisheries research program, northern coastal region. In: Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Department of the Interior, Fish & Wildlife Service, FWS/OBS-82/10.58.

Turner, S.M., Limburg, K.E., and E.P. Palkovacs. 2015. Can different combinations of natural tags identify river herring natal origins at different levels of stock structure? Canadian Journal of Fisheries and Aquatic Sciences, 72(6): 845-854.

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 Special Science Report for Fisheries 550.

Williams, R. O., W. F. Grey, and J. A. Huff. 1975. Anadromous fish studies in the St. Johns River. Florida Department of Natural Resources, Marine Research Laboratory Completion Report, St. Petersburg, Florida.

Winters, G. H., J. A. Moores, and R. Chaulk. 1973. Northern range extension and probably spawning of gaspereau (*Alosa pseudoharengus*) in the Newfoundland area. Journal of the Fisheries Research Board of Canada 30: 860-861.

Appendix A

Present Commonwealth of Massachusetts Regulations pertaining to American shad and river herring management.

The ASMFC annual compliance report requires reporting of relevant regulations annually for American shad and river herring. The following Commonwealth of Massachusetts regulations (CMR) were reported in the 2019 compliance report.

322 CMR: 4.12: Use of Nets for Taking Striped Bass (*Morone saxatilis*) or Shad (*Alosa sapidissima*).

(1) It is unlawful to off-load onto any vessel or to off-load onto any pier, wharf or other structure within under the jurisdiction of Massachusetts any striped bass or shad which was harvested, caught or taken by any net.

(2) It is unlawful for any vessel registered under the laws of the state as that term is defined in M.G.L.c.130, § 1 to harvest, catch or take any striped bass or shad by any net in any waters under the jurisdiction of Massachusetts or in those waters within the United States 200 mile EEZ bounded in such a way that the inner boundary is a line drawn in such a manner that each point on it is 200 nautical miles from the baseline from which the territorial sea is measured, as depicted on nautical charts of the National Oceanic and Atmospheric Administration.

322 CMR 6.17: Shad and River Herring [excerpted to relevant text]

(1) Purpose. 322 CMR 6.17 is promulgated to conserve river herring and shad consistent with the Interstate Management Plan for Shad and River Herring, established by the Atlantic States Marine Fisheries Commission. The harvest of both shad and river herring is prohibited in Commonwealth waters, except where the Director determines that harvest from a particular run is sustainable. For river herring, a person may possess or land a batch of bait fish that comprises up to 5% of river herring, by count, if the bait fish is caught in federal waters.
(2) Definitions.
Catch and Release means a method of angling whereby all catch is released immediately following capture to ensure survival.
Shad means that species of fish known as *Alosa sapidissima*.
(4) Shad Possession Limits

(a) Merrimack and Connecticut Rivers. No fisherman may possess more than 3 shad taken from the Connecticut or Merrimack River.
(b) All Other Waters of the Commonwealth. It shall be unlawful for any fishermen to possess any American shad taken from any waters other than the Connecticut and Merrimack Rivers. All fishing for American shad in these waters shall be limited to catch and release only.

322 CMR 6.17: Shad and River Herring

(1) Purpose. 322 CMR 6.17 is promulgated to conserve river herring and shad consistent with the Interstate Management Plan for Shad and River Herring, established by the Atlantic States Marine Fisheries Commission (ASMFC). The harvest of both shad and river herring is prohibited in Commonwealth waters, except when the Director determines that harvest from a particular run is sustainable. For river herring a person may possess or land a batch of bait fish that comprises up to 5% of river herring, by count, if the bait fish is caught in federal waters.

(2) Definitions.
Batch means all fish in any separate container.
Catch and Release means a method of angling whereby all catch is released immediately following capture to ensure survival.
Container means any box, tote, bag, bucket or other receptacle containing loose fish which may be separated from the entire load or shipment.
Land means to transfer or offload fish from a vessel onto any dock, pier, wharf or other artificial structure used for the purpose of receiving fish.
Managing Entity means the municipality or other entity with the authority under with M.G.L. c. 130 § 94 to control and regulate a river herring spawning run.
River Herring means those species of fish known as alewives (*Alosa pseudoharengus*) and bluebacks (*Alosa aestivalis*).
Spawning Run means those coastal rivers and streams that river herring migrate to for the purpose of spawning.

(3) River Herring

(a) Taking and Possession of River Herring in Waters under the Jurisdiction of the Commonwealth. It shall be unlawful for any person to harvest, possess or sell river herring in the Commonwealth or in the waters under the jurisdiction of the Commonwealth.
(b) Exception for Spawning Runs with Sustainable Harvest Plans. The Director may authorize the opening of particular spawning runs to the harvest of river herring, provided such spawning runs have a SFMP approved by the ASMFC pursuant to Amendment 2 to the Shad and River Herring Fishery Management Plan. The managing entity shall be responsible for the control and regulation of any spawning run authorized to be open by the Director.

1. Process for Opening and Closing a Spawning Run. The Director shall open or close a previously open spawning run in accordance with the following procedure:
a. written notification is filed with the Secretary of the Commonwealth for publication in the Massachusetts Register;
b. a written notification is distributed via the Division's e-mail list serve;
c. a written notification is posted on the Division's Legal Notice webpage;
d. a written notification is provided to the spawning run's managing entity; and
e. a list of open runs is posted on DMF's website.

2. Annual Harvest Permit and Daily Harvest Receipt. The harvest and possession of river herring from an open spawning run shall be in accordance with the following annual permit and daily harvest card requirements:
a. Issuance of Annual Permits. The managing entity shall issue an annual harvest permit to a named individual, which shall expire on December 31st following the date of issuance. On an annual basis, the managing entity shall provide the Division of Marine Fisheries with a list of individuals who have obtained annual harvest permits for the spawning run.
b. Issuance of Daily Harvest Receipts. The managing entity shall issue a daily harvest receipt to the named permit holder upon completion of their harvesting of river herring from the open spawning run during any calendar day. Upon transfer of the receipt from the managing entity to the run to the permit holder, it shall bear an official stamp or mark of the managing entity. The daily receipt shall include the following minimum information: the date of harvest; the harvest limit for the open spawning run established in the ASMFC-approved SFMP, and the amount of river herring harvested by the permit holder; and the expiration date, which shall be three weeks after the date of harvest.

c. Possession of Annual Harvest Permits and Daily Harvest Cards. Except as provided in 322 CMR 6.17(3)(b)2.d., an individual in possession of river herring taken from an open spawning run must hold a valid annual harvest permit and a daily harvest receipt issued by the managing entity for the open spawning run. The daily harvest receipt must be intact and legible. Individuals in possession of river herring shall produce a valid annual harvest permit and daily harvest receipt upon demand of any officer authorized to enforce river herring bylaws and regulations of the Commonwealth.

d. Allowance for Possession of River Herring by Individuals Other than the Annual Harvest Permit Holder. An individual that does not hold a valid annual harvest permit and daily harvest receipt may lawfully possess river herring or use it as bait, provided they are in the physical presence of a valid annual harvester permit holder with a valid daily harvest receipt that accounts for the river herring and all persons are in compliance with all of the other requirements in 322 CMR 6.17(3)(b)2.

e. Violations. Except as authorized by 322 CMR 6.17(3)(b)2.d., it shall be *prima facie* evidence of a violation of the river herring harvest moratorium at 322 CMR 6.17(3)(a) if:

i. An individual is harvesting or attempting to harvest river herring from an open spawning run without a valid annual harvest permit issued to them by the managing entity for that spawning run.

ii. An individual is in possession of river herring and fails to produce or does not hold a valid annual harvest permit.

iii. An individual is in possession of river herring and fails to produce or does not hold a valid annual harvest permit and daily harvest receipt issued by the same managing entity for the same open spawning run.

iv. The annual harvest permit holder is in possession of river herring after the three week expiration date contained in the daily harvest receipt.

v. An individual is in possession of river herring in a quantity that exceeds the harvest limit for an open spawning run identified in the daily harvest receipt and established in accordance with the ASMFC-approved SFMP for the spawning run. Individuals may store or possess a quantity of river herring that exceeds the established harvest limit provided the number of river herring stored or possessed does not exceed the aggregate harvest limit of river herring allowed by the valid daily harvest receipts.

vi. The daily harvest receipt has been rendered illegible.

(c) By-catch Tolerance for Bait Fisheries Conducted in Federal Waters. A person may possess or land a batch of bait fish that comprises up to 5% of river herring, by count, provided the bait fish is caught in federal water. Notwithstanding the foregoing, the operator of a vessel, as defined by 322 CMR 7.01(1)(i), that lands sea herring, or a wholesale dealer, as defined by 322 CMR 7.01(3)(a), that processes sea herring, may possess a batch of bait fish that exceeds 5% of river herring, by count, if said batch has been sorted and graded after the bait fish has landed.

Appendix Tables (1 - 7)

Appendix Table 1. American shad counts at the Connecticut River, (Holyoke Dam Fish Lift, Holyoke), and the Merrimack River (Essex Dam Fish Lift, Lawrence), Massachusetts, 1967–2019. Sources: USFWS Connecticut River Fish and Wildlife Conservation Office and USFWS Central New England Fish and Wildlife Conservation Office.

Year	Connecticut	Merrimack	Year	Connecticut	Merrimack
1967	19,484		1994	181,038	4,349
1968	24,693		1995	190,295	13,861
1969	45,349		1996	276,289	11,322
1970	65,751		1997	299,448	22,661
1971	52,719		1998	315,810	27,891
1972	25,572		1999	193,780	56,461
1973	25,104		2000	225,042	72,800
1974	53,147		2001	273,206	76,717
1975	110,000		2002	374,534	54,586
1976	346,725		2003	286,814	55,620
1977	202,997		2004	191,555	36,593
1978	145,136		2005	116,511	6,382
1979	255,753		2006	154,745	1,205
1980	376,066		2007	158,807	15,876
1981	377,124		2008	153,109	25,116
1982	294,842		2009	160,649	23,199
1983	528,185	5,629	2010	164,439	10,442
1984	496,884	5,497	2011	244,177	13,835
1985	487,158	12,793	2012	490,431	21,396
1986	352,122	18,173	2013	392,967	37,149
1987	276,835	16,909	2014	370,506	38,107
1988	294,158	12,359	2015	412,656	89,467
1989	354,180	7,875	2016	385,930	67,528
1990	363,725	6,013	2017	537,249	62,846
1991	523,153	16,098	2018	275,232	29,069
1992	721,764	20,796	2019	314,361	18,653
1993	340,431	8,599			
			Time series average	269,755	*29,037

* Excludes the 2005 and 2006 counts because high flows caused the lift to be inoperable for much of the spawning run

Appendix Table 2. American shad mean age, mean size, sex, mortality (Z), survivorship (S) and associated standard error (SE) data for adult returns from the Merrimack River, 1991–2019. Ageing switched from scale-based to otolith-based in 2009.

						Ratio	Mean Age		Mean FL (mm)		Mean Wgt (kg)					
Year	Sample N	N (male)	N (Female)	% Male	% Female	(M:F)	Male	Female	Male	Female	Male	Female	Z_{CR}	SE	S_{CR}	SE
2001	204	115	89	56.4	43.6	1.3:1.0	6.0	6.6	427	471	1.04	1.47	0.87	0.24	0.42	0.10
2002	199	79	120	39.7	60.3	0.8:1.0	5.7	6.3	432	482	1.10	1.69	0.94	0.20	0.39	0.08
2003	115	39	76	39.7	60.3	0.5:1.0	5.9	6.7	439	499	1.16	1.92	0.74	0.16	0.47	0.08
2004	257	152	119	45.5	54.5	1.3:1.0	5.8	6.5	433	482	1.08	1.59	0.79	0.11	0.45	0.05
2005	200	105	95	52.5	47.5	1.1:1.0	5.9	6.1	443	477	1.11	1.51	1.03	0.11	0.35	0.04
2006	178	79	99	44.4	55.6	0.8:1.0	4.9	5.7	407	468	0.96	1.49	0.87	0.06	0.42	0.03
2007	212	99	113	46.7	53.3	0.9:1.0	4.4	5.1	429	464	1.16	1.55	0.81	0.12	0.44	0.05
2008	227	113	114	49.8	50.2	1.0:1.0	5.4	5.6	427	464	1.10	1.43	0.96	0.25	0.38	0.10
2009	214	96	118	44.9	55.1	0.8:1.0	5.9	6.5	429	461	1.08	1.38	0.85	0.11	0.42	0.05
2010	181	65	116	36.0	64.0	0.6:1.0	5.1	5.6	412	455	1.04	1.53	0.88	0.17	0.41	0.07
2011	258	148	110	57.0	43.0	1.3:1.0	5.7	6.6	408	452	1.01	1.39	0.76	0.16	0.47	0.07
2012	243	155	88	63.8	36.2	1.8:1.0	5.1	5.5	404	436	0.95	1.28	0.99	0.15	0.37	0.06
2013	144	69	75	48.0	52.0	0.9:1.0	5.3	5.9	407	451	0.93	1.40	1.48	0.51	0.22	0.11
2014	302	158	144	52.0	48.0	1.1:1.0	5.1	5.8	403	449	0.92	1.36	1.21	0.21	0.29	0.06
2015	357	175	182	49.0	51.0	0.9:1.0	4.9	5.4	402	445	0.92	1.35	1.21	0.21	0.30	0.06
2016	225	91	134	40.0	60.0	0.7:1.0	5.3	5.7	400	437	0.90	1.31	2.38	0.58	0.10	0.05
2017	246	115	131	47.0	53.0	0.9:1.0	5.5	5.9	409	443	0.92	1.32	1.65	0.38	0.19	0.07
2018	214	92	122	43.0	57.0	0.8:1.0	5.4	6.0	405	444	0.88	1.29	1.13	0.24	0.32	0.08
2019	180	111	69	62.0	38.0	1.6:1.0	4.9	6.0	385	439	0.73	1.19	0.79	0.45	0.45	0.32

Appendix Table 3. Population demographic information of American shad from the (A) South and (B) Indianhead Rivers (2016 – 2019). The column titled C-R contains Chapman-Robson mortality (Z) and survival (S) estimates and associated standard error (SE).

(A) Indianhead River

Year	N captured	A. Mean CPUE (N/min)	G. Mean CPUE (N/min)	N (male)	N (female)	Ratio (M:F)	Mean TL (mm) Male	Mean TL (mm) Female	Mean Age Male	Mean Age Female	Z_{CR}	SE	S_{CR}	SE
2016	108	0.40	0.20	62	46	1.3:1.0	488	512	5.9	6.0	1.40	0.39	0.24	0.09
2017	117	0.43	0.30	88	29	3.0:1.0	488	512	5.7	6.0	1.39	0.49	0.24	0.12
2018	181	0.50	0.40	126	55	2.3:1.0	465	512	5.2	6.1	0.49	0.09	0.61	0.06
2019	124	0.63	0.40	86	32	2.7:1.0	474	499	5.5	5.5	0.71	0.10	0.49	0.05

(B) South River

Year	N captured	A. Mean CPUE (N/min)	G. Mean CPUE (N/min)	N (male)	N (female)	Ratio (M:F)	Mean TL (mm) Male	Mean TL (mm) Female	Mean Age Male	Mean Age Female	Z_{CR}	SE	S_{CR}	SE
2016	66	0.69	0.52	44	22	2.0:1.0	489	503	6.0	5.6	0.68	0.11	0.50	0.05
2017	79	0.67	0.30	58	21	2.8:1.0	482	521	5.6	6.1	1.42	0.25	0.23	0.06
2018	*58	0.34	0.30	38	20	1.9:1.0	480	521	5.6	6.1	2.08	0.14	0.10	0.01
2019	84	0.51	0.40	48	32	1.5:1.0	465	497	5.3	5.6	0.71	0.10	0.49	0.05

* Estimates based on limited sample size

Appendix Table 4. Biological parameters of alewives collected from select rivers in coastal Massachusetts from 2004 – 2019. Included are mortality (Z) and survivorship (S) and associated standard error (SE) calculated using the Chapman-Robson (C-R) method.

		Sample	Sex Ratio	TL (mm)		Weight (gram)		Mean Age					
River	Year	Size	(M:F)	Male	Female	Male	Female	Male	Female	Z_{CR}	SE	S_{CR}	SE
Nemasket	2004	268	1.1:1.0	283	291	199	230	4.9	5.3	1.17	0.31	0.31	0.10
	2005	277	1.1:1.0	273	280	181	205	4.7	4.8	1.37	0.09	0.25	0.02
	2006	324	1.6:1.0	265	275	178	208	4.0	4.2	1.15	0.11	0.31	0.04
	2007	650	1.5:1.0	273	283	186	221	4.1	4.4	1.42	0.14	0.24	0.03
	2008	504	1.2:1.0	269	282	178	213	4.6	5.0	1.58	0.21	0.20	0.04
	2009	504	1.6:1.0	268	278	176	205	4.6	5.0	0.83	0.22	0.44	0.10
	2010	507	1.3:1.0	272	281	178	213	4.1	4.4	1.07	0.23	0.34	0.08
	2011	502	1.3:1.0	275	287	189	225	4.1	4.3	1.21	0.23	0.30	0.07
	2012	383	1.5:1.0	270	284	186	226	3.5	3.8	0.90	0.20	0.40	0.08
	2013	497	1.3:1.0	270	279	174	201	3.3	3.4	1.32	0.17	0.27	0.05
	2014	560	1.4:1.0	277	287	196	232	3.5	3.6	1.01	0.26	0.36	0.10
	2015	529	1.1:1.0	278	287	200	232	3.8	4.0	2.03	0.10	0.13	0.01
	2016	580	1.2:1.0	282	296	222	269	4.1	4.5	0.98	0.35	0.38	0.13
	2017	541	1.4:1.0	264	277	169	203	3.3	3.6	1.17	0.13	0.31	0.04
	2018	565	2.4:1.0	269	281	180	217	3.4	3.7	1.11	0.29	0.33	0.10
	2019	557	1.2:1.0	277	286	199	230	3.9	4.0	3.48	0.17	0.03	0.01
Monument	2004	166	1.3:1.0	263	271	169	190	4.1	4.2	▪1.74	0.35	60.17	0.06
	2005	150	1.2:1.0	258	265	159	179	4.1	4.3	1.33	0.30	0.26	0.08
	2006	119	1.1:1.0	249	264	142	177	3.7	4.3	1.30	0.16	0.27	0.04
	2007	404	1.2:1.0	259	269	153	180	3.7	3.9	1.61	0.15	0.20	0.03
	2008	512	1.5:1.0	253	263	153	177	4.0	4.5	1.08	0.19	0.34	0.06
	2009	315	1.0:1.0	256	265	154	177	4.3	4.5	1.17	0.17	0.31	0.05
	2010	480	1.2:1.0	259	271	159	187	3.9	4.4	1.08	0.44	0.34	0.15
	2011	283	1.3:1.0	258	269	155	184	3.8	4.2	1.71	0.08	0.18	0.01
	2012	263	1.4:1.0	255	268	155	187	3.2	3.5	1.18	0.10	0.31	0.03
	2013	261	1.7:1.0	255	266	142	168	3.2	3.5	1.39	0.15	0.25	0.04
	2014	388	1.6:1.0	263	275	168	198	3.6	3.8	2.66	0.31	0.07	0.02
	2015	274	0.9:1.0	261	269	159	180	3.8	3.9	▪3.03	0.08	0.04	0.00
	2016	288	1.3:1.0	265	279	169	204	4.2	4.5	▪3.34	0.05	0.03	0.00
	2017	126	1.1:1.0	260	271	161	189	3.7	3.9	0.80	0.19	0.45	0.08
	2018	240	1.4:1.0	256	266	151	177	3.2	3.5	1.37	0.19	0.25	0.05
	2019	331	1.1:1.0	268	278	173	203	3.7	3.8	2.69	0.38	0.06	0.03
Mystic	2004	127	1.3:1.0	252	262	141	169	3.8	4.1	1.54	0.11	0.21	0.02
	2005						[SAMPLE SIZE TOO SMALL]			N/A	N/A	N/A	N/A
	2006	*52	0.7:1.0	237	258	131	175	3.5	4.4	N/A	N/A	N/A	N/A
	2007	273	1.0:1.0	249	260	137	164	3.6	3.9	1.79	0.27	0.16	0.04
	2008	186	1.8:1.0	251	260	139	158	3.8	4.3	1.29	0.16	0.27	0.04
	2009	124	1.1:1.0	252	260	133	154	4.3	4.4	1.15	0.17	0.31	0.05
	2010	*39	0.5:1.0	252	256	134	135	3.6	3.6	N/A	N/A	N/A	N/A
	2011	314	1.6:1.0	255	267	144	176	3.7	4.0	1.36	0.20	0.25	0.05
	2012	316	1.2:1.0	259	271	159	190	3.7	4.0	1.58	0.07	0.20	0.01
	2013	347	1.0:1.0	255	265	139	166	3.3	3.5	1.23	0.16	0.29	0.05
	2014	272	1.1:1.0	256	268	144	174	3.3	3.6	1.13	0.20	0.32	0.07
	2015	318	0.9:1.0	259	269	147	171	3.5	3.6	1.01	0.21	0.36	0.08
	2016	345	0.9:1.0	255	268	141	171	3.4	3.8	0.99	0.17	0.37	0.06
	2017	332	0.7:1.0	262	273	155	181	3.7	4.0	0.75	0.16	0.47	0.08
	2018	366	1.0:1.0	256	267	142	168	3.3	3.8	1.02	0.06	0.36	0.02
	2019	226	0.9:1.0	269	276	164	185	3.9	4.2	1.52	0.14	0.21	0.03

* Results based on low sample size

▪ Results based on only two ages available and must be regarded with caution

Appendix Table 4 (cont.). Biological parameters of alewives collected from select rivers in coastal Massachusetts from 2004 – 2019. Included are mortality (Z) and survivorship (S) and associated standard error (SE) calculated using the Chapman-Robson (C-R) method.

		Sample	Sex Ratio	TL (mm)		Weight (gram)		Mean Age					
River	Year	Size	(M:F)	Male	Female	Male	Female	Male	Female	Z_{CR}	SE	S_{CR}	SE
Town	2004	180	0.9:1.0	259	271	157	184	4.0	4.4	1.28	0.26	0.27	0.07
	2005	297	1.1:1.0	255	266	152	175	4.0	4.3	1.48	0.11	0.23	0.02
	2006	268	1.0:1.0	254	264	154	178	3.8	4.0	▪1.80	0.32	0.16	0.05
	2007	556	1.3:1.0	261	270	176	189	4.0	4.2	1.47	0.07	0.23	0.02
	2008	504	1.2:1.0	258	267	160	184	4.5	4.8	0.88	0.20	0.42	0.08
	2009	457	1.2:1.0	259	268	159	183	4.6	4.9	0.82	0.19	0.44	0.08
	2010	505	1.2:1.0	260	272	158	184	4.2	4.6	0.92	0.20	0.4	0.08
	2011	504	1.1:1.0	263	274	164	191	4.1	4.3	1.31	0.09	0.27	0.02
	2012	421	1.2:1.0	265	279	171	207	3.8	4.1	1.17	0.19	0.31	0.06
	2013	500	0.9:1.0	264	275	165	193	3.7	3.9	1.31	0.09	0.27	0.02
	2014	520	1.1:1.0	254	267	154	186	3.4	3.7	1.03	0.05	0.36	0.02
	2015	519	1.0:1.0	258	268	156	181	3.7	3.8	2.03	0.36	0.13	0.05
	2016	511	1.5:1.0	265	277	175	206	4.2	4.5	2.30	0.37	0.10	0.04
	2017	536	1.1:1.0	258	268	157	183	3.5	3.7	0.95	0.12	0.38	0.05
	2018	592	1.2:1.0	256	268	154	180	3.5	4.0	0.86	0.11	0.42	0.05
	2019	479	0.8:1.0	264	271	164	190	3.7	3.8	1.83	0.31	0.16	0.05
Parker	2012	248	2.3:1.0	261	277	162	209	3.6	4.0	2.07	0.78	0.12	0.10
	2013	249	2.3:1.0	267	279	165	197	3.7	4.2	0.76	0.19	0.47	0.09
	2014	265	1.9:1.0	273	285	180	219	3.9	4.1	1.23	0.13	0.29	0.04
	2015	180	6.5:1.0	276	284	176	208	4.3	4.5	1.15	0.09	0.31	0.03
	2016	239	1.7:1.0	267	278	166	196	3.9	4.0	1.72	0.11	0.17	0.02
	2017	184	3.0:1.0	265	277	158	193	3.7	4.0	0.77	0.11	0.46	0.05
	2018	246	1.5:1.0	264	276	156	190	3.6	4.0	0.84	0.07	0.43	0.03
	2019	421	3.0:1.0	271	283	168	204	4.1	4.1	1.54	0.14	0.21	0.03
Herring	2013	196	1.0:1.0	256	266	155	178	3.2	3.4	1.36	0.14	0.25	0.04
(Harwich)	2014	431	1.6:1.0	260	272	164	191	3.5	3.7	1.00	0.33	0.37	0.12
	2015	500	1.2:1.0	242	253	168	197	4.0	4.0	▪2.71	0.13	0.06	0.01
	2016	427	0.8:1.0	270	280	185	216	4.4	4.7	2.38	0.20	0.09	0.02
	2017	541	1.1:1.0	260	277	164	205	3.7	4.4	0.66	0.19	0.52	0.10
	2018	488	2.1:1.0	255	267	157	190	3.2	3.5	1.51	0.32	0.22	0.07
	2019	523	1.0:1.0	268	278	190	219	3.8	3.9	3.01	1.78	0.05	0.08
Merrimack	2014	275	1.2:1.0	263	273	158	183	3.3	3.5	1.22	0.18	0.29	0.05
	2015	423	1.3:1.0	266	277	163	194	3.5	3.6	1.06	0.30	0.35	0.10
	2016	532	1.1:1.0	271	280	177	200	3.9	4.0	2.73	0.28	0.06	0.02
	2017	220	1.3:1.0	273	281	171	193	3.9	4.1	1.17	0.35	0.31	0.11
	2018	281	0.9:1.0	270	279	168	197	3.9	4.1	1.43	0.18	0.24	0.04
	2019	162	0.9:1.0	278	289	182	208	4.2	4.4	1.29	0.16	0.27	0.05
Back	2015	438	0.9:1.0	285	299	201	237	4.1	4.4	1.24	0.15	0.29	0.04
	2016	509	1.4:1.0	287	299	209	244	4.3	4.6	1.74	0.06	0.17	0.01
	2017	527	1.1:1.0	273	287	179	214	3.4	3.9	0.93	0.07	0.39	0.03
	2018	424	1.1:1.0	272	284	174	207	3.4	3.7	1.03	0.18	0.36	0.07
	2019	594	0.9:1.0	284	293	197	224	3.9	4.0	2.01	0.21	0.13	0.03

* Results based on low sample size

▪ Results based on only two ages available and must be regarded with caution

Appendix Table 5. Biological parameters of blueback herring collected from select rivers in coastal Massachusetts from 2004 – 2019. Included are mortality (Z) and survivorship (S) and associated standard error (SE) calculated using the Chapman-Robson (C-R) method.

		Sample	Sex Ratio	TL (mm)		Weight (gram)		Mean Age					
River	Year	Size	(M:F)	Male	Female	Male	Female	Male	Female	Z_{CR}	SE	S_{CR}	SE
Monument	2004	99	1.0:1.0	243	255	128	150	3.8	4.2	▪1.70	0.34	0.17	0.06
	2005	92	1.2:1.0	242	252	124	142	4.0	4.2	1.29	0.36	0.27	0.10
	2006	122	1.2:1.0	236	247	120	141	4.0	4.2	▪1.47	0.45	0.22	0.10
	2007	150	1.2:1.0	235	250	117	142	3.5	4.0	▪1.92	0.28	0.14	0.04
	2008	146	1.1:1.0	232	244	112	129	3.7	4.2	1.79	0.09	0.16	0.01
	2009	172	1.2:1.0	236	245	114	129	3.8	4.1	1.43	0.28	0.23	0.07
	2010	147	1.2:1.0	238	244	106	125	3.3	3.7	1.12	0.17	0.32	0.06
	2011	227	1.3:1.0	232	246	106	127	3.6	3.9	▪2.90	0.09	0.05	0.01
	2012	197	1.5:1.0	235	246	114	131	3.3	3.7	1.11	0.27	0.33	0.09
	2013	337	2.2:1.0	237	245	114	125	3.4	3.4	1.28	0.24	0.28	0.07
	2014	328	2.0:1.0	236	249	113	135	3.6	3.7	2.30	0.30	0.09	0.03
	2015	320	1.4:1.0	245	256	124	146	4.0	4.1	2.13	0.02	0.12	0.00
	2016	371	1.7:1.0	247	259	131	152	3.9	4.2	1.25	0.23	0.29	0.07
	2017	478	1.8:1.0	240	254	119	142	3.3	3.7	1.15	0.07	0.31	0.02
	2018	424	1.4:1.0	237	246	110	129	3.3	3.4	1.42	0.17	0.24	0.04
	2019	290	1.7:1.0	247	258	135	157	4.0	4.1	▪2.15	0.23	0.11	0.03
Mystic	2004						[SAMPLE SIZE TOO SMALL]			N/A	N/A	N/A	N/A
	2005	124	0.9:1.0	236	252	117	152	3.6	4.1	1.95	0.30	0.13	0.04
	2006	162	3.9:1.0	230	246	104	135	3.7	4.4	1.58	0.17	0.20	0.04
	2007	456	1.1:1.0	239	248	117	142	3.8	4.0	1.41	0.19	0.24	0.05
	2008	211	5.8:1.0	233	250	99	135	3.8	4.5	1.15	0.07	0.31	0.02
	2009	482	2.2:1.0	241	244	104	126	3.2	3.6	1.74	0.23	0.17	0.04
	2010	405	2.4:1.0	239	248	114	132	3.3	3.4	1.37	0.22	0.25	0.06
	2011	329	1.3:1.0	240	251	113	136	3.7	4.0	2.53	0.06	0.08	0.00
	2012	292	1.6:1.0	241	254	128	162	3.6	4.0	0.76	0.20	0.47	0.09
	2013	270	2.0:1.0	233	255	111	154	2.9	3.5	1.08	0.18	0.34	0.06
	2014	434	1.5:1.0	237	247	109	134	3.1	3.2	1.50	0.05	0.22	0.01
	2015	173	1.4:1.0	246	258	130	157	3.7	3.6	2.65	0.28	0.06	0.02
	2016	215	2.1:1.0	240	261	119	158	3.3	4.0	0.73	0.25	0.48	0.12
	2017	290	1.4:1.0	241	253	123	147	3.1	3.2	1.62	0.35	0.20	0.07
	2018	322	1.2:1.0	242	253	119	136	3.1	3.3	1.56	0.18	0.21	0.04
	2019	374	0.8:1.0	248	259	130	152	3.4	3.6	1.04	0.21	0.35	0.07
Parker	2011	248	5.4:1.0	248	258	123	140	3.4	3.4	1.27	0.18	0.28	0.05
	2012	286	2.9:1.0	254	268	136	173	3.8	4.1	2.01	0.25	0.13	0.03
	2013	304	1.4:1.0	254	267	134	153	3.7	3.9	0.78	0.24	0.46	0.11
	2014	416	1.9:1.0	250	257	123	131	3.2	3.2	1.70	0.11	0.18	0.02
	2015	375	2.3:1.0	258	269	141	164	3.9	4.0	2.36	0.18	0.09	0.02
	2016	405	2.9:1.0	263	275	145	172	4.4	4.7	0.87	0.34	0.42	0.14
	2017	135	3.8:1.0	259	268	142	172	3.5	3.6	0.96	0.28	0.38	0.11
	2018	268	1.6:1.0	256	263	132	141	3.3	3.3	1.46	0.20	0.23	0.05
	2019						[SAMPLE SIZE TOO SMALL]			N/A	N/A	N/A	N/A
Herring (Harwich)	2013	*32	2.6:1.0	236	249	124	142	3.6	3.7	N/A	N/A	N/A	N/A
	2014	*23	1.6:1.0	238	252	129	157	3.5	4.1	N/A	N/A	N/A	N/A
	2015	*62	1.3:1.0	264	273	126	145	3.7	3.9	N/A	N/A	N/A	N/A
	2016	191	1.7:1.0	244	258	124	150	3.4	3.9	0.95	0.16	0.39	0.06
	2017	201	1.2:1.0	248	260	130	157	3.9	4.0	1.67	0.06	0.18	0.01
	2018	*22	1.8:1.0	252	261	134	161	3.9	4.1	N/A	N/A	N/A	N/A
	2019	99	2.0:1.0	245	249	135	146	3.4	3.4	1.26	0.09	0.28	0.03
Merrimack	2014	*27	1.7:1.0	242	251	117	132	3.1	3.1	N/A	N/A	N/A	N/A
	2015	*23	0.9:1.0	254	268	149	179	3.9	3.8	N/A	N/A	N/A	N/A
	2016	170	1.9:1.0	244	252	125	142	3.0	3.1	3.38	0.00	0.03	0.00
	2017	*20	0.7:1.0	250	259	130	150	3.1	3.3	N/A	N/A	N/A	N/A
	2018	*45	1.6:1.0	256	273	141	179	4.2	4.5	N/A	N/A	N/A	N/A
	2019						[SAMPLE SIZE TOO SMALL]			N/A	N/A	N/A	N/A

* Results based on low sample size

▪ Results based on only two ages available and must be regarded with caution

Appendix Table 6. River herring counts from select Massachusetts streams. Streams are selected based on 10+ years of statistically reliable run size estimates.

Drainage	CT	Merrimack	North Coast	North Coast	Boston HBR	South Coast	South Coast	South Coast	Buzzards Bay	Buzzards Bay	Buzzards Bay	Buzzards Bay	Cape Cod (N)	Cape Cod (N)	Cape Cod (S)	Cape Cod (S)	Taunton	Taunton
Method	Lift	Lift	*V/V	Visual	•V/C	Counter	Visual	**C/V	Counter	Counter	Counter	Counter	Visual	Visual	Visual	Visual	Visual	Counter
Stream	CT	Merrimack	Parker	Ipswich	Back	Monument	Jones	Town B.	Mattapoisett	Agawam	Wankinco	Acushnet	Stony	Herring (W)	Marstons Mills	Pilgrim Lake	Nemasket	Town R.
1967	356																	
1968																		
1969	10,000																	
1970	188																	
1971	302																	
1972	188		12,097															
1973	302		38,163															
1974	504		34,163															
1975	1,600		24,539															
1976	4,745		13,998															
1977	32,492		6,654															
1978	40,765		13,116															
1979	39,895																	
1980	197,950					91,093												
1981	419,734					135,279												
1982	586,808																	
1983	454,247	4,794																
1984	482,954	1,769				235,354												
1985	632,255	23,112				178,031												
1986	517,521	16,265			120,000	186,537												
1987	358,607	77,209			110,000	175,621												
1988	343,361	361,012			200,000	123,780			22,000									
1989	286,537	387,973			250,000	309,870			40,000									
1990	392,157	254,242			515,000	331,899			47,000									
1991	412,344	379,588			600,000	344,797			47,000									
1992	312,863	102,166			450,000	304,018			44,000									
1993	103,465	14,027			237,000	252,366			44,000									
1994	31,843	88,913			385,000	144,255			44,000									
1995	112,124	33,425			859,000	433,113			75,000									

Appendix Table 6 (cont.). River herring counts from select Massachusetts streams. Streams are selected based on 10+ years of statistically reliable run size estimates.

Drainage	CT	Merrimack	North Coast	North Coast	Boston HBR	South Coast	South Coast	South Coast	Buzzards Bay	Buzzards Bay	Buzzards Bay	Buzzards Bay	Cape Cod (N)	Cape Cod (N)	Cape Cod (S)	Cape Cod (S)	Taunton	Taunton
Method	Lift	Lift	*V/V	Visual	V/C	Counter	Visual	**C/V	Counter	Counter	Counter	Counter	Visual	Visual	Visual	Visual	Visual	Counter
Stream	CT	Merrimack	Parker	Ipswich	Back	Monument	Jones	Town B.	Mattapoisett	Agawam	Wankinco	Acushnet	Stony	Herring (W)	Marstons Mills	Pilgrim Lake	Nemasket	Town R.
1996	55,011	51			358,000	536,440			58,000									
1997	63,945	403	6,396		117,000	398,929			22,000									
1998	11,146	1,362	4,242		66,000	329,180			104,000									
1999	2,699	7,898	1,965		228,000	213,270			107,000									
2000	10,587	19,405	7,894		259,000	671,839			130,000									72,000
2001	10,602	1,550	2,244		347,000	446,900			77,000									33,000
2002	1,939	526	3,500		316,000	207,561			50,000									193,069
2003	1,392	10,866	1,500		247,000	186,899			25,000									310,000
2004	151	15,051	1,447		234,000	161,000			5,300									25,000
2005	534	†99	747	464	80,000	102,000	681		8,000			395					161,995	65,826
2006	21	†1257	500	651	159,000	75,000	1,468		6,300	53,173		202			6,302		214,246	8,738
2007	75	1,169	50	253	158,000	78,000	2,602		6,000	100,473	2,788	366	21,023		13,862		385,412	53,315
2008	84	108	485	1,234	243,000	103,000	572	168,966	10,000	30,429	8,246	978	24,465		42,404	1,235	345,166	27,283
2009	39	1,456	800	1,155	195,200	185,862	566	155,015	10,356	36,354	6,539	1,699	11,865	21,870	10,668	833	294,989	8,596
2010	76	518	1,800	196	200,000	106,210	3,814	195,091	12,319	30,057	10,665	2,710	50,185	12,052	3,944	1,461	408,618	29,465
2011	138	740	3,624	482	252,711	68,639	3,314	130,314	12,857	19,064	10,442	3,679	36,839	9,534	428	908	346,699	93,312
2012	39	8,992	5,416	575	384,650	180,082	1,766	126,500	28,447	73,186	24,764	3,220	53,596	11,593	68,180	4,872	427,393	42,038
2013	976	17,359	7,149	262	380,000	252,871	4,559	104,191	21,613	33,637	8,734	6,033	153,262	24,903	51,969	2,890	682,763	7,059
2014	647	57,213	7,189	105	455,000	278,134	5,121	135,284	55,429	48,873	18,625	10,144	247,942	65,270	36,178	4,852	629,225	22,346
2015	87	128,692	19,852	282	399,554	240,372	4,367	173,231	42,332	24,398	14,170	3,673	246,526	18,099	20,601	4,337	759,769	5,427
2016	137	417,240	75,202	1,057	362,174	144,963	3,325	202,694	18,540	25,098	15,026	4,930	86,231	12,493	10,075	18,115	615,785	3,584
2017	875	91,616	31,869	478	203,242	143,424	4,192	160,372	14,938	31,077	24,762	8,365	19,932	8,044	32,572	26,443	148,370	10,450
2018	1,060	449,346	31,217	409	333,029	316,618	11,111	170,462	5,241	63,010	18,957	6,354	129,010	26,946	7,807	26,655	492,377	10,039
2019	5,052	143,541	39,321	262	396,503	526,929	20,995	221,181	18,156	102,105	14,055	14,385	102,527	45,524	27,528	16,853	543,369	7,943
Mean	114,297	84,350	13,238	524	297,061	242,109	4,650	168,794	37,881	47,924	13,675	4,476	96,396	23,302	26,675	9,121	551,996	51,425

* Parker River - Run size estiated using visual counts (1972 - 2012); counter (2013); video (2014 -)

** Town Brook - Run size estimated using electronic counter (2008 - 2013); visual (2014-)

† Merrimack River - Lift inoperable for extended periods due to high flows (counts not included in time series mean)

• Back River - Counts prior to 2015 were estimated using an area visual estimate, counts changed to electronic counter in 2015 - present